

Project Number : IST-1999-11253-TEQUILA

Project Title : Traffic Engineering for Quality of Service in the Internet, at Large Scale



D3.1 - Overview of the TEQUILA Reference Testbeds

CEC Deliverable Nr : 301/Algosystems/b1

Deliverable Type* : Report

Deliverable Nature ** : Public

Contractual date : 31th December 2000

Actual date : 28th February 2001

Editor : D.Manikis

Contributors : *Alcatel:* D.Goderis, G.Crystallo
Algosystems: P.Georgatsos, G.Kontos, D.Manikis, D.Makris
FT-R&D: C.Jacquet, C.Duret
IMEC: S.Van den Berghe, P.Van Heuven
NTUA: D.Giannakopoulos, E.Mykoniati
Global Crossing (RACAL): H.Asgari, R.Egan
UCL: D.Griffin, M.Feng
UniS: O.Alaily, P.Trimintzios

Workpackage(s) : WP3

Abstract : This Deliverable describes the capabilities of the project testbeds and the chosen simulation environments as deployed and enhanced by the project. The testbed infrastructure is described in terms of network equipment capabilities, test tools, applications and hosts as well as administrative and logistical considerations. Furthermore, the Deliverable presents the experimental focus and role of the testbeds and the simulators. A distinct role is derived for each, to allow the validation activities to be undertaken in parallel.

Keyword List : Experimentation, functional validity, performance assessment, testbeds, network simulation

Project Number : IST-1999-11253-TEQUILA

Project Title : Traffic Engineering for Quality of Service in the Internet, at Large Scale



D3.1 - Overview of the TEQUILA Reference Testbeds

Editor : D.Manikis

Contributors : *Alcatel:* D.Goderis, G.Crystallo
Algosystems: P.Georgatsos, G.Kontos, D.Manikis, D.Makris
FT-R&D: C.Jacquet, C.Duret
IMEC: S.Van den Berghe, P.Van Heuven
NTUA: D.Giannakopoulos, E.Mykoniati
Global Crossing (RACAL): H.Asgari, R.Egan
UCL: D.Griffin, M.Feng
UniS: O.Alaily, P.Trimintzios

Version : Final

Date : 28th February 2001

Distribution : WP3

© Copyright by the TEQUILA Consortium

The TEQUILA Consortium consists of:

Alcatel	Coordinator	Belgium
Algosystems S.A.	Principal Contractor	Greece
FT-CNET	Principal Contractor	France
IMEC	Principal Contractor	Belgium
NTUA	Principal Contractor	Greece
RACAL	Principal Contractor	United Kingdom
UCL	Principal Contractor	United Kingdom
TERENA	Assistant Contractor	The Netherlands
UniS	Principal Contractor	United Kingdom

Executive Summary

Experimentation is an important aspect of the TEQUILA project. It aims at validating, and assessing the performance of the project's service management and traffic engineering solutions. WP3 is the workpackage responsible for the experimentation and demonstration activities of the project.

The main theme of this Deliverable is the description of the environment and infrastructure required for experimentation. This work is necessary to allow the specification of practical experiments to begin according to the test requirements specified by WP1.

The project will execute its validation experiments in both physical testbeds and simulated networks. The testbeds made available to the project by its partners are located in the UK (provided by Global Crossing), France (provided by France Telecom R&D), Greece (provided by Algosystems and NTUA) and Belgium (provided by IMEC). The testbeds are equipped with a combination of commercial and experimental (developed or enhanced during the course of the TEQUILA project) routers and other network elements and test equipment.

Multiple testbeds have been adopted by the project for a number of reasons. Firstly, the validity of project results is increased by experiments being conducted in a variety of environments. Secondly, the use of multiple testbeds exploits the benefits of localisation and parallelism for system integration and experimentation, therefore reducing the overall time, effort and cost required by the system integration and validation tasks.

Simulation experiments complement those conducted in the physical testbeds by facilitating experiments in a variety of network topologies, traffic conditions and system configurations which would otherwise be prohibitively costly, if not impossible, in the testbeds available to the project. Experiments will be executed in the NS and OPNET simulation environments by University College London, the University of Surrey, and Alcatel.

This Deliverable describes:

- the capabilities of the project testbeds and the chosen simulation environments as deployed and enhanced by the project. The testbed infrastructure is described in terms of network equipment capabilities and configurations, test tools, applications and hosts as well as administrative and logistical considerations
- the experimental focus and role of the testbeds and the simulators. The entire TEQUILA functionality is not intended to run in each testbed or simulator. A distinct role is derived for each, to allow the validation activities to be undertaken in parallel. The roles are distinguished according to the major functional areas of the TEQUILA system architecture (SLS management, intra-domain and inter-domain traffic engineering and data plane functional areas, cf. D1.1, D1.2) and the task allocation per partner (cf. D2.2).

This Deliverable demonstrates that the capabilities of the project's testbeds and simulation platforms are sufficient to meet the project's experimentation needs. Furthermore, the role of each platform - in terms of the functionality to be exercised in that environment - is specified so that the complete set of experimentation activities, required to demonstrate and validate the service management and traffic engineering functions addressed by the project, may be executed efficiently.

D3.1 will be superseded by Deliverable D3.2 in April 2001. D3.2 will detail the specific configuration of each testbed and simulation environment according to their experimentation focus and role, and the testing requirements produced by WP1.

Table of Contents

1	INTRODUCTION	8
1.1	PROJECT OVERVIEW	8
1.2	SCOPE AND ORGANISATION OF THE DELIVERABLE	8
2	EXPERIMENTATION PLATFORMS AND FOCUS	9
2.1	PLATFORMS – TESTBEDS AND SIMULATORS	9
2.2	EXPERIMENTATION FOCUS	9
3	TESTBEDS	11
3.1	U.K. TESTBED.....	11
3.1.1	<i>Location</i>	11
3.1.2	<i>Network Equipment</i>	11
3.1.3	<i>Test Tools</i>	11
3.1.4	<i>Applications</i>	11
3.1.5	<i>Hosts</i>	12
3.1.6	<i>Experimentation Focus</i>	12
3.2	FRENCH TESTBED.....	13
3.2.1	<i>Location</i>	13
3.2.2	<i>Network Equipment</i>	13
3.2.3	<i>Test Tools</i>	14
3.2.4	<i>Applications</i>	14
3.2.5	<i>Hosts</i>	14
3.2.6	<i>Experimentation Focus</i>	14
3.3	BELGIAN TESTBED.....	15
3.3.1	<i>Location</i>	15
3.3.2	<i>Network Equipment</i>	15
3.3.3	<i>Test Tools</i>	15
3.3.4	<i>Hosts</i>	15
3.3.5	<i>Experimentation Focus</i>	15
3.4	GREEK TESTBED.....	16
3.4.1	<i>Location</i>	16
3.4.2	<i>ALGO Testbed</i>	16
3.4.2.1	<i>Network Equipment</i>	16
3.4.2.2	<i>Test Tools</i>	16
3.4.2.3	<i>Applications</i>	16
3.4.2.4	<i>Hosts</i>	16
3.4.3	<i>NTUA Testbed</i>	17
3.4.3.1	<i>Network Equipment</i>	17
3.4.3.2	<i>Test Tools</i>	17
3.4.3.3	<i>Hosts</i>	17
3.4.4	<i>Experimentation Focus</i>	17
3.5	OPERATIONAL CONSIDERATIONS	18
4	SIMULATORS	19
4.1	NS ENVIRONMENT.....	19
4.1.1	<i>Node and Network Model</i>	19
4.1.2	<i>Test Tools</i>	19
4.1.3	<i>Applications</i>	19
4.1.4	<i>Hosts</i>	19
4.1.5	<i>Experimentation Focus</i>	19
4.2	OPNET ENVIRONMENT	20
4.2.1	<i>Node and Network Model</i>	20
4.2.2	<i>Test Tools</i>	20
4.2.3	<i>Applications</i>	21
4.2.4	<i>Hosts</i>	21

4.2.5	<i>Experimentation Focus</i>	21
5	REFERENCES	22
6	APPENDIX A – NETWORK EQUIPMENT DESCRIPTION	23
6.1	CISCO ROUTERS	23
6.1.1	<i>Physical Interfaces</i>	23
6.1.1.1	Network Module Options for Cisco 2610 and 3640 Routers	23
6.1.1.2	7513 Line Cards	23
6.1.1.3	GSR 12012 Line Cards	23
6.1.1.4	Interface between Linux and Cisco router.....	23
6.1.2	<i>Capabilities</i>	23
6.1.2.1	Traffic Classification and Conditioning.....	23
6.1.2.2	Per Hop Behaviours.....	24
6.1.2.3	MPLS Forwarding and Traffic Engineering	25
6.2	IFT ROUTERS	26
7	APPENDIX B – TEST TOOLS DESCRIPTION	27
7.1	SMARTBITS.....	27
7.2	HP INTERNET ADVISOR WAN.....	27
7.3	DATA CHANNEL SIMULATOR.....	27
7.4	CISCO TRAFFIC GENERATORS -USER TRAFFIC GENERATOR - TEST TCP (TTCP).....	27
7.5	CISCO MEASUREMENT TOOLS	27
7.5.1	<i>Cisco Service Assurance Agent</i>	27
7.5.2	<i>Ping Tool</i>	28

List of Figures

Figure 1: Geographical representation of FTR&D testing resources	13
Figure 2: IFT Router configurations	26

List of Tables

Table 1: Testbeds' experimentation focus	10
Table 2: Simulators' experimental focus	10
Table 3: Traffic conditioning components of Cisco routers.	24
Table 4: Queuing mechanisms supported in the Cisco routers.....	24
Table 5: Matching Cisco features to the required functionality.	25
Table 6: MPLS function on Cisco routers.	25

1 INTRODUCTION

1.1 Project Overview

The overall objective of TEQUILA [TEQ] is to study, specify, implement and validate service definition and traffic engineering tools for the Internet. The TEQUILA system should provide qualitative and close to quantitative service guarantees through planning, dimensioning and dynamic control of qualitative traffic management techniques based on Diffserv. TEQUILA addresses static and dynamic, intra- and inter-domain Service Level Specifications (SLSs) for both fixed and nomadic users and the protocols and mechanisms for negotiating, monitoring and enforcing them. The other main dimension of the project studies intra- and inter-domain traffic engineering schemes to ensure that the network can cope with the contracted SLSs - within domains, and in the Internet at large.

The overall work in the TEQUILA project is split over 3 workpackages (WPs), and follows a phased approach: a theoretical phase followed by a refinement phase and then an experimentation and dissemination phase.

WP1 - Functional Architecture and Algorithms - (which is responsible for the production of this document) specifies the system architecture and related protocols and algorithms. WP2 - System Design and Implementation - develops the system components and simulators. WP3 - Integration Validation, Assessment and Experimentation - configures the testbed and conducts experiments on the TEQUILA system through the testbed prototypes and the simulators.

1.2 Scope and Organisation of the Deliverable

The Deliverable describes the environment and infrastructure available to the project for experimentation. The project will carry out its experimentation activities in testbeds and in simulators. This work is necessary to allow the specification of practical experiments to begin according to the test requirements specified by WP1.

The Deliverable will be superseded by Deliverable D3.2 in April 2001. D3.2 will detail the specific configuration of each testbed and simulation environment according to their experimentation focus and role, and the testing requirements produced by WP1.

The Deliverable is organised as follows:

Chapter 2 presents the experimental focus (role in experimentation) of the project testbeds and simulators.

Chapter 3 describes the available infrastructure in the project testbeds in terms of network equipment, test tools, applications and hosts as well as administrative and logistical considerations

Chapter 4 presents the network simulation environments.

Finally, Appendices A and B present more information on the commercial and experimental routers, and test tools available in the project testbeds.

2 EXPERIMENTATION PLATFORMS AND FOCUS

2.1 Platforms – Testbeds and Simulators

The project will execute its experimentation activities in both physical testbeds and simulated networks. The testbeds are made available to the project by its partners and are located in:

- UK, provided by Global Crossing,
- France, provided by France Telecom R&D,
- Belgium, provided by IMEC, and in
- Greece, provided by Algosystems and NTUA.

The testbeds are equipped with a combination of commercial and experimental (developed or enhanced during the course of the TEQUILA project) routers and other network elements and test equipment.

The choice for adopting multiple testbeds lies with the following lines:

- Results validity. The validity of project results is increased by experiments being conducted in a variety of environments.
- Focused development, integration and experimentation. Each testbed focuses on the experimentation of particular aspects of the developed prototypes (see next section), allowing therefore the project to utilise the benefits of parallel system integration and experimentation. Further, as testbeds are close to partner premises, the effort and cost required to by the integration and experimentation activities is reduced.

Conclusively, the existence of multiple testbeds facilitates the efficient undertaking of the project integration and experimentation activities, causing no additional overhead to the project. For the reasons presented above, it adds to the validity of the produced results and reduces the overall time, effort and cost required by the system integration and validation tasks.

In addition to testbeds, experimentation is undertaken in network simulation environments. Specifically, the simulation platforms available in the project are the:

- NS platform, provided by University College London and the University of Surrey, and the
- OPNET platform, provided by Alcatel.

The above platforms have been appropriately enhanced (by WP2) to cover the functional requirements and experimental needs of the specified solutions for SLS management and traffic engineering.

By its own virtue, simulation offers a flexible, portable and customisable experimentation means. As such, simulation experiments complement those conducted in the physical testbeds by facilitating experiments in a variety of network topologies, traffic conditions and system configurations which would otherwise be prohibitively costly, if not impossible, in the testbeds available to the project.

2.2 Experimentation Focus

The entire TEQUILA functionality is not intended to be integrated and experimented in each testbed or simulator. A distinct role is derived for each, to allow the experimentation activities to be undertaken in parallel and locally by the system implementation teams, therefore facilitating the undertaking of these activities.

The roles (experimentation focus) are distinguished according to the major functional areas of the TEQUILA system architecture (SLS management, intra-domain and inter-domain traffic engineering and data plane functional areas [D1.1], [D1.2]) and the task allocation per partner ([D2.2]).

Table 1 depicts the experimental focus of the project testbeds and Table 2 the experimental focus of project simulators.

Testbed	Partners involved	Experimentation focus (per major functional area of the TEQUILA system)
U.K.	GCX	Intra-domain MPLS-based traffic engineering functionality
French	FTR&D	Intra-domain IP-based traffic engineering functionality
Belgian	IMEC	Data plane functionality to support SLS management and traffic engineering functions
Greek	ALGO,NTUA	SLS management (TEQUILA SLS-based service subscription and invocation) functionality and interactions with traffic engineering

Table 1: Testbeds' experimentation focus

Simulator	Partners involved	Experimentation focus (per major functional area of the TEQUILA system)
NS	UCL, UniS	Intra-domain traffic engineering functionality
OPNET	ALCATEL	Inter-domain traffic engineering aspects

Table 2: Simulators' experimental focus

It should be noted that although each testbed has a specific testing focus, the (near) complete TEQUILA system will be installed in all testbeds.

The experimentation focus of the testbeds and simulators is described in more detail in the corresponding section of the subsequent chapters, by outlining the tests to be undertaken. The configuration of the testbeds and simulators for carrying out the experiments according to their focus will be included in Deliverable D3.2 (end of April 2001), and the detailed description of the tests to be carried out will be included in Internal Reports I3.5, I3.2 (due end of July 2001).

3 TESTBEDS

3.1 U.K. Testbed

3.1.1 Location

The U.K. testbed is located at the premises of Global Crossing.

3.1.2 Network Equipment

The following equipment is available:

- Cisco 2610 Access Routers (can be VoIP Gateways)
- Cisco 3640 Access Routers (can be VoIP Gateways)
- Cisco 4500 Access Router
- Cisco 7513 Core Routers (4 off)
- Cisco GSR 12012 Core Routers (3 off)

Global Crossing has Cisco support contracts that entitle it to the latest software releases (IOS) and Technical Assistance Centre (TAC) supports.

3.1.3 Test Tools

The following test tools are available:

- SmartBits SMB-2000 and SMB-6000B. For both chassis SmartWin, SmartLib and SmartApps are included
 - ◇ SmartBits SMB-2000 has 2 E3 ATM SmartCard, 2 STM1 ATM SmartCard and 2 Frame Relay E1 WAN SmartCard available interfaces
 - ◇ SmartBits SMB-6000B has 2 Six port 10/100 Ethernet half/full duplex, 2 Single port gigabit Ethernet and 2 One port single mode POS STM4 and STM1 available interfaces
- HP Internet Advisor WAN/LAN
- Data Channel Simulator
- Cisco Traffic Generators Tool
 - ◇ User Traffic Generator - Test TCP (TTCP)
- Cisco Measurement Tools
 - ◇ Cisco Service Assurance Agent
 - ◇ Ping Tool

More details on the above equipment and test tools can be found in Appendix A – Network Equipment Description and Appendix B – Test Tools Description.

3.1.4 Applications

The following applications are available:

- SmartBits applications

- ◇ SmartFlow - Layer 2,3, 4 QoS and BGP Performance Tests
- ◇ Smart VoIPQoS - Voice over IP Network Tests
- ◇ ScriptCenter - Tcl/Tk Scripting tool
- Voice over IP hosted on 26/3600 routers
- FTP and Web based servers (x86 based PC applications)

3.1.5 Hosts

The following hosts are available :

- Linux-based PCs
- NT-based PCs.

3.1.6 Experimentation Focus

As already outlined in chapter 2 (section 2.2), the UK testbed will be used for performing experiments related to the specified MPLS-based traffic engineering (TE) functions. In particular, experimentation in the UK testbed is concerned with:

- Validation of the correct behaviour of the monitoring components (network & SLS monitoring, monitoring GUI and monitoring repository). Correct behaviour is verified by checking actual measurements against expected measurements in controlled load environments.
- Assessment of the overhead (caused by the specific experimental implementation) in getting and forwarding measurements and threshold crossing events.
- Validation of the correct behaviour of the MPLS-based network resource dimensioning and route calculation functions of the TEQUILA system, in a variety of anticipated traffic patterns. Correct behaviour is verified by checking the topological correctness of the resulted configurations (e.g. topologically correct LSPs, link scheduling rates), the information exchanged between the system components, and by checking that the network as configured can indeed sustain gracefully the traffic against which has been configured.
- Assessment of the benefits of the above functions in network operation, as a function of different anticipated traffic patterns. The benefits are assessed by comparing network performance (in terms of well-defined metrics) as this is yielded by configuring the network as a result of above functions, against network performance that is yielded when configuring the network following conventional methods. For example, measuring the bandwidth efficiency gained by implementing hoses versus pipes. These experiments should be in conjunction to the corresponding experiments carried out in the NS environment (see section 4.1.5).
- Validation of the correct behaviour of the dynamic resource (PHB, buffers) and routing (reassignment of flow forwarding) management functions of the TEQUILA system. Correct behaviour is verified by checking actual against expected behaviour (interactions with system components and configuration actions) in a controlled environment (e.g. known triggering conditions).
- Assessment of the benefits of the dynamic resource and routing management in network operation, as a function of different traffic generation patterns. The benefits are assessed by comparing network performance (in terms of well-defined metrics) as this is yielded when these functions are present, against network performance that is yielded when these functions are not present. Traffic is generated within statistical range of estimates against which the network has been initially configured. These experiments should be in conjunction to the corresponding experiments carried out in the NS environment (see section 4.1.5).

- Assess the collective behaviour of the MPLS-based TE functions (i.e. network dimensioning, dynamic resource and management) in terms of overall network performance, as a function of different traffic generation patterns.
- Validate that the MPLS-based TE function behaviours, as measured above, are usefully controlled by the policy management functions.

3.2 French Testbed

3.2.1 Location

The testing platform will not be restricted to the premises of FTR&D Caen (Normandy). It will gracefully benefit from the RIMBAUD (Réseaux Ipv6 et Multicast Basés sur l'Atm et à Usage Démonstratif) network, so that it will also be interconnected to the testing resources that are installed in FTR&D Issy les Moulineaux (Paris suburbs).

The RIMBAUD network is an experimental network which has been deployed in 1998, and which aims at interconnecting the various locations of FTR&D, so that different kinds of evaluation campaigns can be performed, as far as the development of new services (or networks) is concerned.

A generic display of the testing platform in the French testbed is depicted in Figure 1 below.

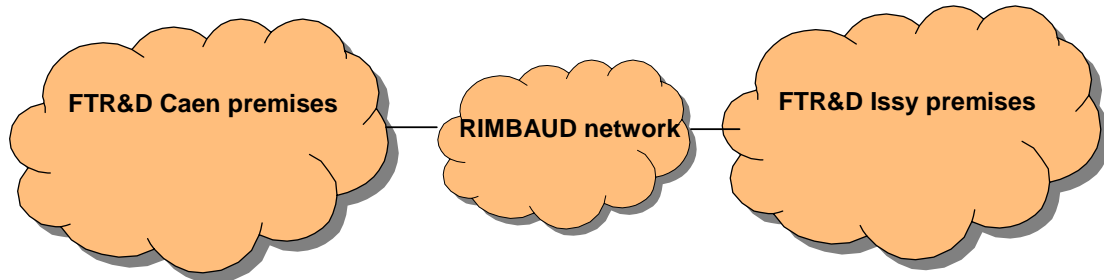


Figure 1: Geographical representation of FTR&D testing resources

Interconnection to other partners' testbeds could be possible via DANTE's MBS service; however, this is not considered by the project.

3.2.2 Network Equipment

Cisco and Linux routers will be used as network elements for testing purposes.

The IP routers (locally installed in FTR&D Issy premises) that will be used for testing purposes, mainly for performance assessment, are composed of the following equipment:

- A Cisco router
- A Linux-based router
- An IFT-based experimental network element

Because of the routing platforms to be used, and taking into account the nature of the TEQUILA project, the Cisco IOS will be chosen so that it supports the most advanced IP features (supporting traffic engineering extensions to OSPF and COPS-PR capabilities).

For more information on Cisco and IFT router configuration models see Appendix A – Network Equipment Description.

3.2.3 Test Tools

Traffic generators and protocol analysers will be used (as Point of Control and Observation (PCO)) to perform the tests.

3.2.4 Applications

Commercial applications will be used (Media Player, Real Audio, HTTP clients and daemon, FTP clients and server, SNMP manager) as different sources of traffic. Such applications are embedded in PCs that are permanently connected to the FTR&D Caen testing platform.

3.2.5 Hosts

The following hosts are available:

- SUN's Ultras (Solaris 2.7/2.8)
- NT and Windows 98 PCs
- Linux PCs

3.2.6 Experimentation Focus

As already outlined in chapter 2 (section 2.2), the French testbed is used for performing experiments related to the specified IP-based traffic engineering (TE) functions. In particular, experimentation in the French testbed can fall into the following test categories (suites):

Traffic engineering test suite:

- Assessment of the switching performance of the Label Edge and Label Switch Routers.
- Validation of the correct behaviour of the IP-based TE capable routers that support the OSPF Opaque LSA, as defined in RFC 2370, as well as the developed TE extensions to OSPF.
- Validation of the correct behaviour of the IP-based TE routers upon invocation of the TEQUILA SLS-based services.
- Assessment of the impact of the support of the OSPF protocol and its traffic engineering extensions on the performance of the system under test (routers, TE system).

Dynamic provisioning of QoS services test suite:

- Validation of the correct behaviour of the PEP (Policy Enforcement Point) embedded in the routers, as far as the processing of COPS messages and the corresponding translation into local configuration information are concerned.
- Assessment of the impact of the support of the PEP on the switching performances of the routers.
- Validation of the correct behaviour of the PDP (Policy Decision Point) server as far as the processing of COPS messages is concerned. Correct behaviour will be verified by checking actual against expected actions/results in a controlled environment.
- Validation of the correct instantiation of the EPD (Encoded Policy Provisioning Data) that is stored and maintained in the IP TE PIB (Policy Information Base).
- Validation of the support of the COPS protocol by the system under test (routers, PDP server) as far as the enforcement of the IP TE policy is concerned.
- Assessment of the impact of the support of the COPS protocol on the performance of the system under test.

3.3 Belgian Testbed

3.3.1 Location

The Belgian testbed is the Atlantis-laboratory located at INTEC (IMEC) premises in Gent, Belgium.

3.3.2 Network Equipment

The following equipment is available:

- Intel- and AMD-based experimental PC's, both in desktop and rack-mounted chases, running the Linux operating system. PC-based systems are used both as end-systems and routers. The available equipment can allow, for instance, for experimentation/development of a medium-size (5-20 hops) Linux-based network.
- Experimental 10/100-BaseT Ethernet network and 155 Mbit multimode fibre ATM network, ADSL-test network
- Commercial network elements:
 - ◊ ADSL-rack / DANA
 - ◊ IBM ATM-switches: 8265, 8285
 - ◊ NEC Atomis ATM switch
 - ◊ Cisco 7507 with 10/100Mbit interfaces and 155 Mbit ATM
 - ◊ 3Com Superstack-II with 155Mbit ATM uplink

3.3.3 Test Tools

The following test tools are available:

- HP BSTS broadband analyser with ATM/Ethernet interfaces
- SmartBits SMB-2000 traffic generator with 10/100Mbit Ethernet interfaces
- PAMS voice evaluation equipment (for evaluating quality of voice transmission, e.g VoIP)
- Multimedia equipment (camera's / Quicknet cards for VoIP / ...)

3.3.4 Hosts

The following hosts are available:

- Intel- and AMD-based experimental PC's, both in desktop and rack-mounted chases, running the Linux operating system
- Sun workstations running Solaris

3.3.5 Experimentation Focus

As already outlined in chapter 2 (section 2.2), the Belgian testbed is used for performing experiments related to the data plane functionality of the TEQUILA system, including the basic router infrastructure (IP/Diffserv/Intserv/MPLS functionality and related protocols) as assumed by the TEQUILA system. In particular, experimentation in Belgian testbed is concerned with:

- Validation of the correct behaviour of the Linux-enhancements undertaken for supporting Diffserv and MPLS functionality/protocols as required by the TEQUILA MPLS-based traffic engineering functions. Correct behaviour is verified by checking actual against expected behaviour in a controlled environment (e.g. LSP set-up through specific interfaces).
- Validation of the correct behaviour of the Generic Adaptation layer to the Linux-based and Cisco routers. Correct behaviour is verified by checking actual against expected outcome when invoking specific configuration and monitoring operations in the router's interface.
- Interworking between Linux-based and commercial routers in MPLS context.
- Validation of correct behaviour of the developed nodal monitoring functionality. Correct behaviour is verified by checking actual against expected measurements in a controlled load environment.
- Assessment of the overhead (caused by the specific experimental implementation) in getting and forwarding measurements and threshold crossing events.

3.4 Greek Testbed

3.4.1 Location

The Greek testbed is located at the premises of Algosystems S.A. (ALGO) and National Technical University of Athens (NTUA).

3.4.2 ALGO Testbed

3.4.2.1 Network Equipment

Cisco network equipment are available; specifically,

- Six routers (2 x 7202, 2 x 7505, 2 x 3600) chassis with 2-4 available ports and Ethernet/Fast Ethernet ports each
- Several port adapter cards (E1, E3, T3, OC-3)
- Two BPX/MGX ATM switches with MPLS support
- Two AS-5300 access routers with voice/fax cards and 4 E1 ports

As Algosystems is a network integrator representing Cisco, additional equipment can be made available as required; technical support is also available. All Cisco equipment has the latest version of IOS.

3.4.2.2 Test Tools

Traffic analyser equipment is to be purchased. Traffic monitoring/analysis software tools are available on Unix and Linux platforms.

3.4.2.3 Applications

Existing applications such as http/tcp clients/servers, Real audio/video applications, VoIP applications, streaming applications –RTSP-based, winamp, shoutcast and other media broadcasting software, can be made available.

3.4.2.4 Hosts

The following hosts are available:

- SUN's Ultras (Solaris 2.7/2.8)

- NT and Windows 98 PCs
- Linux PCs

3.4.3 NTUA Testbed

3.4.3.1 Network Equipment

The following equipment is available:

- One Cisco router 7200 series VXR. The router has the following interfaces:
 - ◊ Three Fast Ethernet at 100MB
 - ◊ Two ATM at 155MB
 - ◊ Eight Ethernet at 10MB
- Two PC-based routers (Pentium III 700MHz, Linux OS with kernel 2.4.0 and three NICs (3COM fast Ethernet) for each PC-based router).

3.4.3.2 Test Tools

The following test tools are available:

- Sniffer pro version 4.50 (software)
- Internet advisor HP (hardware)

3.4.3.3 Hosts

The following hosts are available:

- Four Pentium PCs with Windows NT or Windows 2000

3.4.4 Experimentation Focus

As already outlined in chapter 2 (section 2.2), the Greek testbed is used for performing experiments related to the specified SLS Management functionality (service subscription, invocation) and its interactions with the traffic engineering system. In particular:

The NTUA testbed is used mainly for development and for testing the enhancements related to the RSVP-based invocation of SLS-based QoS services.

The Algosystems testbed is used for performing experiments related to:

- Validation of the correct behaviour of the developed TEQUILA SLS-based service subscription process, in a variety of conditions regarding network state (as made known by the traffic engineering system), requested customer services and number of current active subscription sessions. Assuming a given network state, according to system specifications, correct service subscription behaviour is verified by checking the behaviour of the SrNP (service negotiation protocol) engine and the outcome of the SP subscription logic. Furthermore, by verifying that the necessary configurations in the SP domain required for service provisioning (i.e. for the users to be able to subsequently invoke the subscribed services) have been made, as expected per subscription case.
- Assessment of the performance of the service subscription process in terms of well-defined metrics, as a function of service related parameters (e.g. number of sites) and network related parameters (e.g. number of QoS classes supported).

- Validation of the correct behaviour of the developed TEQUILA SLS-based service invocation process, in a variety of conditions regarding network state (as made known by the traffic engineering system), requested customer services and current active invocation sessions. Assuming a given network state, correct behaviour is verified by checking the outcome of the invocation handling process and by verifying that the users of a tagged customer indeed receive the level of service as specified in the customer's contracted SLSs. Note, that according to the specified service provisioning framework, services can be invoked either in-band (e.g. pre-marked) or out-band, based on RSVP as a signalling means.
- Assessment of the performance of the service invocation process in terms of call-set up/release time, as a function of service related parameters (e.g. type of service –bi/unidirectional, Intserv) and network related parameters (e.g. network state, currently active invocation sessions).
- Validation of the correct operation of the specified SLS management (subscription, invocation, traffic forecasting) and traffic engineering functions for a period of time, in a variety of service subscription and invocation patterns. Assuming a specific pattern for generating/terminating service subscriptions and invoking/releasing services, correctness of operation is verified by checking the outcome of the service request handling processes, the calculation of traffic forecasts and the configuration actions resulted by the traffic engineering functions. Verification is done at epochs, where the outcome of these functions can be safely predicted.

3.5 Operational Considerations

For the experimentation activities to be carried out in the testbeds as described in the previous sections, the following set of requirements should be at least met:

- An administrator should be assigned for each testbed
- The testbeds should be properly configured as required, the equipment should belong in a 'noise-free' Ethernet segment, and support should be provided by the partner responsible
- The TEQUILA system and the agreed operational environment (platforms, operating systems, compilers etc.) should be correctly installed

4 SIMULATORS

4.1 NS Environment

The Network Simulator (NS) is the main simulation tool selected [D2.1] for testing aspects of the specified traffic engineering algorithms in the context intra-domain environments. The OPNET platform has been suitably enhanced by the project (WP2, [D2.2], see also below) to meet the functional requirements and testing needs of the specified intra-domain traffic engineering functions.

4.1.1 Node and Network Model

NS supports a wide variety of routers since it is possible to choose and combine a large number of queue management mechanisms (drop-tail, FIFO, RED, RIO, CBQ, FQ, WFQ, SFQ etc), scheduling mechanisms (RR, WRR, DRR) and routing alternatives (static, distance vector). All these, together with the enhancements undertaken by the project (support of link state/PHB-based routing, DiffServ functionality, MPLS and inter-working between them, [D2.2]) allow to define nodes (routers) with a wide variety of capabilities, as required by the traffic engineering functions/algorithms of the TEQUILA system.

Each router may have any defined number of interfaces. The links (connectivity) between the routers can be of any size (DT1-OC3, OC3-OC192, or anything else).

The number of nodes and links can be as large as desired and the topology can be from very simple to very complex. There is clearly a trade-off between complexity and performance. A special tool for specifying network topologies will be provided by the project.

4.1.2 Test Tools

NS provides a number of traffic generators based on well-known mathematical models (e.g. Poisson, Exponential etc) or trace-based traffic generators. It also provides for a number of mathematical tools, such as support of math functions, random generation for specifying customised traffic generation processes. The TEQUILA provided test tools (cf. Bulk Service Request Generator [D2.2]) will be used to drive the NS traffic generators.

NS supports tracing and monitoring functionality at various levels (per-packet, per-queue, per-flow). It also provides a number of trace-post-processing tools (scripts) and includes a packet-level trace-driven animation tool (NAM).

4.1.3 Applications

NS provides agents for all the known transport protocols (TCP variations, UDP, RTP etc), which any application agent can be attached. The application agents available are CBR, Telnet, FTP, HTTP, Web client/servers, CBR traffic and any of the traffic generators provided. Tapping, i.e. injecting traffic from real network is an additional capability.

4.1.4 Hosts

The hosts in the networking environment can support any of the above. The hosts on which the NS simulation tests will be executed will be SPARC Solaris Workstations or Linux-based PCs. Note that one host is enough for running the simulation tests.

4.1.5 Experimentation Focus

As already outlined in chapter 2 (section 2.2), the focus of the experimentation using NS is on the specified traffic engineering (both MPLS and IP –based) functions and algorithms of the TEQUILA system. In particular, experimentation in the NS environment is concerned with:

- Validation of the correct behaviour of the network resource dimensioning and route calculation functions of the TEQUILA system, in a variety of network topologies and anticipated traffic patterns. Correct behaviour is verified by checking the topological correctness of the resulted configurations (e.g. topologically correct LSPs, link scheduling rates) and by checking that the network as configured can indeed sustain gracefully the traffic against which has been configured.
- Assessment of the performance of the above functions in terms of well-defined metrics (as specified by WP1), in a variety of network topologies and anticipated traffic patterns, as a function of their configuration variables (e.g. parameters of the algorithms or different algorithms).
- Assessment of the benefits of the above functions in network performance, as a function of different network topologies and anticipated traffic patterns. The benefits are assessed by comparing network performance (in terms of well-defined metrics) as this is yielded by configuring the network as a result of above functions, against network performance that is yielded when configuring the network following ad-hoc methods (e.g. random or fully meshed configurations).
- Validation of the correct behaviour of the dynamic resource (PHB, buffers) and routing (e.g. link weights) management functions of the TEQUILA system. Correct behaviour is verified by checking actual against expected behaviour in a controlled environment (e.g. known triggering conditions).
- Assessment of the performance of the dynamic resource and routing management functions (separately and/or individually) in terms of well-defined metrics (as specified by WP1) in a variety of network topologies and traffic generation patterns, as a function of their configuration variables (e.g. threshold levels).
- Assessment of the benefits of the dynamic resource and routing management functions (separately and/or individually) in network performance, as a function of different network topologies and traffic generation patterns. Assuming a given network configuration (resulted from given traffic estimates), the benefits are assessed by comparing network performance (in terms of well-defined metrics) as this is yielded when these functions are present, against network performance that is yielded when these functions are not present. Traffic is generated within statistical range of estimates against which the network has been initially configured.
- Assessment of the behaviours and benefits of the collective network resource dimensioning, dynamic resource and routing management functions in network performance, as a function of different network topologies and traffic generation patterns.

4.2 OPNET Environment

The OPNET simulator is the tool selected by the project for testing inter-domain QoS and traffic engineering aspects, more specifically the BGP-inter-domain (QoS-aware) route selection engine. The OPNET platform has been suitably enhanced by the project (WP2, [D2.2], see also below) to meet the functional requirements and testing needs of the specified inter-domain traffic engineering approach.

4.2.1 Node and Network Model

OPNET provides complete models for routers and nodes. As far as BGP routing is concerned, the model of BGP peers consists of a complete suite of protocols: BGP/TCP/IP. In our model there is no intra-domain routing, i.e. the implementation only focuses on the inter-domain routing.

The network model consists of a set of interconnected ASs. In each AS, BGP peers are directly connected (there is no intra-domain routing).

4.2.2 Test Tools

OPNET provides for traffic generation facilities. The TEQUILA provided test tools (cf. Bulk Service Request Generator [D2.2]) will be used to drive the OPNET traffic generators.

OPNET supports tracing and monitoring functionality at various levels (per-packet, per-queue, per-flow). It also provides a number of trace-post-processing tools (scripts). Probes can also be defined by the user.

4.2.3 Applications

OPNET provides agents for all the known transport protocols (TCP, UDP, RTP etc), to which any application agent can be attached. The application agents available are CBR, Telnet, FTP, HTTP, Web client/servers, CBR traffic and any of the traffic generators provided.

4.2.4 Hosts

The hosts in the networking environment can support any of the above.

4.2.5 Experimentation Focus

As already outlined in chapter 2 (section 2.2), OPNET will be used to test the feasibility of QoS routes calculation at the inter-domain level. The context of this work is described in the IETF draft *“providing quality of service indication by the BGP-4 protocol”* (draft-jacquenot-QoS-nlri-01.txt). This draft presents a way to add QoS information in a new optional attribute: the QoS-NLRI optional attribute. This attribute contains QoS information (such as delay or bandwidth information) that will help finding end-to-end QoS paths through the complete network.

Some BGP peers are QoS-NLRI capable (they recognise the QoS-NLRI attribute; they may even inject QoS information) while others BGP peers are not QoS-NLRI capable (they do not recognise the QoS-NLRI attribute and mark it as “incomplete”).

Implementation and therefore experimentation will focus on the following:

- Definition of an interface where QoS-NLRI capable nodes get QoS information about the destination to which they are attached. The QoS information may be static or dynamic.
- Creation of the optional QoS-NLRI attribute by QoS-NLRI capable nodes.
- Manipulation of the QoS-NLRI attribute. QoS-NLRI capable nodes may modify the QoS information (e.g. increasing the delay) and non-QoS capable nodes will mark the information as “incomplete”.
- Route calculation. Using QoS advertised information, QoS-NLRI capable nodes calculate QoS routes to some destinations. The definition of a new decision process that takes this QoS information into account for the selection of QoS routes is one of the most challenging issues of the work. Special effort is given to loop avoidance.

Implementation and experimentation will evolve through the following three steps:

- In the first step, the QoS information does not evolve as a function of time. The route decision process is purely static. The main focus during this phase is: creation/manipulation of the QoS-NLRI attribute, and calculation of loop-free QoS routes.
- In the second step, dynamicity is added: QoS information varies as a function of time and impacts the route decision process (new QoS information could lead to other QoS routes). This phase analyses the impact of changes in QoS information to routes and leads to the definition of a criterion for the injection of new QoS information (based on the definition of significant changes).
- In the third step, Bandwidth Broker (BB) functionality is implemented in each AS: BBs may trigger BGP QoS route calculation, in order to satisfy the QoS requirements listed in the SLSs they received. When a path is chosen, the newly added traffic should not impact the quality received by the “old” flows.

5 REFERENCES

- [Agilent] Agilent Advisor WAN- Agilent Technologies
<http://www.agilent.com/Top/English/index.html>
- [Cisco-RTR] Cisco's Service Assurance Agent also known as Response Time Reporter - RTR:
http://www.cisco.com/univercd/cc/td/doc/product/software/ios121/121newft/121t/121t1/1dt_saa.htm#80332
- [D1.1] TEQUILA project Deliverable D1.1, "Functional Architecture Definition and Top Level Design", July 2000
- [D1.2] TEQUILA project Deliverable D1.2, "Protocol and Algorithm Specification", January 2001
- [D2.1] TEQUILA project Deliverable D2.1, "Selection of Simulators, Network Elements and Development Environment and Specification of Enhancements", May 2000
- [D2.2] TEQUILA project Deliverable D2.2, "System Design and Implementation Plan", Version 1, February 2001
- [ISO-9646-1] ISO/IEC 9646-1 : 1991, OSI Conformance Testing Methodology and Framework, Part 1 : General Concepts.
- [ISO-9646-2] ISO/IEC 9646-2 : 1991, OSI Conformance Testing Methodology and Framework, Part 2 : Abstract Test Suite Specification.
- [ISO-9646-7] ISO/IEC 9646-7 : 1992, Information Technology – Open Systems Interconnection – Conformance Testing methodology and framework – Part 7 : Implementation Conformance Specification.
- [SmartBits] NetCom Systems Inc. SmartBits <http://www.netcomsystems.com/>
- [TEQ] Information on the TEQUILA project available in the Web at: <http://www.ist-tequila.org>

6 APPENDIX A – NETWORK EQUIPMENT DESCRIPTION

6.1 Cisco Routers

6.1.1 Physical Interfaces

6.1.1.1 Network Module Options for Cisco 2610 and 3640 Routers

The following network modules are available on both types of routers.

- Ethernet
- Synchronous serial (up to 2 Mbps)
- Analogue Voice Interface Cards (mainly E&M).

6.1.1.2 7513 Line Cards

The following port adapters are available on the Cisco 7513 routers.

- Octal E1
- E3
- Gigabit Ethernet
- OC3/STM1 POS

6.1.1.3 GSR 12012 Line Cards

The following line card is available on the Cisco GSR 12012 routers.

- OC48/STM16 POS Line Card

6.1.1.4 Interface between Linux and Cisco router

For connecting Linux routers to the Cisco routers, low speed interface card (e.g., serial interface up to 2Mbps) is required.

6.1.2 Capabilities

In this section, we focus on routers 26/3600, 7513, and GSR-12000.

6.1.2.1 Traffic Classification and Conditioning

Table 3 shows Cisco routers compliance with traffic conditioning components.

Traffic Conditioning Components	Mechanism	Cisco Routers		
		26/3600 Series	7500 Series	GSR-12000
Classification	ACL/Traffic Class	✓	✓	✓
Metering	CAR/Traffic Policer/CB Policer	✓	✓	
Marking	CAR/Traffic Policer/CB Marker	✓	✓	
Traffic Shaping	GTS(WFQ)/CB Shaper	✓	✓ ¹	✓ ²
Dropping	CAR/Traffic Policer/CB Policer	✓	✓ ³	✓ ⁴

Table 3: Traffic conditioning components of Cisco routers.

6.1.2.2 Per Hop Behaviours

Table 4 shows the scheduling/queuing mechanisms supported in the Cisco routers.

Scheduling/ Queuing	Queuing Strategy	Cisco Routers		
		26/3600 Series	7500 Series	GSR-12000
FIFO	Single Queue per I/F	✓	✓	✓
PQ	High, medium, normal, low priority Queues	✓	✓	
FBWFQ	A weighted Queue per traffic flow	✓	✓	
CBWFQ	Single Queue per traffic class	✓	✓	
LLQ	A single strict high PQ	✓	✓	
DRR	Multiple (8) Queues with Round Robin mechanism			✓
MDRR	A high PQ + multiple (7) Queues with RR			✓
WRED	–	✓ ⁵	✓ ⁶	✓ ⁷
Flow WRED	–	✓	✓ ⁸	

Table 4: Queuing mechanisms supported in the Cisco routers.

The two main PHBs (EF and AF) defined by the IETF DiffServ are accommodated by TEQUILA. Table 5 matches the Cisco scheduling/queuing capabilities to the required PHBs functionality.

¹ Distributed Traffic Shaping for 7500 series having Route Switch Processor (RSP).

² Virtual Path shaping

³ CAR is supported in 7500 series with Versatile Interface Processor-based (VIP-40 or greater interface processor).

⁴ Only CAR is supported.

⁵ DiffServ compliant WRED supported on IOS 12.1(5)T.

⁶ DiffServ compliant WRED supported on IOS 12.1(5)T for routers having Route Switch Processor (RSP).

⁷ IP Precedence WRED supported on IOS 12.0 S.

⁸ Supported on the RSP interface card on a Cisco 7500 series router.

Routers and Interfaces	EF - Queuing	AF - Queuing	AF - Discard
26/3600 - Serial	LLQ	CBWFQ	DiffServ Compliant WRED
7513 - Serial	LLQ	CBWFQ	DiffServ Compliant WRED
GSR-POS ⁹ & Gigabit Ethernet	Strict Priority Q (MDRR)	DRR	WRED - IP Precedence

Table 5: Matching Cisco features to the required functionality.

6.1.2.3 MPLS Forwarding and Traffic Engineering

MPLS TE explicitly/dynamically establishes and maintains the tunnel (LSP) across the backbone, using RSVP. The path used by a given tunnel at any point in time is determined based on tunnel resource requirements and network resources such as bandwidth. Available resources are flooded via extensions to link-state based IGP such as IS-IS. MPLS traffic engineering in 12.1(3)T has been updated to support networks running OSPF in addition to IS-IS. Tunnel paths are calculated at the tunnel head based on a fit between required and available resources. The IGP automatically routes the traffic into these tunnels. Typically, a packet crossing the MPLS TE backbone travels on a single tunnel that connects the ingress to the egress point.

Table 6 shows the general availability MPLS and MPLS TE but care has to be taken in the planning phase as this functionality is being released on specific platform and interface technologies (e.g. ATM, POS, Gigabit Ethernet, etc.) in a phased manner and not every combination is supported.

MPLS Functions	Cisco Routers		
	26/3600 Series	7500	GSR-12000
MPLS	✓ ¹⁰	✓	✓
MPLS-TE	✓ ¹⁰	✓	✓

Table 6: MPLS function on Cisco routers.

MPLS CoS

MPLS EXP field at the edge of the network can be set a different value (than IP packet's IP Precedence) by using Policy-map or CAR employing ACLs/Traffic classes. This is the MPLS Class of Service Enhancements introduced in IOS 12.1(5)T.

⁹ POS STM4, POS STM-16, STM-4c ATM line card, POS STM-16c, and POS STM64c (supported on 12400).

¹⁰ Cisco 3600 series support MPLS by using an STM1 ATM interface.

6.2 IFT Routers

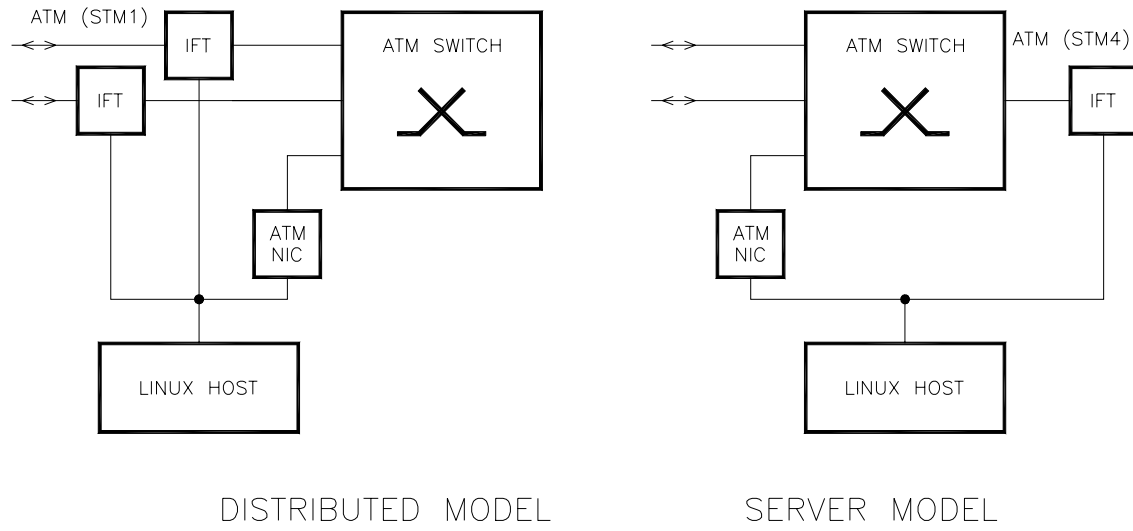


Figure 2: IFT Router configurations

7 APPENDIX B – TEST TOOLS DESCRIPTION

7.1 SmartBits

NetCom Systems Inc. SmartBits [SmartBits] can be used for generating a large amount of user traffic. SmartBits is also known as a powerful testing tool. SmartBits can also be used to create a distributed performance analysis system for measuring end-to-end performance including one-way latency and latency variation.

7.2 HP Internet Advisor WAN

HP Internet Advisor WAN (Agilent Advisor WAN- Agilent Technologies [Agilent]) is a protocol analyser providing network testing and analysis capability. It monitors the data on the line, stores data, and provides packet timestamps and higher layer protocol decodes for traffic in both directions. The available line interfaces are PRI ISDN and synchronous serial (up to 2 Mbps).

7.3 Data Channel Simulator

The Adtech SX/12 Data Channel Simulator is a leased line simulator that introduces bit errors and line delays. The SX/12 is capable of generating a range of rates up to 2.048Mbps.

7.4 Cisco Traffic Generators -User Traffic Generator - Test TCP (TTCP)

The TTCP program can be used to generate TCP (and UDP) traffic on IP based networks. Cisco has embedded a copy of TTCP in IOS 11.2 and later. The Cisco version of TTCP sends and receives TCP data.

To use TTCP, a copy of TTCP in receive mode is started at one place and a second copy in transmit mode is started at another place within the network. The destination doesn't have to be another router. Users have control over the number of packets sent, the port number at which the transmitter and receiver rendezvous, and several other parameters. TTCP reports the amount of data transferred, the transfer time, and the approximate throughput.

The syntax for the **TTCP** command is as follows:

```
TTCP[RECEIVE/TRANSMIT] [TCP/UDP] [ASCII/EBCDIC]
[ HOST( host_name ) ] [ PORT( port_number ) ] [ SYSID( subsystem_ID ) ]
[ BUFLN( buffer_length ) ] [ BUFNUM( number_of_buffers ) ]
[ COUNT( transmit_buffer_count ) ] [ TASKS( number_of_receive_tasks ) ]
```

As can be seen from TTCP syntax, TTCP is not DSCP aware.

TTCP has a real advantage over tools like FTP as traffic generator. It is difficult for any single computer system to transfer data to or from disk at rates which are sufficient for real high performance network testing. TTCP achieves high performance by filling a memory buffer with data, then repeatedly transmitting this data. Since everything is running from memory, the transmitter and receiver can operate at true network speeds.

7.5 Cisco Measurement Tools

7.5.1 Cisco Service Assurance Agent

Cisco's Service Assurance Agent (Formerly known as RTR) tool provides a variety of service monitoring information including:

- ICMP Echo for measuring round trip delay for IP
- ICMP Path Echo for identifying the paths to the destinations
- UDP Echo round trip delay for UDP packets
- TCP Connection for discovering the TCP connection time
- Jitter UDP for measuring one-way jitter and UDP packet loss
- HTTP for measuring round trip delay to connect and access data from an HTTP server
- DHCP for measuring round trip delay of discovering a DHCP server
- DNS for measuring the time to send a request to the server and get a reply back, etc.

Type of service byte in IP header can be set for RTR packets. This provides the ability to mark the test packets with appropriate DS Code Points, enabling the test packet to pass through the same queues and follow the same path as the traffic under test.

IOS release 12.1(1)T introduced new performance measurement operations and enhancements [Cisco-RTR]. It provides new capabilities including the ability to monitor one-way latency reporting through enhancements to the jitter operation. To measure one-way delay between two devices, the clocks of end devices are synchronised via NTP.

7.5.2 Ping Tool

- **Round Trip Delay Measurement:** Ping reports round trip delay for IP data and it depends on ICMP Echo Request and ICMP Echo Reply messages being sent between routers.
- **Round Trip Packet Loss:** It is possible for the Ping originator to compute the packet loss ratio based on the number of the ICMP Echo Request packets that were not received or arrived late.
- **Reachability:** If no reply is received from ping packets sent to a remote node, the remote node is considered unreachable due to either network congestion or node failure.