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General Purpose SUT Adapter for TTCN-3

MASTER OF SCIENCE THESIS

Subject approved by the Department Council on
09.06.2004

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PREFACE

This Master of Science Thesis was done for Plenware Group and Nokia Networks during the period Fall 2003 – Spring 2005. I would like to thank my supervisors and examiners Jarmo Harju and Mika Katara for showing interest on this thesis work and for pointing out errors in the text. Without the support of the following persons on TTCN-3 and tool related matters this thesis work would not have been possible: Federico Engler, Stephan Schulz, Stephan Tobies, Thomas Deiss, and Vesa-Matti Puro.

I would also like to thank Plenware Group and Nokia Networks for financing this work, and the following companies for providing evaluation versions of their TTCN-3 tools: OpenTTCN Oy, Telelogic Finland Oy, Testing Technologies IST GmbH, and Danet Group.

I am very grateful to Tiina for showing extreme patience—most of the time.

Tampere, June 8th, 2005

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ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY

Department of Information Technology

Institute of Communications Engineering

HYRKKÄNEN, ANTTI: General Purpose SUT Adapter for TTCN-3

Master of Science Thesis, 102 pages, 45 enclosure pages.

Examiners: Prof. Jarmo Harju, Sr. Researcher Mika Katara

Financier: Plenware Group Oy, Nokia Networks

June 2005

Keywords: TTCN-3, Testing, System Under Test (SUT), Adaptation, SUT Adapter, Connection Management

TTCN-3 Core Language is a programming language designed for specifying Abstract Test Suites (ATS), which are collections of abstract test cases. These can be used for various kinds of testing (e.g. module, integration, conformance) of the test target, System Under Test (SUT). The communication between the test cases and the SUT is handled by an entity called SUT Adapter. The testing can be message-based and procedure-based, thus the SUT Adapter has to realize both kinds of communication with the SUT.

Because TTCN-3 Core Language is a rather new language (launched in 2000 by ETSI), the present amount of literature on it is very limited. The available literature consists of the TTCN-3 standard, and of overview articles and papers written by the people involved in the development of the language and TTCN-3 tools. The language itself is not very difficult to learn by examples to be able to write simple test cases. To be able to write an own SUT Adapter, one needs to have a deeper understanding what is possible to do with the language, how to use it and when, and how the execution of test cases is seen by the SUT Adapter. In practise, this means that one has to study well the different parts of the TTCN-3 standard.

One purpose of this thesis work is to give the reader an overview of the TTCN-3 Core Language, and what entities and standardized interfaces exist in a TTCN-3 test system. The presentation of these topics is based on different parts of the TTCN-3 standard, putting emphasis on the topics involved in SUT Adapter design. The presented information is then used as the basis for a new concept called Connection Manager System, which is specified in this thesis work. It is an adapter framework, which can be used to design such an adapter for TTCN-3 that provides several different kinds of message- and procedure-based communication means with the SUT. The different communication means can be controlled from the test cases in a uniform way, and new means can be later added without breaking the existing system. The specification of the Connection Manager System should give ideas to the reader what different things need to be considered in SUT Adapter design.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO

Tietotekniikan osasto

Tietoliikennetekniikka

HYRKKÄNEN, ANTTI: General Purpose SUT Adapter for TTCN-3

Diplomityö, 102 s., 45 liites.

Tarkastajat: prof. Jarmo Harju, vanh. tutkija Mika Katara

Rahoittaja: Plenware Group Oy, Nokia Networks

Kesäkuu 2005

Avainsanat: TTCN-3, Testaus, Testikohdejärjestelmä, Adaptaatio, Testikohdeadapteri, Yhteydenhallinta

TTCN-3 Core Language on ohjelmointikieli, joka on suunniteltu määrittelemään abstrakteja testisarjoja, jotka puolestaan koostuvat abstrakteista testitapauksista. Näiden avulla testikohdejärjestelmälle (System Under Test, SUT) voidaan tehdä esimerkiksi moduli-, integrointi- tai vastaavuustestausta. Testikohdejärjestelmän ja testitapausten välisen kommunikoinnin mahdollistaa ohjelma nimeltä testikohdeadapteri (SUT Adapter). Sen tulee pystyä toteuttamaan sekä sanomapohjaista että proseduuripohjaista viestintää testikohteen kanssa, koska kommunikointi voi perustua molempiin näistä.

Koska TTCN-3 Core Language on melko uusi ohjelmointikieli (ETSI:n vuonna 2000 julkaisema), siitä on hyvin vähän kirjallisuutta saatavilla. Olemassa oleva kirjallisuus koostuu lähinnä TTCN-3-standardista ja kielen sekä siihen liittyvien työkalujen kehittämiseen osallistuneiden ihmisten kirjoittamista artikkeleista ja käyttöohjeista. Yksinkertaisia testitapauksia on kuitenkin mahdollista oppia kirjoittamaan esimerkkien avulla, koska kieli itsessään ei ole kovin vaikea. Testikohdeadapterin suunnittelu ja toteutus sen sijaan vaatii kielen ominaisuuksien syvällisempää tuntemusta: miten kieltä kannattaa käyttää eri tilanteissa ja miten testikohdeadapteri näkee testitapausten suorituksen.

Tämän diplomityön yhtenä tarkoituksena on antaa lukijalle yleiskuva TTCN-3-kielestä sekä TTCN-3-testijärjestelmään liittyvistä komponenteista ja niiden välisistä rajapinnoista. Näiden asioiden esitys perustuu TTCN-3-standardin eri osiin ja se keskittyy testikohdeadapterin kannalta oleellisiin tekijöihin. Tämän taustatiedon pohjalta työssä esitetään uusi käsite yhteydenhallintajärjestelmä (Connection Manager System). Yhteydenhallintajärjestelmän tarkoituksena on tarjota runko testikohdeadapterille, joka tarjoaa useita erilaisia sanoma- ja proseduuripohjaisia kommunikointikeinoja käytettäväksi testikohdejärjestelmän kanssa. Näitä erilaisia kommunikointikeinoja hallitaan testitapauksista yhtenäisellä tavalla ja niitä voidaan lisätä myöhemmin adapteriin muuttamatta jo olemassa olevaa toteutusta. Diplomityössä kuvatun yhteydenhallinta-järjestelmän määrittelyn perusteella lukijalle tulisi muodostua kuva siitä, mitä asioita tulee ottaa huomioon testikohdeadapterin suunnittelussa.

TABLE OF CONTENTS

ABBREVIATIONS

CCI	CM Class Interface. The interface between the CM System Component and the CM Classes.
CD	Coding/Decoding
CI	Connection Interface. The TTCN-3 language level user interface to the CM System.
CM	Connection Manager
CSI	CM System Interface. The interface provided by the CM System Component to the SA.
ETS	Executable Test Suite (defined in ISO/IEC 9646-1)
IDL	(CORBA) Interface Definition Language
IUT	Implementation Under Test
MI	Mapping Interface. The interface between the SA and the CMs.
MSC	Message Sequence Chart
MTC	Main Test Component
PA	Platform Adapter
PDU	Protocol Data Unit
PTC	Parallel Test Component
SA	SUT Adapter
SAP	Service Access Point
SUT	System Under Test
T3RTS	TTCN-3 Runtime System
TCI	TTCN-3 Control Interface
TL	Test Logging
TM	Test Management
TMC	Test Management and Control
TRI	TTCN-3 Runtime Interface
TSI	Test System Interface
TTCN-2	Tree and Tabular Combined Notation, 2nd Edition
TTCN-3	Testing and Test Control Notation, version 3

DEFINITIONS OF TERMS

CM Class	Entity that provides communication means of certain kind with the SUT. Each established connection using a class is handled by a CM belonging to the class.
CM System	A general term meaning the CM System Component, the CM Classes, and the CMs, along with their data structures.
CM System Component	Entity that provides the CM System Interface to the SA. It uses the services provided by the CM Classes that are registered into it.
cmClassReg	Data structure within the CM System Component, which contains interfaces to all the CM Classes that are present in the CM System.
Codec	Piece of software that encodes values of abstract TTCN-3 types into transfer syntax form and back.
Connection Manager (CM)	Entity that maintains an opened data connection, and which can be controlled via a control connection.
Control connection	A connection that is used to control one or more data connection of a component.
Control port	A port that is used for configuring connections for data ports.
controlMap	Data structure within the CM System Component, which is used by it to find which data connections are controlled by which control connections.
Data connection	A connection that a component has opened with Connection Interface Open operation.
Data port	A port via which a test case component can communicate with the SUT.
(En)coding attributes	Both the `encode` and `variant` attributes, that can be defined for a TTCN-3 language element with the `with` statement. These are used to select which codecs are used and to guide the codecs in encoding of abstract TTCN-3 values into transfer syntax form.
handlerMap	Data structure within the CM System Component, which is used by it to find which CM Class and which particular CM is handling a certain connection.
Stand-alone control connection	A connection that is not used to control any data connection, but which is used as a signaling link with a CM.
tsiMap	Data structure within the SA, which is used for storing component and port identifiers of connections. Defined in Section 4.3.3.
TTCN-3 tool	A program that either compiles or interprets modules written in TTCN-3 Code Language to make them executable.

1 INTRODUCTION

TTCN-3 is a language designed for specifying Abstract Test Suites (ATS), with which the test target, System Under Test (SUT), is tested. As of writing this document, there is very little literature on TTCN-3 as a test programming language, and even less, if anything at all, on SUT Adapter (System Under Test Adapter, SA) implementation. The reason for this is that TTCN-3 is a new language that was published by European Telecommunications Standards Institute (ETSI) in 2000 and its standard is still evolving. A SUT Adapter is piece of software that handles the actual communication between the SUT and the program that runs test cases and decides their results. When one wants to build an own adapter from the scratch, the material one can resort to is the TTCN-3 standard, and what happens to come with the used TTCN-3 tool. A TTCN-3 tool is a program that is required to interpret or compile the written test suites (ATS) to make them executable. There are no examples in the standard on how one could realize an adapter, and what things should be considered. The standard does provide an interface via which the adapter communicates with the rest of test system, but how one utilizes the interface operations and their parameters is left to the adapter designer. What comes to the documentation and example adapters that currently come with the TTCN-3 tools, these seem to be very minimal as of writing this document. The documentation might only state that "The TRI interface is specified in [T3TRI]. If you need an adapter using TRI interface for a special purpose, please contact our sales department.", which is not very helpful. The example adapter, if such is provided, can be a simple adapter that opens a TCP or UDP connection with a fixed end-point, without much configuration possibilities. It can also be, that this adapter can be used with the message-based operations TTCN-3 language provides, but the procedure-based testing functionality of TTCN-3 cannot be utilised. In addition, this kind of adapter may lack any kind of error handling and it may not be suitable for situations in which test case configuration can change during an on going test case.

The purpose of this thesis work is to give the reader a short overview on TTCN-3 language and test system, and how one can build such an adapter that can be used for establishing communication channels between test targets of different kinds. The presented adapter system alone cannot be used for communication with the test targets, but it provides a framework into which real adapter implementations can be added, and which can be controlled in a uniform way. This adapter framework or system is called as Connection Manager System in this document. The text should give ideas to the reader what things should and could be considered in adapter design, even if the presented framework is not used.

The content of this document is divided into theory and background part (Chapters 2 and 3), which gives to the reader an overview of the TTCN-3 based on its standards, and to practical part (Chapters 4, 5, and Appendix A), which specifies a Connection Manager System that is compatible with the TTCN-3 standards.

Chapter 2, “TTCN-3 Core Language”, gives an overview of TTCN-3 Core Language, which is used for specifying test cases. It contains TTCN-3 code fragments to show what the language looks like, and it contains references to the sections of the standards where the presented features of the language are specified in more detail. Chapter 3, “TTCN-3 Runtime Interface”, describes what different elements and standardized interfaces are present in a TTCN-3 test system, and how they are related to the test cases written in the core language. After this, the interface between executable test cases and the adapter that communicates with the test target is explained in more detail.

The concept of the Connection Manager System is explained in Chapter 4, “General Purpose SA”, which describes the entities present in the system and interfaces between them. The chapter also specifies requirements to the system: how connections and entities are identified within the system, what information is stored and where, and how operations are handled concurrently. The interfaces between the entities are specified in Chapter 5, “Interfaces” and in Appendix A. This is done at an abstract level, meaning that the information that is passed between the elements, and the operations for doing this, are specified in a language independent manner. Message Sequence Charts showing the use of the interfaces can be found in Appendix B. Chapter 6 contains a summary and conclusions of the presented ideas.

2 TTCN-3 CORE LANGUAGE

The TTCN-3 standard is divided into six parts, which each cover a different part of the language: Part 1: TTCN-3 Core Language [T3CORE], Part 2: TTCN-3 Tabular Presentation Format (TFT) [T3TFT], Part 3: TTCN-3 Graphical Presentation Format (GFT) [T3GFT], Part 4: TTCN-3 Operational Semantics [T3OS], Part 5: TTCN-3 Runtime Interface (TRI) [T3TRI], and Part 6: TTCN-3 Control Interface (TCI) [T3TCI]. Of these, the Part 1: TTCN-3 Core Language is the most essential. It specifies the textual syntax of the TTCN-3 language and how one writes test cases with it. It also serves as the syntactical and semantic basis for other non-textual representation formats of the language, such as the tabular format and graphical format, which are specified in Part 2 and Part 3 of the standard. In Part 4: TTCN-3 Operational Semantics, the semantics of the core language is specified in detail by using a flow graph notation. It shows how the statements in a TTCN-3 module (a compilation unit in TTCN-3, such as a .c file in C) are to be interpreted when the test cases are executed.

This chapter provides an overview of the TTCN-3 core language based on ETSI standard ETSI ES 201 873-1 V2.2.1 (2003-02) "Methods for Testing and Specification (MTS); The Testing and Test Control Notation version 3; Part 1: TTCN-3 Core Language" (referenced as T3CORE in the text). Topics of the language relevant to this thesis work are shown in greater detail, while less relevant are only mentioned or completely omitted, irrespective of their importance in the TTCN-3 core language. The text contains references to the sections of [T3CORE] where more detailed information on the presented topics can be found. Where relevant, the text uses the `courier` font to highlight the reserved words of the language.

2.1 TTCN-3 as a Programming Language

TTCN-3 Core Language can be seen as a programming language, which is meant for specifying collections of test cases, Abstract Test Suites (ATS). To be able to execute the test cases within an ATS, a tool (compiler, interpreter) is required to transform the ATS into an Executable Test Suite (ETS). The language is independent of the environment in which the testing is done, what is being tested, and what kind of testing is in question. The testing can be module testing, integration testing, conformance testing, and so on [T3CORE: s. 4]. The test target can be a function library written in some language X, a web server, or a network of components whose joint behavior is tested via some chosen interfaces.

The language does not currently provide syntax for real-time testing; events that occur have no time stamps, and it is not possible to read absolute time, i.e. system time. Hence, one cannot directly test whether something happens at a given time of day, or whether events occur within certain tolerance, without building this functionality by writing custom (external) functions [T3CORE: s. 16.1.0], and by possibly time-stamping events (function calls, messages) outside the TTCN-3 Core Language. In [TIMED] a solution is proposed to extend TTCN-3 to handle real-time requirements.

The difference between TTCN-3 and other programming language is that it has been designed for testing. It provides at language level means for handling test verdicts, operations for procedure- and message-based communication, and extensive abilities to specify and match against data.

2.2 Module

The TTCN-3 language element called `module` corresponds to a compilation unit in traditional programming languages [T3CORE: ch. 7]. It can be analyzed, compiled or interpreted, it may contain a single or several test cases, and it can be used as a library by other modules. The TTCN-3 standard does not mention the relationship between modules and how they are stored into files. Because of this, some TTCN-3 tools allow one to have several modules defined within a file, and some tools only understand one module per file. This may cause problems when the used tool is changed. A smaller problem is that the used file suffix also varies between tools.

Each module is divided into two parts, definitions part and `control` part, both of which are optional. The definitions part contains top-level definitions, such as type definitions, data (template) and constant definitions, port and component definitions, and function and testcase definitions. It is possible to `import` definitions from other modules to make them visible in the referring module. The control part can be seen as the "main function" of the module and its purpose is to call the test cases defined in the definitions part. It contains the logic for executing the test cases in certain order, it can apply execution time restrictions to the test cases, and it can use the definitions specified in the definitions part of the module to specify local variables. Because the control part is optional, the used TTCN-3 tool may provide an alternative way to execute test cases without using the control part. For example, it can have a graphical user interface from which the executed test cases can be selected.

It is possible to specify parameters for a module, meaning that when a test case or the control part of the module is executed, it can read these parameters and behave according to them. The parameters are like module global constants, whose values are set at the start of the execution. For example, one could have the address of the test target and maximum execution time as module parameters.

The following TTCN-3 code fragment shows a module definition of module `MyModule`, which could be stored in file `MyModule.ttcn`:

```
module MyModule
{
   // Definitions part
   import from OtherModule all;

   type integer MyPosInt (0 .. infinity);

   testcase tc_myFirstCase() runs on MyComponent system MyTsi
   {
      ...
   }

   // Control part
   control
   {
      execute(tc_myFirstCase(), 10.0); //Maximum execution time 10.0 seconds
      execute(tc_mySecondCase());      //No maximum execution time
   }
}
```

2.3 A Test Case and Testcase

TTCN-3 Core Language has a language element called `testcase` [T3CORE: ch. 17]. The difference between `testcase` and a “test case” is that `testcase` is language element, while test case is a general term used in this document to mean a set of checks done to the System Under Test (SUT), in order to test some specific behavior. A test case consists of a `testcase`, that can be seen as the main function of a single case, and of any other functionality executed in parallel with the `testcase`. A `testcase` is always executed within an entity called `component`, and it can call normal `function`s and `altstep`s to extend its behavior. The result of executing a `testcase` is a verdict, which tells whether the system under test passed the test.

A test case can be both message- and procedure-based [T3CORE: ch .23]. Message-based testing consists of sending messages to the System Under Test (SUT), receiving messages from it, checking whether messages were not received in time, and of checking whether the received messages are in the right order and that they contain right values. Procedure-based testing consists of calling functions of the SUT, receiving return values and exceptions, receiving function calls, and of passing function return values and raised exceptions to the SUT.

2.4 Components, Ports, and Test Configurations

The behavior of a single test case consists of executing functionality (testcases and functions) in one or more components. A `component` is a user specified entity, which contains user-defined `port`s, via which the component can interact with other components and the SUT with message and procedure operations [T3CORE: s. 8]. In addition to the ports, the component may contain private variables and timers. The component itself does not specify any kind of behavior but it provides an environment for it. This means that one can start functionality in the component and this functionality can then use the ports, variables, and timers of the component. The functionality that can be started in the component can be either a `testcase` or a `function` [T3CORE: s. 22.5. A component is shown conceptually in Figure 2-1.

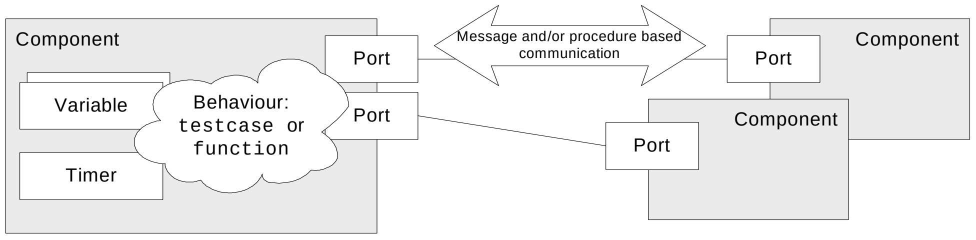

Component
Variable
Timer
Behaviour: testcase or function
Port
Port
Message and/or procedure based communication
Port
Component
Component
Port

Figure 2-1: Component model.

One of the components that exist during a test case is called Main Test Component (MTC). It is special in the sense that when a test case is chosen to be executed, this MTC component is automatically created to execute it. When the MTC reaches the end of its execution, then the test case ends. The MTC is responsible for creating other components, which are called Parallel Test Components (PTC), and for starting functionality in them. The creation of new PTCs and starting of functionality in them can also be done by the PTCs.

Another special component that exists for the duration of the test case is called Test System Interface (TSI) component (or just system component or system for short) [T3CORE: s. 8.3]. Unlike the other components, one cannot start any functionality in it, and it does not have any internal variables or timers. This component acts as an abstract interface between the test case and the System Under Test (SUT). The ports of the system component (TSI) are visible to the SUT Adapter, which routes any messages or procedure operations seen at these ports between the test case components and the real test system interface at the SUT (see Figure 2-2).

The components and TSI are abstract TTCN-3 Core Language level constructs. The actual program that implements the components and test case logic is called TTCN-3 Executable (TE). It interacts with the SUT Adapter via TTCN-3 Runtime Interface (TRI). The TE, SUT Adapter and TRI are not part of the TTCN-3 Core Language, so they are explained later in Chapter 3.

When two components want to communicate with each other, the ports of the components have to be first connected with each other. When a component needs to communicate with the SUT, its port has to be mapped with one of the ports of the TSI component

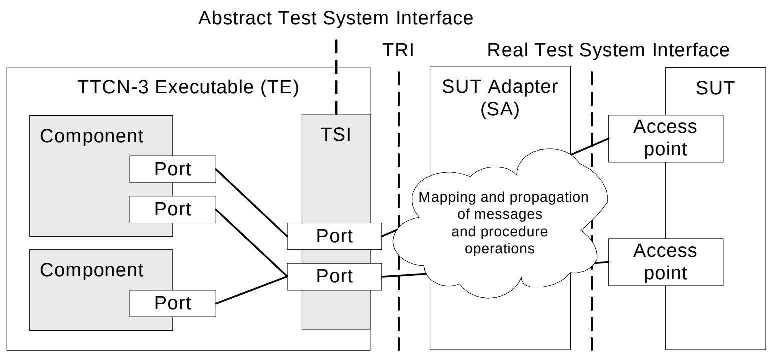

Abstract Test System Interface
TRI
Real Test System Interface
TTCN-3 Executable (TE)
SUT Adapter (SA)
SUT
Component
Port
Port
TSI
Port
Port
Component
Port
Access point
Access point
Mapping and propagation of messages and procedure operations

Figure 2-2: Test System Interface.

(when a port of a component is connected with a port of the TSI component, it is said that they are mapped with each other, instead of connected with each other). After this, the component can perform message-based, procedure-based, or both kinds of communication operations via the port. What messages and procedure calls can be performed via the port depends on the type definition of the port. A type definition of the port specifies whether the port can be used for message-based or procedure-based communication, or for both, and it contains a list of supported message types and procedures signatures. The list also specifies the direction in which each item can move through the port, as seen by the component in which the port is used [T3CORE: s. 8.4.0]. This direction information restricts what kind ports can be connected and mapped with each other: a port has to be able to receive what a connected port may send. The precise rules for legal port connections and mappings can be found in [T3CORE: s. 22.2.1].

When the component sends a message or performs a procedure call via its port that is connected with a port of another component, the message is delivered to the recipient's port queue, which is modeled as an infinite length FIFO queue in TTCN-3 [T3CORE: s. 8.1]. In the case the port of the sending component is mapped with a system component port, the message is delivered to the SUT by some means by the SUT Adapter (SA). It depends on the implementation of the SA how it knows to deliver the messages to the right place. The SA is further explained in Chapter 3.

The components are created, their execution is started and stopped, and their port mappings are done with the configuration operations specified in [T3CORE: ch. 22]. The following TTCN-3 code fragment shows how the component executing the shown function creates a new PTC, connects one of its own ports with a port of the PTC, maps one other port of the PTC with a system port, starts behavior in the PTC, and waits until the PTC stops its execution, after which it explicitly stops itself:

```
function f_startup() runs on MyComp
{
   /* A new component of type SomeComp is created, and a reference to this
    * component is stored into variable cp_someCompRef.
    */
   var SomeComp cp_someCompRef := SomeComp.create;

   /* Local port pt_control is connected with the port pt_ctrl
    * of the newly created component.
    */
   connect(self:pt_control, cp_someCompRef:pt_ctrl);

   /* Port pt_data of the newly created component is mapped
    * with the port tcp of the test system interface component.
    */
   map(cp_someCompRef:pt_data, system:pt_tcp);

   /* Function tp_someBehaviour() is started in the component,
    * and string "10.10.10.1" is given to it as a parameter.
    * .start() is a non blocking command, so the execution continues
    * immediately after the below statement.
    */
   cp_someCompRef.start(tp_someBehaviour("10.10.10.1"));

   // Wait for cp_someCompRef to finish its execution.
   cp_someCompRef.done;

   // Set own verdict to pass.
   setverdict(pass);

   // Stop own execution.
   self.stop;
}
```

2.5 Verdict

Every component that exists during a test case has a local object called verdict, which it can set (`setverdict`) based on how it experiences the behavior of the other components and the SUT [T3CORE: ch. 25]. Components can also read their own current verdict value (`getverdict`). The possible verdict values a component can set are `none`, `pass`, `inconc`, and `fail`. Once a component has set a value for its verdict, it can only "worsen" the verdict value. What this means is that `none` can be seen as the best verdict value and `fail` as the worst, and the verdict value changes only when a value worse than its current value is tried to be set. Thus, one could set `none` verdict to `pass`, and `pass` to `fail`, but not `fail` back to `pass` or `none`. The `inconc` verdict stands for inconclusive, and it can be used for example in situations, in which the SUT does not do anything illegal, but an unexpected situation occurs which the test case has not been designed to handle.

The total verdict of the test case is the worst verdict of the components that participated in the test, and its value is resolved by the used TTCN-3 tool.

For example, when the testing consists of transferring data with the SUT concurrently in two different directions, uplink and downlink, there could exist an own PTC component for handling and verifying the data transfer in each direction. The total verdict of the test case depends now on the verdicts of the uplink and downlink transfer, which can be seen as sub-tests of the whole test case. These sub-tests could exist in some other test cases as stand-alone test cases (uplink data transfer test, downlink data transfer test), or as parts of more complex test cases.

2.6 Testcases, Functions, and Altsteps

TTCN-3 has three different function-like language elements: `testcase`, `function`, and `altstep` [T3CORE: chs 16, 17]. Common to these is that they can define local variables and timers.

A `testcase` is a function whose execution is always started in a component, and its return value is always the total verdict of the test case. The definition of the `testcase` contains information on in which kind of component it can be started (`runs on`), and what kind of test system interface is used during the test case (`system`). The execution of the `testcase` can be started in the control of part of the module, or directly by the used TTCN-3 tool when the control part is not used. In addition to any local definitions, the `testcase` can use the component internal definitions such as ports and variables.

A normal `function` can have input parameters, output parameters, input-output parameters, and it can return a value. It is also possible to specify that the `function` can only be called or started within a component of a certain type, which makes the internal definitions of the component visible to the function (ports, timers, and variables). TTCN-3 has also `external functions`, which can be called from the test cases, but their implementation is outside the TTCN-3. An `external function` call results in a TRI operation, which instructs the used Platform Adapter (PA) to call the specified function (PA will be explained in Chapter 3).

`Altstep` is used for specifying action whose execution is triggered by some "receiving" event or operation, such as a timeout or receipt of a message. Like with `testcase` and `function`, it can be given access to the internal definitions of the component. An example of an `altstep` is given in Section 2.10 Alternative Behaviour.

The below TTCN-3 fragment defines a component type, and a testcase that be executed on an instance of the component type:

```
// Component type definition
type component MyComp
{
   // Component local definitions:

   // Variable
   var charstring g_identifier;
   // Port of type MyPort
   port MyPort    pt_port;
}

/* Testcase definition. This testcase gets executed in Main Test Component
 * of type MyComp, and the used Test System Interface component is of
 * type MyTsiComp.
 */
testcase tc_myCase(in charstring p_id)
   runs on MyComp system MyTsiComp
{
   g_identifier := p_id;
   pt_port.send(g_identifier);
   ...
}
```

2.7 Types and Values

TTCN-3 provides a set of basic and structured types, from which the user can derive own sub-types by restricting their values [T3CORE: s.6]. All these root types are listed in Table 2-1. The word "range" in the sub-type column means, that the user can define an own subtype of the root type by specifying a range of valid values to it, the word "list" means that the user can specify a list of valid values for the type, and "length" means a length restriction for a type that can be indexed. There are no default restrictions on the root types, so a value of type `integer` or `float` can hold any value from -infinity to infinity, and a string have a length from zero to infinity. In practice, the maximum values depend on the used TTCN-3 tool.

Special to TTCN-3, it is possible to define a field of structured type `record` to be optional, meaning that its value can be omitted, and it can be checked whether the field value has been set [T3CORE: ss. 6.3.1, C.15]. The `union` type of TTCN-3 is different from the union type of C-language. It contains only the alternative or variant that has been assigned to it; the alternatives are not different representation formats of the data stored

Table 2-1: Overview of TTCN-3 Types [T3CORE: s. 6.0, Table 3].

Class of type	Keyword	Sub-type
Simple basic types	**integer**	range, list
	char	range, list
	universal char	range, list
	float	range, list
	boolean	list
	objid	list
	verdicttype	list
Basic string types	**bitstring**	list, length
	hexstring	list, length
	octetstring	list, length
	charstring	range, list, length
	universal charstring	range, list, length
Structured types	**record**	list
	record of	list, length
	set	list
	set of	list, length
	enumerated	list
	union	list
Special data types	**anytype**	list
Special configuration types	**address**	▨
	port	▨
	component	▨
Special default types	**default**	▨

into the union. It is possible to ask from a value of union type if a specified variant is stored into it, by using the predefined `ischosen` function [T3CORE: ss. 6.3.5, C.16].

TTCN-3 is not strongly typed language [T3CORE: s. 3.1], but it does require type compatibility as specified in [T3CORE: s. 6.7]. Strong typing is required in the case of `enumerated` type, and in the communication operations that are explained in Section 2.9. In the case of non-structured types the type compatibility is defined as:

```
“value "b" (of type B) is compatible to type "A"if type "B" resolves to the same
root type as type "A" (i.e. integer) and it does not violate subtyping (e.g. ranges,
length restrictions) of type "A".” [T3CORE: s.6.7.1]
```

This mean that one can assign a value of type A to a value of type B, when the allowed values of A is a subset of the allowed values of B.

There is no automatic type conversion or promotion like in C in TTCN-3, so it is not possible to mix for example integers and floats in the same expression. TTCN-3 does provide a set of predefined functions with which it is possible to convert a type of a certain kind to another kind. There is also no "free" type in TTCN-3, that could be used for containing a value of any kind. However, there exists a type called `anytype` that can be used for storing value of any other type, that is defined in the same module in which the value of `anytype` is defined. In other words, the `anytype` is defined "as a shorthand for the union of all known types in a TTCN-3 module" [T3CORE: s. 6.4].

When a component performs a communication operation via its port that is mapped with a TSI port, it is possible, but not required, to use special `address` type to address a specific SUT or an entity within the SUT [T3CORE: s. 8.6]. This address type is specified separately in each module, and it can be set as one of the user specified types, or it can be left as open type. In the case it is left as open type, and when a message or procedure operation is received from the SUT, one can use it to store the address value of the SUT without understanding its contents. The stored address value can then be used when communicating back to the same SUT entity. The SUT Adapter can use the address value (when present) to deliver information between the correct test case component and SUT entity.

2.8 Templates

A `template` is data structure, that can be "used to either transmit a set of distinct values or to test whether a set of received values matches the template specification" [T3CORE: s. 14.0].

A template specifies a single value when it is used for generating data to be transmitted, and it can be optionally parameterized. A parameterized template can contain an expression whose value specifies the value of the template. When the template specifies a value for a structured type, some of the fields of the value can contain fixed values and some are set at run time with the parameters. This is very useful for defining differently parameterized templates of the same type for different situations. For example, when a message corresponding to a protocol data unit (PDU) of protocol X needs to be transmitted, it is feasible that the test case writer needs only to specify values for the fields of interest, and default values are used for the other fields. For example, one parameterized field could be message sequence number, which needs to be increment after each sent PDU. The below TTCN-3 fragment shows a definition for the PDU type and a parameterized template for it:

```
// Type definition of type MyPdu.
type record MyPdu
{
   integer     seqNum,
   charstring  data
}

// Parameterized template of type MyPdu with identifier a_myPdu_s.
template MyPdu a_myPdu_s(integer p_seqNum) :=
{
   seqNum   := p_seqNum,
   data     := "Who are you?"
}
```

When a template is used in the receiving direction to match with received values, each template can specify a set of values that it matches with. The template definition below matches any value, which is of type `MyPdu`, has `seqNum` within range 100 to 200, and contains as data either the character string "Alice" or "Bob":

```
// Matching template. This cannot be sent, only compared against received data.
template MyPdu a_myPdu_r :=
{
   seqNum   := (100 .. 200),
   data     := ("Alice", "Bob")
}
```

In TTCN-3 it is possible to construct a new template from already specified templates, by using them as (field) values within the new template, either by directly assigning them or by passing them as parameters to the new template. A new template can also be defined by modifying a template by redefining it partially. These features make the creation of very complex values easy, but it is also very easy to specify complex hard-to-maintain dependencies between templates. A change in one template might change the matching of several other templates, thus care must be taken and planning used when specifying large sets of test data. The below example shows the use of existing templates to specify new ones:

```
template charstring  a_allowedData  := ("Alice", "Bob");
template integer     a_validRange   := (100 .. 200);

// a_validRange can be passed to a_myPdu2_r as a parameter
template MyPdu       a_myPdu2_r(template integer p_a_seqNum) :=
{
   seqNum   := p_a_seqNum,
   data     := a_allowedData
}

// Modified template, uses a_myPdu2_r as basis.
template MyPdu       a_myPdu3_r(template integer p_a_seqNum)
   modifies a_myPdu2_r :=
{
   data     := "Eve"
}
```

In addition to be able to specify a list or a range of values, TTCN-3 provides other matching mechanisms, such as matching against a string pattern (similar to a regular expression), string of specific length, complement of a list, omitted value, any value, and any-or-omitted value. The matching mechanisms are introduced in [T3CORE: s. 14.3] and their usage is specified in Annex B of the same document.

The examples given in this section concerned only type templates. Of equal importance, TTCN-3 also provides syntax for specifying templates for function calls. These templates can be used to specify which SUT function should be called with what parameter values, and what calls are expected from the SUT.

2.9 Communication Operations

TTCN-3 has both message- and procedure-based communication operations with which components can interact with each other and with the SUT. All the communication operations are listed in Table 2-2.

The operations `send`, `call`, `reply`, and `raise` are called sending operations, and they use syntax similar to each other. Of these, `send`, `reply`, and `raise` operations are automatically non-blocking, meaning that execution continues after the operation call without waiting for the recipient to actually receive and handle the message or procedure

Table 2-2: Overview of TTCN-3 communication operations [T3CORE: s. 23.10, Table 17].

Communication operations			
Communication operation	**Keyword**	**Can be used at message-based ports**	**Can be used at procedure-based ports**
Message-based communication			
Send message	**send**	Yes	▨
Receive message	**receive**	Yes	▨
Trigger on message	**trigger**	Yes	▨
Procedure-based communication			
Invoke procedure call	**call**	▨	Yes
Accept procedure call from remote entity	**getcall**	▨	Yes
Reply to procedure call from remote entity	**reply**	▨	Yes
Raise exception (to an accepted call)	**raise**	▨	Yes
Handle response from a previous call	**getreply**	▨	Yes
Catch exception (from called entity)	**catch**	▨	Yes
Examine top element of incoming port queues			
Check msg/call/exception/reply received	**check**	Yes	Yes
Controlling operations			
Clear port	**clear**	Yes	Yes
Clear and give access to port	**start**	Yes	Yes
Stop access (receiving & sending) to port	**stop**	Yes	Yes

operation. The `call` operation is automatically non-blocking only when the called procedure is explicitly defined to be non-blocking [T3CORE: s.23.3.1.4], or when the caller explicitly specifies that it wants to continue execution without waiting for response from the callee [T3CORE: s.23.3.1.2]. This makes it possible to postpone the response handling and perform other operations meanwhile. All the sending operations specify the local port used for the operation, what information is to be sent, optional recipient information, and an optional response handling part. The information to be transmitted can be the value of a local variable or constant, or like in most cases, a predefined template. In the case the component port is connected with the ports of several other components, the recipient information is used to specify a single recipient. Several recipients cannot be specified, because TTCN-3 does not support multicasting or broadcasting as of writing this document. The following code fragment shows an example procedure call and sending of a message:

```
/* Call function someFunction with parameter values firstParam and
 * secondParam, without waiting the function to return.
 */
pt_myPort.call(someFunction:{firstParam, secondParam}, nowait);

/* Send integer value 1 via port pt_myPort to component that has reference
 * cp_someCompRef
 */
pt_myPort.send(integer:1) to cp_someCompRef;

/* Send parameterized template a_myPdu_s */
pt_myPort.send( a_myPdu_s( currentSeqNum ) );
```

The operations `receive`, `getcall`, `getreply`, `catch`, `trigger`, and `check` are receiving operations. All these operations, except `trigger`, are used to test whether the specified event is as the first event in the port queue of the specified port. If the event is not present, the execution of the component becomes blocked until a matching event occurs. If the event is present, it is then removed from the port queue and the execution continues with the next statement. Exception to this is the `check` operation, which does not remove the event from the queue. Operation `trigger` differs from the other receiving operations so that it removes any non-matching events from the queue until a match is found, after which the execution continues. All the receiving operations specify the examined local port, a matching condition (template), optionally the expected sender, and an optional assignment part. The following TTCN-3 code shows a few different receiving statements:

```
/* Match with integer of value 1, received via port pt_myPort, and sent
 * by component cp_someCompRef
 */
pt_myPort.receive(integer:1) from cp_someCompRef;

/* Match with a value, that matches with the restrictions posed by
 * template a_myPdu_r, and store the received value to variable localVar
 */
pt_myPort.receive(a_myPdu2_r(currentSeqNum)) -> value localVar;

/* Match with function call of myFunction, with any first parameter value
 * and 1 as the second parameter value, and store the first parameter value
 * into local variable firstParam
 */
pt_myPort.getCall(myFunction:{*, integer:1}) -> param (firstParam, -);
```

Because of the blocking semantics of the receiving operations, they are usually used alone only for example for synchronization, when it is sure that the expected event has occurred or will occur as the first event of the specified port. If an event other than what was expected occurs as the first event, the FIFO nature of the port queues causes a deadlock situation: The receiving operations can check only the first event in the queue, not any other events. Hence, a non-matching event blocks the processing of any other events, because the event is not removed from the queue by the non-matching operation. For these situations TTCN-3 provides the `alt` statement.

2.10 Alternative Behaviour

In a test case it is not always known beforehand in which order certain events occur. The SUT can have several legal actions it may perform, and it can behave completely erroneously. The situations in which several alternative events are possible are handled by TTCN-3 `alt` statement. It is specified in [T3CORE: s.20.1] and its evaluation algorithm is specified in more detail in [T3OS: s.9.3].

The `alt` statement specifies a list of receiving operations (alternatives), with which the occurrence of events of interest is conditionally examined. The receiving operations are `receive`, `getcall`, `getreply`, `catch`, `trigger`, and `check` (explained in the previous section), with the addition of `done` and `timeout` [T3OS: s.9.3]. "Conditionally examined" means that each alternative has a boolean guard (expression) before it, and only when its value evaluates to true, the receiving operation following it is tried to be evaluated. The `done` operation blocks the execution of the calling component, until the specified other component has finished its `function` execution. The `timeout` operation blocks until the specified timer reaches a defined value. If the alternative matches with an event, then the code block following the alternative is executed, after which the execution continues after the `alt` statement, unless a `repeat` statement is encountered. If the alternative does not match, then all the following alternatives are tried in the order in which they are listed within the `alt` statement. `Repeat` statement can be used to re-enter the `alt` statement. It is possible to write nested the `alt` statements, by writing a new `alt` statement within the code block of an alternative.

The below TTCN-3 code fragment shows how the `alt` statement is used to handle the events of two ports (`pt_myPort`, `pt_control`) and a timer (`t_timer`):

```
// Function-local timer
timer t_timer;

// Function-local variables
var MyPdu   myPdu;
var integer count := 0;

// Start timer
t_timer.start(10.0);

// Alt-statement
alt
{
   // Receive maximum of maxCount PDUs that match with template a_myPdu_r
   [count < c_maxCount] pt_myPort.receive(a_myPdu_r) -> value myPdu
   {
      // Forward the received message via port pt_myOtherPort
      pt_myOtherPort.send(myPdu);

      setverdict(pass);
      count := count + 1;

      // Wait for next PDU
      repeat;
   }

   /* Else if we receive something else than a_myPdu_r (plain .receive matches
    * with everything)
    */
   [/* Empty boolean guard is treated as true */] pt_myPort.receive
   {
      log("Received something else");

      setverdict(fail);
      // Execution continues at line “self.stop”
   }

   // Else if we receive from control port an instruction to stop
   [] pt_control.receive(charstring: "stop")
   {
      log("Received control message ""stop"" via pt_contrl");
      // Execution continues at line “self.stop”
   }

   // Else if timer expires
   [] t_timer.timeout
   {
      // Execution continues at line “self.stop”
   }
}

self.stop;
```

The evaluation of `alt` statement is based on concept called snapshot, which is taken when the `alt` statement is entered or re-entered. Snapshot is described in the standard as follows:

```
“A snapshot is considered to be a partial state of a test component that includes
all information necessary to evaluate the Boolean conditions that guard alternative
branches, all relevant stopped test components, all relevant timeout events and the
top messages, calls, replies and exceptions in the relevant incoming port queues.
Any test component, timer and port which is referenced in at least one alternative
in the alt statement, or in top alternative of an altstep that is invoked as an
alternative in the alt statement or activated as default is considered to be
relevant.” [T3CORE: s. 20.1.1]
```

`Altstep` is a function like element in TTCN-3 that can be used instead of the receiving operations in the `alt` statement. The below `altstep` definition

```
altstep alt_timeoutHandler(timer p_timer)
{
   [] p_timer.timeout
   {
      log("timer expired");
   }
}
```

could be used within an `alt` statement in the following manner:

```
timer t_timer;
t_timer.start(10.0);

alt
{
   ...
   // If we receive from control port an instruction to stop
   [/* Empty boolean guard is treated as true */]
      pt_control.receive(charstring: "stop")
   {
      log("Received control message ""stop"" via pt_contrl");
      // Execution continues at line “self.stop”
   }

   // Altstep is used to handle t_timer
   [] alt_timeoutHandler(t_timer);
   {
      log("alt_timeoutHandler handled the timeout event");
      // Execution continues at line “self.stop”
   }
}
```

An `altstep` can also be activated as one of the default alternatives. All the activated defaults are that are tried to be evaluated, when none of the listed alternatives in the executed `alt` statement matches [T3CORE: ch. 21], or when a stand-alone receiving statement does not match.

2.11 Timers

TTCN-3 provides at language level syntax for specifying both implicit and explicit timers. The implicit timers are the timers whose values specify maximum execution time for `testcases` and `function` calls [T3TRI: ss. 23.3.1.2, 27.1]. These timers cannot or need to be started, read, or stopped by the user. Explicit timers are the user created timers that can be started, read, and stopped, their timeout can be waited for, and they can be given as parameters to `functions` and `altsteps`. [T3TRI: chs. 11, 24]. In the previous section a timer was used in the context of the `alt` statement, to specify maximum time how long the component waits for messages to be received from the specified ports, until it continues its execution.

2.12 Encoding and Decoding

All the values that exist during a test case can be thought of being in the abstract TTCN-3 type definition form. Their tool specific internal representation form is of no concern to the test case writer. When these values are sent between test case components, they can be passed between the ports of the components in their internal representation form. However, when a value of certain type is sent by a test case component to the SUT via Test System Interface, then the test case writer wants to specify the transfer syntax of the values. All the values that are sent through the Test System Interface ports to the SUT are encoded into some transfer syntax form by the codec system of used TTCN-3 tool. TTCN-3 does not specify any tool independent way to specify transfer syntax for the data, but it is possible to add `encode` and `variant` attributes to a module, group, type and template, and field definitions. These attributes are user specified hints for the used codec system how the values should be encoded. The codec system then interprets the attributes in a tool or codec specific manner.

For example, the plain type definition

```
type integer SeqNum;
```

does not say anything about its transfer syntax; it could be sent as a 32bit length integer value in network byte order; it could be sent as a sequence of 1-bits of length `seqNum`; or it could be sent as a sequence of ASCII-characters containing a textual representation of the value in English, such as “one-hundred fifty-one”, if this is the format understood by the recipient.

A type definition with attributes looks like this:

```
type integer SeqNum with
{
   encode  "integer 32 bits";
   variant "network byte order";
}
```

The `encode` and `variant` attributes are text strings without any restrictions on their content or syntax. The difference between `encode` and `variant` is that the latter one is meant for refining the former.

When a value is sent via Test System Interface to the SUT, it is first automatically passed to some codec, which may read the attributes of the value, and do the encoding based on them. It may also do the encoding based on the type identifier or some other information. Once the value has been encoded, it is passed to the SUT Adapter by the TE (an entity which executes or interprets the test cases, explained in Section 3.1) as a parameter of a TRI interface communication operation (Sections 3.4, 3.5). Therefore, the SA receives the data always in the transfer syntax form and it does not need to understand its contents. In the opposite direction, the SA passes the data received from the SUT in the transfer syntax form to the TE, which takes care of decoding of the data.

The interface via which the codecs are called to do encoding and decoding is specified in the standard [T3TCI: s. 7.3.2 TCI-CD], and the data interface which gives access to the internal representation of the TTCN-3 data types is specified [T3TCI: 7.2 TCI Data], thus it is possible to write own encoders and decoders. How the right codec is called by the TE depends on the used TTCN-3 tool. By using a proprietary interface, the tool could tell the codec writer which types are present in the test case, and the codec writer could then assigns a codec for each of the types, after which the tool knows to call the right codec based on the type identifier of the value to be encoded. Another alternative is that the tool tells the codec writer what different encoding attributes have been defined in the test case, and the codecs are assigned and called based on the attributes the types have. The codecs might also be called based on the used TSI-ports. Since how the codecs are made known to the TE and taken into use is outside the scope of the standards, there is variation between approaches taken by different TTCN-3 tool vendors.

The codec writer does not necessarily have to assign a unique codec for each different type or attribute. The same codec could be used in different situations, because it can be parameterised at the encoding time by the type and the effective attributes of the value that is being encoded. This information can be used by the codec to determine how it should do the coding this time. For example, there could a single codec that knows how to handle all the different string types of TTCN-3. It could use the root type identifier of the to-be-encoded value to access it properly, and use its encoding attributes to determine the right transfer syntax for it.

3 TTCN-3 RUNTIME INTERFACE

The general structure of TTCN-3 test system implementation is explained both in standard ETSI ES 201 873-5 V1.1.1 (2003-02) “Methods for Testing and Specification (MTS); The Testing and Test Control Notation version 3; Part 5: TTCN-3 Runtime Interface (TRI)” [T3TRI] and in ETSI ES 201 873-6 V1.1.1 (2003-07) “Methods for Testing and Specification (MTS); The Testing and Test Control Notation version 3; Part 6: TTCN-3 Control Interface (TCI)” [T3TCI]. The former part concentrates on the interfaces with which the SUT Adapter and Platform Adapter interact with the rest of the test system. The latter part covers test management and control, which, along with other things, specifies the interface for user-implemented codecs.

This chapter gives an overview what interfaces and components are present in TTCN-3 test system implementation. After this the TTCN-3 Runtime Interface of the test system is explained in more detail.

3.1 Structure of TTCN-3 Test System

There are a few differences between Part 5 and Part 6 of the TTCN-3 standard how some of the entities are named and grouped in the test system, but the main idea is the same. Figure 3-1 shows the test system based on them, and it depicts the elements that are present in a real test system (program or several programs) that can execute test cases against a SUT. Four main elements can be distinguished in the TTCN-3 test system

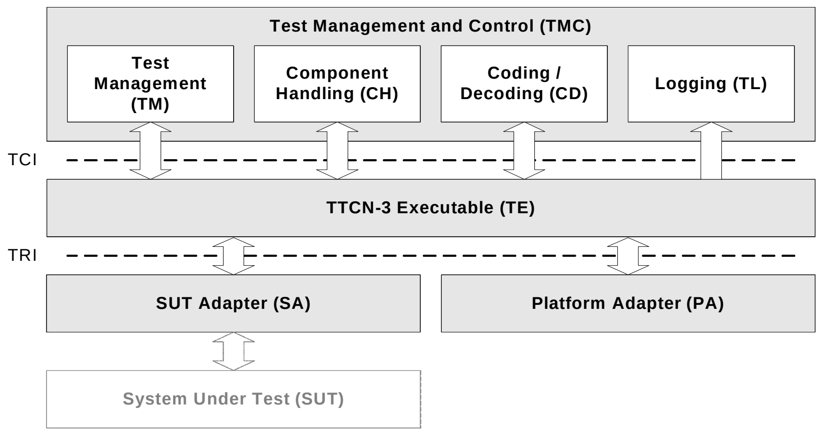


Figure 3-1: General Structure of TTCN-3 Test System.

implementation: Test Management and Control (TMC), TTCN-3 Executable (TE), SUT Adapter (SA), and Platform Adapter (PA). As the standard states, the decomposition of the test system into smaller entities is only a conceptual aid to define interfaces between the entities (e.g. TCI-CD, codec interface between the TE and CD), thus in a real test system implementation this division does not need to be made. The four main elements could all be different parts of the same executable tester program, they could be different programs running on the same device, or they could be different programs running on different devices. How the elements are distributed between programs and devices depends on the used TTCN-3 tool, and whether it supports distribution of the TTCN-3 Executable entity as specified in [T3TCI]. Two standardized interfaces, TTCN-3 Control Interface (TCI) and TTCN-3 Runtime Interface (TRI), exist between the TE and TMC, and between the TE and SA and PA, and they are specified in [T3TCI] and [T3TRI] respectively.

The TE entity corresponds to the executable code resulting from compilation or interpretation of an Abstract Test Suite (ATS), which consists one or more TTCN-3 modules. The ATS may have been written in the TTCN-3 Core language described in Chapter 2, or by using some other alternative format such as the TTCN-3 graphical representation format [T3GFT]. Along with the Executable Test Suite (ETS) corresponding to the ATS, the TE contains a TTCN-3 Runtime System (T3RTS), which handles the interaction of the TE between the TMC, the SA, and the PA entities. It may also contain a tool specific codec system entity (EDS), which is used for encoding and decoding of the data that is sent to and received from the SUT via the SUT Adapter. The T3RTS and EDS are described in [T3TRI: ss. 4.1.2.2, 4.1.2.3] only. The TE can also use a Coding and Decoding (CD) entity to do the encoding and decoding of the data. The interface between the TE and the CD entity is called TCI-CD interface, and it is specified in [T3TCI: s. 7.3.2].

The TMC entity contains a Test Management (TM) entity, a Component Handling entity (CH), the Coding and Decoding CD (CD) entity, and a Test Logging (TL) entity. In [T3TRI] the TMC is actually called as TM, and the TM is called as Test Control. The TM entity may have a user interface. It handles the overall test management by passing TTCN-3 module parameters to the TE, and by instructing it to start and stop execution of the test cases. The CH entity enables the distribution of the TE over several devices (if required) by passing information of test case events between the distributed TEs. The CD entity provides the TE codecs, which are used by it to encode TTCN-3 values into transfer syntax form, when these are sent to the SUT, and to decode data in transfer syntax form back into TTCN-3 values, when the data is received from the SUT. The codecs can be taken into use by using type the encoding attributes described in Section 2.12. The TL entity is responsible for maintaining test logs, which consists of events the TE notifies it about.

The SUT Adapter (SA) realizes the message- and procedure-based communication with the SUT. It may establish static connections with the SUT at the beginning of each test case based on the used TSI ports, and dynamically during it when components `map` and `unmap` their ports with the TSI ports (see Figure 2-2). How the SA knows where and how to establish the connections, and what components use which connections is outside the scope of the standards. The realization of the communication operations (e.g. `send`, `receive`, `call`, `getcall`) is divided between the TE (namely T3RTS) and the SA in the standard in the following way:

> “The T3RTS entity should implement all message and procedure based communication operations between test components, but only the TTCN-3 semantics of procedure based communication with the SUT, i.e. the possible blocking and unblocking of test component execution, guarding with implicit timers, and handling of timeout exceptions as a result of such communication operations. All procedure based communication operations with the SUT are to be realized and identified (in the case of a receiving operation) in the SA as they are most efficiently implemented in a platform specific manner.” [T3TRI: ss. 4.1.2.2]

> “It (SA) is responsible to propagate send requests and SUT action operations from the TTCN-3 Executable (TE) to the SUT, and to notify the TE of any received test events by appending them to the port queues of the TE. Procedure based communication operations with the SUT are implemented in the SA. The SA is responsible for distinguishing between the different messages within procedure-based communication (i.e. call, reply, and exception) and to propagate them in the appropriate manner either to the SUT or the TE” [T3TRI: ss. 4.1.3]

In short, the SA handles the actual interaction with the SUT, when this is requested by the TE or initiated by the SUT, and it also notifies the TE about any incoming events coming from the SUT (messages, function calls). The TTCN-3 semantics of communication is handled by the TE, meaning that test case components are blocked by the TE for example in `receive` or `getcall` port operations until a matching event is received. The SA is not aware of the states of the components, but it knows what component is mapped with which TSI port.

The Platform Adapter (PA) realizes the external function call statements of TTCN-3, and it provides to the TE a timer service. When an external function call statement is encountered during execution of a test case, the TE requests the PA to call the specified function. Similarly, when a timer is created, started or stopped in a test case, the TE instructs the PA to do so. When a timer expires, the PA notifies the TE about this. Because the used TTCN-3 tool might need timers in its own implementation, it may provide the possibility of using its own timer system to handle test case timers, instead of having to implement the timer services in the PA.

3.2 Overview of TTCN-3 Runtime Interface

TTCN-3 Runtime Interface consists of two sub-interfaces. The one between the TTCN-3 Executable (TE) and the SUT Adapter (SA) is called triCommunication interface, and the other one between the TE and the Platform Adapter (PA) is called triPlatform interface (Figure 3-2). These interfaces are specified in implementation language independent manner in CORBA Interface Definition Language, but the standard also gives concrete C and Java language mappings of the interfaces. In addition to the triCommunication and triPlatform interfaces, the standard specifies a data interface, which is a collection of data types used in the two interfaces.

The TRI interface is specified as a procedure-based interface. Most of the operations the interface provides are implemented by the SA and PA, and called by the TE. These operations along with their corresponding TTCN-3 Core Language statements are listed in Table 3-1. The first column specifies a TTCN-3 statement, and the second column lists the resulting TRI operation(s). The operations provided by the TE and called by the SA

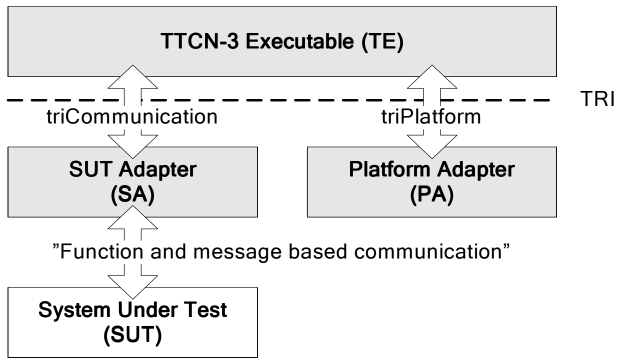


Figure 3-2: TTCN-3 Runtime Interface (TRI).

and PA are listed in Table 3-2. The standard specifies the following requirement for TRI operation implementation:

```
Each TRI operation call shall be treated as an atomic operation in the calling
entity. The called entity, which implements a TRI operation, shall return control to
the calling entity as soon as its intended effect has been accomplished or if the
operation cannot be completed successfully. The called entity shall not block in the
implementation of procedure-based communication. Nevertheless, the called entity
shall block after the invocation of an external function implementation and wait for
its return value. [T3TRI: s 4.3]
```

This prevents the blocking of the caller, meaning that if the TE happens to be implemented with a single execution thread, the whole test case being executed does not halt when one of the test case components for example calls a SUT function, which might never return in the case it behaves erroneously. A test case component may also want to continue its execution without waiting for the function call to return.

Table 3-1:Correlation between TTCN-3 statements and TRI Operation invocations [T3TRI: s. 5.1.3, Table 2, with additions]. Calling of the operations marked with a * depends on the parameters of the TTCN-3 operation.

TTCN-3 Operation Name	TRI Operation Name	TRI Interface Name
execute	triExecuteTestCase	triCommunication TE→SA
	triStartTimer*	triPlatform TE→PA
map	triMap	triCommunication TE→SA
unmap	triUnmap	
send	triSend	
call	triCall	triCommunication TE→SA
	triStartTimer*	triPlatform TE→PA
reply	triReply	triCommunication TE→SA
raise	triRaise	
(sut.)action	triSUTactionInformal*	
	triSUTactionTemplate	
start (timer)	triStartTimer	triPlatform TE→PA
stop (timer)	triStopTimer	
read (timer)	triReadTimer	
running (timer)	triTimerRunning	
TTCN-3 external function	triExternalFunction	
	triSAReset	triCommunication TE→SA
	triPAReset	triPlatform TE→PA

As it can be seen from the tables, one purpose of the PA is to provide a timer service to the TE to realize the timers used in TCN-3 in some platform dependent manner. Second purpose of the PA is to realize the external function calls that can be made from test cases. More detailed description of the PA operations is outside the scope of this document.

The following sections concentrate on the TE-SA interface, which is used by the TE to request the SA to realize the TTCN-3 port operations performed during test cases. The same interface is used by the SA to inform the TE about any messages and procedure operations it receives from the SUT.

Any references to triCommunication and TRI interfaces in rest of this work mean the interface between the TE and the SA. The operation signatures shown in this chapter are in CORBA Interface Definition Language (IDL).

Table 3-2: Operations provided by the TE and called by the SA and PA.

TRI Operation Name:	**TRI Interface Name:**	
`triEnqueueMsg`	triCommunication	SA→TE
`triEnqueueCall`		
`triEnqueueReply`		
`triEnqueueException`		
`triTimeout`	triPlatform	PA→TE

3.3 Connection Handling

The operations `triExecuteTestCase()`, `triMap()`, and `triUnmap()` are called Connection Handling operations in the standard [T3CORE: s. 5.5.2]. With these operations the TE tells the SA what kind of TSI is used in the testcase that is being executed, and what mappings (port connections) exist between the test case components and the TSI component. The SA can use this information to establish and close connections with the SUT at the beginning of each test case and dynamically during it.

Immediately before starting execution of a test case, the TE calls the SA implemented operation `triExecutedTestCase()`. The SA receives as the parameters of this operation the identifier of the test case whose execution is about to start, and the port identifiers of the used TSI component:

```
TriStatusType triExecuteTestCase(in TriTestCaseIdType testCaseId,
                                 in TriPortIdListType tsiPortList)
[T3TRI: s.5.5.2.1]
```

The SA can establish predefined connections for the TSI ports based on the port list, but it does not have to.

Mapping of a component port with a TSI port results in the TE calling the TRI operation `triMap()`. This operation tells the SA that the specified ports are now mapped together:

```
TriStatusType triMap(in TriPortIdType compPortId,
                     in TriPortIdType tsiPortId)
[T3TRI: s.5.5.2.2]
```

From the `TriPortIdType` the SA can extract name and type of the port, and identifier of the component that owns it. The SA can use this information to establish a new connection with the SUT, and to select the right established connection when the component sends a message or performs a procedure operation via this port.

Similar to the `triMap()`, `triUnmap()` is used by the TE to inform the SA that a mapping between a component port and TSI port has been removed, as the result of the execution of the TTCN-3 `unmap` statement.

3.4 Message-based Communication

The message-based communication operations consist of `triSend()` and `triEnqueueMsg()` operations.

When a TTCN-3 `send` statement is executed in a test case, the TE requests the SA to deliver the sent message to the SUT. This is done by the TE by calling the `triSend()`operation, which is defined as:

```
TriStatusType triSend(in TriComponentIdType componentId,
                      in TriPortIdType      tsiPortId,
                      in TriAddressType     SUTaddress,
                      in TriMessageType     sendMessage)
[T3TRI: s.5.5.3.1]
```

As the parameters of this operation the SA receives identifier of the sending component, the TSI port via which the message was sent, SUT address information if present in the `send` statement (address type is explained in Section 2.7 Types and Values, and in [T3CORE: s. 8.6]), and the message in encoded form. The SA can use the component and port identifiers to choose the right connection, that might have been established after the `triExecuteTestCase()` or a `triMap()` operation.

When the SA receives a message from the SUT, it can forward it to the TE by calling the operation `triEnqueueMsg()`:

```
void triEnqueueMsg(in TriPortIdType       tsiPortId,
                   in TriAddressType      SUTaddress,
                   in TriComponentIdType  componentId,
                   in TriMessageType      receivedMessage)
[T3TRI: s.5.5.3.2]
```

By using the mapping information the SA has stored during `triExecute-TestCase()` and `triMap()` operations, it can decide which TSI port and component identifiers to use, i.e., via which TSI port to which component it should send the message that it has received. It should be noted that the port identifier (`tsiPortId`) used in the operation identifies a TSI port, not the component port that is mapped with the TSI port. Because only one port of the component can be mapped with a certain TSI port at a time, the TE knows to route the message to the right component port ([T3CORE: s. 8.2] specifies the allowed connections).

When the SA calls the `triEnqueueMsg()` operation, the TE notifies internally the receiving component, which might be blocked at a `receive` or `alt` statement, about this new event. There is no operation called “triReceive()” to correspond with the TTCN-3 port operation `receive`, thus the execution of the `receive` statement in a test case cannot be observed at the TRI interface.

3.5 Procedure-based Communication

The procedure based communication operations consist of the operations `triCall()`, `triReply()`, `triRaise()`, which are called by the TE and implemented by the SA, and of the operations `triEnqueueCall()`, `triEnqueueReply()`, and `triEnqueueException()`, which are called by the SA and implemented by the TE. Like with the TTCN-3 `receive` statement, there are no TRI operations such as "triGetCall(), triGetReply(), triCatch()", since the `triEnqueue*()` operations are used to enqueue new received events to the test case components.

The `triCall()`, `triReply()`, and `triRaise()` are called by the TE when in test case a component executes the corresponding `call`, `reply` or `raise` statement. The SA should then realize these procedure operations at the SUT (i.e., it should call a SUT function, or pass a return or exception value to a function call when the SUT is the caller). All these TRI operations are very similar. The TE tells with the operations the identifier of the component that executed the statement (`componentId`), from which TSI port the request comes from (`tsiPortId`), optionally a SUT destination address (`SUTaddress`), and identifier of the SUT function that is the target of the operation (`signatureId`). In the case of `triCall()` and `triReply()`, a list of used function parameters is also present (`parameterList`). This parameter list specifies the parameter values and their parameter passing mode, which can be `in`, `out`, or `inout`, depending on the direction in which the parameter passes data (into the function, out of the function). All the parameter values have been encoded by the used codec system, thus the SA does not need to know their structure or to do any encoding and decoding. In the `triReply()` operation, there is also an additional parameter that specifies the return value of the function. The operation `triRaise()` specifies only an exception value and no parameter values.

The signature of the `triCall()` operation is shown below:

```
TriStatusType triCall(in TriComponentIdType   componentId,
                      in TriPortIdType        tsiPortId,
                      in TriAddressType       SUTaddress,
                      in TriSignatureIdType   signatureId,
                      in TriParameterListType parameterList)
[T3TRI: s.5.5.4.1]
```

In the opposite direction, when the SUT calls a function whose implementation is within the test case, or it returns or throws an exception from a function call that is made from the test case, the SA notifies the TE about this event by using the `triEnqueueCall()`, `triEnqueueReply()`, and `triEnqueueException()` operations. These are again very similar to each other, so only the definition of the `triEnqueueCall()` is shown below:

```
void triEnqueueCall(in TriPortIdType        tsiPortId,
                    in TriAddressType       SUTaddress,
                    in TriComponentIdType   componentId,
                    in TriSignatureIdType   signatureId,
                    in TriParameterListType parameterList)
[T3TRI: s.5.5.4.4]
```

When the SA somehow catches a function call made by the SUT (there could be a thread waiting for function calls), it passes the information of the function call to the TE by using the `triEnqueueCall()`, which has parameters identical to its counterpart `triCall()`. Like in the case of `triEnqueueMsg()`, the TE can determine the right values for the TSI port and the component identifier required in the `triEnqueueCall()`, by using the mapping information it has stored during the `triExecuteTestCase()` and the `triMap()` operations, along with any information it has on the connections it has established with the SUT.

4 GENERAL PURPOSE SA

A new concept called Connection Manager System is specified in this chapter. It is a framework for such a SUT Adapter, that provides simultaneously different kinds of connections with the test target. A connection can be of any kind: it can be a simple TCP over IP connection, or it can be a connection that performs library function calls at the SUT.

The framework has the following properties: Connections can be established and controlled from TTCN-3 test case level during test case execution. This can be done in a uniform way, meaning that there is a fixed set of operations with which all the different kinds of connections can be handled. The system does not limit the number of different connections to the number Test System Interface ports. A test case component can configure a connection via any TSI port by using any connection means, independently of any other connections that other components might have configured via the same TSI port. All the control information is separated from user data, meaning that the type definitions of the tested protocol or function parameter types contain no extra fields. New connection methods can be added easily into the system, and they can have their own parameters, which affect how connections are established and controlled.

4.1 Motivation and Background

The purpose of the SA is to provide means for the TE to communicate with the SUT. As it was described in the Chapters 2 and 3, TTCN-3 provides both message- and procedure-based communication operations between the TE and the SA. When the communication is message-based, from the TE to the SUT direction, the SA receives an instruction from the TE to deliver a message from a TE component to a certain access point at SUT. In the case of procedure-based communication, the SA receives an instruction to call a function, or to reply to function call, at a certain access point at the SUT.

In both cases, the SA has to transfer instructions from the TE to an entity at a SUT service access point (SAP), which finally performs according to the instructions. The purpose of the SAP entity is for example to pass messages to the SUT, or to call SUT interface functions and to pass return values to them. Depending on the case, the SAP entity can be seen either as part of the SA, or as a part of the SUT. In the case the SUT is a TCP/IP - capable WWW server, then the SAP entity is the TCP/IP implementation of the SUT, with which the SA establishes TCP/IP connections. If the SUT is a function library, then the SA has to implement the SAP entity, which calls the tested functions according the instructions received from the TE.

Implementing an own specific SA for each SUT is unreasonable. In many cases a similar access points with the SUT exists, or they can be implemented without great effort. An SA implementation that knows how to use TCP/IP can be used with any SUT, that understands how to receive and transmit messages over TCP/IP. An SA with a Frame Relay implementation can communicate with a SUT with a Frame Relay access point. In the case of testing library functions, a dedicated protocol can be used to instruct the receiving entity at SUT-side of the connection to perform function calls or to receive them.

These different SAs can be integrated into one super-SA, which provides their combined functionality in one package. The benefit of this is that during a single test case it is possible to establish connections with the SUT with more than one different communication means, which gives the test case designer more freedom on what kind of test cases can be written. To make the usage of all the different connection means easy to the test case writer, the super-SA should provide a single uniform control interface for them. To make further development of the super-SA feasible, its design has to be such that one can add new connection means to the system without causing changes to any existing TTCN-3 test case code. At the SA level it has to support registration of different kinds of connection means into the system, without making any assumptions on how they work internally.

Figure 4-1 shows a snapshot of a possible test configuration, in which the Implementation Under Test (IUT) is a module having a network interface visible outside the SUT, and internal procedure interfaces for communication with the other SUT-internal modules. The super-SA contains functionality for establishing both network connections and procedure connections at the same time. The network connection can be a TCP-socket connection with the IUT module, with which the network-side behaviour of the IUT

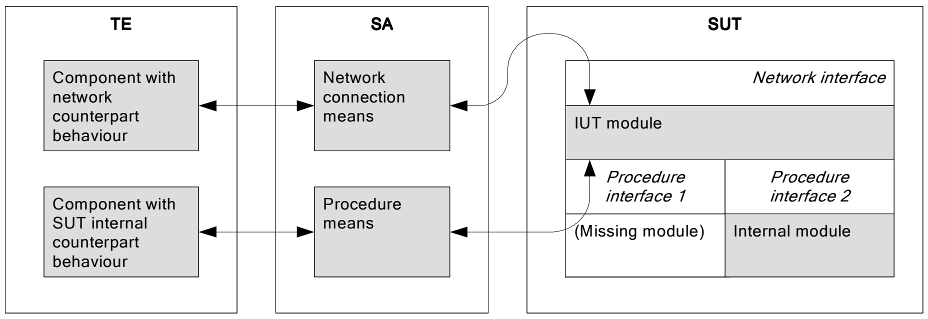


Figure 4-1: Two different connection means during a test case.

module is tested. In addition to this, the procedure connection can be used to verify that the tested IUT module performs correctly with the SUT module, whose implementation a test case component imitates. The test case could be such, that first a message is sent to the IUT module via the network connection. As the result, the IUT calls a certain interface function, whose call is observed via the procedure connection. In the test case, it is then checked that the IUT called the right function with the right parameters, after which a return value of the function is passed back to the IUT module via the procedure connection, and the IUT can continue its execution.

4.2 Connection Manager System Concept

By using the Connection Manager System (CM System) introduced in this section, the SA can maintain *connections* during test cases. The concept of the system is presented in Figure 4-2. The CM System is a subsystem within the SA entity. The term SA is used in this document to reference to that part of SA, which implements the TRI interface and any other functionality that is not implemented by the CM System. The CM System consists of a CM System Component, Connection Manager Classes (CM Classes), and Connection Managers (CMs). Interfaces between the Test Case Component and the CM, the SA and the CM System Component, the CM System Component and the CM Class, and the SA and the CM entities are specified in Chapter 5 and in Appendix A. The greyed out entities in the figure provide optional helper services, and their purpose is only briefly discussed in this work. CM-prefix is omitted in the text when referencing to the class and system entities, when this causes no ambiguity. The presentation in the figure is abstract, meaning that in a real implementation each element can represent a class, but they do not have to.

The term *connection* has different meanings in this document depending on the context where it is used. When the CM System Component is requested to open a communication channel for a certain test case component by using some CM Class, and the system component manages to pass the request to the chosen class, then from the behalf of the CM System Component a *connection* has been opened. This does not necessarily mean that a transmission protocol link has been established with the target. Each *connection* is managed by a Connection Manager, which the test case component may instruct to open a *connection* with a certain SUT point, or to accept *connection* requests from it. If the transmission protocol used by the CM is invisible to the test case component, i.e. the component receives the data payload only and no status information regarding the used protocol, then the *connection* between it and the SUT as seen by the component is present, whenever the component may assume it is valid to send to or expect a message from the SUT. This is irrespective of the state of the transmission protocol, which is handled by the Connection Manager. If applicable, the Connection Manager may open a new *connection* between it and the SUT for each message, and this can be invisible to the test case component.

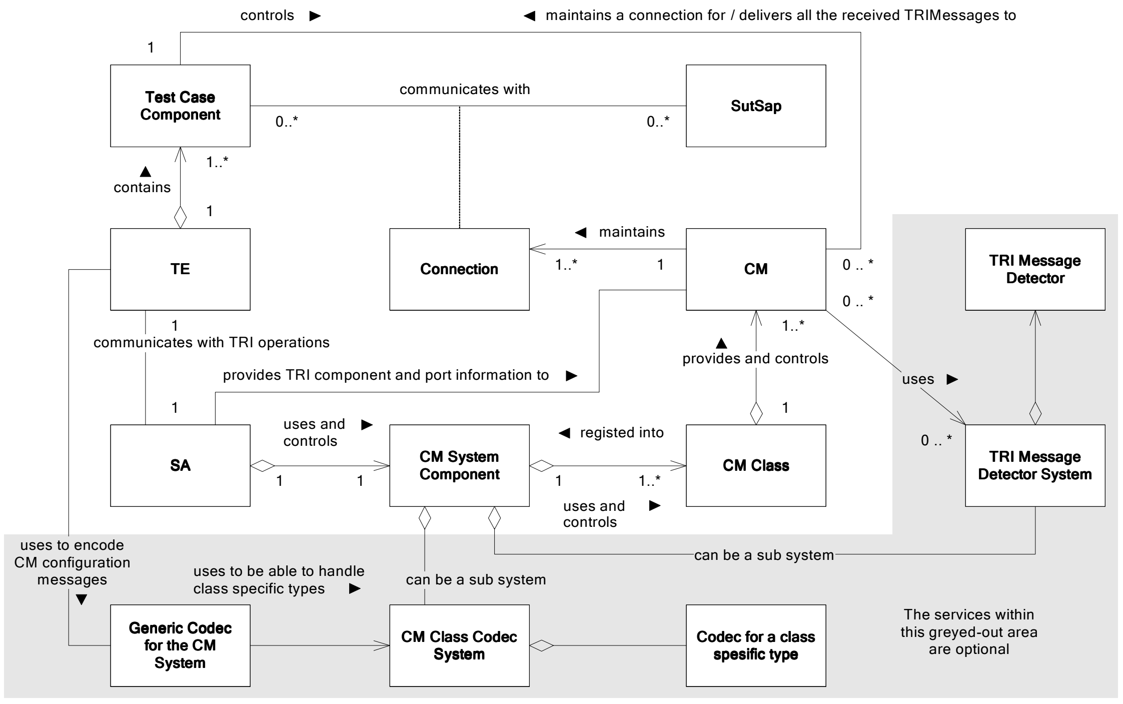

controls ►
◄ maintains a connection for / delivers all the received TRIMessages to
1
Test Case Component
communicates with
SutSap
0..*
0..*
1..*
▲ contains
1
◄ maintains
TE
Connection
1..*
1
CM
0 .. *
0 .. *
TRI Message Detector
1
communicates with TRI operations
1..*
▲ provides and controls
provides TRI component and port information to ►
uses ►
1
uses and controls ►
◄ registed into
1
0 .. *
SA
CM System Component
CM Class
TRI Message Detector System
1
1
1
1..*
uses and controls ►
can be a sub system
uses to encode CM configuration messages ▼
uses to be able to handle class specific types ►
can be a sub system
Generic Codec for the CM System
CM Class Codec System
Codec for a class spesific type
The services within this greyed-out area are optional

Figure 4-2: Relationships between the entities in the Connection Manager System concept in UML-notation. Note: This is an abstract representation of the system; the class entities in a real implementation can be different.

The purpose of the Connection Manager is to take care of a connection during its existence, starting from the establishment of the connection to its tear down procedures. Once the connection has been opened, the Connection Manager handles all the details of the protocol (or protocols) that forms the transmission means between a test case component and the SUT. Every Connection Manager belongs to a certain CM Class, and they can be seen as instances of the class or as entities controlled by the class. Each CM Class provides certain kind of connection means, or other services, for test case components, and they all offer the same interface to the CM System Component. The CM System Component has an interface with the SA, which allows the classes to be registered into the system, and via which the SA can use the services provided by the CM System.

Test case writer configures the CMs via a Test System Interface port that has been selected to be one of the control ports. All the messages the SA receives via the control port are interpreted as control messages to the CM System Component. If a non-control message is sent via the control port, it is considered as corrupted message by the recipient. There can be more than one control ports in the system if this is applicable. In addition to these CM System configuration ports, there can be dedicated ports for configuring the SA itself, but that feature is outside the scope of this document. All the other TSI ports are called data ports, since all the messages received from them contain encoded data, that the SA delivers to the SUT by using the CM System.

When a component in the TE wants to send a message to a certain SUT address, or to make a procedure operation, it executes a TTCN-3 communication statement (e.g. `send`, `call`) with the following results. The TE calls the TRI communication operation (`triSend()`, `triCall()`) corresponding to the communication statement to request the SA to perform according to the statement. Next, the SA constructs a request from the parameters of the TRI communication operation, and passes it to the System Component to be handled. The SA does not have to know anything about CMs, classes or their configuration; it only sees the interface provided by the System Component. Once the SA has passed the request to the system, it returns from the TRI operation call, without having to wait for the request to be completed by the system. The System Component passes the request to the right CM of the used CM Class, which finally transmits the message to the SUT end-point of the connection, or performs a procedure operation such as function call. Depending on the implementation of the interface functions, the CM System Component passes the message either directly, or via the CM Class, to the right CM. The chain of events in sending and receiving direction is show in Figure 4-3.

In the receiving direction the events are simpler: The CM receives a message or procedure operation from the SUT. After this it requests the TE to enqueue the message or the procedure operation to the port queue of the right component by using a `triEnqueue*()` operation of the TRI interface. These operations require as parameters the identifier of the receiving component (`TriComponentIdType`) and identifier of the TSI port (`TriPortId`) with which the component's data port has been mapped. The CM can query for this information from the SA.

Depending on the transmission protocol used by the CM, it is either trivial or not for the CM to determine in message-based communication when the data received from the SUT should be enqueued to a component. In the case each transport protocol PDU always contains data for one test case level message, then the enqueueing is easy, since it can be done after each received transport protocol PDU. If a single transport PDU may contain several encoded TTCN-3 messages, or if the messages may arrive in several transport PDUs, then message detection is needed. This is because the only form in which the CM can pass the received data to the TE is the form of `TriMessageType` (Section 3.4 shows the operation signatures), which has to contain all the encoded data that is needed by a decoder to decode a single value. It is not possible to pass data for several values simultaneously, or to append more data to the already enqueued data. If the passed data does not contain a single value in its encoded form, then its decoding will fail and the data is lost.

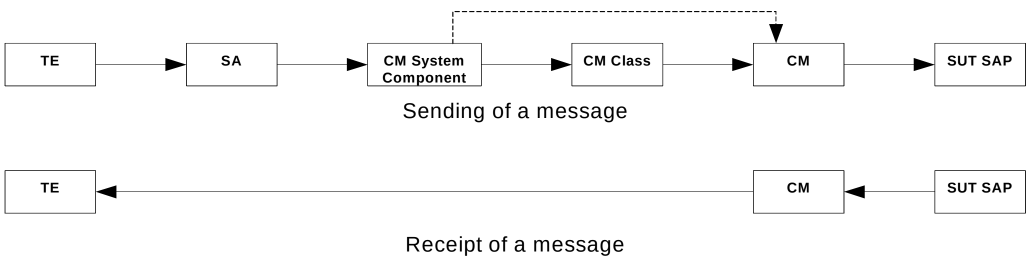


Figure 4-3: Send and receipt of a message.

TRI Message Detector System is an optional system used by the connection managers to identify messages and their boundaries from the receive data. A single TRI Message Detector detects message boundaries by a certain general rule, which is either a generic rule or specific to the messages that are expected be received from the SUT. The message detectors are independent of the used transmission protocol; they only see a stream of payload data. The detectors are registered into the TRI Message Detector System, which offers a single interface via which the detectors can be used. The Connection Manager may use one or more different detectors on the received data at the same time. The detector system can be seen as a rough decoder system, which decodes the received data just enough to be able to determine the message boundaries. The complete decoding is done later by the TTCN-3 codec system. Further specification of TRI Message Detector System is outside the scope of this document.

In the following example detection is needed. A Connection Manager uses a connection-oriented protocol like TCP as the transmission protocol. It is wanted, that the connection is kept open during the test case so that several TTCN-3 level messages can be exchanged without having to re-establish the connection after every message. The encoded messages contain length field as the first field, so the Connection Manager can use a TRI Message Detector that decodes the length field and keeps track on the received byte count. When enough data has been received for a complete test case level message (a value of a certain TTCN-3 type), the detector notifies the Connection Manager about this. In order that the Connection Manager knows to use a specific message detector, the test case writer has to configure the CM to use it. This can be done for example at the time when the connection is opened, by giving the CM a list of used detectors as open-request parameters.

CM Class Codec System is optional system, which can be used to implement generic codecs for the CM System. The connections with the SUT are configured with CM System Component specific configuration-message types, which in turn contain CM Class specific types (5.2 Connection Interface). When a configuration message is sent to or received from a CM, a codec associated with the configuration message is called, and this codec should be able do the encoding and decoding of the whole message. The codec could be a generic one, or there may be an own codec for each of the configuration-message types. Because it is allowed that each CM Class may use any kind of class specific configuration parameters, the configuration messages contain these class specific parameter values encoded in a class specific manner. Without a generic codec this is a problem, for the reason that one should be able to add new CM Classes into the system without the need to rewrite existing code. If new CM Classes were added into the system, then in the case of a non-generic configuration-message codec one would have to rewrite the codec to contain coding instructions for the types of the new classes. For a generic codec approach the CM Class Codec System provides methods for the configuration-message codecs to query for class specific codecs by type identifiers and by encoding attributes, when they are unable to do the encoding on their own. The class specific codecs can be registered into the CM Class Codec System at the same time when the classes are registered into the CM System, or at some other time when the tool specific initialization operations are done (if such exist).

4.3 Requirements

The CM System has requirements at TTCN-3 core language level, and at the SA implementation language level.

At TTCN-3 core language level is the user, to whom the system should be easy to be used and hard to be misused. The user should have access only to the configuration parameters of connection, and not to any meta-data that is meant to be used internally by the system. In addition to this, any configuration data should be kept separate from any user data, meaning that when the user tests a certain protocol, the type definitions of this protocol contain only the message fields of this protocol; there are no extra control fields added to these type definitions. This allows (or forces) the CM System to deliver the user data between test target and the test case components transparently, without the need to strip away and add control data to every sent and received message. All the different connection types should be configurable using the same methods, and it should be possible to query status of the connections when required. Addition of new connection means to the system should not affect the functionality of any existing test cases or other connection means.

At the SA level, the system should provide the possibility to add new transport protocols into the system easily, without having to do major code modifications into the system. The CM System may not assume anything about the implementation of the CM Classes. The user (or test case) should be automatically reported about error situations, such as when a connection with a target is lost, or the target cannot be reached.

In the terms of performance, the CM System implementation should be as light as possible; it should only cause minor overhead to the TRI-operation handling. Concrete performance requirements depend on what is being tested, and what kinds of transport protocols are used.

4.3.1 Connections

In Figure 4-4, two test case components can be seen communicating with *four* SUT addresses over *three* data connections. Component X has its data port Port 1 mapped to TSI Port 1. This connection is handled by a connection manager CM A1, which belongs to CM Class A. Connection Managers of this class use a protocol A to realize at the SUT the test case statements, that are executed using the component ports. The same component has another connection via Port 2 to another SUT address. This connection belongs also to Class A, but it is handled by the manager A2, independently from the first connection. Component Y uses a single port, Port 1, to communicate with two different

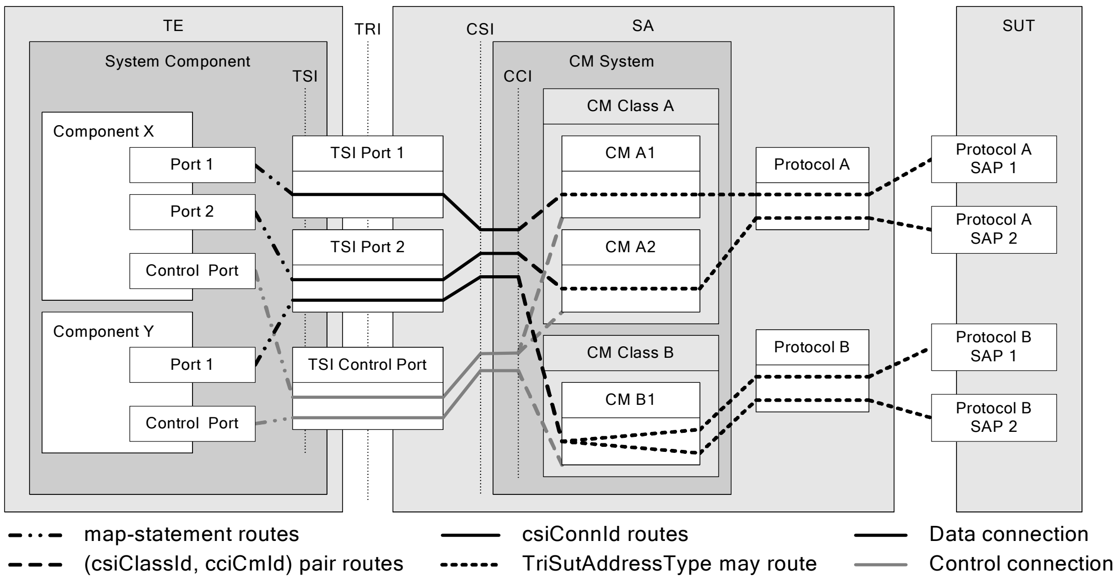


Figure 4-4: Connections and identifiers.

SUT SAPs. This is possible, because the Class B connection manager uses `sutAddresses` to identify two different protocol-B destination addresses. Class B CMs could be servers, which accept incoming connection requests and data from one or more SUT addresses, which do not have to be known before the test case. This may be the case when the protocol B is TCP or UDP, and the operating system of the SUT assigns any free port addresses to the connections established from it. The protocols used by the CMs do not have to be network protocols. They can be any methods, like function calls, with which the CM realizes the intended effect of the TTCN-3 Core Language port operations at the SUT.

In the same figure Port 2 of Component X and Port 1 of Component Y share the same TSI port, but both communicate with the SUT over different protocols. It is possible to choose the used CM Classes independently from the TSI port configuration. This means, that it is not a prerequisite to have a TSI port of certain name or type specified in a test case to be able to use a certain CM Class. The test case designer may choose to configure all the TCP connections via the same “tcp”-titled TSI port, but this is not required by the system.

Every component mapped with a TSI data port has at least one control port, which is mapped with a TSI control port. This control port of the component is used for establishing and maintaining the data port connections of the component. The messages sent by the component via the control port are received by a CM, and the messages the component receives from it are sent by the CM, hence, there is a bi-directional control connection between the component and the CM. A single control port can be used to control several data connections, which are each handler by an own CM, as is the case with Component X in the Figure 4-4. The CM System Component knows how to route the control messages to the right CM.

The data port to be configured is identified by a value of type `CiTsiPortId`, which is present in every configuration message that is passed between a component and a connection manager (Section 5.2, Table 5-2, Figure 5-3, Figure 5-4). This value contains the name of TSI port (text string), with which the data port of the component has been mapped; it is not the name of the data port of the component. `CiTsiPortId` uniquely determines the data port of the component, because according to the standard [T3CORE:

s. 8.2] only one port of a component may be mapped with a certain TSI port at a time. Also, when a message should be delivered to a certain port of a component with a TTCN-3 Runtime Interface communication operation (Section 3.4), the port is identified by the name of the TSI port, with which it has been mapped. The TE takes care of passing of the message to the right port of the component.

Each component may only configure its own data connections. The reason for not allowing one component to configure a connection via a port of another component is that the components do not have names or identifiers, which could be used to address them both at the TTCN-3 language level and at the SA implementation level. At the TTCN-3 language level a component does have component reference that can be stored into a variable of the type of the component, and which can be used to address a component within a test case, but this reference value cannot be passed to the CM System via the TRI interface. This is for the reason that the TCI interface does not provide operations for encoding and decoding of the values of the component reference kind.

The components may not share connections by simply mapping their own port with a TSI port, which is already used by another component. If a component has configured a connection of a certain kind via a certain TSI data port, and another component maps its data port with the same TSI data port, this second component cannot send or receive messages or procedure operations via the TSI data port, until the second component has performed its own port configuration operations. When the SUT sends a message to the TE via a TSI port, which has been mapped with several components, but only one of them has configured the TSI port, then the received message is relayed only to the component that has done the configuration. If they all want to receive messages via the TSI port, they have to do their own configuration. This restriction comes from the design choice, that each component may configure an own connection independently via any TSI port, irrespective of any other possible connections that use the same TSI port. If it is required, that several components mapped with the same TSI port share the same connection, then this functionality has to be provided by the used CM Class. In this case, each of the components may do the configuration by instructing the CM Class, that they want to join a shared connection.

The port of the component used for a data connection must be mapped with a TSI data port, before the connection through it is attempted to be configured via a control port. This is required to avoid the situation, in which data is received from the SUT right after the connection has been opened, and it is directed to a component data port that has not been mapped to a TSI port. This does not necessarily mean, that data is automatically started to be received from the SUT when a new connection is opened. It depends on the used CM Class and its configuration, whether a separate control messages exists, with which one can instruct a CM to start and stop sending of the received data to the component.

Once a component has mapped its control port to a TSI control port, and has configured a connection for a data port, it should remain mapped to the control port for the lifetimes of all those connections that are controlled via the control port. Because this requirement cannot be enforced, the SA should instruct the CM System Component to terminate all the existing connections the component has that are maintained via a control port, when this control port is unmapped from the TSI control port. In Figure 4-4 this means, that if Component X unmaps its control port, then the data connections via its ports 1 and 2 become automatically terminated.

When a component does not need anymore a data connection, it should instruct the CM of the connection to close the data connection. Because this requirement cannot be enforced, the SA should instruct the CM System Component to terminate the data connection, when the related data port of the component is unmapped from the TSI data port.

The SA does not need to know which TSI port or ports are used for the control. The CM System Component performs the identification of the ports on the behalf of the SA.

4.3.2 Identifiers

Each connection is handled by a Connection Manager, which belongs to a certain CM Class. Every class has to provide at least one manager that can handle at least one connection at the same time, but there can be several managers running concurrently within the class, serving several simultaneous connections. It is a design choice of the class how many connections the class supports at a time, and whether one manager handles them all. Seen from outside the class, each connection is always handled by an own manager, which has a unique identifier within the class.

All the connection related operations the CM System Component provides to the SA use an identifier called `csiConnId`. It can be extracted from the (`TriComponentIdType componentId`, `TriPortIdType tsiPortId`)–pair, which is present in all the TRI communication operations (Sections 3.4 and 3.5 describe these operation). This identifier is used by the CM System Component to uniquely identify connections, thus all the CM System Interface operation calls done with the same `csiConnId` as a parameter operate on the same connection. It is worth noticing, that the `componentId` identifies a *test component*, but the `tsiPortId` identifies a port of the *test system interface component*. These types and their contents are shown in Figure 4-5. Types of the internal fields of `TriComponentIdType` and `TriPortIdType` are not shown in the figure, since these depend on the used language mapping (C, Java) of the TRI interface. The types used within `csiConnId` are specified in Section A.1 CM System Interface.

The `csiConnId` identifier is now defined to be the triplet (`componentInstString`, `portNameString`, `portIndex`) (see Figure 4-5). The `componentInstString` is the string stored in the `componentInst` field of `TriComponentIdType componentId` in the ANSI C type definition of TRI language mapping. In Java mapping, it is the value received with `getComponenId()` method of the `TriComponentId` interface. `portNameString` and `portIndex` are the fields of `TriPortIdType tsiPortId`.

Within the CM System Component, `csiConnId` is mapped to the identifier of the Connection Manager, that is handling the related connection. This CM identifier is called `cciCmId`, and it is unique within a CM Class. A CM Class identifier, `csiClassId`, is

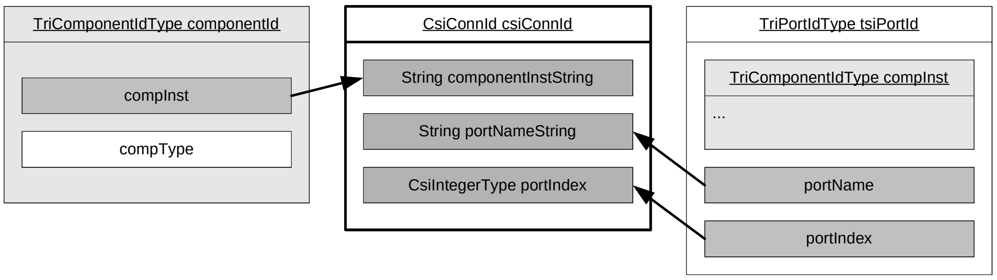


Figure 4-5: Structure of `csiConnId`.

used together with the `cciCmId` to uniquely identify a CM between classes. The classes are registered into the CM System Component with their unique `csiClassId` identifier, whose value is the field name of the class in the TTCN-3 union type `Ci<OperationName>Params`: E.g., a variable `CiOpenParams class` is a union value, whose different field names could be `.socket`, `.frameRelay`, `and .atm`. Each of these serves as the `csiClassId` identifier of the related class. This is explained further in Section 5.2.2.

The `TriAddress sutAddress` value, which is present in the TRI communication operations as one of the parameters, is not used in the `csiConnId`. The reason is that its TTCN-3 core language level form, `address` value, is optionally present in the communication operations. If it was used in the `csiConnId`, then it would have to be either used, or not used at all, in all the core language level communication statements (`call`, `send`) concerning a certain connection, because the CM System Component maps the value of `csiConnId` to the identifier of CM that handles the connection (explained later in 4.3.3 Information storage). Its usage would also complicate error handling in the situation in which connections are closed improperly, because it is not present in the `triUnmap()` operation (A.1.2 Operations: csiConnTerminate). Nevertheless, the `address` value is always passed transparently by the CM System Component to the CM Classes. Since the `csiConnId` is not dependent on the usage of the address value, the address can be used for example only when a new connection is opened, and it may be omitted in all the operations after that, if this is permitted by the used CM Class. The CM handling the connection may use the `address` values to address several elements within the SUT by using them as sub-connection identifiers.

4.3.3 Information storage

The CM System and the SA have to maintain information on the connections. It must be know how components are mapped into Test System Interface, so that the system knows where the received messages should be delivered to. In order for the CM System to know what CM Classes are present in the system and how they can be accessed them, a class register is needed. When data should be delivered to the SUT, it must be known to which connection the data belongs, and what CM is handling the connection. For each connection, it must be known what is the SUT end-point address of the used transport protocol, and what is the state of connection. One way to store the information is shown in Figure 4-6, which is explained in the following paragraphs.

The SA maintains the mapping information of the Test System Interface (TSI). During the `triExecuteTestCase()` operation it stores the port list of the interface and removes the old one if such exists. In the `triMap()` and `triUnmap()` operations it updates a register called `tsiMap` to contain the information which component port is currently mapped with which TSI port. As the parameters of the `triMap()`, the SA receives `TriPortIdType compPortId`, and `TriPortIdType tsiPortId`. From the `compPortId` it extracts the identifier of the component, `TriComponentId componentId`, from which a component identifier string can be extracted. From the `tsiPortId` the SA extracts the `portName` and `portIndex` values. Together with the component identifier string, the `portName` and `portIndex` form a `csiConnId` as explained in Section 4.3.2. By using this `csiConnId` value as the key, the SA stores the (`TriComponentIdType componentId`, `TriPortIdType tsiPortId`)–pair into `tsiMap`. When a CM has to perform a `triEnqueue*()` operation (Chapter 3), it queries the parameters of this operation from the `tsiMap` data structure by using a `csiConnId` as the key. The relationship between the types is illustrated in Figure 4-7.

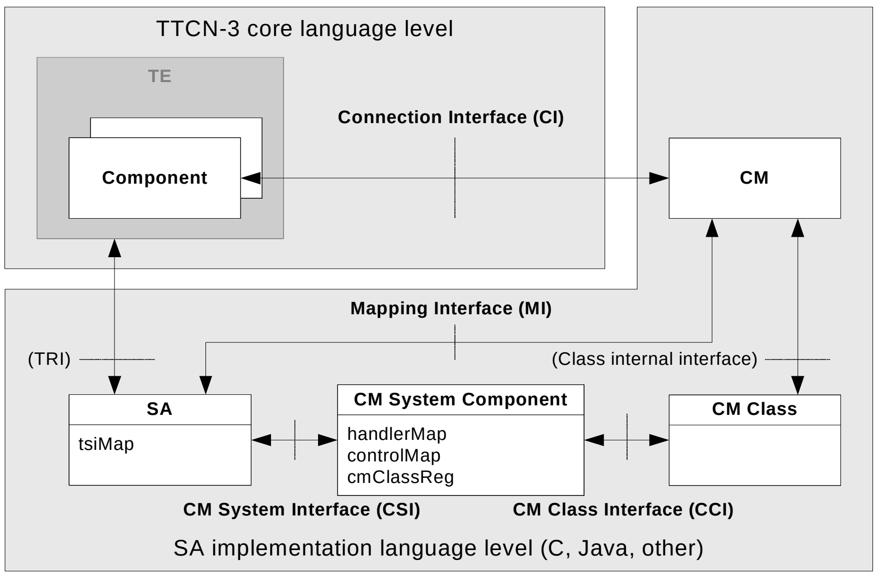
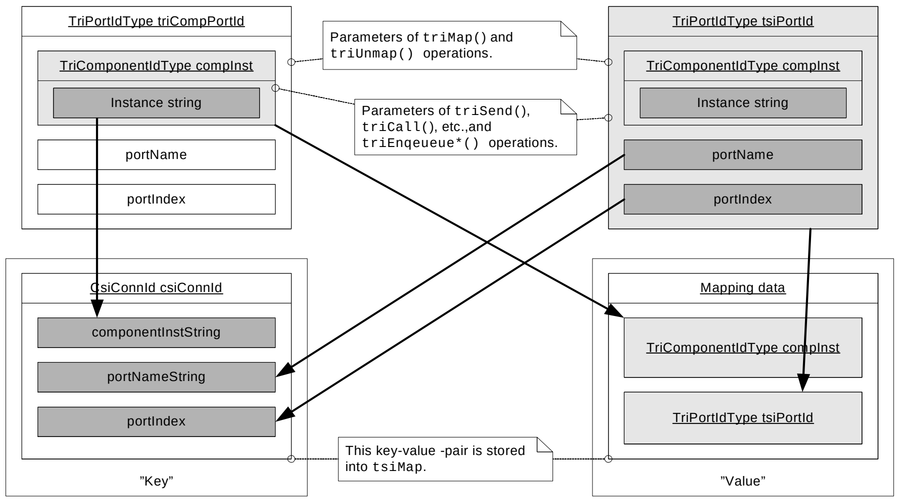

TTCN-3 core language level
TE
Component
Connection Interface (CI)
CM
Mapping Interface (MI)
(TRI)
(Class internal interface)
SA
tsiMap
CM System Component
handlerMap
controlMap
cmClassReg
CM Class
CM System Interface (CSI)
CM Class Interface (CCI)
SA implementation language level (C, Java, other)

Figure 4-6: Required interfaces and information storage in the CM System.

The reason why the component and port identifiers are stored into the `tsiMap` which is located in the SA, instead of passing own copies to the CMs that need them, is to keep their values always valid. A copy of a (`componentId`, `tsiPortId`)–pair stored into a CM would become invalid when the specified component unmaps its own port from the specified TSI port. The standards leave it open what happens if a `triEnqueue*()` operation is called with out-of-date values, thus the `tsiMap` is used to make the system portable between different TTCN-3 tools. Its usage prevents the TE from altering mapping information with the `triMap()` or `triUnmap()` operations, when a CM is about to use a certain (`componentId`, `tsiPortId`)–pair to send a message or procedure operation to a component. The usage of `tsiMap` is further specified in Appendix A.3.

The CM System Component maintains a class register, `cmClassReg`, which contains the information what CM Classes are available to the system, and how the CM Class Interface functions implemented by them can be called. Each class can have their own implementation of the CM Class Interface functions, but they all share the same interface.

In addition to the class register, the CM System Component contains a data structure `handlerMap`, which is used by the CM System Component to pass all the communication operation requests from the SA to the right CMs. This data structure contains mappings from a `csiConnId` to the pair (`csiClassId`, `cciCmId`), in which



TriPortIdType triCompPortId
TriComponentIdType compInst
Instance string
portName
portIndex
Parameters of triMap() and triUnmap() operations.
Parameters of triSend(), triCall(), etc.,and triEnqeueue*() operations.
TriPortIdType tsiPortId
TriComponentIdType compInst
Instance string
portName
portIndex
CsiConnId csiConnId
componentInstString
portNameString
portIndex
"Key"
This key-value -pair is stored into tsiMap.
Mapping data
TriComponentIdType compInst
TriPortIdType tsiPortId
"Value"

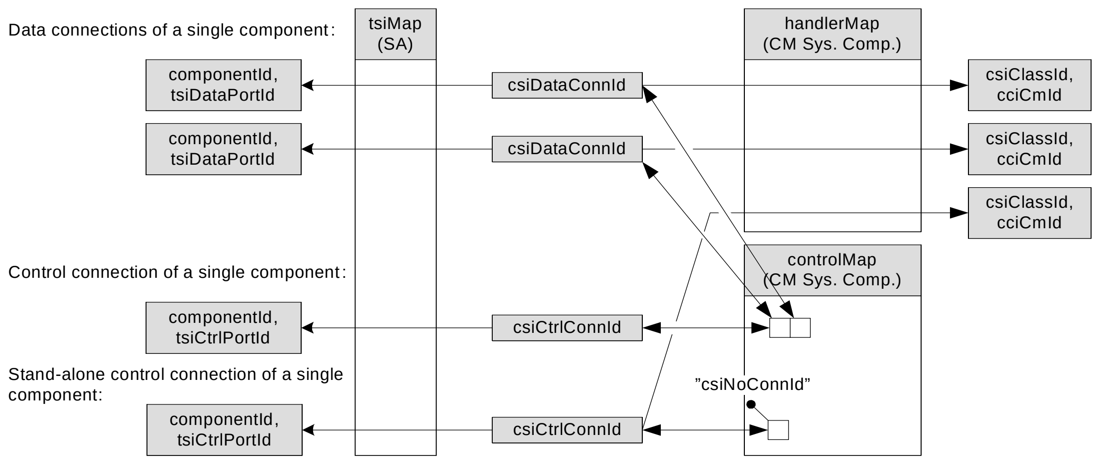
Figure 4-7: The information stored in `tsiMap` data structure and the relationship between `CsiConnId`, `TriPortIdType`, and `TriComponentIdType`.

`csiClassId` is the class identifier of the CM, and `cciCmId` is the identifier of the CM, that is handling the connection (see Figure 4-8). The `cciCmIds` are generated by the CM Classes, when the CM System Component requests them to create new managers to handle new connections. These identifiers are unique within a class. It would be possible to place a mapping data structure similar to the `handlerMap` within each class, but then each class would have to implement it, instead of having it done in one place.

Because of the requirement, that the data connections related to a control connection are closed when the control connection is terminated, the CM System Component has to maintain a data structure, which contains the information which data connections are controlled by a certain control connection, and what is the control connection of a certain data connection. This information is stored into the data structure called `controlMap` (see Figure 4-8).

Each CM Class maintains identifiers of its CMs. When the CM System Component passes an operation request along with a `cciCmId` identifier to a CM Class by using CM Class Interface operations, the class knows from the identifier which CM should handle the request.

Each CM maintains information on the connection it is handling. Either it knows the `csiConnId` of the data connection it is handling and the identifier of the related control connection, or it asks them from its class. The CM can use the `csiConnId` to ask from



Data connections of a single component:
tsiMap (SA)
handlerMap (CM Sys. Comp.)
componentId, tsiDataPortId
csiDataConnId
csiClassId, cciCmId
componentId, tsiDataPortId
csiDataConnId
csiClassId, cciCmId
csiClassId, cciCmId
Control connection of a single component:
controlMap (CM Sys. Comp.)
componentId, tsiCtrlPortId
csiCtrlConnId
Stand-alone control connection of a single component:
"csiNoConnId"
componentId, tsiCtrlPortId
csiCtrlConnId

Figure 4-8: Relationship between the mapping data structures and the identifiers. Double-headed arrow means that the mapping is in both directions.

SA the related (componentId, tsiPortId)–pair, which is stored into tsiMap, when it wants to send messages and procedure operations to a test case component with the triEnqueue*() operations. When a new data connection is opened (related operations are A.1.2: csiConnOpen, A.2.2: cciConnOpen), the csiConnId of the data connection and its control connection are passed the CM Class, which in turn may pass them to the CM.

The following summarizes the usage of the mapping data structures shown in Figure 4-8: The tsiMap maps a csi*ConnId value to a (componentId, tsiPortId)–pair, which is needed by the CM when it has to pass a message and procedure operation to a test case component. When a csi*ConnId value identifies a control connection, then the controlMap is used by the CM System Component to retrieve the identifiers of the data connections, that are controlled by the control connection. The handlerMap is used by the CM System Component to map a data connection identifier to the (csiClassId, cciCmId)–pair, in order to find out which class and which particular CM is handling the data connection. In the special case when a control connection does not control any data connection, the identifier of the control connection is used directly with the handlerMap. The CM System Component uses the csiClassId to find the right interface functions from its cmClassReg (not shown in the figure), when it needs to pass a connection related operation to CM of a certain class.

4.3.4 Concurrency

In TTCN-3 Runtime Interface [T3TRI: s. 4.3] it is specified, that all the TRI operations, except the external function call, are non-blocking. With non-blocking it is meant, that blocking during a TRI operation may not have any effect on the test system at the test case level. The non-blocking requirement can be fulfilled by having separate worker threads and a task queue, into which the TRI operations are enqueued.

To make the CM System independent of the concurrency model of the TE implementation, and of the SA implementation, all the CM System Interface operations belonging to the connection category (listed in A.1) must be non-blocking and thread-safe. All the system and class category operations of CM System Interface are thread-safe but blocking. They are blocking because they are initialization and finalization related operations. It is wanted that they do not return until their intended effect has been completely performed, so that the state of the CM System can be guaranteed after these operations.

4.3.5 Operation handling order

When a test case component performs a sending operation (`send`, `call`, etc.) on a port that is mapped with a TSI port, this results in a corresponding TRI operation. In TTCN-3 Runtime Interface Standard [T3TRI] it is specified, that as the result of a TE-initiated TRI communication operation, the SA can act according to the operation. It is not required that the SUT has experienced the intended effect of the operation before the TRI operation returns, thus the operation can be delayed by buffering it into a queue. How and when the operations are handled is outside the scope of the standard. The CM System provides the SA the means to handle the TRI operations. With *operation handling order* it is meant the order in which the CM System Component, the CM Classes, and the CMs, process the operation request the SA makes to the CM System. This order is not self-evident; it depends on the interpretation of the test system interface, and on what is wanted.

On interpretation of the test system interface

The test system interface is an abstract interface, which in some way provides a mapping to the real interface(s) of the SUT. It is not specified where this abstract interface is located. It can be though of being located at the SUT, or at the TE or SA, or somewhere in between.

If it is assumed that the ports of the TSI reside at the SUT as illustrated in Case A of Figure 4-9, and that a mapping between a component port and a TSI port works the same way as a connection between two component ports, then it could be assumed that all the port operations performed on a component port mapped with a TSI port are seen at the TSI port in an unchanged order. It would be up to the SA or the CM System to make sure the operations appear in order at a SAP of the SUT. Of course, one might argue that the propagation of messages from a component port to a TSI port does not have the same

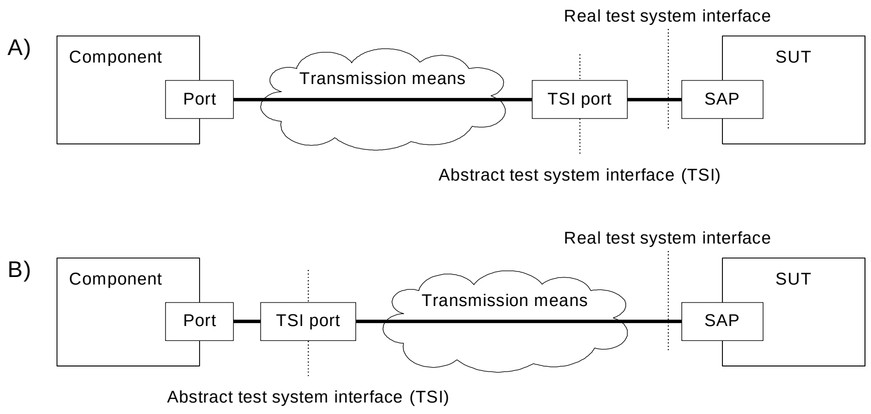

A)
Component
Port
Transmission means
TSI port
Real test system interface
SAP
SUT
Abstract test system interface (TSI)
B)
Component
Port
TSI port
Transmission means
Real test system interface
SAP
SUT
Abstract test system interface (TSI)

Figure 4-9: Two interpretations of the location of the TSI.

meaning as when they move between two component ports, and it is subject to effects of the used transmission means, but this would make it harder to write test cases in which the order of events is guaranteed.

If it is assumed, that the TSI ports are at the SA as show in the Case B in Figure 4-9, do the operations now have to be guaranteed to be experienced by the SUT in the same order in which they are executed in a test case? The answer to this is not necessarily. If the communication with the SUT can only be accomplished by using a connectionless protocol like UDP, and the SUT has been designed and intended to communicate over this unreliable protocol, it would not make sense to build such a mechanism into the SA, CM System or the SUT, that ensures unchanged packet order during transmission. In this case, the person who runs the test cases should ensure that the transmission network used in the test system is simple enough not to introduce any changes to the packet order.

Because the situation B in Figure 4-9 gives more freedom on what kind of transmission means can be used, that interpretation is chosen in this document. It does not mean that the operation order is never preserved, but that it can be an optional feature of the used CM Class.

Operation handling within the CM System Component

Because the test case components or ports have no execution priority, it is natural that all the communication operation requests are handled by the CM System Component in the first-come, first-served manner. The CM System entity does not have understanding on the parameters with which connections have been configured, thus they have no effect on the handling order. When the SA has requested the CM System to perform connection related operations by using the CM System Interface operations (A.1.2 Operations), the CM System may choose to enqueue these operation requests into a list, or it may handle the operations directly, but it may not change their relative order. With the handling it is meant, that CM System Component passes the requests to the right CM Classes and CMs.

Operation handling within a CM Class

The CM System Component requests the CM Classes to perform connection related operations by using the CM Class Interface (CCI) as specified in A.2.2 Operations. The identifier of the CM that is handling the connection is present in these operations. The order in which the CM Class forwards the operation request concerning a single connection to a specific CM is the same as in which they have been requested to be done by the CM System Component.

However, it is allowed that the relative order of operation requests that are directed to different CMs (i.e. do not belong to the same connection) does not need to be preserved. This is because a CM Class could provide priority parameters for the connections, and since each connection is handled by an own CM, the priority of the connection is the priority of the CM. Any requests directed to the CMs may be forwarded to them in a manner, which takes the priority in account. This feature could be used in high-load situations.

Operation handling between CM Classes

It is not required the classes to preserve handling order over the class boundaries. This is to allow the classes to provide any kind of transport means to the user: slow or fast, with or without guaranteed transmission order. If the classes did have a common synchronization for preserving the operation handling order, this might cause problems for example in the case, where the buffered operations of a slow connection class block the usage of faster connection class, until all the operations have been handled.

Some of the classes may provide mutual synchronization, but this should be an optional user configurable feature, unless these classes are meant to be used together and their functionality requires this.

Operation handling within a CM

Each CM preserves the relative order of the requests concerning a connection it is handling, unless the optional `address` parameter of the TTCN-3 communication statements is used by the CM as a sub-connection identifier.

If the SUT address is used by the CM to identify sub-connections, then it depends on the used CM Class and configuration parameters of the connection in which order the operation requests are handled.

With the handling within a CM it is meant, that the CM interacts with the SUT when the requested operation requires this, but it does not say anything about the order in which the SUT experiences the results of the operations. There is a possibility that the operations become rearranged during transmission, if the transport protocol used by the CM does not guarantee in-order transmission.

Operation handling between CMs of different classes

As it is not required to have synchronization between different CM Classes, it is not required to have synchronization between the CMs of different classes.

An example situation where synchronization would be harmful is two connections, one using a CM Class, which uses TCP as the transport protocol and is used for data, and another one using UDP and is used for control messages for controlling the TCP data connection. If the sending order of the messages was preserved between the classes, and if the send buffer of the TCP connection becomes full, then no control messages via the UDP connection can be sent until all the TCP data has been sent to the SUT. The situation would be even worse if the two connections were unrelated. For example, there could be one component using a UDP connection for completely other purpose than to control the TCP connection. This other UDP connection might be used for some kind of heartbeat protocol, which requires a transmission of a message at fixed intervals. It would not make sense if the sending problems with TCP data connection affected the UDP connection, since their purposes are unrelated.

Operation order at test case level

When writing a test case, in which a component communicates with several targets over several protocols, the test case writer has to choose and configure the used CM Classes and CMs so that they do preserve the test case's intended delivery order of messages and procedure operations. This is not guaranteed by default and depends on the context and the used CM Classes.

It should be noted, that when a CM passes a message or a procedure operation to a component via some specific TSI port, lets say "Port A", by using a TRI interface `triEnqueue*()` operation, and then passes another message or procedure operation via other TSI port "Port B", the receiving component cannot automatically determine which event occurred the first. The messages or the parameters of the procedure operation needs to contain a timestamp or sequence number, with which the test case component can reconstruct the order of events if this is needed, because TTCN-3 core language does not provide means to determine or compare the order of events between two ports.

5 INTERFACES

This chapter specifies the functionality of the following interfaces: Connection Interface (CI), Mapping Interface (MI), CM System Interface (CSI), and CM Class Interface (CCI), which are shown in Figure 4-6. Of these, the Connection Interface is specified in detail, because it can be thought as TTCN-3 Core Language level user interface to the services provided by the CM System, thus making it of interest to the test case writer. Understanding it also helps in understanding what the other interfaces try to accomplish. The Mapping Interface, CM System Interface, and CM Class Interface are "under the hood" at SUT Adapter level, so only an overview of them is given in this chapter. These interfaces are used for keeping TSI port information consistent (`tsiMap`), for registering new CM Classes into the system, and for using their services to communicate with the SUT. Their detailed description can be found in Appendix A. Selected MSC diagrams showing how the operations of the interfaces work together can be found in Appendix B.

5.1 Notation

All the interface operation in this chapter and in Appendix A are specified using the following format:

Operation identifier (Caller or Sender → Callee or Recipient)

In:	The parameters passed from the caller to the callee.
Out:	The parameters passed from the callee to the caller.
Return:	Return value of the operation.
Purpose:	Description what the operation is used for.
When:	Description when the operation is performed and what triggers it.

The parameters and return values are in format:

```
TypeIdentifier variableIdentifier
```

Operation has no mandatory parameters or return value if the corresponding part has been omitted in the text.

The operations and data types are specified at an abstract level. It is not required that every operation exist in an actual implementation, which may be done in C or Java language. The operations describe what needs to be done, and the in part and out part describe the mandatory information that is passed between the caller and the callee in the operations. It is not considered how the parameters are passed, when memory is allocated and freed, or what is the representation format of the types in an actual implementation. The language mappings from the abstract operations and data types to C or Java are not defined in this work.

An example situation in which the implementation does not need to follow the abstract definitions is the `csiConnDecodeOp()` of CM System Interface. This operation is called by the SA to determine which CM System Interface operation it should use to handle a `triSend()` operation call. It is possible to replace all the connection category operations (excluding `csiConnTerminate`) with a single operation, which performs the action of `csiConnDecodeOp()` and then calls the right operation directly, instead of returning the identifier of the right operation to the SA, and having it call the right operation. This would make the interface simpler for the SA, but it would unnecessarily complicate the specification of the different steps that need to be done.

5.2 Connection Interface

Connection Interface contains the operations needed to configure connections between component ports and the SUT (control operations), and for using them for communication (data operations). All the control operations are realized with the message-based `send` and `receive` statements, with a particular TTCN-3 type as the parameter. The data operations consist of all the TTCN-3 port operations that are used for communication with the SUT via a data port (`send`, `call`, `reply`, `raise`). All the operations of the Connection Interface are listed in Table 5-1.

5.2.1 On design choices

One reason for defining the Connection Interface control operations as message-based, instead of using procedure statements, is the simpler syntax of the message statements at the TTCN-3 core language level, and simpler parameters at the TRI interface.

Table 5-1: Operations at Connection Interface.

Category:	**Direction:**	**Operation identifier:**
Control	Component → CM	ciOpen
	Component → CM	ciControl
	Component → CM	ciClose
	CM → Component	ciOpened
	CM → Component	ciStatus
	CM → Component	ciClosed
Data	Component → CM	ciData
	CM → Component	ciDataInd

Another reason for using message ports is the semantics of the procedure port statements. In a test case, when a procedure is called with the port operation `call`, it is expected that at some point of time the procedure returns, and that is handled with a `getreply` statement. Similarly, after the receipt of a procedure call with the `getcall` statement, the test case should contain a matching `reply` statement. The procedure port operations can therefore been see as request-response pairs, with a dedicated pair of operations depending on which side performs the procedure call. Because of this, if the procedure ports were used, then the Connection Interface operations should also be used in a paired manner. However, it is useful to allow the connection managers to send information concerning connections without explicitly requesting for it, or without responding to it. For instance, when a CM notices that the connection it is handling is closed by the SUT or by a transmission error, it may notify the test case component related to the connection with the message-based `ciClosed()` operation. This operation is not a reply or an acknowledgement to any action performed by the component, and the component does not need an acknowledgement to it.

There exist a few reasons why the procedure-based approach could be preferred to the message-based approach, even though this approach is not taken in this work. If an own TTCN-3 signature (i.e., function declaration) is specified for each of the CI operations, then the identifier of the signature can be used to identify the CI operation. This identifier is passed over the TRI interface separately from the parameters of the function, and it does not go through any kind of encoding or decoding, unlike the parameter values (Section 3.5 describes TRI interface operations). In the message-based approach there has to be a separate operation identifier field in the transfer syntax of the messages (specified in Section 5.2.3), which has to be decoded and extracted by the recipient. This work could be avoided by using the procedure-based approach. In the procedure-based approach it is easier to access the different function parameter values, since they can be read from the parameter list. In the message-based approach they are concatenated as sequence of bytes and the recipient has to figure out when one parameter value ends and the next one starts. However, the overhead in the message-based approach is minimal, because of the few number of parameters. In the procedure-based approach the decoding of the parameters is slightly easier, since the TE knows to call the right decoders directly, meaning the decoders assigned to the parameter types. In the message-based approach, the TE has to attempt to decode from the received data a value of any of the types, that can be received from the used port, and which are being expected by the component. For example, if a component expects in an `alt` statement either a `ciOpened` or a `ciClosed` message, and a `ciClosed` message is sent by the CM, then a decoding attempt is possibly first made for the `ciOpened` type, and when this fails, a second successful attempt is made for the `ciClosed` type. These unsuccessful decoding attempts have no real effect on the performance though, since a CI operation decoder can decide from the first decoded bytes of the received data which CI operation is in question (5.2.3: Table 5-3), thus it can tell immediately without further decoding whether the decoding will be successful or not.

Instead of doing the configuration via dedicated control ports with messages or procedure calls, one might consider using `action` statements or `external function` call statements. The problem with the `action` statements is that information can only be passed in the direction of from the test case to the SA. Hence, the receipt of any acknowledgements or status reports from the SA has to be implemented in some other way. In addition to this, the next version of the TTCN-3 standard possibly allows only the passing of textual data with the `action` statement; it is not possible to pass a value or a template with this mechanism any more [T3MOCKUP: s. 26]. By using the external function calls it is possible to return information back to the test case, but the problem is that the resulting `triExternalFunction()` call is blocking; it will not return until the invoked external function has returned. If the TE is implemented with a single execution thread, then the whole test system becomes blocked for the duration the of connection establishment with the SUT, if the `ciOpen()` operation is implemented as an external function call. The `ciOpened()` operation would in this case be implemented as the return value or out-parameter of the external function. Depending on the used CM Class, it may take some time before the connection has been opened and the `triExternalFunction()` can return. This time may be long enough to affect the behaviour or the result of the test case that is being executed, which should not happen.

5.2.2 Type definitions

The TTCN-3 type definitions specified in the end of this section (Figure 5-3) are used to define the Connection Interface operations. Their encoding and encoding attributes are discussed in the Section 5.2.3, and their usage is explained in the Section 5.2.4.

Connection Interface operation message types can be defined in several ways in TTCN-3 Core Language. The following aspects need to be considered when deciding what kind of type definitions will be used for the Connection Interface operation message types, and for the CM Class specific parameter-type definitions.

Firstly, the information content of the Connection Interface operation messages go through two or three different representation formats when they are used. In a test case, the Connection Interface operation messages are defined and used in some TTCN-3 core language representation format. When the messages are sent, the CM System Component receives them in an encoded form, since all messages that are sent via a TSI port are encoded by the codec system. Before the CM System Component can use the received message, it may have to decode it to a more suitable internal format.

Secondly, there are two kinds of information present in the operation messages. The first kind is the information that is used to control the connections and which the test case writer can set. This information comprises the connection establishment parameters, SUT addresses, and so on. The second kind of information is the meta-data needed by the CM System to be able to handle the operation messages. This consists of message identifiers, type identifiers, class identifiers, data length values, and so on, which should be of no concern to the test case writer.

If the types are defined in a way, in which the data is structured in TTCN-3 language form close to how it is structured in the format in which it is to be sent to the CM System, the encoding and decoding of the data becomes easier. An example of this is shown in Figure 5-1. A TTCN-3 record, which contains IP addresses and port numbers for both the TE and the SUT, is supposed to be encoded into a consecutive string of bits. If the IP addresses and port addresses are separated into two different records, like in `HeaderA`, and the transfer syntax is such as shown in the figure, then the encoding becomes more difficult. Either the codec has to encode the two internal records simultaneously to be able to encode the information consecutively, or it encodes one record first and leaves empty space holder in the encoded bit string, and fills in this space later while processing the second record. Why this kind of situation could be wanted to be avoided is that there could be a generic codec that is designed to encode any record type. One could call it recursively to process nested records, but it would be difficult to encode the `HeaderA` with it because of the used transfer syntax.

If the types are defined in the way the data is used by the CM System, the data handling becomes easier to the CM System, but to the test case writer the system might become harder to use, since the use might need to have internal understanding on the implementation of the used transport protocols and the CM System. For example, it would be convenient for a CM Class providing connections over Unix Sockets, if the received control data contained: a filled in `struct sockaddr` value to be used with `connect()` function, an address family value, a socket type value, and a protocol

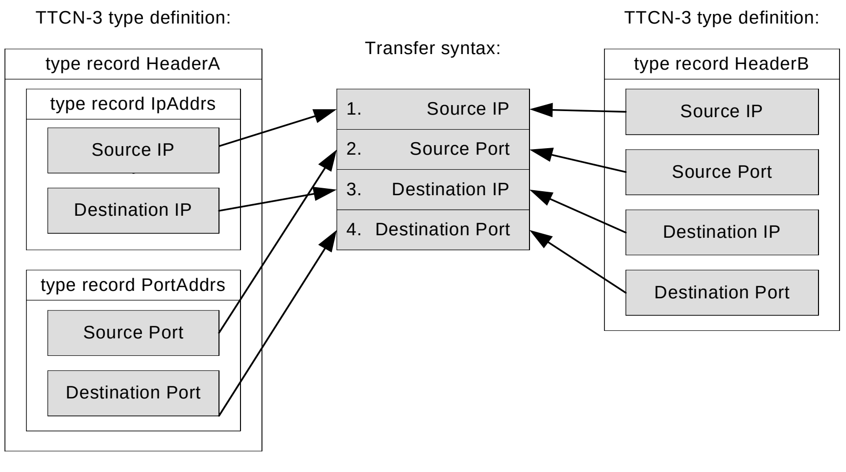


Figure 5-1: Two different type definitions for the same data.

specifier value to be used with `socket()` function [UNIX: ch. 4]. However, for a user with no knowledge on socket programming the usage of these parameters would be difficult.

A user friendlier approach is to define types in such a way, that they give a higher-level abstraction of what is provided, without the possibility to unintentionally set illegal parameter combinations, or to change the values of the meta-data used by the CM System. The values used within the implementation of the CM System can be derived from higher-level parameters by combining them with extra information, which is stored in the form of type definitions and the type attributes of the control messages. This approach is used with the types defined at the Connection Interface. At the encoding phase the codecs can add the extra information to the to-be-sent data based on the type identifiers, type classes and type attributes. The type classes are defined in [T3TCI: s. 7.2.2.1], and they specify the base or root type of any user specified type: e.g. integer, record, set of, and so on. At the decoding phase, the codecs can use the extra information within the received data to build the right TTCN-3 types.

In the case of a CM Class providing connections over Unix Sockets, the type definitions for its connection-parameter types could be as outlined in Figure 5-2. By using the type definitions shown in the figure, the test case writer can only define a valid set of properties for a connection because of how the information has been grouped and structured. For example, it is not possible to mistakenly define a TCP connection with options from the UDP class, or to require that the local port uses TCP but the destination port uses the UDP protocol. When encoding the values into transfer syntax form, the encoder is responsible for adding the information which alternative of a union is present in the data.

```
module CmSocket
{
   type union Open
   {
      SockUdp        udp,
      SockTcp        tcp,
      SockRaw        raw,
      SockDomain     unix
   }

   type record SockTcp
   {
      IpPeerRec      addr,
      UdpOptions     opt
   }

   type record SockUdp
   {
      IpPeerRec      addr,
      TcpOptions     opt
   }

   type record IpPeerRec
   {
      PortAddr       localPort,
      PortAddr       remotePort,
      IpAddr         localIp,
      IpAddr         remoteIp
    }

   type union IpAddr
   {
      IpV4Addr       ipv4,
      IpV6Addr       ipv6
   }

   type charstring   IpV6Addr;
   type charstring   IpV4Addr;
   type charstring   PortAddr length (1 .. 5);

   type record       UdpOptions { /* ... */ }
   type record       TcpOptions { /* ... */ }
   ...
} with
{
   encode (Socket, IpAddr)      "UnionAltEncoder";
   encode (IpV6Addr, IpV4Addr)  "CStringEncoder";
   encode (SockUdp, SockTcp, UdpOptions, TcpOptions, IpPeerRec) "RecursiveEncoder";
   ...
}
```

Figure 5-2: Socket Class example.

The Connection Interface type definitions along with their descriptions are listed in Table 5-2. The corresponding TTCN-3 type definitions are shown in Figure 5-3, Figure 5-4, and Figure 5-5.

Table 5-2: Connection Interface type definitions.

Type Identifier:	**Description:**
`CiOpen`	`ciOpen()` operation is performed, when a value of this record type is sent by a component via its control port to a CM. It contains fields of type `CiTsiPortId` (optional) and `CiOpenParams` (mandatory).
`CiOpened`	`ciOpened()` operation is performed, when a value of this record type is sent by a CM to a component via its control port. This type contains fields of type `CiTsiPortId` (optional) and `CiOpenedParams` (mandatory).
`CiClose`	`ciClose()` operation is performed, when a value of this record type is sent by a component via its control port to a CM. It contains fields of type `CiTsiPortId` (optional) and `CiCloseParams` (mandatory).
`CiClosed`	`ciClosed()` operation is performed, when a value of this record type is sent by a CM to a component via its control port. This type contains fields of type `CiTsiPortId` (optional) and `CiClosedParams` (mandatory).
`CiControl`	`ciControl()` operation is performed, when a value of this record type is sent by a component via its control port to a CM. It contains fields of type `CiTsiPortId` (optional) and `CiCloseParams` (mandatory).
`CiStatus`	`ciStatus()` operation is performed, when a value of this record type is sent by a CM to a component via its control port. This type contains fields of type `CiTsiPortId` (optional) and `CiStatusParams` (mandatory).
`CiTsiPortId`	A value of this record type is used to identify a TSI port. It contains fields `CiTsiPortName` (mandatory) and `CiTsiPortIndex` (optional).
`CiTsiPortName`	Subtype of TTCN-3 `charstring` type. A value of this type is used to identify a TSI port (array) by its name. The TSI port (array) name is one of the port identifiers of the component that is being used as the system component.
`CiTsiPortIndex`	Subtype of TTCN-3 `integer` type. A value of this type is used to identify a particular port in a port array that is identified with the field CiTsiPortName `name` of `CiTsiPortId` type. The special value `omit` of denotes that `CiTsiPortName` refers to a single port instead of a port array. Any other non-negative refers to an element of the array. The `omit` value is encoded as –1 (see Table 5-3), which is in line with Java and C language mappings of the type `TriPortIdType` [T3TRI: ss. 6.3.2.1 and 7.2.1].

Table 5-2: Connection Interface type definitions. (continued from the previous page)

Type Identifier:	**Description:**
`CiOpenParams`	This union of CM Class specific types contains parameters for opening a new connection. For example, it can contain peer addresses for the used connection protocol, buffer sizes, and so on. The field names of the union are used as the identifiers of the CM Classes at CM System Interface.
`CiOpenedParams`	This union of CM Class specific types contains parameters for an opened connection. A CM Class can use this type to return information about the opened connection to the test case. The field names of the union are used as the identifiers of the CM Classes at CM System Interface.
`CiCloseParams`	This union of CM Class specific types contains parameter for closing a connection. For example, it may contain information about what should be done with any possibly buffered data, or with the data that is possibly received from the SUT after it has been instructed to close the connection. The field names of the union are used as the identifiers of the CM Classes at CM System Interface.
`CiClosedParams`	This is a union of CM Class specific types with which the CM can return any information about the connection that was closed. For example, it may contain a status report telling whether the connection was closed cleanly or if there were any problems. The field names of the union are used as the identifiers of the CM Classes at CM System Interface.
`CiControlParams`	This union of CM Class specific types can be used to implement any CM Class specific extra functionality that involves sending a message to the CM Class or CM. For example, parameters of opened connections can be modified with this type. The field names of the union are used as the identifiers of the CM Classes at CM System Interface.
`CiCfgPort`	This port type is used to define Connection Interface control ports.
`CiStatusParams`	This union of CM Class specific types can be used to implement any CM Class specific extra functionality that involves sending a message from a CM Class or CM to a test case component. For example, this can contain a status report of a connection that has been established with the SUT. The field names of the union are used as the identifiers of the CM Classes at CM System Interface.

Every operation type in Figure 5-3 is a record with two fields: port record `tsiDataPortId` and class-parameter union `class`. The `tsiDataPortId` field identifies the test system interface data port that is the target of the operation (and at the same time a component data port). This value is optional and may be omitted, which can be useful in controlling server-like CMs without having a data connection with it (explained further in 5.4.7 TCP server example). The class-parameter union `class` is a union of class specific parameter types used in the operation. It also selects the used CM Class. If a class does not want to use parameters in a CI operation, (e.g. in `ciOpened()`), this can be done by defining the type of the class specific parameter value (`ciOpened.class.udp`) as an empty record. The parameter type may be different in each of the CI operations, but it can also be the same (i.e., one set of parameters for opening a connection – another set for closing it, or the same set of parameters for both operations). The `encode` attribute strings will be explained in Section 5.2.3.

```
group ciOperations
{
   type record CiOpen
   {
      CiTsiPort         tsiDataPort   optional,
      CiOpenParams      class
   }

   type record CiOpened
   {
      CiTsiPort         tsiDataPort   optional,
      CiOpenedParams    class
   }

   type record CiControl
   {
      CiTsiPort         tsiDataPort   optional,
      CiControlParams   class
   }

   type record CiStatus
   {
      CiTsiPort         tsiDataPort   optional,
      CiStatusParams    class
   }

   type record CiClose
   {
      CiTsiPort         tsiDataPort   optional,
      CiCloseParams     class
   }

   type record CiClosed
   {
      CiTsiPort         tsiDataPort   optional,
      CiClosedParams    class
   }
} with
{
   encode               "CiOperation";
}
```

Figure 5-3: Connection Interface control operation types in TTCN-3 Core Language.

Figure 5-4 contains example type definitions of the `class` unions of `ciOpen`, `ciOpened`, `ciClose` and `ciClosed` operation messages, and the definition of the control port. Selecting a union alternative of `Ci<OperationName>Params` determines the used CM Class. The union alternative identifiers (`socket`, `frameRelay`) identify the classes at the CM System Interface. The TTCN-3 type identifiers of the alternatives are irrelevant to the CM System (`CmSocket.Open`, `CmFrameRelay.Open`), making it possible to rename the modules and types used by the classes without affecting the CM System.

Each component may only configure its own ports; therefore, no component identifier field is present in the operation messages. All the Connection Interface control operations are performed via ports of type `CiCfgPort`, the TTCN-3 definition of which is given in

```
group ciFieldTypes
{
   type charstring   CiTsiPortName  length (1 .. infinity);
   type integer      CiTsiPortIndex (0 .. infinity);

   type record CiTsiPort
   {
      CiTsiPortName     name,
      CiTsiPortIndex    index    optional
   }

   type union CiOpenParams
   {
      CmSocket.Open              socket,
      CmFrameRelay.Open          frameRelay,
      CmLangCModuleTest.Open     langCModTest,
      CmLangJavaModuleTest.Open  langJavaModTest
      ...
   }

   type union CiOpenedParams
   {
      CmSocket.Opened            socket,
      ...
   }

   type union CiCloseParams
   {
      CmSocket.Close             socket,
      ...
   }

   type union CiClosedParams
   {
      CmSystem.Closed            sys,            //See Section 5.3 Error Handling
      CmSocket.Closed            socket,
      ...
   }
   ...
}
with
{
   encode (CiOpenParams, CiOpenedParams, CiCloseParams, CiClosedParams,
           CiControlParams, CiStatusParams)
      "CiOperationParams";
   encode (CiTsiPort)
      "CiTsiPort";
}
```

Figure 5-4: Field types of the Connection Interface operation-message types.

```
type port CiCfgPort message
{
   // To the CM System:
   out   CiOpen;
   out   CiControl;
   out   CiClose;

   // From the CM System:
   in    CiOpened;
   in    CiStatus;
   in    CiClosed;
}
```

Figure 5-5: Connection Interface port types in TTCN-3 Core Language.

Figure 5-5. The Connection Interface data operations are performed via any other user-defined port types.

5.2.3 On transfer syntax and encoding

Because all the CI operations are implemented as TTCN-3 types, the test case initiated CI operations are seen at TRI interface as `triSend()` calls, where all the CI operation information is encoded within the `TriMessageType sendMessage` parameter of the TRI operation. Similarly, every CM or CM Class initiated CI operation is seen by the decoders of the codec system of the TE as a string of bytes within the `receivedMessage` parameter of the `triEnqueueMsg()` operation. Table 5-3 defines abstract transfer syntax for the CI operations, in which the operations are passed between the test case components and the CM System. The actual encoding of the fields depends on the implementation language. The endianness of the computer in which CM System is being executed may also affect the encoding, unless it is decided that all the values are always encoded in network byte order.

The CI operation messages in the format of Table 5-3 are referred to being in format `CmSysControlMessage`. All the fields are interpreted as a consecutive sequence of bytes. The position column tells the relative order of the fields, which may be stored into one or more bytes each. When needed in encoding and decoding, the total length of the `CmSysControlMessage` can be retrieved from `sendMessage` and `receivedMessage`, within which the codecs of the TE and the CM System receive the messages.

Table 5-3: Connection Interface transfer syntax.

CmSysControlMessage		
Pos.	**Field name**	**Description**
1	`CiOperationId`	Fixed width value that is used by the codecs of the TE and the CM System Component to identify the CI operation in question. The encoder that handles the CI operation type, or types, derives the right value based on the type identifier of the value that is being encoded, i.e. CiOpen, CiClose, CiStatus, etc. The value is encoded in the same representation format as the `CsiCiOpIdType` (Table A-2) has in the implementation of the CM System.
2	`TsiPortNameLen`	Fixed width value that tells the number of bytes used for the `TsiPortName` field. The value is encoded in the same representation format as the `CsiIntegerType` (Table A-2) has in the implementation of the CM System. This value is 0, when the tsiDataPort field has been omitted in CI operation message.
3	`TsiPortName`	Variable width value that contains the name of the target port of the operation (value of `tsiDataPort.name`). The value is encoded as a sequence of values of type `CsiCharacterType` (Table A-2) of length `TsiPortNameLen`, in which each `CsiCharacterType` is in the representation format used by the CM System. This value is not present when `TsiPortNameLen` is 0.
4	`TsiPortIndex`	Fixed width value that identifies the target port index of the operation (value of `tsiDataPort.index`). The value is encoded in the same representation format as the `CsiIntegerType` has in the implementation of the CM System. This value is -1, when the `tsiDataPort.index` has been omitted in the CI control message.
5	`ClassIdLen`	Fixed width value that tells the number of bytes used for the `ClassId` field. The value is encoded in the same representation format as the `CsiIntegerType` has in the implementation of the CM System.

Table 5-3: Connection Interface transfer syntax. (continued from the previous page)

Pos.	Field name	Description
6	`ClassId`	Variable width value, which identifies the CM Class that handles the CI operation. The codec that handles encoding of the `class` field of the CI operation messages derives this value from the field name of the currently selected union alternative, for example `class.socket`. TCI-CD operation `TString getPresentVariantName()` [T3TCI:s. 7.2.2.2.15] can be used to determine the field name. The value is encoded as a sequence of values of type `CsiCharacterType` of length `ClassIdLen`, in which each `CsiCharacterType` is in the representation format used by the CM System.
7	`ClassDataLen`	This fixed width value contains the length of `ClassData` field. The value is encoded in the same representation format as the `CsiIntegerType` has in the implementation of the CM System.
8	`ClassData`	This value contains the value of the selected union alternative encoded in a class specific format, e.g. `class.socket`. It is encoded as a byte sequence of length `ClassDataLen`.

When the CM System implementation language is C and fixed-length fields are used, it might be a tempting idea to do the encoding and decoding by type casting. Because the `CmSysControlMessage` uses variable length fields, this kind of decoding cannot be used for the whole `CmSysControlMessage`. However, for the class specific data part this could be done in the following way.

To encode a structured value, one could fill in a corresponding C-struct with the right values, and then interpret the structure as a sequence of bytes by giving a char pointer to it. Care must be taken when decoding the data back into the C-struct type because of the data type alignment used by the processors. When a codec encodes a TTCN-3 value into a sequence of bytes to be transmitted over TSI, a pointer value to this byte sequence gets stored into a `TriMessage` `sendMessage` (or into `receivedMessage` in the case of decoding of a value). When the `sendMessage` passes through the TRI interface, there is no guarantee by the TTCN-3 standards that the pointer value within `sendMessage` is the same as the one set by the codecs; it could point at a copy of the data, which may be differently aligned in memory than the original data. Thus, simply type casting the data and reading the fields may cause hardware exception in certain environments because of the misaligned data. Therefore, the data in the `sendMessage` should be copied into a new memory location with the same byte alignment as the type has, i.e. into a value of the type, before accessing the fields within the data. The compiled CM System and the codecs need also to have a common understanding about any possible padding in the structures and ordering of the fields, which may depend on the compilation parameters. Because of these problems, it is safer to do the encoding and decoding one field at a time.

There are no standardized methods with which one could gain access to a codec, but it would be very useful to be able to call a codec from another codec. Some TTCN-3 tools provide their own methods with which the codecs can be queried and called, but using these makes the codecs tool dependent. If the tool does not provide these operations, then the root codec of a structured type has to know how to encode the whole structure from top down to its atomic nodes. For example, if one has written type definitions with encoding rules for a PDU of a protocol and codecs for it, and later on would want to encapsulate this PDU within a PDU of another protocol, then it would be nice if the codec of the outer PDU could call the codec of the inner PDU to do its encoding. Otherwise, the outer PDU codec has to re-implement the codec of the inner PDU.

If the tool does not provide its own methods for accessing codecs from codecs, or if the encoding is wanted to be as tool independent as possible, it might be worth implementing an own codec system, which provides methods for registering codecs into it by type identifiers, type classes, encoding attributes, or by other identifiers. To use this codec system, a single relay codec is needed, which implements the TCI-CD interface's `encode()` and `decode()` operations. This relay codec could be registered to the used TTCN-3 tool as the codec for all the types, type classes, or encoding attributes (depends on the used tool how this can be done), so it will always be called when a value should be encoded or decoded. The relay codec gets the right codec from the codec system by querying it with the encoding attributes of the value. The Generic Codec in Figure 4-2 is this relay codec, and CM Class Codec System can be seen as the codec system, which provides the methods for querying and calling the codecs needed to do the encoding and decoding of their types.

As of writing this document, the TTCN-3 Control Interface standard [T3TCI] does not provide operations with which a decoder could ask for the types of the alternatives of a union type, or attributes of the union alternatives. This makes it hard to write a generic union type decoder, because a union decoder has to contain hard-coded information about the types of the alternatives to know how it should process each field. A decoder of a `Ci<OperationName>Params` union type has to be updated after addition of a new CM Class to make it aware of the new union alternative type. This conflicts with the idea, that one should be able to add new CM Classes to the system without having to modify the program code of the existing encoder and decoders. Some of the TTCN-3 tools do provide the type information for union fields, either by tool specific extra operations, or by slightly changing the definitions of some of the TCI operations. The drawback in using these non-standard methods is that the decoder code cannot be used with more than one tool without changes. To avoid this, the CM Class Codec System of Figure 4-2 can be used in implementing a generic union decoder for `Ci<OperationName>Params` type in a tool independent way. Because the union alternative names can be always retrieved from union type (TCI provides an operation for this), and in the case of `Ci<OperationName>Params` type they serve as the CM Class identifiers, the union decoder can ask from the CM Class Codec System what is the codec for a certain CM Class by using "<cmClassId><operationName>" as the key. This of course requires that when the CM Classes are registered into the CM System, the class specific codecs are registered into the CM Class Codec System as well.

The attributes in Table 5-4 are used with the TTCN-3 type definitions of the CI interface (Figure 5-3, Figure 5-4) to select the codecs, which do the encoding between the CI interface types and the `CmSysControlMessage` format of Table 5-3. If the used TTCN-3 tool does not support attributes, then the codecs can be selected based on the TTCN-3 type identifiers.

Table 5-4: Connection Interface type encoding-attributes.

Attribute:	Value:	Description:
Encode	CiOperation	This attribute selects the base codec for the all the CI-operation types. Its responsibility is to encode and decode the value of `OperationId` field of `CmSysControlMessage` based on the type of the CI operation message being coded (`CiOpen`, `CiOpened`, `CiControl`, etc.). It shall also call the codecs of the CI-operation message fields `CiTsiPort tsiDataPort`, `Ci<OperationName>Params class`.
Encode	CiTsiPort	This attribute selects the codec, which handles the encoding and decoding between the `CiTsiPort tsiDataPort` field of the CI operations messages and the fields `TsiPortNameLen`, `TsiPortName`, and `TsiPortIndex` of `CmSysControlMessage`.
Encode	CiOperationParams	This attribute selects the codec, which handles the encoding and decoding between `Ci<OperationName>Params class` field of the CI operation messages and the fields `ClassIdLen` and `ClassId` of the transfer syntax. The value of `ClassId` is the identifier of the selected union alternative of `class`. The advantage of using the alternative name as the identifier is that codec does not need to have built-in information about the identifiers, thus new classes can be added without changing the code of this codec. The codec calls the right class specific codec based on the `ClassId`, and the called codec then encodes and decodes the selected union alternative of into and from the fields `ClassDataLen` and `ClassData` of the `CmSysControlMessage`.

5.2.4 Operations

All the operations, except `ciData` and `ciDataInd`, are performed by sending or receiving a value of TTCN-3 type via control ports. The `ciData` and the `ciDataInd` operations are performed via data ports.

ciOpen (Component → CM)

In: `CiOpen open_s`

Message of type `CiOpen`. See Table 5-2 for its contents.

Purpose: With this operation a component can request the CM System to open a new data connection between a component data port and the SUT, by sending a message of type `CiOpen` via its control port. The message specifies the TSI data port via which the connection is to be opened, the CM Class to be used to handle the connection, and any class specific parameters.

When the connection has been opened, the component receives via its control port an acknowledgement in the form of `ciOpened` message. If the connection cannot be opened for some reason, the component receives a `ciClosed` message. No other CI operation addressing *the same* TSI data port may be performed by the component, until an acknowledgement for this operation has been received; other components may try to configure the same TSI data port for their use, and the same component may try to configure other TSI data ports while waiting for the acknowledgement.

When: After the component has its control port mapped with TSI control port, and the data port of the connection has been mapped with a TSI data port.

ciOpened (CM → Component)

In: `CiOpened opened_r`

Message of type `CiOpened`. See Table 5-2 for its contents.

Purpose: This operation is confirmation to the `ciOpen()` operation, and it consists of a CM sending `CiOpened` message to component in the encoded form (`CmSysControlMessage`, Table 5-3), and of the receipt of this message by the component with the `receive` port-statement. The CM can construct the encoded message with the help of CM Class Interface operation `cciEncodeCiCtrlOp()` (A.2.2). The message contains the information which TSI data port and which CM Class is in question, hence the receiving component knows which `ciOpen` message this acknowledges. The `ciOpened` contains also any class specific parameters concerning the opened connection.

When the component has received the `ciOpened` message, it may start using the configured data port to communicate with the SUT. It depends on the used CM Class and the parameters of the `ciOpen()` request, whether the connection is ready for sending, receiving, or for the both.

This operation is always a response to the `ciOpen()` operation. It cannot be used for example to notify a test case component about opened connections in the case, when the CM is a server listening for multiple connection establishment attempts from the SUT, and for each established connection the CM has to notify the component. Situations like this can be handled by notifying the component with the `ciStatus` message.

When: In a response to `ciOpen()` operation, when the CM System was able to provide a CM to handle the new connection, and the CM has performed any actions needed to make the new connection ready to be used.

ciClose (Component → CM)

In: `CiClose close_s`

Message of type `CiClose`. See Table 5-2 for its contents.

Purpose: With this operation a previously opened connection can be closed. The component specifies the to-be-closed connection by sending a message of type `CiClose` via its control port. The message specifies the TSI data port, via which the connection has been previously established, the used CM Class, and any class specific parameters that may affect the way the connection should be closed.

Once this operation has been performed, the component may not perform any other CI operations for the same TSI data port until this operation has been confirmed by the receiving CM with the `ciClosed()` operation. Like with the `ciOpen()` operation, this operation has no effect on the configuration of other TSI data ports, or on configuration done by any other components.

When: When a successfully opened connection needs to be closed.

ciClosed (CM → Component)

In: `CiClosed close_r`

Message of type `CiClosed`. See Table 5-2 for its contents.

Purpose: This operation is A) confirmation to the `ciClose()` operation, B) an indication that a `ciOpen()` operation has failed, or C) a closing indication concerning a previously opened connection.

When: A) In a response to `ciClose()` operation, after the connection has been closed so, that the CM Class is ready to re-establish the connection if requested.

B) In a response to `ciOpen()` operation, when a new connection could not be opened for some reason. In this case the `CiClosed` message can also be sent by the CM System, if it notices before it has passed the open request to a CM Class, that the request cannot be fulfilled. Section 5.3 Error Handling contains more details on error handling.

C) As an indication to the component, that the connection it had previously opened has been closed without the component requesting for it. This may occur for example when the CM notices that the SUT has terminated the connection, or that the transmission medium becomes unavailable or does not behave correctly (e.g. unplugged network cable, network congestion). When exactly this indication is sent depends on the used CM Class and the used configuration parameters.

ciControl (Component → CM)

In: `CiControl control_s`

Message of type `CiControl` .See Table 5-2 for its contents.

Purpose: With this operation it is possible to send CM Class specific control information to the CM handling a previously opened connection. The meaning of this operation depends on the used CM Class.

For example, if the CMs of the used class are server programs that can listen for connection establishment attempts from several SUT addresses, this operation can be used accept and disconnect those connections one by one. When the server is not needed anymore, it can be closed with the `ciClose()` operation. See Section 5.4.7 for an example scenario.

When: When a connection has been previously opened with the `ciOpen()` operation, and the used class supports this optional operation.

ciStatus (CM → Component)

In: `CiStatus status_r`

Message of type `status_r`. See Table 5-2 for its contents.

Purpose: With this operation a CM can send CM Class specific status information to the test case. This operation may be used as a response to the `ciControl()` operation, or it may be sent by the CM as a result of certain event. See Section 5.4.7 for an example scenario.

When: When a connection has been previously opened with the `ciOpen()` operation, and the used class supports this operation.

ciData (Component → CM)

In: Any TTCN-3 value, template, or function signature.

Purpose: This operation is refers to the TTCN-3 port statements `send`, `call`, `reply`, and `raise`, which are performed on a data port, via which a data connection has been previously opened with the `ciOpen()` operation. These operations can be seen as requests to the CM System to deliver to the SUT.

When: When a connection has been previously opened with the `ciOpen()` operation.

ciDataInd (CM → Component)

In: `triEnqueue*()` parameters.

Purpose: This operation refers to the CM sending an event to a component via a TSI port, for which the component has previously opened a data connection with the `ciOpen()` operation.

When: When a connection has been previously opened with the `ciOpen()` operation, and the CM handling the connection has received a message or procedure operation from the SUT, which should be delivered to the component.

5.3 Error Handling

During any of the operations it is possible that something goes wrong. Some of the CSI, CCI, and MI operations specified in Appendix A have a return value of type `csiStatus`, which tells whether the operation could be handled or not, but this may not be sufficient error handling, since these return values are not seen at the test case level. In this section it is shortly outlined how the error handling can be extended to the test case level and performed there, if required.

In case a CM Class or its CM detects an error, it may choose to notify the test case component with the `ciStatus` or `ciClosed` message. The message may contain in a class specific format a description of the error that occurred. An error occurs for example in the following situations: the class is not able to decode the parameter data it receives, or the user tries to communicate with the SUT with procedure-based operations but the used class supports only message-based communication.

The situation is more difficult when an error affecting a connection occurs within the CM System Component. For example, if the CM System Component is handling a `ciOpen` message and it fails to forwards the open-request to the right CM Class, the CM System Component should be able to negatively acknowledge the `ciOpen` message with a `ciClosed` message as required in 5.2.4 Operations. As it is shown in Figure 5-3 and Figure 5-4, the `ciClosed` message (like all the other CI control operation messages) contains a parameter field `class`, which is a union of the class specific parameter types of every CM Class. The selected union alternative is used to specify the used CM Class. Even if the CM System Component knew for which class it should create an error indication, it cannot send a `ciClosed` message on behalf of any of the classes, because only the classes know the contents and transfer syntax they use for their class specific parameters.

It could be required, that each class provides a method with which the CM System Component can request the class to send the message to the component on its behalf. Unfortunately, this does not work in the situation in which an unregistered or non-existing class is tried to be used from the test case level, since the CM System is unable to call the method.

A new CI control message of type `ciError` could be introduced, which would be used by the CM System Component to send error indications to the test case components. If this new type was added, then its exact meaning would have to read from its context or contents: is it an error acknowledgement to `ciOpen` or to some other operation, or is it a stand-alone error indication. If the `ciError` did exist, then it might be as well used by the CM Classes in addition to the CM System Component. The `ciError` type would then need to contain either a union of class specific error types, just like the parameter unions are used in the other CI control messages. Alternatively, it could contain a separate field for identifying the CM Class and a field of a common data type for the error information. At this point the `ciError` type is almost identical to the other CI control message types, except that its meaning (e.g. is it a negative acknowledgement to the `ciOpen`) has to be included within its error information field, which complicates its interpretation and handling.

Instead of using a separate `ciError` message, it may be easier to specify a union alternative `sys` for the `Ci<OperationName>Params` types, which is used by the CM System Component in the CI control messages whenever it has to communicate with a test case component. The `sys` alternative should be present at least in the `CiStatus` and `CiClosed` message types, as shown in Figure 5-6 for the `CiClosed` type.

In the `CiClosed` type the `sys`-alternative can be used to negatively acknowledge the `ciOpen` messages, for example when the user tries to use a CM Class that does not exist in the CM System. In `CiStatus type` it can be used by the CM System Component to indicate about situations in which no connection has been closed but an error is detected within the CM System. An example of this is that the CM System Component is unable to decode a CI operation message that it receives in the transfer syntax form, because of an erroneous encoding.

If the test case writer has to handle all the possible error messages that might be received from the CM System or from the CM Classes, the test cases soon become obfuscated by the error handling. To prevent this situation, all the CM System and the CM Classes

```
module CmSystem
{
...
   group ciOperations
   {
      ...
      type record CiClosed
      {
         CiTsiPort        tsiDataPort  optional,
         CiClosedParams   class
      }
      ...
   }

   group ciFieldTypes
   {
      type union CiClosedParams
      {
         /* This is the alternative used by the CM System with
          * the ciClosed operation.
          */
         CmSystem.Closed     sys,
         /* This is the alternative used by the class Socket with
          * the ciClosed operation.
          */
         CmSocket.Closed     socket,
         ...
      }
      ...
      /* The type could be just a string describing why the CM System
       * closed a connection or why it could not open it.
       */
      type charstring Closed;
      ...
   }
}
```

Figure 5-6: The `sys`-alternative used by the CM System.

should provide default `altsteps`, which do the error handling on the behalf of the test case writer. These default alternatives (see Section 2.10) can be activated by the user in the beginning of each test case for those components and ports that use the CI control messages. The defaults provided by the CM System can be seen as top-level error handlers. Because the firstly activated defaults are evaluated the last, the defaults provided by the CM System should be activated before the defaults of CM Classes, which in turn should be activated before any user specified defaults. If a class provides several defaults, then it could be useful if the class provided a parameterized function, which can be used to activate all or some of the defaults with a single call.

A simple default `altstep` provided by the CM System could be such as shown in Figure 5-7. It sets the test case verdict to inconclusive when a `CiClosed` message is received from the CM System, after which it calls a function that notifies the MTC about the situation. The MTC in turn shuts down all the existing test case components in a centralized manner. The way in which the expected `CiClosed` message has been defined with an inline-template is not necessarily considered as good TTCN-3 programming style, but is used here for the sake of brevity.

```
module cmSystem
{
   ...
   altstep d_ciClosedHandler(CiCfgPort p_port)
   {
      // If we receive a CiClosed message sent by the CM System Component
      [] p_port.receive( CiClosed: {?, {sys := ?}} )
      {
         setverdict(inconc);
         notifyMainTestComponentAndShutDown();
      }
   }
   ...
}
```

Figure 5-7: An example default `altstep()` for handling the `CiClosed` messages sent by the CM System.

5.4 Connection Interface Usage Examples

This section shows with two examples how the Connection Interface can be are used to open communication channels with the SUT. In the first example a connection with the SUT is actively opened, while in the second one a server program is created to passively listen for connection establishment attempts from the SUT.

5.4.1 Operation messages

The test case writer has three different Connection Interface type definitions, which are used to configure connections by sending messages of these types via control ports:

```
CiOpen,
CiControl,
CiClose.
```

The responses or acknowledgement messages to these are sent by the CM System and their types are:

```
CiOpened,
CiStatus,
CiClosed.
```

Of these, only the `CiOpened` message is strictly an acknowledgement message, and it is always sent by the CM System as a response to `CiOpen` when a connection has been successfully opened. `CiClosed` is sent by the CM System as an error indication when a connection cannot be opened, or when a previously opened connection has been closed by the SUT, or the connection has been lost for some other reason. The usage of `CiStatus` is class specific; it can be used as a response to `CiControl` message, but it can also be used independently of it for example when the used CM Class needs to notify the test case about an event.

All the message types contain the same two fields. The first field

```
ciOpen.tsiDataPort
```

identifies the TSI port that is being configured. The port is identified by its name and by an index value if the TSI port is a port array. The configuration is done per component basis, so another component may configure the very same TSI port for completely different use, without affecting any configurations done by other components.

The second field is used to choose and identify the used CM Class (transport mechanism). It is a union of all the present communication mechanisms available to the users. The CM System takes care, that when a test case component sends a value of `CiOpen` type in which field

```
ciOpen.class.tcp
```

is present, this is automatically routed to the class that is identified by name "`tcp`".

Similarly,

```
ciOpen.class.udp
```

is routed to the class "`udp`". When a test case component receives a message from the CM System, the union alternative of `class` field identifies the class that sent the message. For example, when the `tcp` alternative is present in the message, it means the message was sent by the class "`tcp`":

```
ciOpened.class.tcp.
```

All the other parameters the user can set depend on the used class. For example, a CM Class called "`tcp`" could contain the following parameter fields:

```
ciOpen.class.tcp.localPort,
ciOpen.class.tcp.localIp.ipv4,
ciOpen.class.tcp.remotePort,
ciOpen.class.tcp.remoteIp.ipv6,
ciOpen.class.tcp.options.rxBufferSize.
```

If a new communication mechanism is implemented, a new alternative is simply added into the `class` field of the CI operation messages to make it usable. A new communication mechanism could be identified as "`ethernet`", and when it is added into the `ciOpen.class` union, the CM System automatically routes the configuration messages in which this new alternative is present to the CM Class identified as "`ethernet`".

5.4.2 TCP connection – open request

The test system configuration could be as shown in Figure 5-8: Two different components want to use the same TSI port "`pt_protoX`" to communicate with different SUT end points. For both of these connections, there will be an own CM, which takes care of maintaining the connection with the SUT. The CMs encapsulate all the messages received from the components within TCP-frames and deliver them to the SUT.

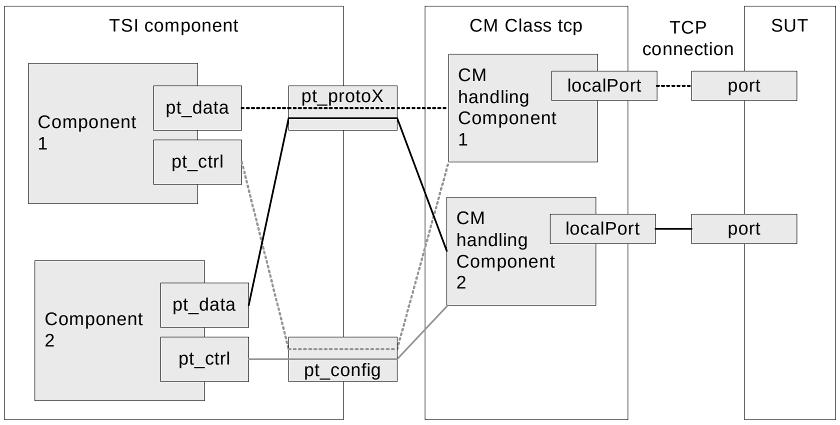


Figure 5-8: Class “tcp” example.

In this example the test case components are defined as:

```
type component TestComponent
{
   port CiCfgPort pt_ctrl;
   port ProtocolX pt_data;
}
```

The used test system interface component is defined as (or is compatible with):

```
type component TsiComponent
{
   port ProtocolX pt_protoX;
   port CiCfgPort pt_config;
}
```

When the user wants to establish a TCP connection between local IPv4 address "127.0.0.1:4242" (which in this case stands for the IP address assigned to one of the network interfaces of the computer, in which the test case is executed) and IPv6 destination "fe80::20f:20ff:fe73:80", then the required TTCN-3 code for a component to request the CM System to open the TCP connection could be the following:

```
...
var CiOpen ciOpen;
ciOpen.tsiDataPort.name := "pt_protoX"   // Refers to system port
ciOpen.tsiDataPort.index := omit; // Single port, not an array
ciOpen.class.tcp.localPort := "4242";
ciOpen.class.tcp.localIp.ipv4 := "127.0.0.1";
ciOpen.class.tcp.remotePort := "80";
ciOpen.class.tcp.remoteIp.ipv6 := "fe80::20f:20ff:fe73";
ciOpen.class.tcp.options.rxBufferSize := 1024;
...
map(self:pt_data, system:pt_protoX);
map(self:pt_ctrl, system:pt_config);
pt_ctrl.send(ciOpen);
...
```

The code fragment sends a request to the CM System to open via TSI port “pt_protoX” a connection using CM Class “tcp”, with the following class specific parameters: local and remote port, local and remote IP, and receipt buffer size (which could be used to set TCP window size, but which in here is just an example parameter).

To avoid the need of filling in all the different parameter fields, the used CM Class could provide a TTCN-3 module containing parameterised templates for different purposes, with default values for seldom used parameters.

5.4.3 TCP connection – opened confirmation

Before a component can start to send or receive data via a connection, whose configuration it has started by sending the CiOpen message, the component is required to receive a CiOpened message to confirm that the connection is ready to be used. The component may send concurrently another CiOpen message for another connection that should be opened before receiving an acknowledgement to the first one. Similarly to CiOpen message, its positive and negative acknowledgement messages CiOpened and CiClosed contain the fields .tsiDataPort and .class:

```
ciOpened.tsiDataPort
ciOpened.class.tcp

ciClosed.tsiDataPort
ciClosed.class.tcp
```

The class specific parameters do not have to be the same as in CiOpen, because a class does not necessarily need to or want to echo back to component the same parameter values the component sent to it. The parameters of CiOpened message could contain for example status information and identifiers that can be used in further communication. The parameters of CiClosed message could contain an error code, which explains why the connection could not be opened to help in solving the problem.

Going back to the "tcp"-class example, the TTCN-3 code for the receipt could be the following: First, it is checked that the response is to the right CiOpen message by checking that the port identifier and the present class are correct in the received message (i.e. the same as in the sent ciOpen message). If the connection was successfully opened, the positive acknowledgement ciOpen is received from the CM that handles the connection. It contains the MAC-address of the network adapter of the SUT, if this can be resolved (just for an example). In the case the connection could not be opened, the received `CiClosed` message contains a description of what went wrong. The actual TTCN-3 code for doing this could be the following:

```
...
var CiClosed ciClosed;
var CiOpened ciOpened;
...
alt
{
   // The .receive(..) contains an inline template definition of type CiOpened:
   [] pt_ctrl.receive(CiOpened:{ciOpen.tsiDataPort, {tcp := ?}) -> value ciOpened;
   {
      log("Connection opened successfully.");
      // Store the mac address of the SUT
      g_myMac := ciOpened.class.tcp.sutMac;
   }
   [] pt_ctrl.receive(CiClosed:{ciOpen.tsiDataPort, ?}) -> value ciClosed
   {
      log("Connection could not be opened successfully.");

      /* Note: the below use of concatenation operator is not
       * standardized as of writing this document.
       */
      log("Error reason: " & ciClosed.class.tcp.errorCode);
      setverdict(inconc);
   }
   [] pt_ctrl.receive
   {
      log("Unexpected message received.");
      setverdict(inconc);
   }
}
...
```

To simplify the test case writing, the CM Classes could provide a set of altstep, which can be used to automatically handle the receipt of acknowledgements. The test case writer can activate these as default `alt` statement alternatives, or they can be called manually in an `alt` statement. The classes could also provide functions, which contain both the sending of requests and the handling of the confirmation messages, thus the TCP connection opening –example could then be reduced to a single function call. The following TTCN-3 code fragment shows how function the `f_tcpOpen()`, provided by the class “`tcp`”, could be used to open a TCP connection. The function is simply called a component, and it returns a boolean value, which tells to the caller whether the connection was opened successfully or not:

```
...
var TcpMac         myMac;
var CiTsiPortId    tsiDataPort := {"pt_protoX", omit};

if (not f_tcpOpen(pt_ctrl,
                  tsiDataPort,
                  a_tcpOpenDefault("fe80::20f:20ff:fe73",
                                   "80"),
                  myMac)
   )
{
   setverdict(false);
   stop;
}
...
```

The definition of the used `f_tcpOpen()` could be the following:

```
function f_tcpOpen
(
   inout CiCfgPort      p_controlPortOfTheComponent,
   in    CiTsiPortId    p_tsiDataPortIdentifier
   in    TcpOpenParams  p_tcpClassSpecificParams,
   out   TcpMac         po_macAddr
)
   return Boolean
{
   // Sending of ciOpen request:
   ...
   /* Usage of alt-statement like shown earlier in this section to handle
    * the ciOpened confirmation and the possible ciClosed failure indication.
    * If CiOpened is received, function returns true, else it returns false.
    */
   ...
}
```

The first parameter is the control port of the component via which the function should send and expect control messages. The second parameter identifies the TSI port via which a new data connection is wanted to be opened, and the third parameter contains the class specific parameters. The fourth parameter returns to the caller the MAC-address of the SUT. The port is passed as parameter to the function, because the function does not have a `runs on` -clause, which would be needed to make the ports of the component visible to the function (see Section 2.6). According to the TTCN-3 definitions, the above function cannot invoke internally any altsteps or functions for which a `runs on` –clause has been specified, because it self does not contain the `runs on` –clause. To fix this problem, the function definition could be as above except that the port parameter is omitted, and a runs on clause is added:

```
function f_tcpOpenWithRunsOn
(
   in    CiTsiPortId    p_tsiDataPortIdentifier
   in    TcpOpenParams  p_tcpClassSpecificParams,
   out   TcpMac         po_macAddr
)
   runs on CiControl
   return Boolean
{
   ...
}
```

The definition of the component type `CiControl` on which the function `f_tcpOpenWithRunsOn` is specified to run could be defined as:

```
type component CiControl { CiCfgPort pt_ctrl }
```

This definition of `CiControl` is `runs on` –compatible with the definition of `TestComponent`:

```
type component TestComponent
{
   port CiCfgPort pt_ctrl;
   port ProtocolX pt_data;
}
```

This means that `f_tcpOpenWithRunsOn` can be called from a component of type `TestComponent`, and `f_tcpOpenWithRunsOn` has an access to the `CiCfgPort ctrl` -port, without the need to provide it as one of the function parameters. This is useful, because when the functions the class “`tcp`” are designed, it is not known in which kind of component types want to use the services provided by the class. Because of this, all the functions and altsteps the class provides could be defined to be run on components of the type `CiControl`. As long as the client test case components are `runs on` –compatible with the `CiControl`, they can call the functions provided by the class.

5.4.4 TCP connection – data

Once the component has received the `ciOpened` confirmation message from the CM System, it can start using the opened data connection. For example, when the SUT is assumed to be a web-server and HTTP GET method is used to request web page via the opened TCP connection, the TTCN-3 code could be something like the following:

```
...
var ParsedHttpResponse response;
...
pt_data.send( a_httpGet( "~kermie/index.html" ) );
t_getTimer.start;

alt
{
   [] pt_data.receive( a_httpOk(?) ) -> value response
   {
      // Got the requested page
      ...
   }
   [] pt_data.receive( a_httpNotFound(?) )
   {
      // Did not receive the page, even though it should be there
   }
   ...
   [] t_getTimer.timeout
   {
   ...
}
```

5.4.5 TCP connection – close request

When a connection is not needed anymore, it should be explicitly closed during test case by sending a `CiClose` message, just as it was done with `CiOpen` message to open the connection. The class specific parameter for closing the connection may contain parameters on how the connection should be closed: are possibly buffered messages transmitted or discarded, and is it waited until the SUT acknowledges closing of the connection.

In the case of the point-to-point TCP example, the TTCN-3 code for requesting the CM System to close a connection could be the following:

```
var CiClose ciClose;
ciClose.tsiDataPort.name         := "pt_protoX";
ciClose.tsiDataPort.index        := omit;
ciClose.class.tcp.shutdownMethod := "graceful";

pt_ctrl.send(ciClose);
```

If the situation is like in Figure 5-8 and Component 1 executes the above code, the CM System will close the data connection that the component has via its port `pt_data`, which is mapped with the TSI port `pt_protoX`. Once the component has sent the `CiClose` message, it is illegal for it to send any other messages concerning the same connection, until the `CiClose` message has been acknowledged by the CM System with a `CiClosed` message. The component may configure or use other connections (not shown in the figure) while waiting for the acknowledgement. The closing of the connection done by Component 1 has no effect on the connection that Component 2 has via the same TSI port, because every component that exists during a test case may configure any of the TSI ports independently from each other.

5.4.6 TCP connection – closed confirmation and indication

Similarly as `CiOpened` message is used to acknowledge the `CiOpen` message, the CM System uses `CiClosed` message to acknowledge the `CiClose` message. `CiClosed` message is also used as a negative acknowledgement to `CiOpen`, when opening of a new connection fails for some reason, and as an indication, when a previously opened connection has been closed. Because of this, a well-written test case has to be ready to accept the `CiClosed` messages at any time via its control port. The non-requested or unexpected closing indications can be handled by activating a class provided default altstep in the beginning of the testcase or a function, like is done in the below code:

```
testcase tc_example()
   runs on  TestComponent
   system   TsiComponent
{
   ...
   /* pt_ctrl is port reference this components control port,
    * {"pt_protoX", omit} is a value of type CiTsiPortId
    */
   activate(def_tcpClosedInd(pt_ctrl, {"pt_protoX", omit}));
   ...
```

The `def_tcpClosedInd` is an altstep, which takes a reference to the control port of the component as the first parameter, and identifier of the TSI port as the second parameter, to be able to know which component port is used for the CI control messages, and which data connection is in question.

A confirmation to the `CiClose` message could be handled with a class provided altstep, or manually like in the below TTCN-3 code fragment. The `receive` statement re-uses the TSI port name from the sent `ciOpen` message (`ciOpen.tsiDataPort`):

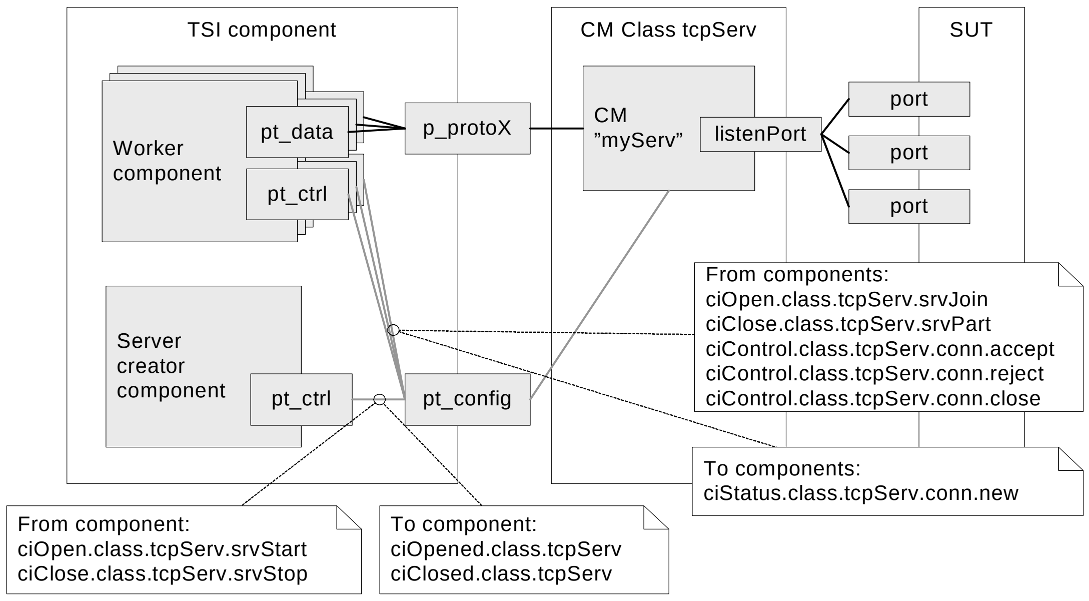
```
var CiClosed ciClosed;
pt_ctrl.receive(CiClosed:{ciOpen.tsiDataPort, {tcp := ?}) -> value ciClosed;

/* The below log statement call is not standardized, but
 * an example of how one might return statistics data within the
 * ciClosed message, and have them printed into the log file.
 */
log("Connection closed successfully. Statistics of the connection:");
log(ciClosed.class.tcp.connStats);
```

5.4.7 TCP server example

In some test cases, it should be possible to accept incoming connection establishment attempts from the SUT. To handle situations like this, the used CM Class needs to provide CMs that are servers, which listen to establishment attempts from specified sources. Depending on how the class is implemented, some extra signalling might be needed to notify test components when new connections have been established. This extra signalling can be done with `CiControl` and `CiStatus` messages, which are used also in this example.

The usage of a CM Class called "`tcpServ`" is explained next. The "`tcpServ`" is just like any other CM Class: to communicate via TSI, one must first open a new connection by sending a `CiOpen` message. The difference between "`tcpServ`"-class as the "`tcp`"-class is that here "opening" of a connection means either starting of a TCP socket server process or joining it (i.e. opening a communication channel with it). Which action is done depends on the class specific parameter values. From the CM System Component point of view the `CiOpen` message always means "please open a new connection", with no other particular meaning. The complete meaning of sending a `CiOpen` message depends entirely on the used CM Class. During handling of the `CiOpen` message, the CM System Component stores a mapping from the test case component to a certain CM, which in this case is happens to be a TCP-server process.

There is more than one approach how a class like "`tcpServ`" could be used from the test case level. One way to use the class is that one of the test case components is a creator-component, which creates the TCP-server, and then creates and assigns worker-components to handle any new SUT established connections, the existence of which is reported to the creator-component by the TCP-server. A variation of this is to have one component to create the server, but this time the TCP-server assigns the handling of the established connections to the available worker-components, that have joined with the server. In both cases, each of the components using the server must first open a connection with the server by using the `CiOpen` message, so that the server knows their existence, before they can start sending or receiving data via any of the TSI port. In this example, the latter approach is used and the test system configuration is as in Figure 5-9.



TSI component
CM Class tcpServ
SUT
Worker component
pt_data
pt_ctrl
p_protoX
CM "myServ"
listenPort
port
port
port
Server creator component
pt_ctrl
pt_config
From components:
ciOpen.class.tcpServ.srvJoin
ciClose.class.tcpServ.srvPart
ciControl.class.tcpServ.conn.accept
ciControl.class.tcpServ.conn.reject
ciControl.class.tcpServ.conn.close
To components:
ciStatus.class.tcpServ.conn.new
From component:
ciOpen.class.tcpServ.srvStart
ciClose.class.tcpServ.srvStop
To component:
ciOpened.class.tcpServ
ciClosed.class.tcpServ

Figure 5-9: Class “tcpServ” example.

The server creator component is responsible for starting up the CM entity called “myServ”, which acts as a TCP socket server. After this, the worker components may join with the server to make themselves known to it. The server notifies free worker components about any new connections the SUT opens with the server. A worker component can reply to the server whether it is willing to handle a particular connection or should the connection be closed by the server. Each of the worker components is mapped with the same TSI port “`pt_protoX`”, but they each communicate with different SUT address via the server.

The test case components need a way to identify the used server if the CM Class is such that it supports several differently configured servers simultaneously. The server identifier could be given to the server by the component that creates it, or it could be given by the CM Class of the server. If the identifier is given by the CM Class, it can be made known to the test case components as one of the return values of the `CiOpened`-message that acknowledges the server creation. In this example this is done the other way round. The creator-component decides the identifier for the server, so the class specific part of the `CiOpen` message contains the server identifier as one of its fields. It also passes this identifier to all the worker-components it creates.

The following TTCN-3 type definitions are used to start up the server and to join it:

```
// From common Connection Interface type definitions: e.g. CiMessages.ttcn3:
type record CiOpen
{
   CiTsiPortId       tsiDataPort    optional,
   CiOpenParams      class
}

type union CiOpenParams
{
   CmFrameRelay.Open frame,
   // Open type from module CmTcpServ:
   CmTcpServ.Open    tcpServ,
   ...
}

// From TcpServ class specific definitions: e.g. CmTcpServ.ttcn3:
type union Open
{
   ServStart   srvStart,
   ServId      srvJoin
}

type record ServStart
{
   Port        listenPort,
   ServId      servName
}

type charstring   ServId  length (1 .. 64);
type integer      Port    (1 .. 99999);
```

To start a server, the server creator component first sends a `CiOpen` message with the following contents via its control port:

```
ciOpen.tsiDataPort := omit;
ciOpen.class.tcpServ.srvStart.listenPort := 5000;
ciOpen.class.tcpServ.srvStart.servName := "myServ";
```

The `tsiDataPort` value is here omitted, because the server creator component has no need for a data connection and it does not have a data port (see Figure 5-9).

This causes the CM Class "`tcpServ`" to start up a new CM with name "`myServ`", which listens for incoming connections at TCP port 5000. The CM acknowledges that it is fully functional by sending `CiOpened` to the server creator component via the control port. It is here assumed, that the server rejects any incoming connection attempts from the SUT as long as there are no free worker components present.

To handle SUT established connections, the worker components make their existence known to the server by each sending a `CiOpen` message via their control ports. The message has the following contents:

```
ciOpen.tsiDataPort.name      := "pt_protoX";
ciOpen.tsiDataPort.index     := omit;
ciOpen.class.tcpServ.srvJoin := "myServ";
```

The CM System Component knows from the `tsiDataPort` value via which TSI port a component wants to open a data connection (with the server). The CM Class "`tcpServ`" knows from the server identifier "`myServ`", that a component wants to use this previously created server. The CM "`tcpServ`" acknowledges to each of the worker components with a `CiOpened`, that the component is now connected with the server.

When the SUT establishes a connection with the server, the server notifies one of the joined components about this with a `CiStatus` message, which contains the IP- and port-address of the SUT. The component then decides whether it accepts the connection, and sends its conclusion to the server in a `CiControl` message. If the component accepted the connection, the server starts to forward any data received from the specific SUT address to the worker component via the chosen data port, and the other way round. In the case the component decided to reject the connection, the server closes the TCP-socket. The below code fragment shows the type definition of the `CiControlParams` union used in the `CiControl` message, and the class specific types `Control` and `ServConn`:

```
// From common Connection Interface type definitions, e.g. CiMessages.ttcn3:
type record CiControl
{
   CiTsiPortId       tsiDataPort    optional,
   CiControlParams   class
}

type union CiControlParams
{
   ...
   // Control type from module CmTcpServ:
   CmTcpServ.Control tcpServ,
   ...
}

// From TcpServ class specific definitions, e.g. CmTcpServ.ttcn3:
type record Control
{
   ServId         server,
   ServConn       conn
}

type union ServConn
{
   IpAddrAndPort  accept, // This alternative accepts a connection
   IpAddrAndPort  reject, // This rejects
   IpAddrAndPort  close   // This closes
}
```

When a worker component wants to close a connection assigned to it, it send a `CiControl` message with "close" instruction to the server. When a component wants to "part" the server, as opposed to joining it, or when it wants to shut down the server, it sends an appropriate `CiClose` message to the server. The `CiClosed` message contains a class specific part like in `CiOpen` and `CiControl`, with which the desired action is chosen:

```
// From common Connection Interface type definitions, e.g. CiMessages.ttcn3:
type union CiCloseParams
{
   ...
   // Control type from module CmTcpServ:
   CmTcpServ.Close tcpServ,
   ...
}

// Used in union CiCloseParams.
type union Close
{
   ServId      srvPart,   // This alternative parts from a server
   ServId      srvClose   // This alternative closes a server
}
```

5.5 Overview of CM System Interface

The CM System Interface (CSI) is used by the SA to use the services provided by the CM System (Component). There are three categories of operations at the CM System Interface: system, class, and connection. With the system level operations the SA can initialize and shutdown the whole CM System. The class level operations are used by the SA to register the used CM Classes into the system. In registration of a class the SA passes an interface object or method to the CM System. This interface object is used by the CM System Component to call classes' implementations of the CM Class Interface operations, which are explained in the next section. Once the registration is completed, the SA can instruct the CM System Component to call the class specific initialization function of each class. During test case execution, the SA uses the connection level operations to forward the TRI operations resulting from Connection Interface operations to the CM System to be handled.

The connection level operations are listed in Table 5-5. When a test case component wants to open a new connection by using the `ciOpen()` operation (5.2.4, 5.4.2), this is seen by the SA as the `triSend()` operation at the TRI interface. Because the SA does not know which TSI ports are control ports, it does not know whether the `sendMessage` parameter of the `triSend()` contains a control message or user data.

Table 5-5: Connection operations of CM System Interface.

Category:	**Call Direction:**	**Operation Identifier:**
Connection	SA → CM System Comp.	csiConnDecodeOp:
	SA → CM System Comp.	csiConnOpen
	SA → CM System Comp.	csiConnControl
	SA → CM System Comp.	csiConnClose
	SA → CM System Comp.	csiConnSend
	SA → CM System Comp.	csiConnCall
	SA → CM System Comp.	csiConnReply
	SA → CM System Comp.	csiConnRaise
	SA → CM System Comp.	csiConnTerminate

The CM System Component provides operation `csiConnDecodeOp()` to the SA, which identifies the message for the SA and tells it what CSI interface operation it should call to handle the message. If the message was received via a TSI control port, then it is assumed to contain a control message, such as the `ciOpen` message encoded in the format of `CmSysControlMessage` (specified in Table 5-3). In this case the `csiConnDecodeOp()` also decodes the message. If it was received via a TSI data port, then it contains user data and no decoding is done. Because in this example the `sendMessage` does contain the `ciOpen` message, the `csiConnDecodeOp()` decodes it and instructs the SA to call the `csiConnOpen()` with the decoded values. After this the SA has done everything needed. All the `triSend()` invocations are handled in this way.

In the case of procedure-based operation (such as `call`), the SA calls directly the right CSI operation (`csiConnCall()`, `csiConnReply()`, `csiConnRaise())` without first consulting the decode operation, because the procedure-based communication can contain only user data.

The operations and data types of the CM System Interface are specified in detail in Appendix A.1

5.6 Overview of CM Class Interface

The CM Class Interface is the interface between the CM System Component and the CM Classes. The operations consist of class and connection level operations, and of an encoding operation. With the class level operations the CM System Component can initialize the CM Classes before they are used. The connection level operations provided by the CM Classes correspond with the connection level operations of the CSI interface (previous section), and they are `cciConnOpen()`, `cciConnControl()`, `cciConn-Close()`, `cciConnData()`, and `cciConnTerminate()`. The `cciConnData` operation groups together all the non-configuration operations (`csiConnSend()`, `csiConnCall()`, `csiConnReply()`, `csiConnRaise()`). All these CM Class Interface operations are implemented by the CM Classes in a class specific manner.

The CM System Component provides operations `cciConnClosed()` and `cciEncodeCiCtrlOp()` to the CM Classes. The operation `cciConnClosed()` is used by the CM Class or its CMs to indicate to the CM System Component when a connection is closed without the CM System Component requesting for it, so that it knows to update its `controlMap` and `handlerMap` data structures accordingly. When a CM wants to send a Connection Interface level message (`CiOpened`, `CiClosed`, `CiStatus`) to the test case component, it can use `cciEncodeCiCtrlOp()` to do the encoding of the CI control message into `CmSysControlMessage` format (Table 5-3). Thus, the CM Classes and their CMs do not need to known the transfer syntax of the Connection Interface control messages, except for their own class specific parameter part.

The operations and data types of the CM Class Interface are specified in detail in Appendix A.2.

5.7 Overview of Mapping Interface

Mapping Interface (MI) is a small interface between the CMs and the SA, and all the operations are provided by the SA. With these operations the CM can lock and release a test case component identifier and a TSI port identifier stored in the SA's `tsiMap` data structure for a small duration of time, when it is about to enqueue a message or procedure operation to the test case component by using a TRI interface `triEnqueue*()` operation. The CM uses `csiConnId` (explained in 4.3.2, 4.3.3) as the key to query for a (component identifier, TSI port identifier)–pair. If no pair matching with the `csiConnId` can be found, the CM knows from this that the component has unmapped its port from the TSI port, and it does not try to communicate with it. When a (component identifier, TSI port identifier)–pair is found, it becomes locked for the CM. If the SA tries to call the `triUnmap()` operation while a pair is locked, it becomes blocked in invocation of the operation (see section 3.3) until the pair is released by the CM. This is needed to avoid the situation in which a CM might call a TRI operation with invalid out-of-date values. The TTCN-3 standard does not specify what is the result of using out-of-date values, hence this interface is used to avoid any undesirable effects on the test case verdict and to make the system more portable between different TTCN-3 tools of different vendors.

This interface specifies only the lock and release operations used by the CM, and they can be found in Appendix A.3. In addition to these, the SA has to implement its `tsiMap` data structure and `triUnmap()` operation in such a way that they take the locking into account.

6 CONCLUSIONS

In the first part of this thesis work an overview of the TTCN-3 Core Langue was given and it was explained what kind of entities and standardized interfaces exist in TTCN-3 test system. In the second part it was shown how one could design on the top of the TTCN-3 standard such a connection management system, that provides simultaneously several kinds of the connection means with the SUT. These different connection means can be used in a uniform way from TTCN-3 test cases, and when new means are developed, these can be easily added into the system without breaking the existing TTCN-3 source or SUT Adapter code.

When designing new CM Classes one needs to consider how the connection management related parameters are seen at the test case level by the user. Are they made easy to be encoded into to a transfer syntax form, or are they designed easy to be used by the user and perhaps bit harder to be encoded. Some thought needs to be put on how codecs can be taken into use in the chosen TTCN-3 tool, and how they are designed and implemented. This is needed to avoid situations in which addition of a new field to a type, or changing a type identifier breaks an existing codec. Designing a generic codec by using the interfaces provided by the standard can be difficult, thus in this work an idea of a CM Class Codec System was introduced. It helps in adding new classes into the system without breaking the codecs of the Connection Interface messages (`CiOpen`, `CiOpened`, and so on), by giving the codecs of these types an access to the class specific codecs.

What was not considered in this work are the exact language mappings (such as for C or Java) of the CM System Interface, the CM Class Interface, and the Mapping Interface. The types used in the interfaces probably need own functions with which they can be operated. For example, there could be a function or a method that generates a `csiConnId` identifier from the component and port identifiers that are received as the parameters of the `triSend()` operation. When designing language mappings of the interfaces, one needs to consider how parameters are passed over the interfaces. In the given abstract interface specifications all the values are assumed to be passed safely by copying. In a real implementation this pass-by-copy would be inefficient. Based on the experience gained on the prototype code that was written during this thesis work, one should be able to rather easily specify the interfaces in a way that avoids excess copying.

A topic that was not considered in the text is how the used TTCN-3 types should be grouped into modules, and what kind of TTCN-3 types, templates, functions and altsteps the modules of the different CM Classes should provide. The definitions related to a CM Class could be stored into an own module, but this class specific module could be divided even further: the (public) definitions required to use the services provided by the class could be stored into one module, and the (private) definitions that are used by the class internally could be stored into another module. TTCN-3 Core Language contains also a language element called `group`, which can be used to group definitions within a single module. It could be used if it turns out that it is more feasible to keep the definitions in a single module, instead of having a public and a private module. A common naming convention used in the modules of the different CM Classes might worth be considering. If the “top level” error handling altstep provided by every class were titled as “`alt_errorTop`”, then the user would directly know which altstep to use.

The test case writer can open connections by using the Connection Interface operations directly. Instead of having to write the operation parameters and the port statements each time by hand, it could be required that every CM Class provides a set of functions and default altsteps for doing this on the behalf of the test case writer. Some functions and altsteps could be mandatory for every class (such as the ones for error handling) and they could use similar parameters differing only in their type but not in their meaning. Another useful feature would be to have some kind of centralized error handling that could be started in one of the test case components. It would take care of instructing all the test case components to close their connection, when there is a problem with one of the connections. If this kind of centralized error handling was designed, it should work over the CM Class boundaries by being able to shutdown connections of any kind.

In the text the Connection Managers were presented as entities, that maintain connections with the SUT. However, nothing prevents the Connection Managers to provide services other than connections with the SUT. They could be data generators, traffic generators, databases, script language interpreters, or any other kind of services that might be utilized during a test case. Usage of the Connection Interface operations in their case would mean establishing connections with these service providers.

As it was mentioned in the Introduction, as of writing this thesis work there is not much literature or other material available on TTCN-3 and SUT Adapter design. This thesis raised issues that need to be considered in the adapter design, and it specified a framework, which supports several kinds of connection means with the SUT. The framework should prove very useful over time when new kinds of targets are needed to be tested. If a framework like the one presented or one with similar capabilities was widely used and its interfaces were made public, then different companies and communities could participate in the development of free and commercial Connection Manager plug-ins. One could then expand the capabilities of an own test system with these plug-ins without the fear of losing any already existing functionality, thus greatly reducing time and resources spent in making changes to the existing system, before new kinds of targets can be tested.

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APPENDICES

A INTERFACES IN DETAIL

A.1 CM System Interface

The CM System Interface is used by the SA to use the services provided by the CM System. There are three categories of operations at the CM System Interface. The ones that affect the system as a whole are prefixed with "`csi`". With these, the whole CM System is initialized before it is taken into use, and finalized when its services are not needed any more. Similarly, the operations used at connection manager class level have "`csiClass`" prefix. With these operations the classes are registered to the system and initialized before taken into use. The operations that are used to open, control, and close connections, and to send data through them, begin with "`csiConn`" prefix. All the operations are procedure calls and they are listed in Table A-1.

Table A-1: Operations at CM System Interface. Decode Port Operation is used to identify the connection related operations that are listed below it.

Category:	Call Direction:	Operation Identifier:
System	SA → CM System Comp.	csiInit
	SA → CM System Comp.	csiFinalize
	SA → CM System Comp.	csiReset
Class	SA → CM System Comp.	csiClassReg
	SA → CM System Comp.	csiClassDeReg
	SA → CM System Comp.	csiClassInit
	SA → CM System Comp.	csiClassFinalize
Connection	SA → CM System Comp.	csiConnDecodeOp
	SA → CM System Comp.	csiConnOpen
	SA → CM System Comp.	csiConnControl
	SA → CM System Comp.	csiConnClose
	SA → CM System Comp.	csiConnSend
	SA → CM System Comp.	csiConnCall
	SA → CM System Comp.	csiConnReply
	SA → CM System Comp.	csiConnRaise
	SA → CM System Comp.	csiConnTerminate

A.1.1 Data types

The following abstract data types are used with the CM System Interface operations.

Table A-2: Data types at CM System Interface.

Type Identifier:	**Description:**
`CsiCharacterType`	This type can hold a single character value.
`CsiCiOpIdType`	Each of the Connection Interface operations has a unique identifier at SA and CM System implementation language level. This enumerated type provides identifiers for the operations: `csiCiOpenId`, `csiCiOpenedId`, `csiCiControlId`, `csiCiStatusId`, `csiCiCloseId`, `csiCiClosedId`, `csiCiDataId`, and `csiCiDataIndId`. NOTE: When a component sends a CI control category message (5.2 Connection Interface), the CM System Component uses `csiCiOpenId`, `csiCiControlId`, and `csiCiCloseId` values to determine which operation is in question (A.1.2 Operations: `csiConnDecodeOp()`). When a CM or CM Class wants to build a CI control category message with the CM System Component provided operation `cciEncodeCiCtrlOp()` (A.2.2 Operations), the values `csiCiOpenedId`, `csiCiStatusId`, and `csiCiClosedId` are used to determine which message should be built. The values `csiCiDataId` and `csiCiDataIndId` are not used in this document. NOTE 2: This type is of fixed length.
`CsiClassDataType`	A value of this type contains CM Class specific configuration data of a Connection Interface operation encoded in a class specific form. It contains a length field, and the data field. The CM Class does the encoding and decoding of the data, thus its contents are not visible to the CM System Component.
`CsiClassIfaceType`	A value of this type contains a method for accessing the CM Class Interface operations of a class (see Table A-4). Depending on implementation language, the method can be a function pointer array of the class operations, or it can be an interface object that provides the class operations as its methods.

Table A-2: Data types at CM System Interface. (continued from the previous page)

Type Identifier:	Description:
`CsiConnIdType`	Unique identifier for a connection. It contains fields `String componentInstString`, `String portNameString`, and `CsiIntegerType portIndex`, which contain values as explained in Section 4.3.2. A special null value, `csiNoConnId`, can be used as the value for non-existing connections. This special value contains zero length `componentInstString` and `portNameString` values, and -1 as the `portIndex` value.
`CsiConnParamsType`	Base class type for the following types: `CsiCtrlParamsType`, and `CsiDataParamsType`.
`CsiCtrlParamsType`	Record with fields: `String csiClassId`, `CsiClassDataType csiClassData`.
`CsiDataCallType`	Record with fields: `TriSignatureIdType signatureId`, `TriParameterListType parameterList`. The both field types are specified in [T3TRI: s. 5.3.2]]. The values stored into the fields are the parameters of the `triCall()` operation.
`CsiDataMsgType`	A value of this type contains a `TriMessageType sendMessage`.
`CsiDataParamsType`	Base class type for the following types: `CsiDataMsgType`, `CsiDataSigType`.
`CsiDataRaiseType`	Record with fields: `TriSignatureIdType signatureId`, `TriExceptionType exception`. All the field types are specified in [T3TRI: s. 5.3.2], and the values stored into the fields are the parameters of `triRaise()` operation
`CsiDataReplyType`	Record with fields: `TriSignatureIdType signatureId`, `TriParameterListType parameterList`, `TriParameterType returnValue.` All the field types are specified in [T3TRI: s. 5.3.2], and the values stored into the fields are the parameters of `triReply()` operation.
`CsiDataSigType`	Base class type for the following types: `CsiDataCallType`, `CsiDataReplyType`, and `CsiDataRaiseType`.
`CsiIntegerType`	This type can hold a single signed integer value of fixed length.

Table A-2: Data types at CM System Interface. (continued from the previous page)

Type Identifier:	**Description:**
CsiOpIdType	Each of the test case component initiated Connection Interface operations has a corresponding CM System Interface operation. Each of these CSI operations has unique identifier, which can one of the following: csiConnOpenId, csiConnCloseId, csiConnControlId, csiConnSendId, csiConnCallId, csiConnReplyId, and csiConnRaiseId. Of these, the csiConnSendId, csiConnCallId, csiConnReplyId, and csiConnRaiseId, are used with the cciConnData() operation to identify which particular operation is in question.
CsiPortIdListType	A list of values of type CsiPortIdType.
CsiPortIdType	Record containing port name and port index fields of the TriPortIdType.
CsiStatusType	This type has two values: CSI_OK, and CSI_ERR. The CSI_OK value is returned by the CSI operations, when the operation call was successful. CSI_ERR is returned otherwise. In the case of CSI_ERR, the effect of the operation call is the same as if it was never called.
String	This type can hold a sequence of character values. When the implementation language is C, char* can be used. In the case of Java, java.lang.String can be used.
TriAddressType	Type defined in TTCN-3 Runtime Interface standard [T3TRI: s. 5.3.2]. A value of this type addresses an entity within the SUT. Its TTCN-3 Core Language counterpart is the type address.
TriComponentIdType	Type defined in TTCN-3 Runtime Interface standard [T3TRI: s. 5.3.1]. A value of this type identifies a test case component.
TriPortIdListType	Type defined in TTCN-3 Runtime Interface standard [T3TRI: s. 5.3.1]. A value of this type contains a list of values of type TriPortIdType.
TriPortIdType	Type defined in TTCN-3 Runtime Interface standard [T3TRI: s. 5.3.1]. A value of this type identifies either a TSI port or a component port, depending on the TRI operation in which it is used.

A.1.2 Operations

The following procedure operations are specified at the CM System Interface.

csiInit (SA → CM System Component)

In: `CsiPortIdListType controlPorts`

List of the TSI ports that are used as the control ports by default. There has to be at least one.

Return: `CsiStatusType csiStatus`

Status code of the operation call.

Purpose: This operation is used by the SA to initialize the CM System. During the initialization, the CM System Component may initialize its internal data structures and do memory allocations if required. As a parameter of this operation the CM System Component receives a list of the ports that are used as control ports. After the initialization, the CM System Component is ready to accept `csiClassReg()` operation calls.

When: A) At the start-up procedures of the test executable. How the initialization operation is called depends on the tool that produces the test executables from the TTCN-3 modules.

B) This operation can be called tool-independently during `triExecute-TestCase()` operation, but the CM System Component is possibly unnecessarily initialized at the beginning of every test case.

C) At the control part of a TTCN-3 module this can be called with TTCN-3 external function call or action statements, before any test cases are executed. This is seen by the SA as `triAction()` or `triExternalFunction-Call()` operation, from which this operation can be called. Because the control part of a TTCN-3 module is optional, and the TCI Test Management interface [T3TCI: s. 7.3.1] allows starting of test cases directly without executing the control part, it possible that the initialization is mistakenly excluded by the test case executor. This approach is tool independent.

D) Another tool independent approach is to perform this operation during the first test case of a test suite with an external function call or action statement. It is also possible to use a special identifier for the test case (such as `tc_initCmSystem`), so the SA knows by it to call this operation.

E) Yet another approach is that the SA is instructed to call this operation in the preamble part of each test case.

The advantage of the alternatives in which the initialization is started from the TTCN-3 language level is that the identifiers of the control ports of the used TSI can be passed down to the CM System; the control ports do not have to be fixed, they can vary between the test cases or test suites. The drawback is that the test case user has to remember to do this.

csiFinalize (SA → CM System Component)

Purpose: With this operation the SA tells the CM System to shutdown. This consists of calling the finalization operations of any present connection manager classes and releasing of any dynamically allocated memory. After this operation no connections to SUT exist, and no other operations than `csiInit()` can be used.

When: A) During finalization procedures of the test executable, if such exist. This approach is tool dependent.

B) At the control part of a TTCN-3 module, like in the case of initialization. This approach is tool independent.

C) During `triSAReset()` operation. Problem with `triSAReset()` is that is not visible to TTCN-3 language level. There is no corresponding TTCN-3 statement, hence it may vary from tool to tool when this operation is called. This approach is tool dependent.

D) In the last test case of the suite, the only purpose of which is to shutdown the CM System. The test case identifier (such as `tc_finCmSystem`) can be used to inform the SA that it should shutdown the CM System. This approach is tool independent.

csiReset (SA → CM System Component)

Purpose: This operation is used to clear any connection related data from the CM System (`handlerMap`, `controlMap`) and to close any possibly open connections. The CM System Component calls the reset operations of every registered class during this operation.

This operation is blocking to the caller and will not return until all the connections have been successfully closed and all connection related data has been cleared.

When: During `triSAReset()` operation.

csiSetControlPorts (SA → CM System Component)

In: `TriPortIdListType tsiPortList`
List of the current TSI ports that are used as the control ports. There has to be at least one in the list.

Return: `CsiStatusType csiStatus`
Status code of the operation call.

Purpose: This operation is used by the SA to tell to the CM System Component what TSI ports exist in the current test case. The CM System Component processes the input parameter `tsiPortList`, and checks from each port in the list if it is of type `CiCfgPort` (defined in Section 5.2.2). If it is of the control port type, then the CM System Component marks into some internal data structure that the port should be treated as a control port. This operation also clears any previously existing control port information.

Note: This operation can possibly be used only in a C implementation. Unlike the C mapping of the `TriPortId` type, the Java language mapping does not provide a method with which one could ask the type identifier of the port.

When: During `triExecuteTestCase()`, if it is wanted that the TSI control port(s) can be different in every executed test case.

csiClassReg (SA → CM System Component)

In: `String csiClassId`

Class identifier of the to-be-registered class.

`CsiClassIfaceType csiClassIface`

Method for the CM System Component to call the class specific operations described in A.2 CM Class Interface.

Return: `CsiStatusType csiStatus`

Status code of the operation call.

Purpose: This operation is used to register all the available CM Classes into the CM System, after which the transmission means provided by them are present in the system. A class is registered into the system by its name, which is the same as the field name of the class in `Ci<OperationName>Params` union type. The union types are defined in the Connection Interface (Table 5-2, Figure 5-4). As the result of this operation, the CM System Component can use `csiClassIface` to access the CM Class Interface operations of the registered class.

When: After the `csiInit()` operation has been performed. The class information can be stored in a configuration file from which it is passed to the CM System Component with this operation, or the class information can be hard coded into the function, which calls this operation.

csiClassDeReg (SA → CM System Component)

In: `String csiClassId`

Class identifier of the to-be-removed class.

Purpose: With this operation it is possible to remove class information of a previously registered CM Class from the CM System, if this is required for some reason. After this operation the CM System Component has no knowledge on the removed CM Class, hence the transmission means provide by the removed class is not available anymore. This operation performs the CM Class Interface operation `cciClassFinalize()` to the class.

When: When the class has been first registered into the system with the `csiClassReg()` operation.

csiClassInit (SA → CM System Component)

Return: `CsiStatusType csiStatus`

Status code of the operation call.

Purpose: With this operation the CM System Component is instructed to call the class specific initialization operations of every registered CM Class. After this, the classes are ready to provide connection managers of their kind.

When: After all the classes have been registered with the `csiClassReg()` operation.

csiClassFinalize (SA → CM System Component)

Purpose: This operation is opposite to the Class Initialize function. All the resources reserved by the registered connection manager classes are freed by the system by calling their class specific finalization operations.

When: This operation is automatically called from the `csiFinalize` operation. The SA can also call this explicitly, if the classes are wanted to be finalized separately from the whole CM System.

csiConnDecodeOp (SA → CM System Component)

In: `CsiConnIdType csiConnId`

The SA derives this value from the `triSend()` operation parameters as shown in Figure 4-7. In the case the `triSend()` operation call is a result of a test case calling the `ciOpen()`, the `ciControl()`, or the `ciClose()` operation, the value of `csiConnId` identifier a control connection; otherwise it identifies a data connection.

`TriMessageType sendMessage`

Encoded control data in the format of `CmSysControlMessage`, or non-control data in any user specified format.

Out: `CsiOpIdType csiOpId`

Identifier of the resulting CSI operation.

`CsiConnIdType csiDataConnId`

Identifier of the data connection that will be the target of the CSI operation specified by the output parameter `csiOpId`.

`CsiConnParamsType csiConnParam`

Contains a parameter value for the `csiConn*()` operation, that is identified by the output parameter `csiOpId`.

Return: `CsiStatusType csiStatus`

Status code of the operation call. The return value is CSI_ERR, if the to be decoded data could not be decoded, or if the CSI System has not been initialized. CSI_OK is returned otherwise.

Purpose: When a message-based Connection Interface operation is performed in a test case, that is seen as a `triSend()` operation at the TRI interface. `CsiConnIdDecodeOp()` is used to decode the corresponding CSI operation from the `sendMessage` parameter of the `triSend()` operation (see MSC diagrams B.1, B.2, B.4). The decoding is done by the CM System Component, because the used transfer syntax (`CmSysControlMessage`, Table 5-3) is an internal matter to the CM System, and it is wanted that the CM System is independent from the SA implementation.

If the port identifier within the in-parameter `csiConnId` is identified as one of TSI data ports by this operation, then the `sendMessage` is not decoded, because it contains only user data, which should be delivered as it is to the SUT. The resulting CSI operation in this case is `csiConnSend()`, thus the output parameter `csiOpId` is set to value `csiConnSendId`, the output parameter `csiDataConnId` is set to the same value as the input parameter `csiConnId` has, and the output parameter `csiConnParam` is set to a value of type `CsiDataMsgType`, which contains the in-parameter `sendMessage`.

If the port identifier within the in-parameter `csiConnId` is identified as one of the control ports, then this operation decodes the `sendMessage`, which contains data in the format of `CmSysControlMessage` (Table 5-3). The following information is decoded:

```
CsiCiOpIdType      ciOperationId
String             tsiPortName
CsiIntegerType     tsiPortIndex
String             csiClassId
CsiClassDataType   csiClassData
```

Based on this information and the in-parameter `csiConnId`, the values for out-parameters are determined. The resulting CSI operation and the value of out-parameter `csiOpdId` depend on the decoded `ciOperationId` value according to the table below:

Table A-3: Mapping from the CI operations to the CSI operations.

ciOperationId value	Resulting CSI-op.	Corresponding csiOpId value
`csiCiOpenId`	`csiConnOpen()`	`csiConnOpenId`
`csiCiControlId`	`csiConnControl()`	`csiConnControlId`
`csiCiCloseId`	`csiConnClose()`	`csiConnCloseId`

For example, if the decoded `ciOperationId` value is equal to `csiCiOpenId`, the out-parameter `csiOpdId` is set to value `csiConnOpenId`, and based on this value the SA knows to call the CSI operation `csiConnOpen()`.

The output parameter `csiDataConnId` is built from the decoded `tsiPortName` and `tsiPortIndex` values, and from the `compInstString` field of in-parameter `csiConnId` (Figure 4-7 shows the contents of the `CsiConnId` type). If this built value equals to the special value `csiNoConnId`, then the test case component that sent the `sendMessage` did not specify any data port. This means that it wants to have a control connection without any data connections with the class specified by the decoded `csiClassId` value. In any case, the value of the output parameter `csiDataConnId` is built it this manner.

The out-parameter `CsiConnParamsType csiConnParam` is set to contain the decoded `csiClassId` and `csiClassData` stored into a value of type `CsiCtrlParamsType`. (`CsiConnParamsType` is the base type for the type `CsiCtrlParamsType`.)

After this operation, the SA knows which CSI operation it should perform (`csiOpId`), what data connection the operation concerns (`csiDataConnId`), and what other parameters the operation has (`csiConnParam`).

When: During `triSend()` operation, that is executed as a result of a message-based Connection Interface operation at the TTCN-3 language level. This operation may not be called from the `triCall()`, the `triReply()`, or the `triRaise()` operation, because the CM System Interface operations result from message-based Connection Interface operations only.

csiConnOpen (SA → CM System Component)

In: `CsiConnIdType csiCtrlConnId`

Identifier of the control connection that is used for controlling the data connection, which is identified by the in-parameter `csiDataConnId`. The value of the `csiCtrlConnId` is derived by the SA from the `triSend()` operation's in-parameters `tsiPortId` and `componentId`. This is the same value the SA used as the input parameter `csiConnId` of `csiConnDecodeOp()`.

`CsiConnIdType csiDataConnId`

Identifier of the data connection that should be opened. This is the same value that the SA received as the `csiDataConnId` out-parameter of the `csiConnDecodeOp()` operation. In the case a test case component has no data ports, i.e. it does not want to open a data connection, `csiDataConnId` has the special value `csiNoConnId`.

`CsiCtrlParamsType csiCtrlParams`

This value contains identifier of the used CM Class and encoded parameter data for the class. The parameter data is only meaningful to the CM that is handling the connection, thus the CM System Component passes the parameter data to the CM without trying to interpret it. This value is the same value the SA received as out-parameter `csiConnParam` of `csiConnDecodeOp()` call.

`TriAddressType sutAddress`

This is the `sutAddress` value that was received by the SA as a parameter of the `triSend()` operation. This parameter value is meaningless to the SA and to the CM System Component, but it may be used by the CM Class to determine the SUT end-point of the connection.

Return: `CsiStatusType csiStatus`

Status code of the operation call. This value is CSI_ERR, if the CM System Component is unable to handle the operation request due to non-initialized

CM System Component, non-existing CM Class, insufficient resources, or due to any other reason. CSI_OK is returned otherwise.

Purpose: With this operation the SA can request the CM System to open a new connection as the result of the Connection Interface `ciOpen()` operation, which has been performed in a test case. The CM System Component starts a new connection manager to handle the connection, by using the CCI interface operation `cciConnOpen` (MSC diagram B.1).

The opened connection can be either a data connection, or a stand-alone control connection. If the input parameter `csiDataConnId` contains value other than `csiNoConnId`, then a data connection is opened, and it is controlled by the control connection identified with `csiCtrlConnId`. If the `csiDataConnId` parameter value is equal to `csiNoConnId`, then a stand-alone control connection is opened.

The CM System Component stores the mapping from the `csiCtrlConnId` parameter value to the `csiDataConnId` parameter value into its `controlMap`, to know which data connection is controlled by which control connection (Figure 4-8). This information is needed by the System Component to be able to terminate all the data connections related to the control connection, in the case the SA orders to do so by calling `csiConnTerminate()`.

From the input parameter `csiCtrlParams` the System Component gets the identifier (`csiClassId`) of the class, whose `cciConnOpen()` it should call to request the class to create a new CM to handle the connection. As the result of successful CM Class Interface `cciConnOpen()` call, the System Component receives the `cciCmId`, which identifies the CM, that handles the connection (A.2.2 Operations contains more details on the CM Class Interface Operations).

If the input parameter `csiDataConnId` has the value of `csiNoConnId`, meaning that no data connection is specified, the System Component stores the mapping from `csiCtrlConnId` to (`csiClassId`, `cciCmId`)–pair into its `handlerMap` data structure (Figure 4-8). Otherwise, the System Component stores the mapping from the `csiDataConnId` value to (`csiClassId`, `cciCmId`)–pair.

After this, if the `csiDataConnId` contained a value other than `csiNoConnId`, the System Component knows which CM handles this opened data connection. Other wise it knows which CM handles the stand-alone control connection identified by `csiCtrlConnId`.

This operation returns once the CM System Component has determined, whether it is capable of requesting a class to create a new CM for the connection. This does not necessarily mean that the CM System Component requests a CM Class to create a new CM during this operation, since this operation call may be buffered and handler later by the CM System Component (A.2.2 Operations explains buffering further).

When: When a new connection is requested to be opened in a test case with the `ciOpen()` operation of Connection Interface, that is seen as this operation at the CM System Interface. MSC diagram B.1 shows how the operation propagates through the interfaces.

csiConnControl (SA → CM System Component)

In: `CsiConnIdType csiCtrlConnId`

This is the same value the SA used as the input parameter `csiConnId` of `csiConnDecodeOp()`.

`CsiConnIdType csiDataConnId`

Identifier of the data connection that should be controlled. This is the same value the SA received as the `csiDataConnId` output parameter of `csiConnDecodeOp()`.

`CsiCtrlParamsType csiCtrlParams`

This value is used as in `csiConnOpen()` operation, and it was received by the SA as the output parameter `csiConnParams` of `csiConnDecodeOp()`.

`TriAddressType sutAddress`
`The sutAddress` that the SA received as a parameter of the `triSend()` operation.

Return: `CsiStatusType csiStatus`
Status code that is used in the same way as in `csiConnOpen()`.

Purpose: With this operation the CM System Component is instructed to pass a control message to a connection manager. The control message may for example ask a connection manager to report its status to a test case component, to configure a sub-connection for a particular `sutAddress` value, or to modify certain parameters of the connection.

The CM System Component uses the `handlerMap` data structure to determine the identifier of the connection manager (`cciCmId`) to which the control message should be delivered (Figure 4-8). Since the `handlerMap` contains mappings from values of type `CsiConnIdType` to (`csiClassId`, `cciCmId`)–pairs, it depends on the values of the input parameter `csiDataConnId` and `csiCtrlConnId` which one of them is used as the connection identifier to find the matching (`csiClassId`, `cciCmId`)–pair. If `csiDataConnId` has the value of `csiNoConnId`, then `csiCtrlConnId` is used to find the right pair. Otherwise, `csiDataConnId` is used.

The CM System Component uses `cciConnControl()` of the class `csiClassId` to pass the control request to the right connection manager.

When: When an existing data connection or a stand-alone control connection is tried to be controlled in a test case with the `ciControl()` operation, that is seen as this operation at the CSI-interface. MSC diagram B.2 illustrates the how the operation propagates through the interfaces.

csiConnClose (SA → CM System Component)

In: `CsiConnIdType csiCtrlConnId`

This is the same value the SA used as the input parameter `csiConnId` of `csiConnDecodeOp()`.

`CsiConnIdType csiDataConnId`

Identifier of the data connection that should be closed. This is the same value the SA received as the `csiDataConnId` output parameter of `csiConnDecodeOp()`.

`CsiCtrlParamsType csiCtrlParams`

This value is used as in `csiConnOpen()`, and it was received by the SA as the output parameter `csiConnParams` of `csiConnDecodeOp()`.

`TriAddressType sutAddress`

This is the `sutAddress` value that was received by the SA as a parameter of the `triSend()` operation. The value is meaningless to the SA and to the CM System Component, but it may be used by the CM Class to determine what is the SUT end-point of the connection that will be closed.

Return: `CsiStatusType csiStatus`

Status code that is used in the same way as in `csiConnOpen()`.

Purpose: With this operation the CM System Component is instructed to close a connection. The CM System Component starts the closing procedures by calling `cciConnClose()` operation of the class interface. For the `cciConnClose()` call the CM System Component needs to know the identifier of the CM (`cciCmId`) that is handling the connection, and which CM Class is in question (`csiClassId`). Identically to `csiConnControl()` operation, the CM System Components uses the `handlerMap` data structure to find the right (`csiClassId`, `cciCmId`) pair, by using either the input parameter `csiCtrlConnId` or csiDataConnId as the key, depending on whether the csiDataConnId is equal to constant csiNoConnId or not (Figure 4-8).

After calling cciConnClose(), the CM System Component can remove the csiDataConnId to (csiClassId, cciCmId)–pair entry from its handlerMap, if csiDataConnId is not equal to constant csiNoConnId. Otherwise the csiDataConnId to (csiClassId, cciCmId) entry is removed (Figure 4-8). The CM System Component also removes from its controlMap the mapping entry between csiCtrlConnId and csiDataConnId.

NOTE: The SA may not remove the entries corresponding to csiCtrlConnId and csiDataConnId from its tsiMap-data structure. These entries are still needed by the CM to acknowledge to the test case component when it has closed its connection with the SUT. This is explained in Section 5.2 Connection Interface:ciClosed() and in A.3 Mapping Interface.

When: When an existing data connection is closed in a test case with the Connection Interface operation ciClose(), that is seen as this operation at the CSI interface. MSC diagram B.4 shows how the operation propagates through the interfaces.

CsiConnTerminate (SA → CM System Component)

In: CsiConnIdType csiConnId

SA generated identifier for the connection that should be terminated.

String reason

A string containing the termination reason. It can be for example “unmap”.

Purpose: This operation is used by the SA to instruct the CM System to forcefully terminate a connection and the connection manager handling it. As the result, all the buffered data related to the connection is immediately discarded and the connection manager is terminated.

If the `csiConnId` is an identifier of a control connection, then all the related data connections are also terminated (`csiConnId` contains identifier of a port, and the CM System Component knows which ports are control ports, hence it knows if `csiConnId` identifies a control connection). The CM System Component can use `controlMap` to determine what are the identifiers of the data connections to be terminated.

The identifier of the CM handling the connection(s) and its class can be found from `handlerMap`. The CM System Component terminates all the related connections by calling `cciConnTerminate()` operation for each of them (see A.2.2 Operations for more details on calling the CM Class Interface Operations).

The termination reason string `reason` is passed by the CM System Component to the CM that is handling the connection, which in turn may notify a test case component about termination of the connection with a report message including the `reason` string.

After calling `cciConnTerminate()`, the CM System Component clears the entries corresponding the identifier `csiConnId` from its `handlerMap` and `controlMap`.

When: The difference between this and `csiConnClose()` operation is that this operation is initiated by the SA as a result of `triUnmap()` operation, or if the SA somehow detects an error that affects the connection. MSC diagram B.6 shows the operation sequence this operation.

Note: This operation is always called when a component unmaps its port from a TSI port, even if the connection using the TSI had been properly closed. In this case the `handlerMap` has no entry for the `csiConnId` parameter value, thus this operation returns without calling the `cciConn-Terminate()` operation.

csiConnSend (SA → CM System Component)

In: `CsiConnIdType csiDataConnId`

Identifier of the data connection via which a message should be sent. This value is the output parameter t`siDataPortId` of `csiConnDecodeOp()` operation.

`CsiDataMsgType csiDataMsg`

This value contains a `sendMessage` that should be delivered to the SUT. It was received by the SA as the output parameter value `csiConnParam` of `csiConnDecodeOp()`.

`TriAddressType sutAddress`

`The sutAddress` value that was received as a parameter of the `triSend()` operation.

Return: `CsiStatusType csiStatus`

Status code of the operation call. This value is CSI_ERR, if the CM System Component is unable to handle the operation request due to insufficient resources, non-existing data connection, or due to any other reason that the CM System Component can determine during the operation call. CSI_OK is returned otherwise.

Purpose: With this operation the CM System is instructed to send a message to the SUT. The CM System Component handles this by forwarding the request to the CM that is handling the connection by calling `cciConnData()` operation (see A.2.2 Operations for more details on calling the CM Class Interface Operations). Identifier of the CM (`cciCmId`) and its class can be found from the system's `handlerMap` data structure by using `csiDataConnId` as the key.

When: TTCN-3 `send` statement executed using a data port that is mapped with a TSI port is seen as this operation at the CM System Interface. MSC diagram B.7 illustrates how the operation propagates through the interfaces.

csiConnCall (SA → CM System Component)

In: `CsiConnIdType csiDataConnId`

SA generated identifier of the data connection, for which a procedure call should be performed. This value is derived by the SA from the `tsiPortId` and `componentId` parameters of the `triCall()` operation.

`CsiDataCallType csiDataCall`

This value contains the signature of the procedure that should be called, and a parameter list for it. This is derived by the SA from `signatureId` and `parameterList` parameters of `triCall()`.

`TriAddressType sutAddress`

`The sutAddress` value that the SA received as a parameter of the `triCall()` operation.

Return: `CsiStatusType csiStatus`

Return value that is used in the same way as in `csiConnSend()`.

Purpose: With this operation the CM System is instructed to perform a procedure call at the SUT. The system handles this operation similarly to `csiConnSend()`.

When: TTCN-3 `call` statement executed using a data port that is mapped with a TSI port is seen as this operation at the CM System Interface. MSC diagram B.8 shows how the operation propagates through the interfaces.

csiConnReply (SA → CM System Component)

In: `CsiConnIdType csiDataConnId`

SA generated identifier of the data connection, for which a procedure return should be performed. This value is derived by the SA from the `tsiPortId` and `componentId` parameters of the `triReply()` operation.

`CsiDataReplyTypecsiDataReply`

This value contains the signature of the procedure that should return, parameter list for it, and a return value of the procedure. This is generated by the SA from the `signatureId`, `parameterList`, and `returnValue` values that it received as parameters of `triReply()`.

`TriAddressType sutAddress`
The `sutAddress` that was received as a parameter of the `triReply()` operation.

Return: `CsiStatusType csiStatus`
Return value that is used in the same way as in `csiConnSend()`.

Purpose: With this operation the CM System is instructed to perform a procedure-return at the SUT. The system handles this operation similarly to `csiConnSend()`.

When: TTCN-3 `reply` statement executed using a data port that is mapped with a TSI port is seen as this operation at the CM System Interface. MSC diagram B.8 shows how the operation propagates though the interfaces.

csiConnRaise (SA → CM System Component)

In: `CsiConnIdType csiDataConnId`
SA generated identifier of the data connection, for which a procedure exception raise should be performed. This value is derived by the SA from the `tsiPortId` and `componentId` parameters of the `triRaise()` operation.

`CsiDataRaiseType csiDataRaise`
This value contains the signature of the procedure that should raise an exception, and a value for the exception, and it is generated by the SA from `signatureId`, `parameterList`, and `exception` that it has received as parameters of `triRaise()`.

`TriAddressType` `sutAddress`

`The sutAddress` value that was received as a parameter of the `triRaise()` operation.

Return: `CsiStatusType csiStatus`

Status code that is used in the same way as in `csiConnSend()`.

Purpose: With this operation the CM System is instructed to raise an exception at the SUT. The system handles this operation similarly to `csiConnSend()`.

When: TTCN-3 `raise` statement executed using a data port that is mapped with a TSI port is seen as this operation at the CM System Interface. MSC diagram B.8 shows how the operation propagates though the interfaces.

A.2 CM Class Interface

The CM Class Interface contains the operations between the CM System Component and the CM Classes. Implementation of the CM Class Interface –operations, in which CM System Component is the caller, is class specific, but the interface is the same for every class. When the classes are registered into the CM System, the CM System Component stores into its `csiClassReg` for each class a method (Table A-2: `CsiClassIfaceType`), with which it can the interface functions of the class (the operations of Table A-4 in which CM System Component is the caller). These operations

Table A-4: Operations at CM Class Interface.

Category:	**Call Direction:**	**Operation Identifier:**
Class	CM System Comp. → CM Class	cciInit
	CM System Comp. → CM Class	cciFinalize
	CM System Comp. → CM Class	cciReset
Connection	CM System Comp. → CM Class	cciConnOpen
	CM System Comp. → CM Class	cciConnControl
	CM System Comp. → CM Class	cciConnClose
	CM System Comp. → CM Class	cciConnData
	CM System Comp. → CM Class	cciConnTerminate
	CM Class → CM System Comp.	cciConnClosed
Encoding	CM Class → CM System Comp.	cciEncodeCiCtrlOp

are used by the CM System Component to distribute the operation requests it receives from the SA to the right CMs. The interface also provides an operation with which a CM Class can notify the CM System Component about a situation, in which it has closed a connection without the CM System Component requesting for it. To make the transfer syntax of the Connection Interface operations (5.2.3 On transfer syntax and encoding) invisible to the classes, the CM System Component provides a procedure with which the classes can do the encoding of CI operations. All the operations are procedure calls.

A.2.1 Data types

The abstract data types defined in Table A-5 are specific to the CM Class Interface. All the other used data types are defined at the CM System Interface (Table A-2).

Table A-5: Data types at CM Class Interface.

Type Identifier:	Description:
`CciCmIdType`	Base-class type for class specific CM identifiers. This is used to hide the differences of the CM identifiers used by different CM Classes; one class might address its CM instances with a memory address value, while another class uses integer or character string identifiers.

A.2.2 Operations

It was required in Section 4.3.4, that the connection category operations of the CM System Interface operations the CM System Component provides to the SA are non-blocking. This can be guaranteed by having an operation buffer in the CM System Component, in which the operation requests are buffered. The CM System Component can contain several worker threads that process the requests stored in the buffer one by one when they have time. Alternatively, the every CM Class could have a similar buffer into the operation requests done by the CM System Component to the CM Class are buffered.

In the case every CM Class implements their an own operation buffers, the `cciConn*()` operations become non-blocking to the CM System Component. Therefore, the CM System Component should call the `cciConn*()` operations directly from `csiConn*()` operation invocations, without using its own buffer, in order to avoid double buffering. In the case the buffering is always done in the CM System Component, then it is allowed that the `cciConn*()` operations are blocking to the CM System Component. Regardless of the chosen buffering policy, the `csiConn*()` operations are always non-blocking the SA.

The following procedure operations are specified at the CM Class Interface.

cciInit (CM System Component → CM Class)

Return: `CsiStatusType status`
Status code of the operation call. The return value is CSI_OK, if the class was successfully initialized.

Purpose: This class specific operation is used to initialize the class in question. The class may reserve memory dynamically, establish static connections with SUT, or it may perform any other actions that has to be done by the class to become usable.

When: The CM System Component calls this operation for every registered class during the `csiClassInit()` operation.

cciFinalize (CM System Component → CM Class)

Purpose: This operation is opposite to the `cciInit()` operation. All the resources reserved by the class are freed. The class must forcefully terminate any possibly open connections.

When: The CM System Component calls this operation for every registered class during the `csiFinalize()` operation, or for a single class when the `csiClassFinalize()` is called.

cciReset (CM System Component → CM Class)

Purpose: This operation is used to clear all the connection related data and to terminate any possibly existing connections.

When: The CM System Component calls this operation for every registered CM Class as the result of the `csiReset()` operation.

cciConnOpen (CM System Component → CM Class)

In: `CsiConnIdType csiCtrlConnId`

Identifier of the control connection that is used to control the data connection identified by the input parameter `csiDataConnId`. This is the same value as the corresponding input parameter of the `csiConnOpen()` operation.

`CsiConnIdType csiDataConnId`

Identifier of the connection that should be opened. This is the same value as the corresponding input parameter of the `csiConnOpen()` operation.

`CsiClassDataType csiClassData`

Class specific configuration data in encoded form. This the same value that is stored in the input parameter `csiCtrlParams` of the `csiConnOpen()` operation.

`TriAddressType sutAddress`

Value that can be used to specify the SUT end point of the connection, if it is not encoded within the `csiClassData` parameter value. This the same value that is stored in the input parameter `sutAddress` of the `csiConnOpen()` operation.

Out: `CciCmIdType cciCmId`

Class generated value that identifies the CM that handles the opened connection. This value remains valid until CM System Component calls either `cciClose()` or `cciTerminate()` operation, or until the CM Class notifies the CM System Component with `cciClosed()` operation that the connection has been closed. No other opened connection may have the same `cciCmId` value.

Return: `CsiStatusType status`

Status code of the operation call. The return value is CSI_OK, if the class had enough resources to attempt to open a new connection and there were no errors with the in-parameters of the operation.

Purpose: With this operation the CM Class is instructed to create a new connection manager to handle the data connection which is identified by `csiDataConnId`, and which controlled by the control connection identified by `csiCtrlConnId`. As the return value of this operation, the CM System Component receives the identifier of the new manager (`cciCmId`) that handles the connection. This identifier is used in all the other CM Class Interface connection operations to address the right CM.

If the value of `csiDataConnId` is equal to `csiNoConnId` then this operation is interpreted by the receiving CM Class as a request to open a stand-alone control connection. What this means is class dependent. The stand-alone control connections can be used for example for starting and controlling class provided server entities. An example of this is given in Section 5.4.7 TCP server example, in which a single component takes care of starting and stopping of a TCP server entity, and other components then join with it to handle any connections that the SUT establishes with the server entity.

Successful return from this operation does not indicate that the connection is usable; it only indicates that the class understood the request and will process it. The CM System Component updates its `handlerMap` to contain the information, that the opened connection is handled by the CM, that is identified by the value of the output parameter `cciCmId`.

Once the connection has been opened, the CM handling the connection reports this to the test case component by performing `ciOpened()` operation. If for some reason it cannot open the connection, it performs `ciClosed()` operation, and it also notifies the CM System Component with the `cciConnClosed()` operation to clear its data structures of any connection related data.

When: This operation is called as a result `csiConnOpen()` operation, which is called as a result of `ciOpen()` operation of the Connection Interface. MSC diagram B.1 shows how the operation propagates through the interfaces.

cciConnControl (CM System Component → CM Class)

In: `CciCmIdType cciCmId`

Identifier of the CM, that is handling the connection.

`CsiClassDataType csiClassData`.

Class specific configuration data in encoded form. This is the same value that is stored in the input parameter `csiCtrlParams` of the `csiConnControl()` operation.

`TriAddressType sutAddress`

Value that can be used to specify the SUT end point of the connection.

Return: `CsiStatusType status`

Status code of the operation call. Used in the same way as in `cciConnOpen()`.

Purpose: With this operation the CM System Component component passes class specific control data to the CM identified by `cciCmId`. The control data may instruct the CM to modify the data connection related options, or it may contain other class specific commands to the CM. What it does depends completely on the CM Class.

When: This operation is called as a result of `csiConnControl()` operation, which is called as a result of `ciControl()` operation of the Connection Interface. MSC diagram B.2 shows how the operation propagates through the interfaces.

cciConnClose (CM System Component → CM Class)

In: `CciCmIdType cciCmId`

Identifier of the CM, that is handling the connection that should be closed.

`CsiClassDataType csiClassData`.

Class specific configuration data in encoded form. This is the same value that is stored in the input parameter `csiCtrlParams` of the `csiConnClose()` operation.

`TriAddressType sutAddress`

Value that can be used to specify the SUT end point of the connection.

Return: `CsiStatusType status`

Status code of the operation call. Used in the same way as in `cciConnOpen()`.

Purpose: With this operation, the class is instructed to close the connection handled by the CM, which is identified by `cciCmId`. As the result, the class starts shutdown procedures for the connection. When they have finished and connection with SUT has been closed, the manager handling the connection acknowledges this to the component of the connection by performing the `ciClosed()` operation of Connection Interface. The shutdown procedures may include transmission of all the data in send-buffer of the connection manager, and waiting for any data that has not yet been received, but is expected, that should be delivered to the component. What is done depends on class and its class specific parameters in `csiClassData`. The `cciCmId` value becomes invalid to the caller (CM System Component) when this operation returns.

Once the connection manager has closed the connection with SUT, it reports this to the test case component by performing the `ciClosed()` operation.

When: This operation is called as a result `csiConnClose()` operation, which is called as a result of `ciClose()` operation of the Connection Interface. MSC diagram B.4 shows how the operation propagates through the interfaces.

cciConnTerminate (CM System Component → CM Class)

In: `CciCmIdType cciCmId`

Identifier of the CM, that is handling the data connection which should be terminated.

`String reason`

String containing the reason why the connection should be terminated.

Purpose: This operation is used for the special case, in which a CM is needed instructed to forcefully shut down the connection it is handling and to discard immediately all the connection related data.

The CM may try to send a `ciClosed`–indication (see 5.2.4 Operations) to the component whose connection it is handling. If the termination cause was that the component unmapped its control port, then this attempt by the CM will fail, because the CM cannot get anymore the needed parameters from the SA for a `triEnqueueMsg()` call by using the `miLock()` operation of the Mapping Interface (see A.3 Mapping Interface), because the SA does not have the information anymore.

When: This operation is called as a result `csiConnTerminate()` operation, which can be a result of unmapping of the component port, which was being used for a data or a control connection. In normal situation this operation is never called, since the connections should be properly closed from the test case with the `ciClose()` operation before the unmapping is done. If a connection has been closed successfully, then the CM System Component will not call this operation even if `csiConnTerminate()` is called. MSC diagram B.6 shows how the operation propagates through the interfaces.

cciConnData (CM System Component → CM Class)

In: `CciCmIdType cciCmId`
Identifier of the CM that is handling the connection.

`CsiOpIdType operationId`
Operation identifier.

`CsiDataParamsType dataParams`
Operation specific parameter.

`TriAddressType sutAddress`
Value that can be used to specify the SUT end point of the connection that should be closed.

Return: `CsiStatusType status`
Status code of the operation call. Used in the same way as in `cciConnOpen()`.

Purpose: With this operation the CM System Component requests the CM identified by the `cciCmId` to the handle the CSI interface communication operation identified by `operationId`. The operation can be one of the following: `csiConnSend`, `csiConnCall`, `csiConnReply`, or `csiConnRaise`. `dataParams` contains the parameters for the operation. If this operation returns successfully, then the CM of the connection attempts to perform the requested operation.

When: This operation is called from `csiConnSend`, `csiConnCall`, `csiConnReply`, and `csiConnRaise` operations. MSC diagrams B.7 and B.8 show how the operation propagates through the interfaces.

cciConnClosed (CM Class → CM System Component)

In: `CsiConnIdType csiCtrlConnId`
Identifier of the control connection that is used to control the data connection identified by the input parameter `csiDataConnId`.

`CsiConnIdType csiDataConnId`
Identifier of the data connection that should be closed.

Purpose: With this operation a CM Class can indicate to the CM System Component, that a previously opened connection has been closed. The CM System Component can update its `controlMap` and `handlerMap` data structures based on the input parameters. Figure 4-8 shows how the data structures and identifiers are related.

The CM System Component removes from its `controlMap` the mapping between the `csiDataConnId` and `csiCtrlConnId`.

If the value of `csiDataConnId` is other than the constant `csiNoConnId`, then the CM System Component uses the value of `csiDataConnId` to remove the entry from `handlerMap`.

If the value of `csiDataConnId` is equal to constant `csiNoConnId`, then the CM System Component uses the value of `csiCtrlConnId` to remove the entry from `handlerMap`.

When: This operation is called by the CM Class, or by one its CMs, when the connection with the SUT has been closed without the CM System Component requesting for it. Possible reasons are SUT terminated connection, failed attempt to establish a connection with the SUT, or an error on transmission path. This operation is *always called before* a CM Class or CM performs a `ciClosed()` operation, which is *not* a confirmation to the `ciClose()` operation, but is a negative acknowledgement to the `ciOpen()` operation or an indication to the test case that a connection has been closed. The CM System Component has to be notified about the closed connection before notifying the test case component, to avoid the situation, in which the test case component might be able to try to re-open the closed connection before the CM System Component has cleared the old entry. Both of the connections would have the same identifier in this error situation in the CM System Component.

Situations after which this operation may not be called are the following: the CM System Component calls `cciReset()`, `cciFinalize()` `cciConnClose()`, or `cciConnTerminate()`.

MSC diagram B.5 shows how the operation propagates through the interfaces.

cciEncodeCiCtrlOp (CM Class → CM System Component)

In: `CsiCiOpIdType csiCiOpId`
Identifier of the CI operation, for which a message is wanted to be encoded. The value can be `csiCiOpenedId`, `csiCiStatusId`, or `csiCiClosedId`.

`String csiClassId`
Identifier of the class calling this operation. This is the same identifier with which the class was registered into the CM System Component (with operation `csiClassReg()`), and which is used as the field name of this class in the `class` field of the CI control operation messages (Definitions can be found in Section 5.2.2 Type definitions).

`CsiConnIdType csiDataConnId`
Identifier of the data connection, for which the calling class wants to encode a Connection Interface control category operation message (listed in Section 5.2 Connection Interface).

`CsiClassDataType csiClassData`
Class specific configuration data in encoded form. The calling CM Class has done the encoding of the data.

Out: `TriMessageType receivedMessage`
A value containing an encoded CI interface control category operation message in the form of `CmSysControlMessage` (defined in Table 5-3).

Purpose: With this operation the CM Classes can request the CM System Component to encode a Connection Interface control message of type `CiOpened`, `CiStatus`, or `CiClosed`, into the form of `CmSysControlMessage`. This makes the transfer syntax of the control messages invisible to the CM Classes, and each of the classes does not have to implement their own encoder for the control messages, except for their class specific data part.

After calling this operation, the out-parameter value `receivedMessage` can be sent by the caller to a test case component with the `triEnqueueMsg()` operation.

NOTE: There exists no decode operation for the CM Classes, because the decoding (excluding class specific part) of the incoming CI control messages is done by the CM System Component within the `csiConnDecodeOp()` operation.

When: This operation is called by a CM Class or a CM when it wants to create an encoded CI control message to be sent to a component (MSC diagrams B.1, B.3, B.4, B.5, B.6, and B.9).

A.3 Mapping Interface

Mapping Interface provides operations, with which the CM Classes and the CMs can query from the SA the current TSI mapping information of a connection by a connection identifier. The mapping information of a connection consist of a (`TriPortId tsiPortId`, `TriComponentIdType componentId`)–pair, which can be used as the parameter of a `triEnqueue*()` operation call.

The mapping information is stored into a single shared data structure called `tsiMap` in the SA, instead of distributing copies of it to the CMs when new connections are being created. The reason for this is that the port mappings may changed during a test case, causing a copy of a (`tsiPortId`, `componentId`)–pair to become out of date. TRI interface standard does not specify what is the result of calling `triEnqueue*()` operations with invalid parameters. The used TTCN-3 tool may choose to ignore the operation call without affecting the verdict of the test case, or it may set `error` test verdict, or do something else. To avoid this situation with unknown results, it is required, that the TSI mapping information stored in `tsiMap` is not readable by a CM or CM Class, when it is being modified by the SA, and it cannot be modified by the SA, when a CM or CM Class is about to call a `triEnqueue*()` operation with a (`tsiPortId`, `ComponentId`)–pair.

The specified Mapping Interface operations provide the means with which a CM or CM Class can signal to the SA, that it wants to reserve a (`tsiPortId`, `componentId`)–pair from `tsiMap` into its use, or that it does not need the pair anymore. In addition to this functionality, the implementations of the TRI interface operations `triMap()` and `triUnmap()` have to be such that they take into account the reservations before updating the information stored in `tsiMap`. If a (`tsiPortId`, `componentId`)–pair has been reserved, then the SA must wait for the pair to become unreserved, until it may modify the mapping information related to the pair and complete the TRI operation in question.

The operations with which the SA handles the reservations and stores the mapping information into the `tsiMap` are internal to the SA and outside the scope of this document.

A.3.1 Data types

This interface has no own data types.

A.3.2 Operations

miLock (CM → SA)

In: `CsiConnIdType csiConnId`

Identifier of a connection, whose (`tsiPortId`, `componentId`)–pair is wanted to be locked. The CM received this value when the connection was opened.

Out: `TriPortIdType tsiPortId`

`tsiPortId` corresponding to the input parameter `csiConnId`.

`TriComponentIdType componentId`

`componentId` corresponding to the input parameter `csiConnId`.

Return: `CsiStatusType status`

Status code of the operation. The value is CSI_OK, if the pair corresponding to the `csiConnId` existed and was successfully reserved. CSI_ERR is returned if there exists no entry for the `csiConnId` that could have been reserved.

Purpose: With this operation a CM can retrieve and reserve from `tsiMap` the `tsiPortId` and `componentId` values corresponding to the `csiConnId`. The values remain reserved for the CM until it calls the `miUnlock()` operation with the same `csiConnId`.

If the values corresponding to `csiConnId` have already been reserved for an other caller, this operations blocks until they have been released with the `miUnlock()` operation.

The implementations of the TRI interface operations `triMap()` and `triUnmap()` operations has to be such that if a CM has reserved a certain (`tsiPortId`, `componentId`)–pair, and the TRI operation would have an effect on this pair, then the TRI operation will block until the CM has released the pair by calling the `miUnlock()` operation. Similarly, the `miLock()` operation will block if the `triMap()` or the `triUnmap()` operation is being called by the TE.

When: The CM calls this operation right before it is going to call a `triEnqueue*()` operation. It also calls the `miUnlock()` operation right after the `triEnqueue*()` operation has finished.

miUnlock (CM → SA)

In: `CsiConnIdType csiConnId`

Identifier of a connection, whose (`tsiPortId`, `componentId`)–pair is wanted to be unlocked. The CM received this value when the connection was opened.

Purpose: With this operation a CM can unlock the (`tsiPortId`, `componentId`)–pair identified by the input parameter `csiConnId`. The CM must have locked the pair previously with the `miLock()` operation to prevent any modifications to the mapping information for the duration of a `triEnqueue*()` operation call.

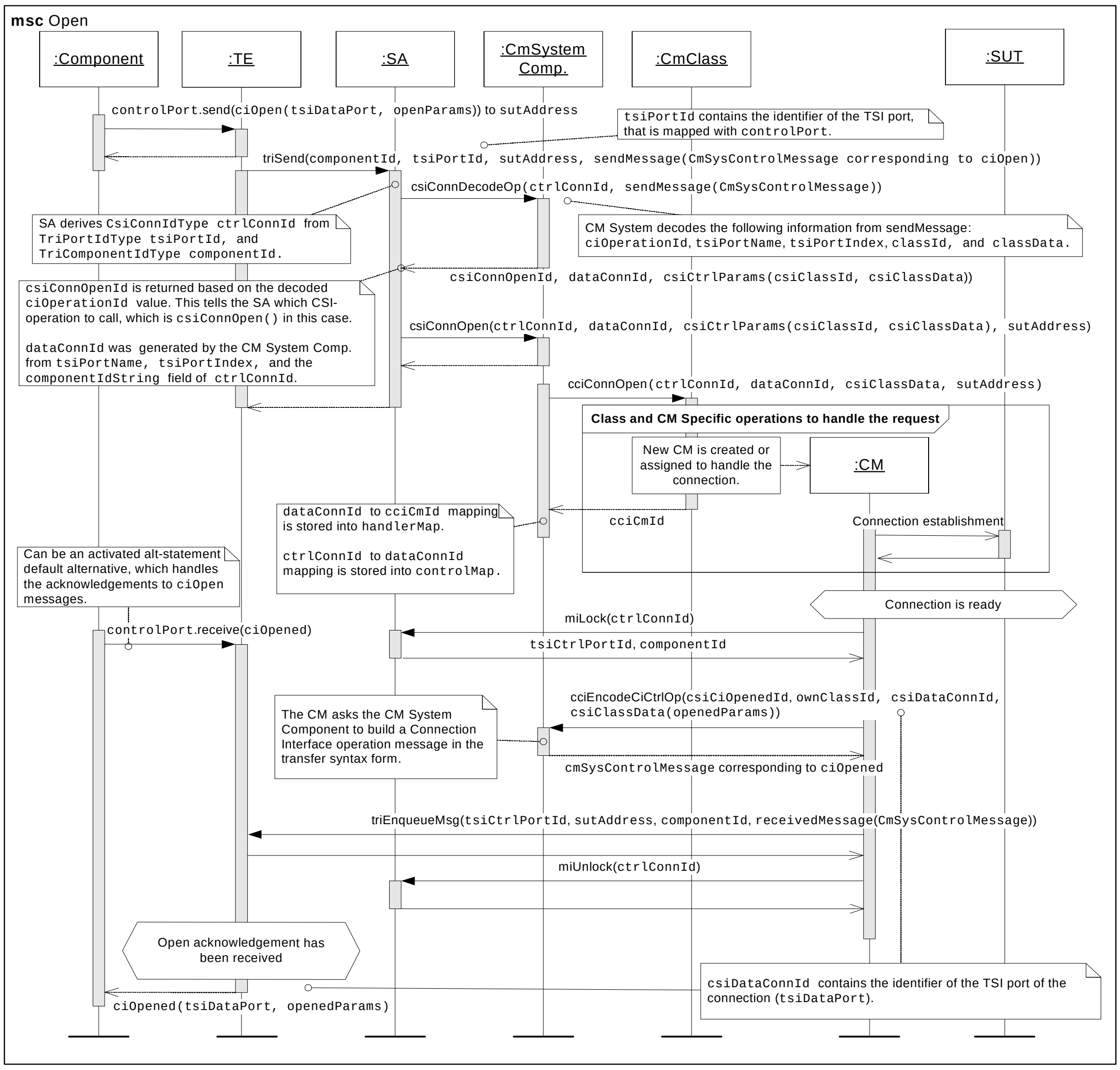
When: The CM calls this operation right after its `triEnqueue*()` operation call has returned, not to unnecessarily prevent the TE and the SA from doing any possibly modifications to the mapping information.

B MSC DIAGRAMS

This section contains selected message sequence chart diagrams, which illustrate how the interfaces and their operations specified in Chapter 5 and Appendix A work together.

B.1 Open

This MSC diagram shows how a data connection is opened from the test case by a component and what interface operations this results in. If the open procedure fails, then the CM closes the connection as in MSC B.5 Closed, by notifying the CM System Component and the test case component.



msc Open
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:SUT
controlPort.send(ciOpen(tsiDataPort, openParams)) to sutAddress
triSend(componentId, tsiPortId, sutAddress, sendMessage(CmSysControlMessage corresponding to ciOpen))
csiConnDecodeOp(ctrlConnId, sendMessage(CmSysControlMessage))
csiConnOpenId, dataConnId, csiCtrlParams(csiClassId, csiClassData))
csiConnOpen(ctrlConnId, dataConnId, csiCtrlParams(csiClassId, csiClassData), sutAddress)
cciConnOpen(ctrlConnId, dataConnId, csiClassData, sutAddress)
Class and CM Specific operations to handle the request
New CM is created or assigned to handle the connection.
:CM
cciCmId
Connection establishment
Connection is ready
miLock(ctrlConnId)
tsiCtrlPortId, componentId
controlPort.receive(ciOpened)
cciEncodeCiCtrlOp(csiCiOpenedId, ownClassId, csiDataConnId, csiClassData(openedParams))
cmSysControlMessage corresponding to ciOpened
triEnqueueMsg(tsiCtrlPortId, sutAddress, componentId, receivedMessage(CmSysControlMessage))
miUnlock(ctrlConnId)
Open acknowledgement has been received
ciOpened(tsiDataPort, openedParams)

tsiPortId contains the identifier of the TSI port, that is mapped with controlPort.

SA derives CsiConnIdType ctrlConnId from TriPortIdType tsiPortId, and TriComponentIdType componentId.

CM System decodes the following information from sendMessage: ciOperationId, tsiPortName, tsiPortIndex, classId, and classData.

csiConnOpenId is returned based on the decoded ciOperationId value. This tells the SA which CSI-operation to call, which is csiConnOpen() in this case.

dataConnId was generated by the CM System Comp. from tsiPortName, tsiPortIndex, and the componentIdString field of ctrlConnId.

dataConnId to cciCmId mapping is stored into handlerMap.

ctrlConnId to dataConnId mapping is stored into controlMap.

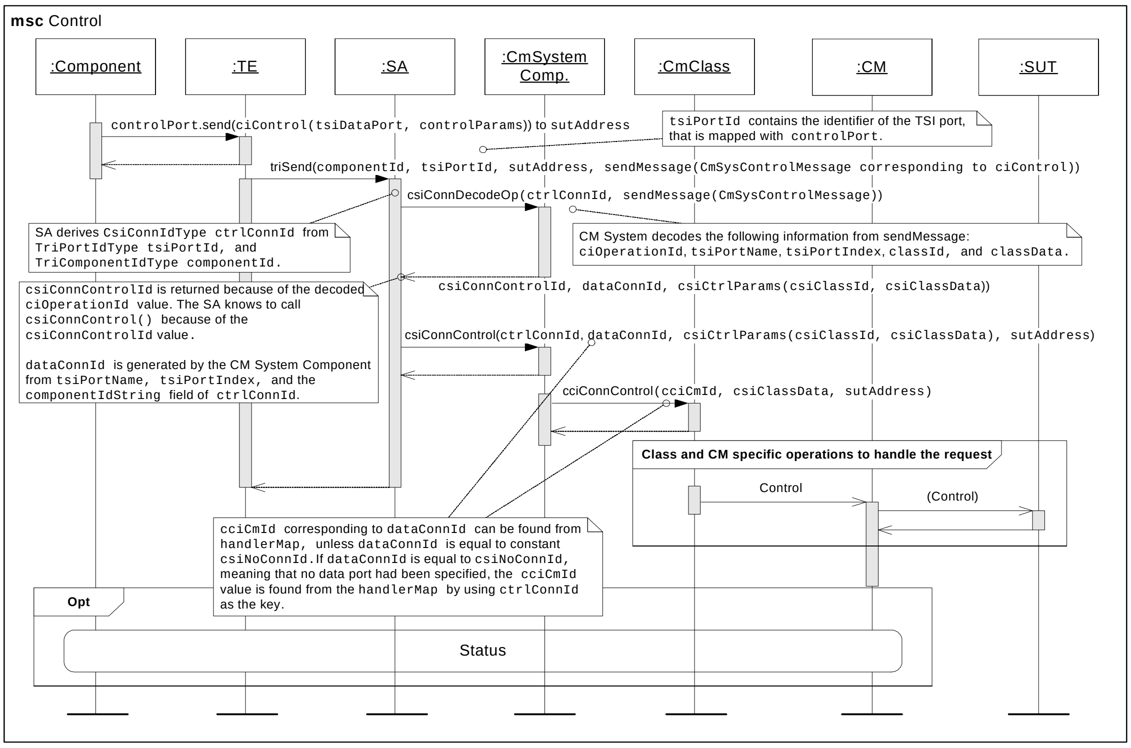
Can be an activated alt-statement default alternative, which handles the acknowledgements to ciOpen messages.

The CM asks the CM System Component to build a Connection Interface operation message in the transfer syntax form.

csiDataConnId contains the identifier of the TSI port of the connection (tsiDataPort).

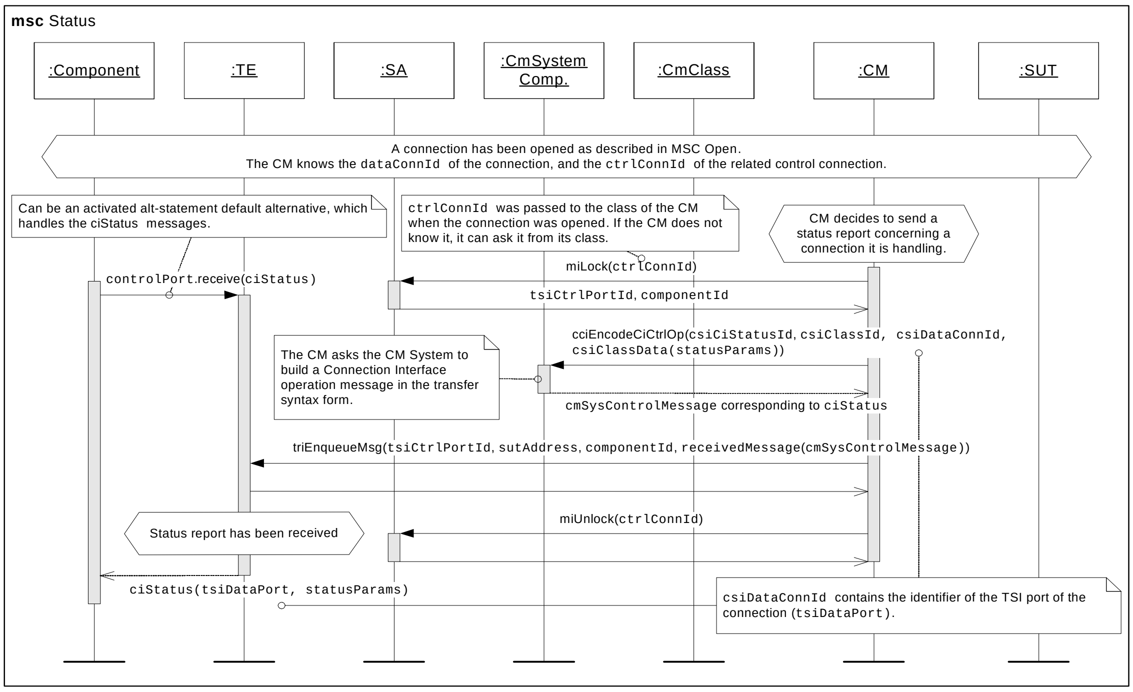
B.2 Control

This MSC diagram illustrates how a connection can be controlled, when it has been successfully opened as shown in MSC B.1 Open.


msc Control
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
controlPort.send(ciControl(tsiDataPort, controlParams)) to sutAddress
tsiPortId contains the identifier of the TSI port, that is mapped with controlPort.
triSend(componentId, tsiPortId, sutAddress, sendMessage(CmSysControlMessage corresponding to ciControl))
csiConnDecodeOp(ctrlConnId, sendMessage(CmSysControlMessage))
SA derives CsiConnIdType ctrlConnId from TriPortIdType tsiPortId, and TriComponentIdType componentId.
CM System decodes the following information from sendMessage: ciOperationId, tsiPortName, tsiPortIndex, classId, and classData.
csiConnControlId, dataConnId, csiCtrlParams(csiClassId, csiClassData))
csiConnControlId is returned because of the decoded ciOperationId value. The SA knows to call csiConnControl() because of the csiConnControlId value.
dataConnId is generated by the CM System Component from tsiPortName, tsiPortIndex, and the componentIdString field of ctrlConnId.
csiConnControl(ctrlConnId, dataConnId, csiCtrlParams(csiClassId, csiClassData), sutAddress)
cciConnControl(cciCmId, csiClassData, sutAddress)
Class and CM specific operations to handle the request
Control
(Control)
cciCmId corresponding to dataConnId can be found from handlerMap, unless dataConnId is equal to constant csiNoConnId. If dataConnId is equal to csiNoConnId, meaning that no data port had been specified, the cciCmId value is found from the handlerMap by using ctrlConnId as the key.
Opt
Status

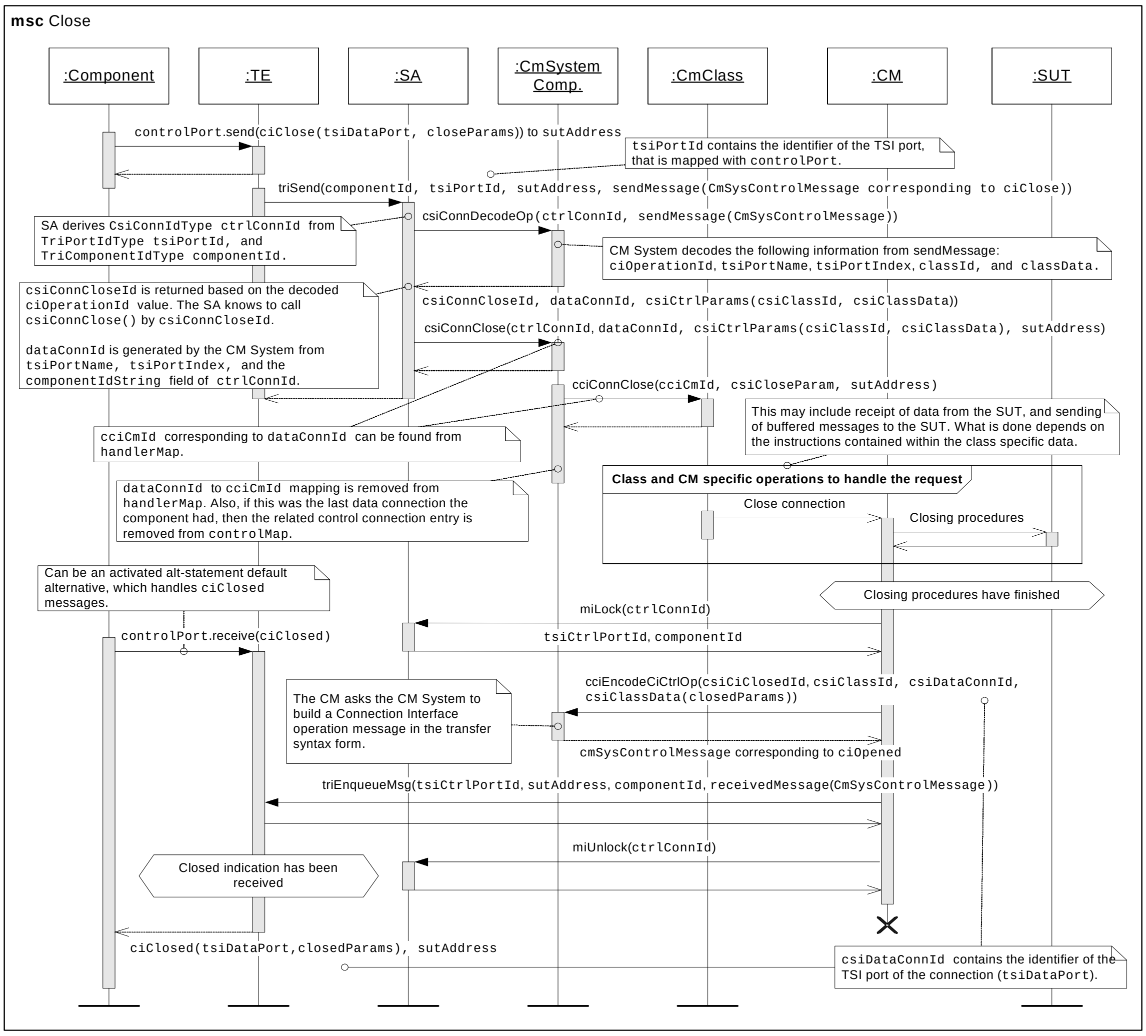
B.3 Status

This MSC diagram illustrates how a connection manager can send a status message regarding a connection it is handling to the test case component that opened the connection.


msc Status
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
A connection has been opened as described in MSC Open.
The CM knows the dataConnId of the connection, and the ctrlConnId of the related control connection.
Can be an activated alt-statement default alternative, which handles the ciStatus messages.
ctrlConnId was passed to the class of the CM when the connection was opened. If the CM does not know it, it can ask it from its class.
CM decides to send a status report concerning a connection it is handling.
miLock(ctrlConnId)
controlPort.receive(ciStatus)
tsiCtrlPortId, componentId
cciEncodeCiCtrlOp(csiCiStatusId, csiClassId, csiDataConnId, csiClassData(statusParams))
The CM asks the CM System to build a Connection Interface operation message in the transfer syntax form.
cmSysControlMessage corresponding to ciStatus
triEnqueueMsg(tsiCtrlPortId, sutAddress, componentId, receivedMessage(cmSysControlMessage))
miUnlock(ctrlConnId)
Status report has been received
ciStatus(tsiDataPort, statusParams)
csiDataConnId contains the identifier of the TSI port of the connection (tsiDataPort).

B.4 Close

This MSC diagram illustrates how connection is closed when this is requested by a test case component.


msc Close
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
controlPort.send(ciClose(tsiDataPort, closeParams)) to sutAddress
triSend(componentId, tsiPortId, sutAddress, sendMessage(CmSysControlMessage corresponding to ciClose))
csiConnDecodeOp(ctrlConnId, sendMessage(CmSysControlMessage))
csiConnCloseId, dataConnId, csiCtrlParams(csiClassId, csiClassData))
csiConnClose(ctrlConnId, dataConnId, csiCtrlParams(csiClassId, csiClassData), sutAddress)
cciConnClose(cciCmId, csiCloseParam, sutAddress)
Class and CM specific operations to handle the request
Close connection
Closing procedures
Closing procedures have finished
miLock(ctrlConnId)
tsiCtrlPortId, componentId
controlPort.receive(ciClosed)
cciEncodeCiCtrlOp(csiCiClosedId, csiClassId, csiDataConnId, csiClassData(closedParams))
cmSysControlMessage corresponding to ciOpened
triEnqueueMsg(tsiCtrlPortId, sutAddress, componentId, receivedMessage(CmSysControlMessage))
miUnlock(ctrlConnId)
Closed indication has been received
ciClosed(tsiDataPort,closedParams), sutAddress

tsiPortId contains the identifier of the TSI port, that is mapped with controlPort.

SA derives CsiConnIdType ctrlConnId from TriPortIdType tsiPortId, and TriComponentIdType componentId.

CM System decodes the following information from sendMessage: ciOperationId, tsiPortName, tsiPortIndex, classId, and classData.

csiConnCloseId is returned based on the decoded ciOperationId value. The SA knows to call csiConnClose() by csiConnCloseId.

dataConnId is generated by the CM System from tsiPortName, tsiPortIndex, and the componentIdString field of ctrlConnId.

cciCmId corresponding to dataConnId can be found from handlerMap.

This may include receipt of data from the SUT, and sending of buffered messages to the SUT. What is done depends on the instructions contained within the class specific data.

dataConnId to cciCmId mapping is removed from handlerMap. Also, if this was the last data connection the component had, then the related control connection entry is removed from controlMap.

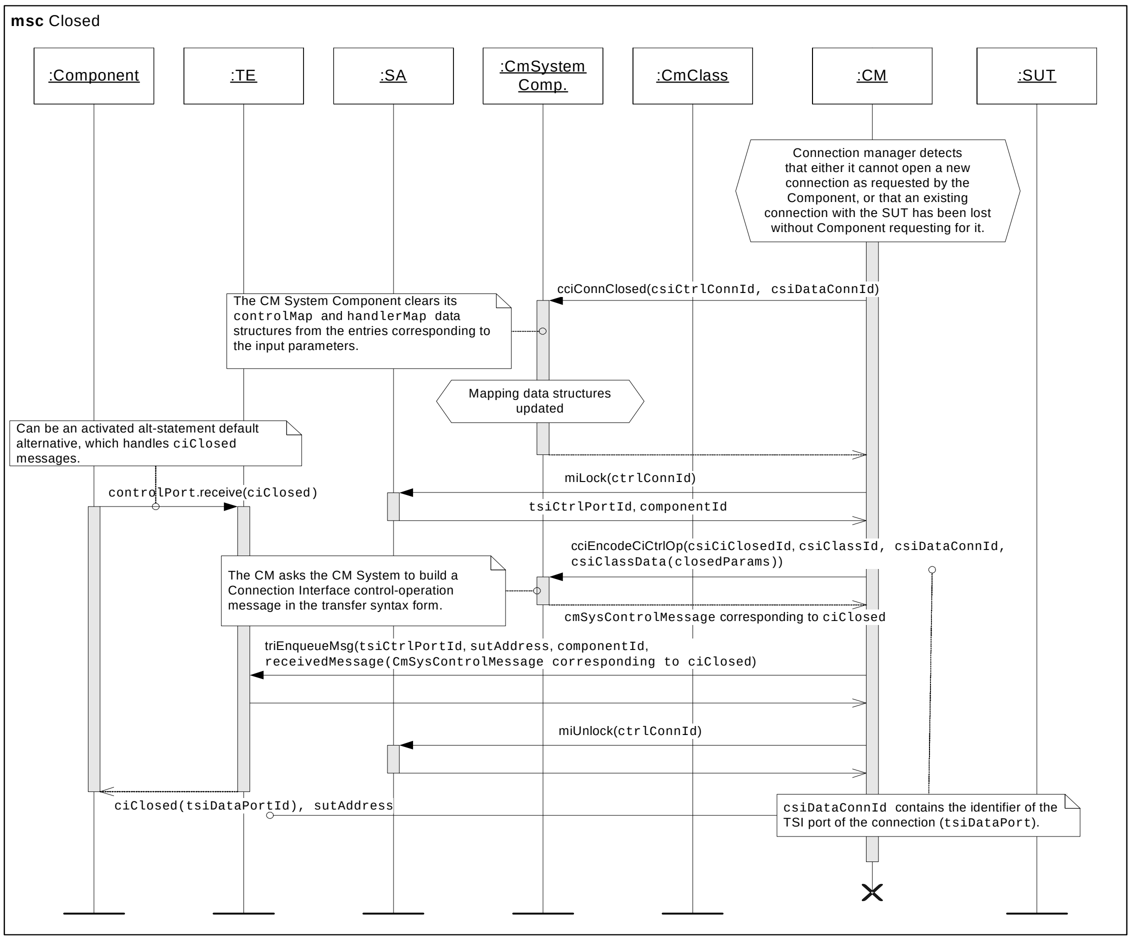
Can be an activated alt-statement default alternative, which handles ciClosed messages.

The CM asks the CM System to build a Connection Interface operation message in the transfer syntax form.

csiDataConnId contains the identifier of the TSI port of the connection (tsiDataPort).

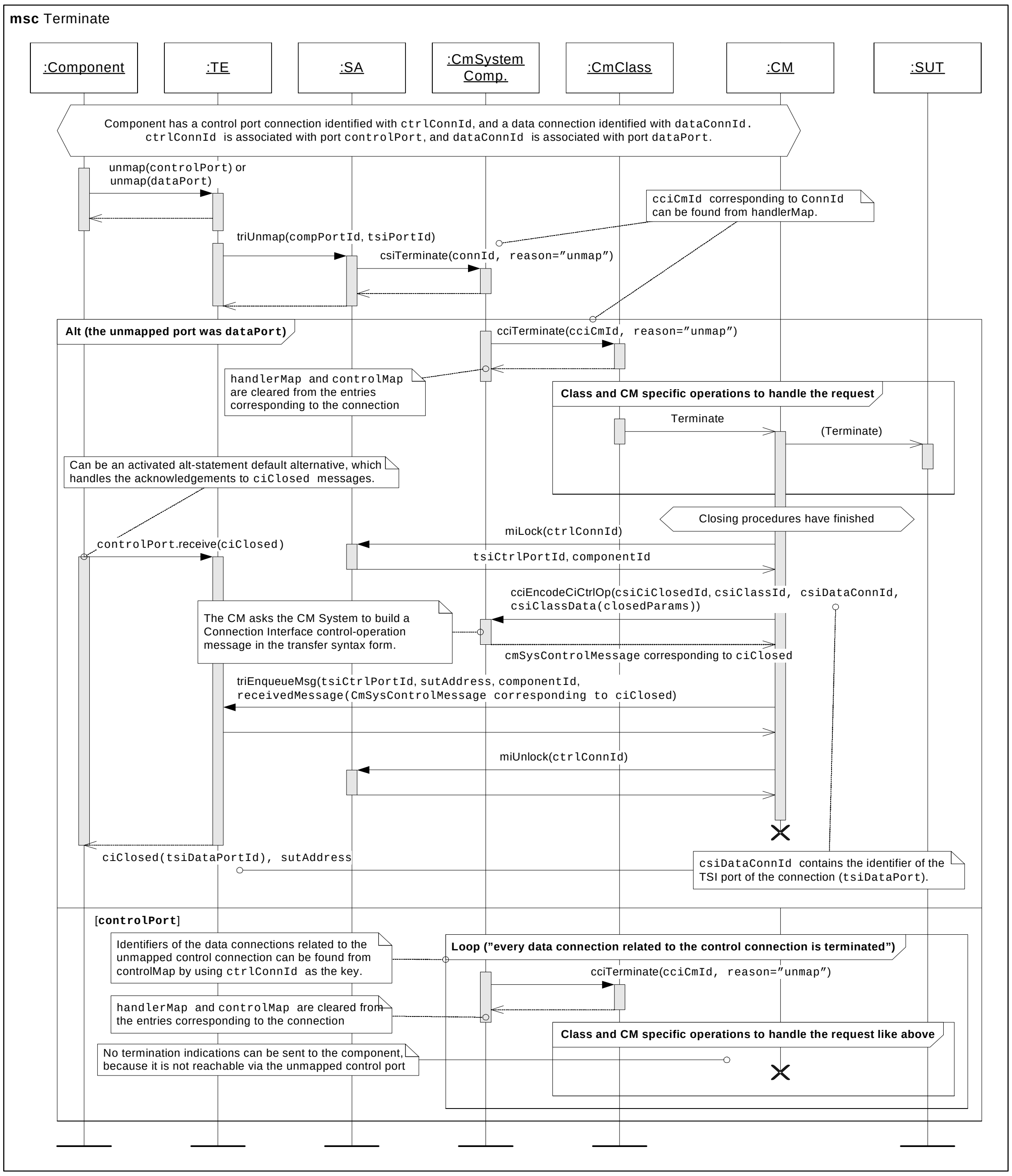
B.5 Closed

This MSC diagram illustrates how a connection is closed when this is initiated by a CM Class or a CM, as result of failure to open a new connection or when an existing connection is lost. The CM notifies first the CM System Component about the event, after which it notifies the test case component.


msc Closed
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
Connection manager detects that either it cannot open a new connection as requested by the Component, or that an existing connection with the SUT has been lost without Component requesting for it.
cciConnClosed(csiCtrlConnId, csiDataConnId)
The CM System Component clears its controlMap and handlerMap data structures from the entries corresponding to the input parameters.
Mapping data structures updated
Can be an activated alt-statement default alternative, which handles ciClosed messages.
miLock(ctrlConnId)
controlPort.receive(ciClosed)
tsiCtrlPortId, componentId
cciEncodeCiCtrlOp(csiCiClosedId, csiClassId, csiDataConnId, csiClassData(closedParams))
The CM asks the CM System to build a Connection Interface control-operation message in the transfer syntax form.
cmSysControlMessage corresponding to ciClosed
triEnqueueMsg(tsiCtrlPortId, sutAddress, componentId, receivedMessage(CmSysControlMessage corresponding to ciClosed)
miUnlock(ctrlConnId)
ciClosed(tsiDataPortId), sutAddress
csiDataConnId contains the identifier of the TSI port of the connection (tsiDataPort).

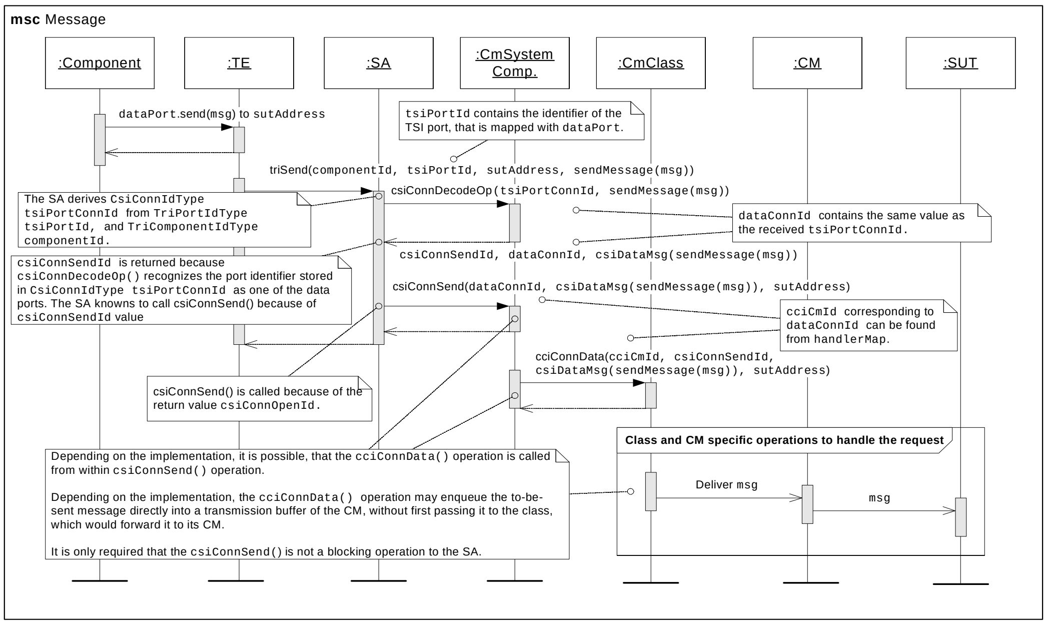
B.6 Terminate

This MSC diagram illustrates how a connection is terminated by the SA, when a component unmaps its port, for which it opened a connection, but not explicitly closed by sending a `ciClose` message as in MSC B.4. `csiTerminate()` has no effect if there are no open connections, and `cciTerminate()` is not called.


msc Terminate
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
Component has a control port connection identified with ctrlConnId, and a data connection identified with dataConnId. ctrlConnId is associated with port controlPort, and dataConnId is associated with port dataPort.
unmap(controlPort) or unmap(dataPort)
cciCmId corresponding to ConnId can be found from handlerMap.
triUnmap(compPortId, tsiPortId)
csiTerminate(connId, reason=”unmap”)
Alt (the unmapped port was dataPort)
cciTerminate(cciCmId, reason=”unmap”)
handlerMap and controlMap are cleared from the entries corresponding to the connection
Class and CM specific operations to handle the request
Terminate
(Terminate)
Can be an activated alt-statement default alternative, which handles the acknowledgements to ciClosed messages.
Closing procedures have finished
miLock(ctrlConnId)
controlPort.receive(ciClosed)
tsiCtrlPortId, componentId
cciEncodeCiCtrlOp(csiCiClosedId, csiClassId, csiDataConnId, csiClassData(closedParams))
The CM asks the CM System to build a Connection Interface control-operation message in the transfer syntax form.
cmSysControlMessage corresponding to ciClosed
triEnqueueMsg(tsiCtrlPortId, sutAddress, componentId, receivedMessage(CmSysControlMessage corresponding to ciClosed)
miUnlock(ctrlConnId)
ciClosed(tsiDataPortId), sutAddress
csiDataConnId contains the identifier of the TSI port of the connection (tsiDataPort).
[controlPort]
Identifiers of the data connections related to the unmapped control connection can be found from controlMap by using ctrlConnId as the key.
Loop (”every data connection related to the control connection is terminated”)
cciTerminate(cciCmId, reason=”unmap”)
handlerMap and controlMap are cleared from the entries corresponding to the connection
Class and CM specific operations to handle the request like above
No termination indications can be sent to the component, because it is not reachable via the unmapped control port

B.7 Message

This MSC diagram illustrates how a message is sent by a component via a data port, for which it has previously opened a connection.



msc Message
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
dataPort.send(msg) to sutAddress
triSend(componentId, tsiPortId, sutAddress, sendMessage(msg))
csiConnDecodeOp(tsiPortConnId, sendMessage(msg))
csiConnSendId, dataConnId, csiDataMsg(sendMessage(msg))
csiConnSend(dataConnId, csiDataMsg(sendMessage(msg)), sutAddress)
cciConnData(cciCmId, csiConnSendId, csiDataMsg(sendMessage(msg)), sutAddress)
Class and CM specific operations to handle the request
Deliver msg
msg

`tsiPortId` contains the identifier of the TSI port, that is mapped with `dataPort`.

The SA derives `CsiConnIdType tsiPortConnId` from `TriPortIdType tsiPortId`, and `TriComponentIdType componentId`.

`dataConnId` contains the same value as the received `tsiPortConnId`.

`csiConnSendId` is returned because `csiConnDecodeOp()` recognizes the port identifier stored in `CsiConnIdType tsiPortConnId` as one of the data ports. The SA knowns to call csiConnSend() because of `csiConnSendId` value

`cciCmId` corresponding to `dataConnId` can be found from `handlerMap`.

csiConnSend() is called because of the return value `csiConnOpenId`.

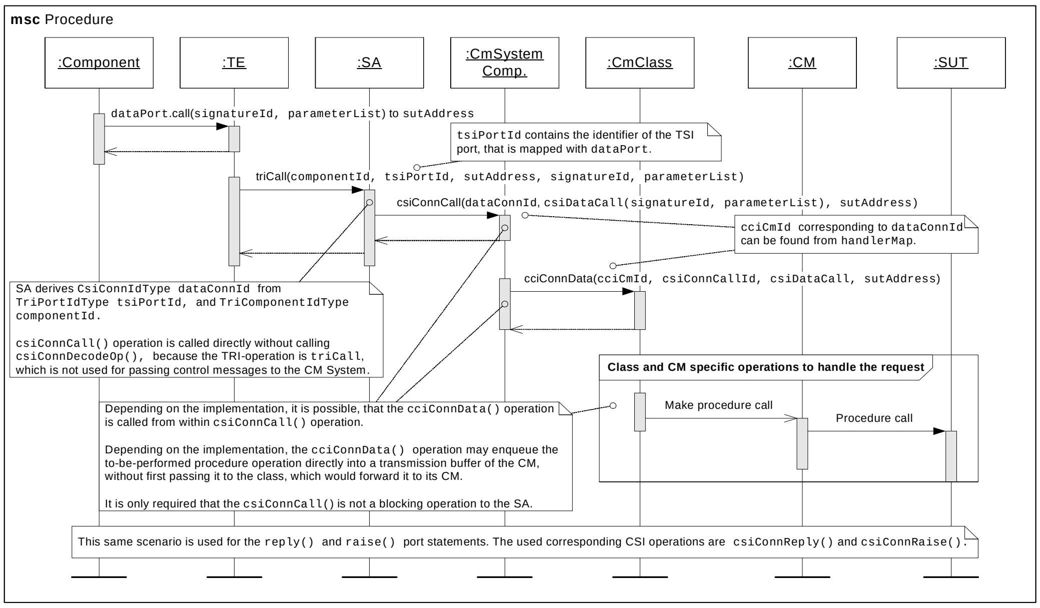
Depending on the implementation, it is possible, that the `cciConnData()` operation is called from within `csiConnSend()` operation.

Depending on the implementation, the `cciConnData()` operation may enqueue the to-be-sent message directly into a transmission buffer of the CM, without first passing it to the class, which would forward it to its CM.

It is only required that the `csiConnSend()` is not a blocking operation to the SA.

B.8 Procedure

This MSC diagram illustrates how a component performs a procedure call via a data port, for which it has previously opened a connection.



msc Procedure
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
dataPort.call(signatureId, parameterList) to sutAddress
triCall(componentId, tsiPortId, sutAddress, signatureId, parameterList)
csiConnCall(dataConnId, csiDataCall(signatureId, parameterList), sutAddress)
cciConnData(cciCmId, csiConnCallId, csiDataCall, sutAddress)
Class and CM specific operations to handle the request
Make procedure call
Procedure call

`tsiPortId` contains the identifier of the TSI port, that is mapped with `dataPort`.

`cciCmId` corresponding to `dataConnId` can be found from `handlerMap`.

SA derives `CsiConnIdType dataConnId` from `TriPortIdType tsiPortId`, and `TriComponentIdType componentId`.

`csiConnCall()` operation is called directly without calling `csiConnDecodeOp()`, because the TRI-operation is `triCall`, which is not used for passing control messages to the CM System.

Depending on the implementation, it is possible, that the `cciConnData()` operation is called from within `csiConnCall()` operation.

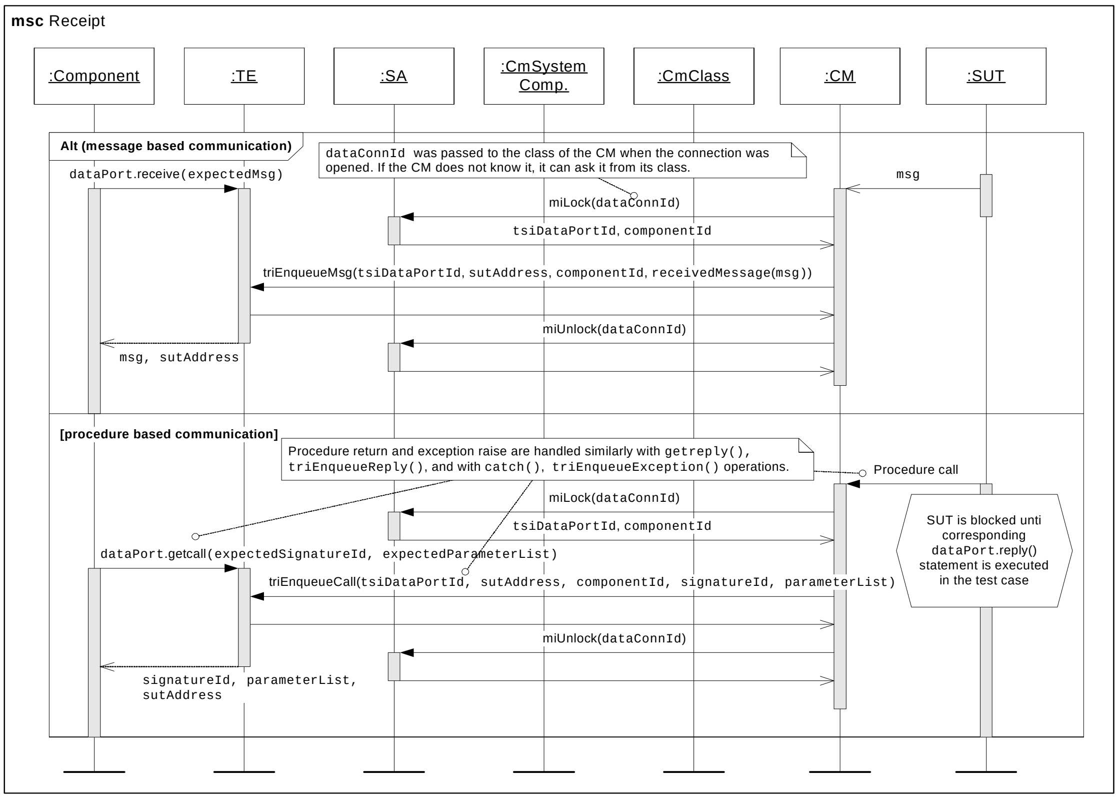
Depending on the implementation, the `cciConnData()` operation may enqueue the to-be-performed procedure operation directly into a transmission buffer of the CM, without first passing it to the class, which would forward it to its CM.

It is only required that the `csiConnCall()` is not a blocking operation to the SA.

This same scenario is used for the `reply()` and `raise()` port statements. The used corresponding CSI operations are `csiConnReply()` and `csiConnRaise()`.

B.9 Receipt of a message or procedure operation

This MSC diagram illustrates how both message- and procedure-based communication events concerning a data connection are enqueued by the CM to the test case component that opened the data connection.



msc Receipt
:Component
:TE
:SA
:CmSystem Comp.
:CmClass
:CM
:SUT
Alt (message based communication)
dataConnId was passed to the class of the CM when the connection was opened. If the CM does not know it, it can ask it from its class.
dataPort.receive(expectedMsg)
msg
miLock(dataConnId)
tsiDataPortId, componentId
triEnqueueMsg(tsiDataPortId, sutAddress, componentId, receivedMessage(msg))
miUnlock(dataConnId)
msg, sutAddress
[procedure based communication]
Procedure return and exception raise are handled similarly with getreply(), triEnqueueReply(), and with catch(), triEnqueueException() operations.
Procedure call
miLock(dataConnId)
tsiDataPortId, componentId
SUT is blocked unti corresponding dataPort.reply() statement is executed in the test case
dataPort.getcall(expectedSignatureId, expectedParameterList)
triEnqueueCall(tsiDataPortId, sutAddress, componentId, signatureId, parameterList)
miUnlock(dataConnId)
signatureId, parameterList, sutAddress