TECHNICAL REPORT

TR-143

Enabling Network Throughput Performance Tests and Statistical Monitoring

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Summary

This document defines the CPE data model objects for Network Service Providers to initiate performance throughput tests and monitor data on the IP interface of a CPE using the Diagnostic mechanism defined in TR-069 Amendment 2 [1].

The Network Service Provider provides network infrastructure and services to its customers, such as Content Service Providers who source the information and end users who consume the information. In order to minimize the downtime of network services, the Network Service Provider needs tools to enable monitoring the performance of the network continuously and diagnose the problem when it occurs.

The architecture of TR-069 Amendment 2 [1] enables device management with the CPE devices both at the customer's gateway, and with devices within the customer's home network. The diagnostic and monitoring objects provided with this document will assist the Network Service Provider in determining whether the problem occurs in the Network Service Provider's network or the customer's home network.

1 Purpose

As broadband Network Service Providers endeavor to provide quantitative QoS and/or qualitative QoS distinctions, they require some means of base lining nominal service levels and validating such QoS objectives. Active Monitoring of the broadband access network represents one important tool for achieving this objective. The key benefit of Active Monitoring is that it allows the network operator to characterize the performance of end to end paths and/or path segments depending on the scope of the probing. An example use case is to perform active tests between the subscriber RG and a Network Test Server located at the Network Service Provider’s Point of Presence (POP). This scenario gives the Network Service Provider the ability to measure the contribution of the Network Service Provider network (i.e. the portion of the end to end path under the provider’s control) to the overall user experience (which is dictated by the composite effect of the segments their applications traverse end to end). A natural extension of this use case is to place Network Test Servers at multiple locations in the subscriber path towards the provider’s Internet Peering Point. Moreover, Active Monitoring enables the measurement of performance metrics conducive to establishing Service Level Agreements for guaranteed and business class service offerings.

The throughput tests proposed in this document are intended to measure the user experience via traffic emulation. Though it is arguable that the user experience can be inferred solely from network performance parameters (e.g. packet loss, packet delay, etc.), network operators can benefit from having the ability to measure user level performance metrics such as transaction throughput and response time in a proactive or an on-demand basis. This document includes throughput and response time test types in an overall portfolio of Active Monitoring. Such tests inherently account for the nuances and n-th order effects of transport protocol behavior such as TCP flow control by emulating application layer transactions (HTTP, FTP) and explicitly measuring parameters of interest such as transaction throughput, round trip time, and transaction response time. Since the network operator can bound the scope of the measurement segment (e.g. to within a broadband access network or autonomous domain, etc.) these measurements greatly enhance the performance characterization of network segments of interest in a manner most intuitively aligned with the user experience. A preliminary set of test transaction types are proposed but the concept is extensible to other transaction types.

2 Scope

This document defines an Active Monitoring test suite which can be leveraged by Network Service Providers to monitor and/or diagnose the state of their broadband network paths serving populations of subscribers who utilize TR-069 compliant CPE. Active Monitoring supports both Network Initiated Diagnostics and CPE Initiated Diagnostics for monitoring and characterization of service paths in either an ongoing or on-demand fashion. These generic tools provide a platform for the validation of QoS objectives and Service Level Agreements.

This document introduces a Network Test Server, which is a conceptual endpoint for the testing described herein. Operation of this server is out of scope for this document.

2.1 Definitions

The following terminology is used throughout this document.

Active Monitoring	Actively transmitting or receiving data in a controlled test.
Content Service Provider	Provides services to the customer premise via the Network Service Provider Network.
Internet Peering Point	A location within the Network Service Provider network where the Network Test Server is placed.
Network Service Provider	Provides the broadband network between the customer premise and the Internet.
Network Test Server	Peer testing endpoint for the CPE within the Network Service Provider network.
Quality of Service	Quality of service is the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow.
Service Level Agreement	An agreement between the Network Service Provider and the Content Service Provider to insure Quality of Service.
UDP Echo Service	Services that ‘echos’ a UDP packet back to the client.
UDP Echo Plus Service	Extension to UDP Echo Service defined in [4]

2.2 Abbreviations

This document defines the following abbreviations:

CPE	Customer Premise Equipment
FTP	File Transfer Protocol
HTTP	Hypertext Transfer Protocol
ICMP	Internet Control Message Protocol
IPDV	IP Delay Variation
POP	Point of Presence
QoS	Quality of Service
RG	Residential Gateway
TCP	Transmission Control Protocol
TR	Technical Report
UDP	User Datagram Protocol

WG	Working Group

2.3 Conventions

In this document, several words are used to signify the requirements of the specification. These words are often capitalized.

MUST	This word, or the adjective "REQUIRED", means that the definition is an absolute requirement of the specification.
MUST NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the adjective "RECOMMENDED", means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications must be understood and carefully weighted before choosing a different course.
MAY	This word, or the adjective "OPTIONAL", means that this item is one of an allowed set of alternatives. An implementation that does not include this option MUST be prepared to interoperate with another implementation that does include the option.

3 References

The following references constitute provisions of this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this document are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below. A list of the currently valid DSL Forum Technical Reports is published at www.dslforum.org.

[1] TR-069 Amendment 2, *CPE WAN Management Protocol*, DSL Forum Technical Report, 2007

[2] RFC 2616, *Hypertext Transfer Protocol -- HTTP/1.1*, http://www.ietf.org/rfc/rfc2616.txt, 1999

[3] RFC 3986, *Uniform Resource Identifier (URI): Generic Syntax*, http://www.ietf.org/rfc/rfc3986.txt, 2005

[4] RFC 862, *Echo Protocol*, http://www.ietf.org/rfc/rfc862.txt, 1983

[5] RFC 3393, *IP Packet Delay Variation Metric for IP Performance Metrics (IPPM)*, http://www.ietf.org/rfc/rfc3393.txt, 2002

[6] RFC 959, *File Transfer Protocol*, http://www.ietf.org/rfc/rfc959.txt, 1985

[7] RFC 3449, *TCP Performance Implications of Network Path Asymmetry*, http://www.ietf.org/rfc/rfc3449.txt, 2002

[8] TR-106 Amendment 1, *Data Model Template for TR-069-Enabled Devices*, DSL Forum Technical Report, 2006

[9] TR-098 Amendment 1, *Internet Gateway Device Version 1.1 Data Model for TR-069*, DSL Forum Technical Report, 2006

4 Active Monitoring

Active Monitoring is described by the introduction of controlled traffic diagnostic suites that are network layer centric and are agnostic to the underlying access network. Diagnostics that use standard TCP and UDP based protocols and are controlled through diagnostic objects can be applied to any CPE device. The remote endpoints can be placed throughout the Provider network at strategic locations to determine possible points of network congestion or fault. Active Monitoring can also be used to characterize the quality of paths in the broadband access network. This document defines a basic monitoring architecture that can provide some operational experience in CPE based monitoring to be refined, and expanded upon in future releases

The UDP Echo Plus test is a UDP Echo as defined in [4] with the addition of performance specific fields in the payload. The UDP Echo Plus payload allows for time-stamping and sequencing to support additional inferences on packet loss and jitter beyond the capabilities of the standard UDP Echo. Using UDP Echo Plus packets as probes, the UDP Echo Plus test provides a sampling based monitoring approach.

The CPE Upload and Download Diagnostic throughput test simulates the client behavior in the client/server paradigm performing an FTP or HTTP transaction to a corresponding remotely located FTP or HTTP server. The CPE throughput tests provides a bulk transfer based measurement approach, to perform throughput and response time measurements for the test initiated (injected) transaction over select network links.

The diagnostic tests are not designed to run in parallel and their results are based on normal traffic occurring on the link and utilizing any remaining bandwidth. Multiple tests may consume excess bandwidth and skew results. Active Monitoring traffic can be generated from a CPE or a Network Testing Server endpoint. Figure 1 is a conceptual diagram to illustrate this.

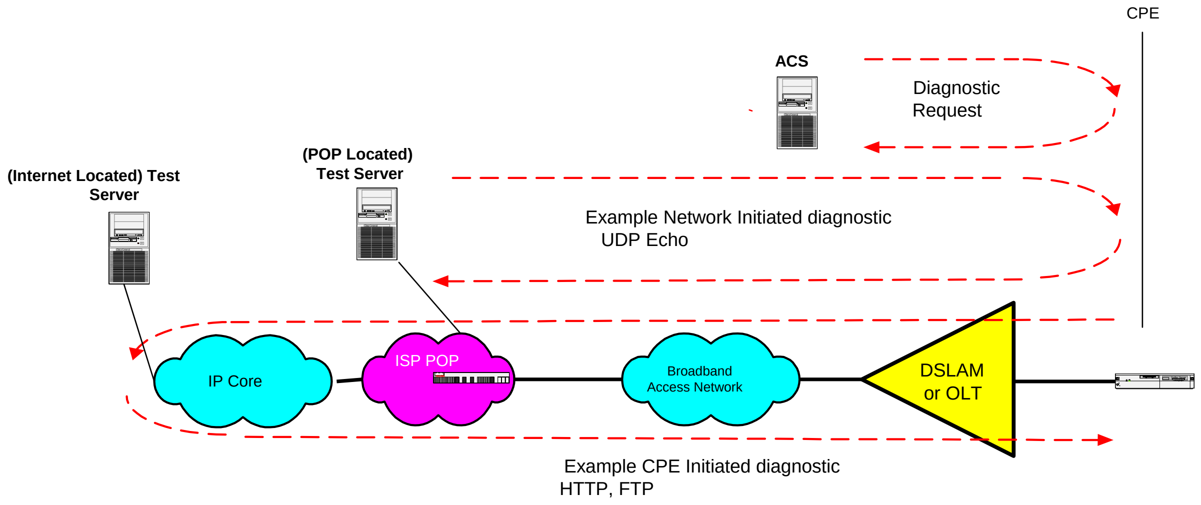

CPE
ACS
Diagnostic Request
(POP Located) Test Server
(Internet Located) Test Server
Example Network Initiated diagnostic UDP Echo
IP Core
ISP POP
Broadband Access Network
DSLAM or OLT
Example CPE Initiated diagnostic HTTP, FTP

Figure 1 Performance testing components

4.1 CPE initiated diagnostics

In a CPE initiated UploadDiagnostics and DownloadDiagnostics the following endpoints perform the following functions.

The ACS initiates the DownloadDiagnostics request to the CPE, setting test parameters and initiating the test. The CPE initiates the Diagnostic (FTP or HTTP client transaction), and stores the test results. A Network Test Server responds to the Diagnostic (FTP or HTTP) request via a HTTP/FTP server.

In Figure 2 is an example diagram of a DownloadDiagnostics using an HTTP URL.

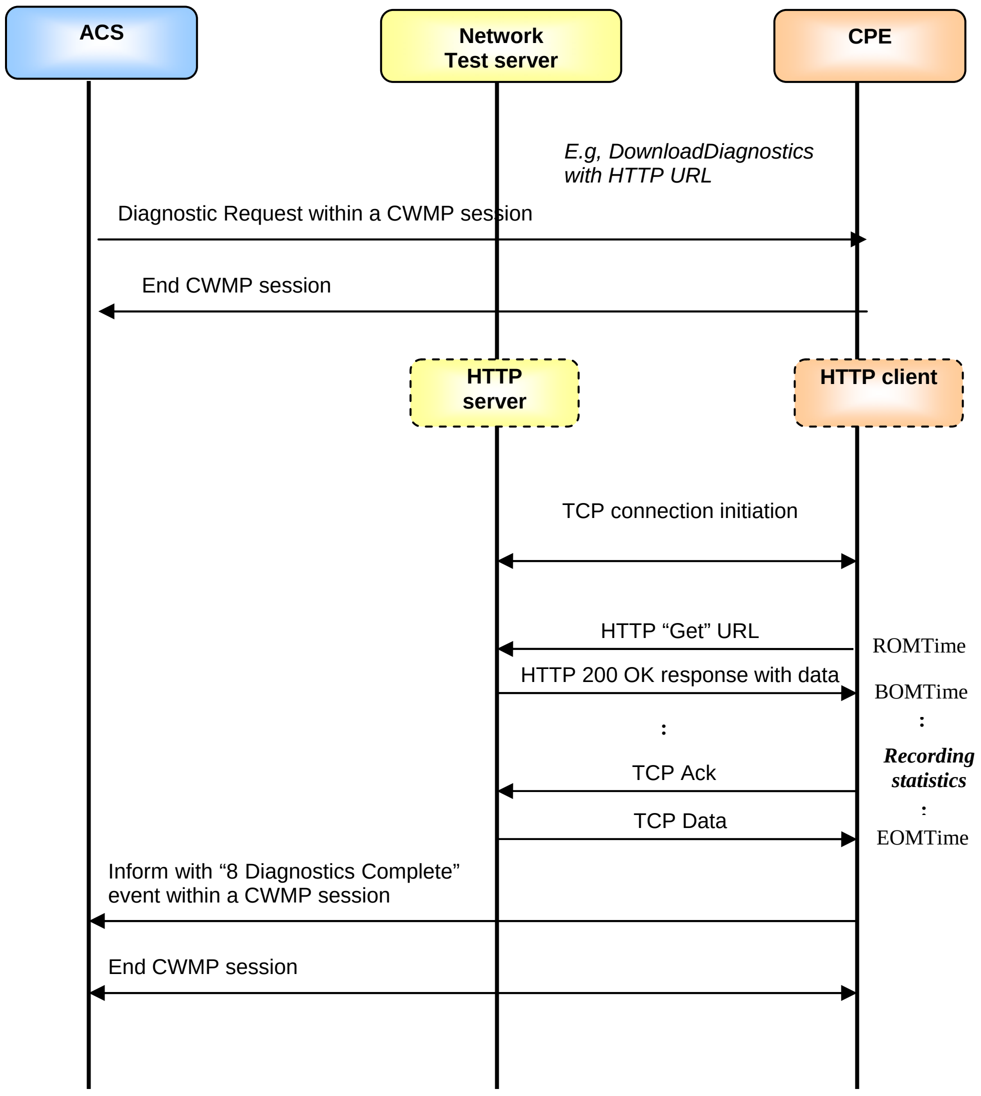

ACS
Network Test server
CPE
E.g, DownloadDiagnostics with HTTP URL
Diagnostic Request within a CWMP session
End CWMP session
HTTP server
HTTP client
TCP connection initiation
HTTP "Get" URL
ROMTime
HTTP 200 OK response with data
BOMTime
:
Recording statistics
:
TCP Ack
TCP Data
EOMTime
Inform with "8 Diagnostics Complete" event within a CWMP session
End CWMP session

Figure 2 CPE DownloadDiagnostics using HTTP transport.

4.2 Network initiated diagnostics

The Network initiated diagnostics represents an alternative approach to minimize the burden on the ACS for Network Service Providers that want to support continual proactive monitoring of samplings of CPE. For example, dedicated Network Test Servers distributed per serving area can perform Network initiated diagnostics to continually characterize the state of broadband access paths to samplings of subscribers and build performance trends on those paths. For the Network Initiated diagnostics model, the ACS would first need to enable the CPE to function as a server (UDPEchoConfig). For security the source IP address of the Network Test are the only requests the CPE protocol servers will respond to. Defined in A.1 is the UDP Echo tests sourced by the Network Test Server and responded to by the CPE UDP Echo server. In a Network initiated UDP Echo test the following sequence is used to perform the test;

The ACS configures the CPE to enable the UDP Echo server. The Network Test Server initiates the client request, and sends the UDP echo packets. The CPE UDP Echo server responds to the UDP echo packets.

5 Parameter Definitions

To support the functionality defined in this specification, an extension to the Device data model is specified in Table 1. This extension is considered part of Device:1.2 (version 1.2 of the Device data model), which extends version 1.1 of the Device data model defined in TR-106 Amendment 1 [8].

If the CPE is an Internet Gateway, the same extension applies to the InternetGatewayDevice data model. This extension is considered part of InternetGatewayDevice:1.3 (version 1.3 of the InternetGatewayDevice data model), which extends version 1.2 of the InternetGatewayDevice data model defined in TR-098 Amendment 1 [9].

In both cases, the new parameters specified here are defined to exist as top level objects, meaning that they reside in the Internet Gateway Device object or Device object.

Table 1 lists the objects associated with Network Throughput Tests and their associated parameters. The notation used to indicate the data type of each parameter follows the notation defined in [8].

Table 1 Parameter definition for Network Throughput Tests

Name[1]	Type	Write[2]	Description	Object Default
.Capabilities.	object	-	The capabilities of the device. This is a constant read-only object, meaning that only a firmware upgrade will cause these values to be altered.	
.Capabilities.- PerformanceDiagnostic.	object	-	The capabilities of the Performance Diagnostics (DownloadDiagnostics and UploadDiagnostics) for the device.	
DownloadTransports	string	-	Comma-separated list of supported DownloadDiagnostics transport protocols for a CPE device. Each item in the lis is an enumeration of: "HTTP" "FTP" (OPTIONAL)	-
UploadTransports	string	-	Comma-separated list of supported UploadDiagnostics transport protocols for a CPE device. Each item in the lis is an enumeration of: "HTTP" "FTP" (OPTIONAL)	
.DownloadDiagnostics.	object	-	This object defines the diagnostics configuration for a HTTP and FTP DownloadDiagnostics Test. Files received in the DownloadDiagnostics do not require file storage on the CPE device.	--

[1] The name of a Parameter is formed from the concatenation of the base path, (refer to [8]section 2.1), the object name shown in the yellow header, and the individual Parameter name.

[2] "W" indicates the parameter MAY be writable (if "W" is not present, the parameter is defined as read-only). For an object, "W" indicates object instances can be Added or Deleted.

Name[1]	Type	Write[2]	Description	Object Default
DiagnosticsState	string	W	Indicate the availability of diagnostic data. One of: “None” “Requested” “Completed” “Error_InitConnectionFailed” “Error_NoResponse ” “Error_TransferFailed” “Error_PasswordRequestFailed” “Error_LoginFailed” “Error_NoTransferMode” “Error_NoPASV” “Error_IncorrectSize” “Error_Timeout” If the ACS sets the value of this parameter to Requested, the CPE MUST initiate the corresponding diagnostic test. When writing, the only allowed value is Requested. To ensure the use of the proper test parameters (the writable parameters in this object), the test parameters MUST be set either prior to or at the same time as (in the same SetParameterValues) setting the DiagnosticsState to Requested. When requested, the CPE SHOULD wait until after completion of the communication session with the ACS before starting the diagnostic. When the test is completed, the value of this parameter MUST be either Completed (if the test completed successfully), or one of the Error values listed above. If the value of this parameter is anything other than Completed, the values of the results parameters for this test are indeterminate. When the diagnostic initiated by the ACS is completed (successfully or not), the CPE MUST establish a new connection to the ACS to allow the ACS to view the results, indicating the Event code "8 DIAGNOSTICS COMPLETE" in the Inform message. After the diagnostic is complete, the value of all result parameters (all read-only parameters in this object) MUST be retained by the CPE until either this diagnostic is run again, or the CPE reboots. After a reboot, if the CPE has not retained the result parameters from the most recent test, it MUST set the value of this parameter to “None”. Modifying any of the writable parameters in this object except for this one MUST result in the value of this parameter being set to “None”. While the test is in progress, modifying any of the writable parameters in this object except for this one MUST result in the test being terminated and the value of this parameter being set to “None”. While the test is in progress, setting this parameter to Requested (and possibly modifying other writable parameters in this object) MUST result in the test being terminated and then restarted using the current values of the test parameters.	-

Name[1]	Type	Write[2]	Description	Object Default
Interface	string(256)	W	Specifies the IP-layer interface over which the test is to be performed. The content is the full hierarchical parameter name of the interface. The value of this parameter MUST be either a valid interface or an empty string. An attempt to set this parameter to a different value MUST be rejected as an invalid parameter value. If an empty string is specified, the CPE MUST use the default routing interface.	-
DownloadURL	string(256)	W	The URL as defined in [3], for the CPE to perform the download on. This parameter MUST be in the form of a valid HTTP [2] or FTP [6] URL. When using FTP transport, FTP binary transfer MUST be used. When using HTTP transport, persistent connections MUST be used and pipelining MUST NOT be used. When using HTTP transport the HTTP Authentication MUST NOT be used.	-
DSCP	unsignedInt [0:63]	W	The DiffServ code point for marking packets transmitted in the test. The default value SHOULD be zero.	-
EthernetPriority	unsignedInt [0:7]	W	Ethernet priority code for marking packets transmitted in the test (if applicable). The default value SHOULD be zero.	-
ROMTime	dateTime	-	Request time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the client sends the GET command. For FTP this is the time at which the client sends the RTRV command.	-
BOMTime	dateTime	-	Begin of transmission time in UTC, which MUST be specified to microsecond precision For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the first data packet is received. For FTP this is the time at which the client receives the first data packet on the data connection.	-
EOMTime	dateTime	-	End of transmission in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the last data packet is received. For FTP this is the time at which the client receives the last packet on the data connection.	-
TestBytesReceived	unsignedInt	-	The test traffic received in bytes during the FTP/HTTP transaction including FTP/HTTP headers, between BOMTime and EOMTime,	-
TotalBytesReceived	unsignedInt	-	The total number of bytes received on the Interface between BOMTime and EOMTime.	-

Name[1]	Type	Write[2]	Description	Object Default
TCPOpenRequestTime	dateTime	-	Request time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the TCP socket open (SYN) was sent for the HTTP connection. For FTP this is the time at which the TCP socket open (SYN) was sent for the data connection. Note: Interval of 1 microsecond SHOULD be supported.	-
TCPOpenResponseTime	dateTime	-	Response time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the TCP ACK to the socket opening the HTTP connection was received. For FTP this is the time at which the TCP ACK to the socket opening the data connection was received. Note: Interval of 1 microsecond SHOULD be supported.	-
.UploadDiagnostics.	object	-	This object defines the diagnostics configuration for a HTTP or FTP UploadDiagnostics test. Files sent by the UploadDiagnostics do not require file storage on the CPE device, and MAY be an arbitrary stream of bytes	--

Name[1]	Type	Write[2]	Description	Object Default
DiagnosticsState	string	W	Indicate the availability of diagnostic data. One of: “None” “Requested” “Completed” “Error_InitConnectionFailed” “Error_NoResponse” “Error_PasswordRequestFailed” “Error_LoginFailed” “Error_NoTransferMode” “Error_NoPASV” “Error_NoCWD” “Error_NoSTOR” “Error_NoTransferComplete” If the ACS sets the value of this parameter to Requested, the CPE MUST initiate the corresponding diagnostic test. When writing, the only allowed value is Requested. To ensure the use of the proper test parameters (the writable parameters in this object), the test parameters MUST be set either prior to or at the same time as (in the same SetParameterValues) setting the DiagnosticsState to Requested. When requested, the CPE SHOULD wait until after completion of the communication session with the ACS before starting the diagnostic. When the test is completed, the value of this parameter MUST be either Completed (if the test completed successfully), or one of the Error values listed above. If the value of this parameter is anything other than Completed, the values of the results parameters for this test are indeterminate. When the diagnostic initiated by the ACS is completed (successfully or not), the CPE MUST establish a new connection to the ACS to allow the ACS to view the results, indicating the Event code "8 DIAGNOSTICS COMPLETE" in the Inform message. After the diagnostic is complete, the value of all result parameters (all read-only parameters in this object) MUST be retained by the CPE until either this diagnostic is run again, or the CPE reboots. After a reboot, if the CPE has not retained the result parameters from the most recent test, it MUST set the value of this parameter to “None”. Modifying any of the writable parameters in this object except for this one MUST result in the value of this parameter being set to “None”. While the test is in progress, modifying any of the writable parameters in this object except for this one MUST result in the test being terminated and the value of this parameter being set to “None”. While the test is in progress, setting this parameter to Requested (and possibly modifying other writable parameters in this object) MUST result in the test being terminated and then restarted using the current values of the test parameters.	-

Name[1]	Type	Write[2]	Description	Object Default
Interface	string(256)	W	IP-layer interface over which the test is to be performed. The content is the full hierarchical parameter name of the interface. The value of this parameter MUST be either a valid interface or an empty string. An attempt to set this parameter to a different value MUST be rejected as an invalid parameter value. If an empty string is specified, the CPE MUST use the default routing interface.	-
UploadURL	string(256)	W	The URL as defined in [3], for the CPE to Upload to. This parameter MUST be in the form of a valid HTTP [2] or FTP [6] URL. When using FTP transport, FTP binary transfer MUST be used. When using HTTP transport, persistent connections MUST be used and pipelining MUST NOT be used. When using HTTP transport the HTTP Authentication MUST NOT be used.	-
DSCP	unsignedInt [0:63]	W	DiffServ code point for marking packets transmitted in the test. The default value SHOULD be zero.	-
EthernetPriority	unsignedInt [0:7]	W	Ethernet priority code for marking packets transmitted in the test (if applicable). The default value SHOULD be zero.	-
TestFileLength	unsignedInt	W	The size of the file (in bytes) to be uploaded to the server. The CPE MUST insure the appropriate number of bytes are sent.	-
ROMTime	dateTime	-	Request time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the client sends the PUT command For FTP this is the time at which the STOR command is sent.	-
BOMTime	dateTime	-	Begin of transmission time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the first data packet is sent. For FTP this is the time at which the client receives the ready for transfer notification.	-
EOMTime	dateTime	-	End of transmission in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time when the HTTP successful response code is received. For FTP this is the time when the client receives a transfer complete.	-
TotalBytesSent	unsignedInt	-	The total number of bytes sent on the Interface between BOMTime and EOMTime.	-

Name[1]	Type	Write[2]	Description	Object Default
TCPOpenRequestTime	dateTime	-	Request time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the time at which the TCP socket open (SYN) was sent for the HTTP connection. For FTP this is the time at which the TCP socket open (SYN) was sent for the data connection Note: Interval of 1 microsecond SHOULD be supported.	-
TCPOpenResponseTime	dateTime	-	Response time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 For HTTP this is the Time at which the TCP ACK to the socket opening the HTTP connection was received. For FTP this is the Time at which the TCP ACK to the socket opening the Data connection was received. Note: Interval of 1 microsecond SHOULD be supported.	-
.UDPEchoConfig.	object	-	This object allows the CPE to be configured to perform the UDP Echo Service defined in [4] and UDP Echo Plus Service defined in Appendix A.1.	-
Enable	boolean	W	MUST be enabled to receive UDP echo. When enabled from a disabled state all related timestamps, statistics and UDP Echo Plus counters are cleared.	-
Interface	string(256)	W	IP-layer interface over which the CPE MUST listen and receive UDP echo requests on. The content is the full hierarchical parameter name of the interface. The value of this parameter MUST be either a valid interface or an empty string. An attempt to set this parameter to a different value MUST be rejected as an invalid parameter value. If an empty string is specified, the CPE MUST listen and receive UDP echo requests on all interfaces. Note: Interfaces behind a NAT MAY require port forwarding rules configured in the Gateway to enable receiving the UDP packets.	-
SourceIPAddress	string	W	The Source IP address of the UDP echo packet. The CPE MUST only respond to a UDP echo from this source IP address.	-
UDPPort	unsignedInt	W	The UDP port on which the UDP server MUST listen and respond to UDP echo requests.	-
EchoPlusEnabled	boolean	W	If True the CPE will perform necessary packet processing for UDP Echo Plus packets.	-
EchoPlusSupported	boolean	-	True if UDP Echo Plus is supported.	-
PacketsReceived	unsignedInt	-	Incremented upon each valid UDP echo packet received.	-
PacketsResponded	unsignedInt	-	Incremented for each UDP echo response sent.	-
BytesReceived	unsignedInt	-	The number of UDP received bytes including payload and UDP header after the UDPEchoConfig is enabled.	-
BytesResponded	unsignedInt	-	The number of UDP responded bytes, including payload and UDP header sent after the UDPEchoConfig is enabled.	-

Name[1]	Type	Write[2]	Description	Object Default
TimeFirstPacketReceived	dateTime	-	Time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456, The time that the server receives the first UDP echo packet after the UDPEchoConfig is enabled.	-
TimeLastPacketReceived	dateTime	-	Time in UTC, which MUST be specified to microsecond precision. For example: 2008-04-09T15:01:05.123456 The time that the server receives the most recent UDP echo packet.	-

6 Notification Requirements

CPE MUST support Active Notification as described in [1], for all parameters defined in the Parameter Definitions (section 5) with the exception of those parameters listed in Table 2. For only those parameters listed in Table 2, the CPE MAY reject a request by an ACS to enable Active Notification via the SetParameterAttributes RPC by responding with fault code 9009 as defined in [1] (Notification request rejected).

CPE MUST support Passive Notification as described in [1], for all parameters defined in the Parameter Definitions (section 5), with no exceptions.

Table 2 Parameters for which Active Notification MAY be denied by the CPE

Parameter[5]
.UDPEchoConfig.
PacketsReceived
PacketsResponded
BytesReceived
BytesResponded
TimeFirstPacketReceived
TimeLastPacketReceived
.DownloadDiagnostics.
DiagnosticsState
ROMTime
BOMTime
EOMTime
TestBytesReceived
TotalBytesReceived
TCPOpenRequestTime
TCPOpenResponseTime
.UploadDiagnostics.
DiagnosticsState
ROMTime

[5] The name of a Parameter referenced in this table is the concatenation of the object name shown in the yellow header, and the individual Parameter name.

Parameter[5]
BOMTime
EOMTime
TotalBytesSent
TCPOpenRequestTime
TCPOpenResponseTime

7 Profile Definitions

7.1 Notation

The following abbreviations are used to specify profile requirements:

Abbreviation	Description
R	Read support is REQUIRED
W	Both Read and Write support is REQUIRED
P	The object is REQUIRED to be present
C	Creation and deletion of the object via AddObject and DeleteObject is REQUIRED

7.2 Download Profile

Table 3 defines the Download:1 profile for a Device:1 and an InternetGatewayDevice:1 object. The minimum required version for this profile is Device:1.2 and InternetGatewayDevice:1.3.

Table 3 Download:1 profile definition for a Device:1 and an InternetGatewayDevice:1

Name	Requirement
.DownloadDiagnostics.	P
DiagnosticsState	W
Interface	W
DownloadURL	W
DSCP	W
EthernetPriority	W
ROMTime	R
BOMTime	R
EOMTime	R
TestBytesReceived	R
TotalBytesReceived	R
TCPOpenRequestTime	R
TCPOpenResponseTime	R
.Capabilities. PerformanceDiagnostic.	P
DownloadTransports	R

7.3 DownloadTCP Profile

The DownloadTCP:1 profile for a Device:1 and an InternetGatewayDevice:1 object is defined as the union of the Download:1 profile and the additional requirements defined in Table 4. The minimum required version for this profile is Device:1.2 and InternetGatewayDevice:1.3.

Table 4 DownloadTCP:1 profile definition for a Device:1 and an InternetGatewayDevice:1

Name	Requirement
.DownloadDiagnostics.	P
TCPOpenRequestTime	R
TCPOpenResponseTime	R

7.4 Upload Profile

Table 5 defines the Upload:1 profile for a Device:1 and an InternetGatewayDevice:1 object. The minimum required version for this profile is Device:1.2 and InternetGatewayDevice:1.3.

Table 5 Upload:1 profile definition for a Device:1 and an InternetGatewayDevice:1

Name	Requirement
.UploadDiagnostics.	P
DiagnosticsState	W
Interface	W
UploadURL	W
DSCP	W
EthernetPriority	W
ROMTime	R
BOMTime	R
EOMTime	R
TestFileLength	R
TotalBytesSent	R
TCPOpenRequestTime	R
TCPOpenResponseTime	R
.Capabilities. PerformanceDiagnostic.	P
UploadTransports	R

7.5 UploadTCP Profile

The UploadTCP:1 profile for the Device:1 and an InternetGatewayDevice:1 object is defined as the union of the Upload:1 profile and the additional requirements defined in Table 6. The minimum required version for this profile is Device:1.2 and InternetGatewayDevice:1.3.

Table 6 UploadTCP:1 profile definition for a Device:1 and an InternetGatewayDevice:1

Name	Requirement
.UploadDiagnostics.	P
TCPOpenRequestTime	R

Name	Requirement
TCPOpenResponseTime	R

7.6 UDPEcho Profile

Table 7 defines the UDPEcho:1 profile for a Device:1 and an InternetGatewayDevice:1 object. The minimum required version for this profile is Device:1.2 and InternetGatewayDevice:1.3.

Table 7 UDPEcho:1 profile definition for a Device:1 and an InternetGatewayDevice:1

Name	Requirement
.UDPEchoConfig.	P
Enable	W
Interface	W
SourceIPAddress	W
UDPPort	W
PacketsReceived	R
PacketsResponded	R
BytesReceived	R
BytesResponded	R
TimeFirstPacketReceived	R
TimeLastPacketReceived	R
EchoPlusSupported	R

7.7 UDPEchoPlus Profile

The UDPEchoPlus:1 profile for a Device:1 and a InternetGatewayDevice:1 object is defined as the union of the UDPEcho:1 profile and the additional requirements defined in Table 8. The minimum required version for this profile is Device:1.2 and InternetGatewayDevice:1.3.

Table 8 UDPEchoPlus:1 profile definition for Device:1 and an InternetGatewayDevice:1

Name	Requirement
.UDPEchoConfig.	P
EchoPlusEnabled	W

Appendix A: Theory of Operations

A.1 UDP Echo Plus

A.1.1 Introduction

The UDP Echo Service is defined by [4]. UDP Echo Plus utilizes the UDP Echo Service and extends it by additional packet field definitions and new server behaviors. The UDP Echo server utilizes improved security provided by UDPEchoConfig object.

A.1.2 Motivation

The notion of active probe based sampling of network paths and/or path segments has long been established as a viable methodology for making inferences on the state of such paths (and path segments), with regard to link and network layer performance metrics such as packet/frame/cell loss, delay, delay variation and others. A very useful tool for realizing probing and general debugging (such as path continuity and integrity verification), is an echo service. In the link layer context, OAM loopback messages such as defined ITU-T I.610, for the ATM case, have been employed. In the IP context, ICMP echo (i.e. ping) has been widely used for such purposes due to its ubiquitous availability in network routers and hosts. However, the viability of using ping measurements suffers from the fact that many routers process pings with lower priority than actual user packet's and may delay or discard ICMP echo requests in a manner that skews the measurement results. The UDP Echo Service is defined at the UDP (or TCP) port level rectifies this issue (unless explicitly port filtered at an intermediate or end host or router). UDP echo packets traverse the same intermediate nodes and logical queuing paths as the user data traffic of the same class of service. The class of service is dictated by DHCP code bit settings, etc. or other network operator specific criteria.

UDP Echo Plus proposes extensions to UDP echo for improved monitoring capabilities. UDP Echo Plus is backwards compatible with UDP echo and devices capable of supporting UDP Echo Plus have no discernable effect on cooperating devices running standard UDP echo. However, when both cooperating devices are UDP Echo Plus capable, the utility of UDP echo is extended by the additional information provided in the five data fields specified in Table 9.

UDP Echo Plus provides additional capability beyond UDP Echo Service including:

- The ability to discern which direction packet drops occur (i.e. one way packet loss per each direction).
- One way packet delay variation per each direction.

- The ability to discern packets discarded in the network from those discarded at the UDP Echo Plus server device.

A.1.3 Security Considerations – Network initiated tests

A UDP Echo Plus Network initiated test requires the CPE device to respond to the UDP echo request on the defined interface(s). In order to prevent a DOS (Denial of Service) attack on the CPE, the CPE will only respond to the UDP request from a Source address defined in SourceIPAddress, and will only service the port defined in UDPPort.

A.1.4 UDP Echo Plus Packet format

The UDP Echo Plus packet contains the packet fields specified in Table 9. Each field is 4 bytes (32 bits) each. Timestamps require a continuous wrapping 32 bit (Big Endean) counter that begins on startup and counts in microseconds.

When a UDP Echo Plus capable service receives a standard UDP Echo packet, the UDP Echo Plus server just reflects the request back towards the source with no payload modification.

When UDP Echo request packets are larger than the minimal packet length for UDP Echo Plus packets, the first 20 bytes of payload are filled as described in this section, with the remaining payload unmodified.

Table 9 UDP Echo Plus packet format

Source Port	Destination Port
Length	Checksum
TestGenSN	
TestRespSN	
TestRespRecvTimeStamp	
TestRespReplyTimeStamp	
TestRespReplyFailureCount	
Data…	

- **TestGenSN** – The packet's sequence number set by the UDP client in the echo request packet, and is left unmodified in the response. It is set to an initial value upon the first requests and incremented by 1 for each echo request sent by the UDP client.

Note the initial value of TestGenSN is implementation specific.

- **TestRespSN –** The UDP Echo server's count that is incremented upon each valid echo request packet it receives and responded to. This count is set to 0 when the UDP Echo server is enabled.

- **TestRespRecvTimeStamp** is set by the UDP Echo Plus server to record the reception time of echo request packet and is sent back to the server in this data field of the echo response packet.

- **TestRespReplyTimeStamp** is set by the UDP Echo Plus server to record the forwarding time of the echo response packet.

- **TestRespReplyFailureCount** is set by the UDP Echo Plus server to record the number of locally dropped echo response packets. This count is incremented if a valid echo request packet is received but for some reason can not be responded to (e.g. due to local buffer overflow, CPU utilization, etc...). It is a cumulative count with its current value placed in all request messages that are responded to. This count is set to 0 when the UDP Echo server is enabled.

Note #1: The counter will roll over every 71.5 minutes. Every two successive UDP Echo Plus packets used in the same test would need to be sent within that interval for jitter computation (loss computation of course would not have this restriction).

Note #2: Devices that don't support 1usec timestamp resolution, will still compute the timestamp in microseconds, providing a multiplier. For example a device with 1msec resolution, will increment the 32bit timestamp field in steps of 1000 (instead of steps of 1).

A.1.5 UDP Echo and UDP Echo Plus server setup.

When enabled the UDP Echo server will accept UDP Echo packets. When enabled the UDP Echo Plus server will accept UDP Echo Plus packets and perform the specific operation in the following sections. When UDP Echo server is enabled all counters are reset to 0.

A.1.6 UDP Echo Plus Client

The UDP Echo client sends packets that match the UDP Echo Plus server configuration (Destination and Source IP address, UDP port). The UDP Echo Plus client controls the provisional settings such as DHCP code point settings, packet size and inter-arrival spacing. The UDP Echo Plus client will place a 32 bit sequence number value, which increments by 1 for each request packet sent, in the **TestGenSN** field of each UDP Echo Plus request.

Note: Unlike Bulk Data transfer tests, the UDP Echo and UDP Echo Plus tests are typically performed to probe the state of the network at low sampling rates. The_UDP Echo or Echo Plus request stream is usually generated at a slow enough rate so that it has negligible impact on the workloads seen by the network nodes the Echo packets traverse.

A.1.7 UDP Echo Plus server

After UDP Echo Plus server configuration and enabling, the UDP Echo Plus server waits for the arrival of UDP Echo Plus (or regular UDP Echo) packets. The UDP Echo server determines a valid request by criteria specified in UDPEchoConfig such as the source IP address of the request, transport protocol and destination port number. An example reference behavior for a UDP Echo Plus server is as follows.

1. The UDP Echo server determines that the UDP Echo Plus request is a valid request, if not, the request is ignored.
2. If the "valid echo request" criteria is met, the arrival time of the UDP Echo Plus request (i.e. time the last bit of the packet is read from the media), is time stamped with **TestRespRecvTimeStamp**.
3. The UDP Echo Plus server prepares a UDP Echo response packet with the data from the request packet.
4. If the packet size is large enough to support the UDP Echo Plus data fields, then the first 20 bytes are populated according to Table 9:
    - **TestGenSN** is left unmodified.
    - **TestRespSN** is a sequence number maintained by the server which indicates the number of requests that have been successfully responded to.
    - **TestRespRecvTimeStamp** is the timestamp recorded in step 2.
    - **TestRespReplyTimeStamp** is the timestamp indicating the time the last bit of the response is placed on the physical media.
    - **TestRespReplyFailureCount** is the cumulative number of valid requests that the UDP Echo Plus server could not respond to for whatever reason up to that point in time since the server was enabled. (Due to processing, buffer resource limitations, etc.).

A.1.8 Performance Metrics examples with UDP Echo Plus

The metrics presented in the section are some ***examples*** of what can be inferred by UDP Echo Plus measurements.

For all example metrics refer to the UDP Echo Plus event sequence diagram depicted in Figure 3. This depicts the sequence of UDP Echo Plus requests and corresponding responses during time interval T_{start} to T_{end}. These time boundaries could correspond to the time duration which the UDP Echo Plus server is provisioned to actively respond to request packets (i.e. the time period for which UDP Echo Plus server is enabled).

- Gs_i, is the time the UDP Echo Plus client sends the UDP Echo Plus request.
- Gr_i is the time the UDP Echo Plus client receives the UDP Echo Plus response.

- Rr_i is the time the UDP Echo Plus server receives the UDP Echo Plus request (**TestRespRecvTimeStamp)** .
- Rs_i is the time the UDP Echo Plus server sends the UDP Echo Plus response (**TestRespReplyTimeStamp)**.

These are the timestamp values placed in the "i-th" UDP Echo Plus received by the UDP Echo Plus server. In the following examples a UDP Echo Plus client and UDP Echo Plus server begin with sequence numbers equal to 1. The UDP Echo Plus client may also require a successful round trip of the UDP Echo Plus to give the proper sequence number offset.

A.1.8.1 *One Way Packet Loss*

The UDP Echo Plus client keeps a local tally of the number of request packets that were successfully responded to (within some timer expiration threshold). Refer to this value as the SucessfulEchoCnt. Then upon receiving a UDP Echo Plus response packet from the UDP Echo Plus server at some time Gr_i, the UDP Echo Plus client can determine RoundTripPacketLoss as :

RoundTripPacketLoss = (**TestGenSN –** SucessfulEchoCnt)

Sent packet loss (from UDP Echo Plus client to UDP Echo Plus server path) is determined by subtracting the total requests received by the UDP Plus server (**TestRespSN**) from the total request sent by the UDP Echo Plus client (**TestGenSN)**. The total request received by the UDP Echo Plus server is conveyed to the UDP Echo plus client via the sum **TestRespSN + TestRespReplyFailureCount.** Therefore upon receiving a UDP Echo Plus response packet from the UDP Echo Plus server at some time Gr_i, the UDP Echo Plus client can determine:

Sent packet loss = **TestGenSN – (TestRespSN + TestRespReplyFailureCount)**

Receive packet loss (the UDP Echo Plus server to UDP Echo Plus client path Packet loss), can be calculated upon receiving a UDP Echo Plus response packet from the UDP Echo Plus server at some time Gr_i, by:

Receive packet loss = RoundTripPacketLoss **–** Sent packet loss

A.1.8.2 *Round Trip Delay*

Upon receiving a UDP Echo Plus response packet from the UDP Echo Plus server at some time Gr_i, corresponding to the “i-th” request sent, like standard UDP Echo, a UDP Echo Plus client can compute the Round Trip Delay (RTD) simply according to:

$$RTD_i = Gr_i - Gs_i$$

UDP Echo Plus capability allows for the removal of the UDP Echo Plus server’s delay component from each RTD value and removes the processing delays at the UDP Echo Plus server. Denoting the RTD measurements with UDP Echo Plus server delay contribution removed as Effective-RTD, then at time Gr_i the UDP Echo Plus client can compute:

Effective-$RTD_i = Gr_i - Gs_i$ – (**TestRespReplyTimeStamp - TestRespRecvTimeStamp**)

A.1.8.3 *One Way IP Packet Delay Variation (IPDV)*

UDP Echo Plus capability can also provide the computation of IPDV (IP Delay Variation) singletons as defined in [5] for each direction to infer One Way IPDV statistics of a time interval over which UDP Echo Plus is performed.

This is done by first defining $Gs_{Previous}$,$Gr_{Previous,}$ $Rr_{Previous,}$ $Rs_{Previous}$ as the times a previous UDP Echo Plus round trip was successful, then comparing those time stamps against the current successful round trip times stamps in the below calculations:

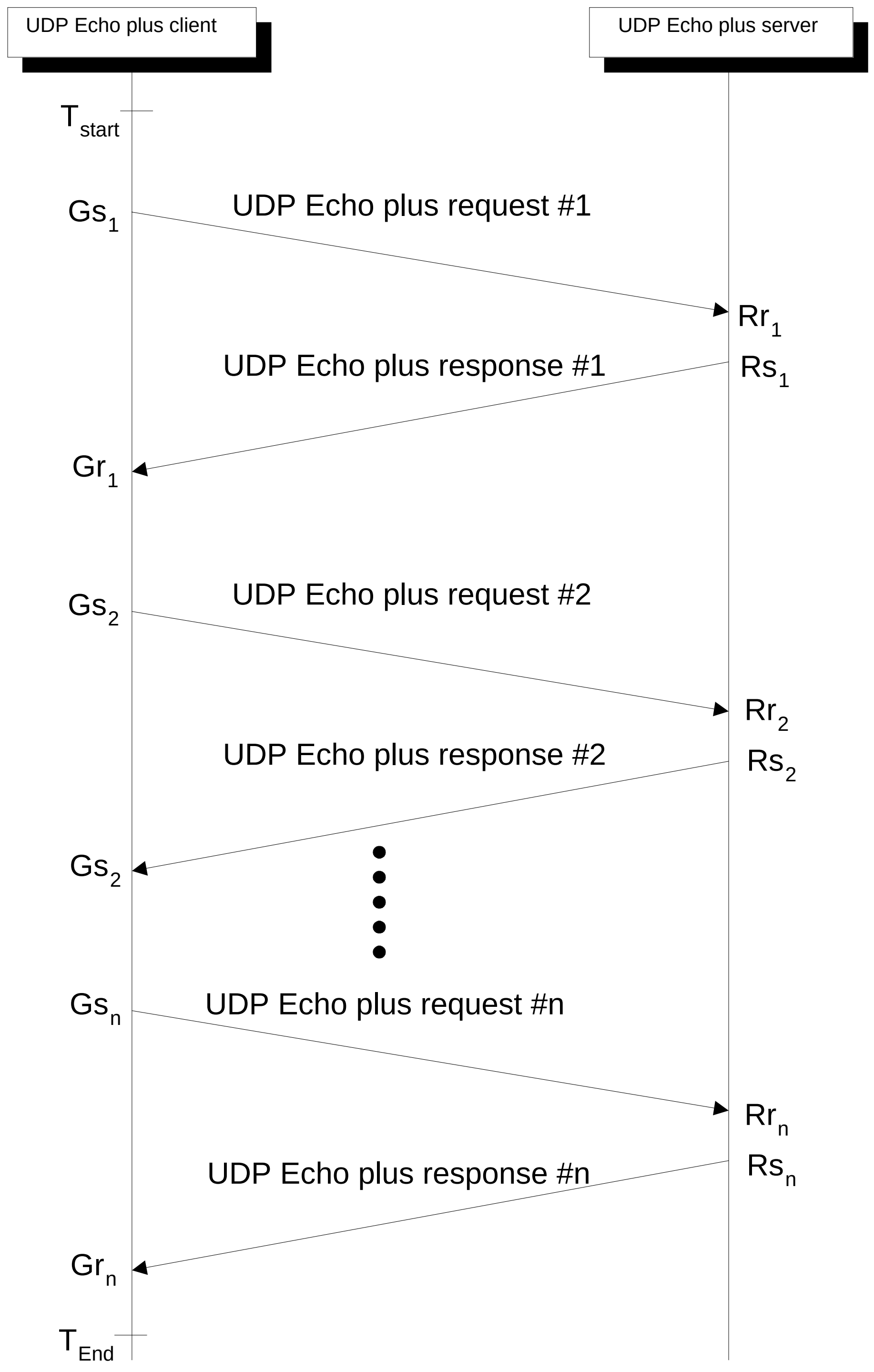
- An IPDV singleton on the Sent path (from UDP Echo Plus client to UDP Echo plus server) measured at the UDP Echo Plus client at time Gr_i by

  Send time delta= Gs_i - $Gs_{Previous}$
  Receive time delta = Rr_i – $Rr_{Previous}$
  Sent path IPDV (i) = Send time delta – Receive time delta

- An IPDV singleton on the Receive path (from UDP Echo Plus server to UDP Echo Plus client) measured at the UDP Echo Plus client at time Gr_i by

  Response time delta = Rs_i – $Rs_{Previous}$
  Receive time delta = Gr_i - $Gr_{Previous}$
  Receive path IPDV (i) = Response time delta – Receive time delta

A sequence of IPDV singletons calculations utilizing [5] may be applied to compute IPDV statistics for each direction.



-

Figure 3 UDP Echo Plus event sequence

A.2 DownloadDiagnostics utilizing FTP transport

The DownloadDiagnostics test is being used to test the streaming capabilities and responses of the CPE and the WAN connection. The measurements are made during the download process, the 'files' that are Downloaded are arbitrary, and are only temporary. The file received is a stream of arbitrary bytes of a specified length. There is no bound on file size.

The FTP [6] server response to the FTP SIZE command gives the CPE the size of the file being Downloaded. The FTP server response to the FTP [6] RTRV command will initiate the data sent on the FTP [6] data connection.

The CPE counts the number of file bytes received successfully and compares it to the response to the FTP [6] SIZE command. The CPE is not required to retain the file in memory.

Once the CPE has successfully received the number of file bytes specified in the FTP [6] SIZE command it must terminate the FTP control connection.

Table 10 Statistics and Protocol layer reference for FTP DownloadDiagnostics

Above Socket (FTP [6])	Socket Layer	Below Socket
ROMTime	EOMTime	TotalBytesReceived (Ethernet)
	BOMTime	EthernetPriority (Ethernet)
	TCPOpenRequestTime	DSCP setting (IP)
	TCPOpenResponseTime	
	TestBytesReceived	

For the DownloadDiagnostics test utilizing FTP transport, the FTP client emulates an FTP download transaction to an FTP URL as specified by DownloadURL. A sequence of events and corresponding actions are described below, reference of Figure 4.

1. Open a TCP socket for the FTP control connection.

2. Upon receiving the control connection response:
   - If a FTP positive response is received, send a FTP USER command with user value set to "anonymous" to indicate an anonymous user login is being request.

Error Condition - If a FTP negative response is received or a timeout has occurred, then set DiagnosticsState to Error_InitConnectionFailed and terminate the test.

3. Upon receiving an “enter password” request:
   - Perform a PASS command using any string (e.g. “dummypwd@”) to be used as the password for the anonymous login.

Error Condition -If the “enter password” request fails or times out, then set DiagnosticsState to Error_PasswordRequestFailed and terminate the test.

4. Upon receiving a password response:
   - If the response was “successfully logged in”, then send a TYPE command with argument character set to ‘I’ for binary mode.

Error Condition -If a “successfully logged in” is not received or the response times out, then set DiagnosticsState to Error_LoginFailed and terminate the test.

5. Upon receiving an transfer mode response:
   - If the transfer mode was set successfully, send a PASV command to request the server be placed in passive mode.

Error Condition -If a transfer mode response fails or times out, then set DiagnosticsState to Error_NoTransferMode and terminate the test.

6. Upon receiving passive mode response:
   - If the passive mode response is successful, request the establishment of the FTP data connection.
   - Set TCPOpenRequestTime to the current time.

Error Condition -If a passive mode response fails or times out, then set DiagnosticsState to Error_NoPASV and terminate the test.

7. Upon receiving the TCP data connection response: for the FTP date connection:
   - If it was successfully established then set TCPOpenResponseTime, equal to the current time value.

Error Condition -If the connection could not be opened or times out, then set DiagnosticsState to Error_NoResponse and terminate the test.

- Send the SIZE command on the FTP control connection to obtain the size of the file to be downloaded.

8. Upon receiving the response to the SIZE command:
   - Record the file size in bytes. Send a RTRV command to request the contents of the file.
   - Set the ROMTime to the current time value.

Error Condition - If a valid response was not received from the server in response to the SIZE command or a timeout has occurred, then set DiagnosticsState to Error_IncorrectSize and terminate the test.

9. Upon receiving the first unit of data (at the socket interface) of the FTP data connection (i.e. corresponding to the first segment of data in the file):
   - Set BOMTime equal to the current time value.
   - Record the current value of the Ethernet bytes received on the Interface, to be used has reference later in TotalBytesReceived calculation.

Error Condition - If the FTP transfer times out, then set DiagnosticsState to Error_Timeout and terminate the test.

10. Upon receiving the last packet of data on the FTP data connection (i.e. corresponding to the last segment of data in the file):
    - Set EOMTime equal to the current time value.
    - Record the current value of the Ethernet bytes received on the Interface and calculate the TotalBytesReceived (using the previous value sampled at BOMTime).

    Note: In binary transfer mode, a count of the total bytes received at the socket level can be maintained and compared to the file size obtained by the SIZE command in step #8 above.

11. Once the EOMTime is set:
    - Set DiagnosticsState to the Completed state.
    - The server closes the connection or sends a TCP RESET flag if a timeout occurs.

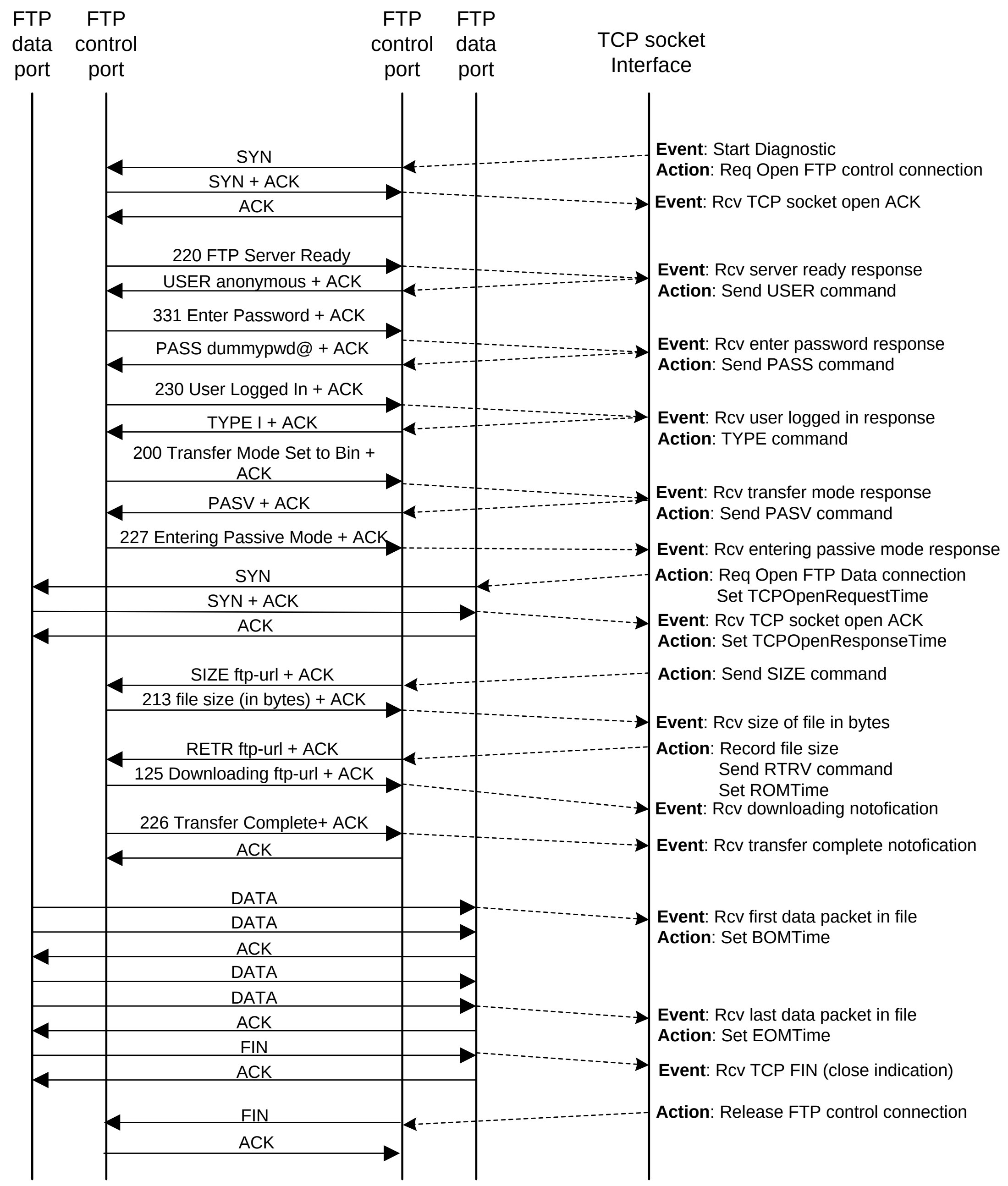

FTP data port
FTP control port
FTP control port
FTP data port
TCP socket Interface
SYN
SYN + ACK
ACK
220 FTP Server Ready
USER anonymous + ACK
331 Enter Password + ACK
PASS dummypwd@ + ACK
230 User Logged In + ACK
TYPE I + ACK
200 Transfer Mode Set to Bin + ACK
PASV + ACK
227 Entering Passive Mode + ACK
SYN
SYN + ACK
ACK
SIZE ftp-url + ACK
213 file size (in bytes) + ACK
RETR ftp-url + ACK
125 Downloading ftp-url + ACK
226 Transfer Complete+ ACK
ACK
DATA
DATA
ACK
DATA
DATA
ACK
FIN
ACK
FIN
ACK
Event: Start Diagnostic
Action: Req Open FTP control connection
Event: Rcv TCP socket open ACK
Event: Rcv server ready response
Action: Send USER command
Event: Rcv enter password response
Action: Send PASS command
Event: Rcv user logged in response
Action: TYPE command
Event: Rcv transfer mode response
Action: Send PASV command
Event: Rcv entering passive mode response
Action: Req Open FTP Data connection
Set TCPOpenRequestTime
Event: Rcv TCP socket open ACK
Action: Set TCPOpenResponseTime
Action: Send SIZE command
Event: Rcv size of file in bytes
Action: Record file size
Send RTRV command
Set ROMTime
Event: Rcv downloading notofication
Event: Rcv transfer complete notofication
Event: Rcv first data packet in file
Action: Set BOMTime
Event: Rcv last data packet in file
Action: Set EOMTime
Event: Rcv TCP FIN (close indication)
Action: Release FTP control connection

Figure 4 DownloadDiagnostics using FTP transport

A.3 UploadDiagnostics utilizing FTP transport

The UploadDiagnostics test is being used to test the streaming capabilities and responses of the CPE and the WAN connection. The measurements are made during the Upload process, the ‘files’ that are Uploaded are arbitrary, and are only temporary. There are no storage requirements on the CPE for the Uploaded files. The CPE sends a file of size TestFileLength (actual values in bytes sent is arbitrary). There is no bound on file size.

The FTP[6] server response to the FTP STOR command gives the CPE a ready for transfer and it may begin the file transfer.

The CPE counts the number of bytes sent successfully on the FTP data socket. The CPE is not required to retain the file in memory.

Once the CPE has successfully sent the number of bytes specified in the FTP [6] SIZE command and receives the transfer complete, it must terminate the FTP control and data connections.

Table 11 Statistics and Protocol layer reference for FTP UploadDiagnostics

Above Socket (FTP[6])	Socket Layer	Below Socket
ROMTime	EOMTime	TotalBytesSent (Ethernet)
	BOMTime	EthernetPriority (Ethernet)
	TCPOpenRequestTime	DSCP setting (IP)
	TCPOpenResponseTime	

For the UploadDiagnostics test utilizing FTP transport, the FTP client emulates a FTP upload transaction to an FTP server with filename as specified by UploadURL. A sequence of events and corresponding actions are described below, reference Figure 5.

1. Open a TCP socket for the FTP control connection.

2. Upon receiving the FTP control connection response:
    - If a FTP server ready response is received, send a FTP USER command with user value set to "anonymous" to indicate an anonymous user login is being request.

Error Condition - If a FTP negative response is received, or a timeout has occurred, then set DiagnosticsState to Error_InitConnectionFailed and terminate the test.

3. Upon receiving an "enter password" request:
    - Perform a PASS command using any string (e.g. "dummypwd@") to be used as the password for the anonymous login.

Error Condition -If the enter password request times out, then set the DiagnosticsState to Error_PasswordRequestFailed and terminate the test.

4. Upon receiving a password response:
    - If the response was "successfully logged in", then send a TYPE command

with argument character set to ‘I’ for binary mode.

Error Condition -If a “successfully logged in” response was not received or times out, set the DiagnosticsState to Error_LoginFailed and terminate the test.

5. Upon receiving a transfer mode response:
   - If the transfer mode was set successfully, send a PASV command to request the server be placed in passive mode.

Error Condition -If the set transfer mode failed or times out, then set DiagnosticsState to Error_NoTransferMode and terminate the test.

6. Upon receiving passive mode response:
   - If the passive mode was successful, request establishment of a TCP socket for the FTP data connection.
   - Set TCPOpenRequestTime to the current time.

Error Condition -If a setting the passive mode fails or times out, then set DiagnosticsState to Error_NoPASV and terminate the test.

7. Upon receiving the TCP socket response for the FTP data connection:
   - If it was successfully established then set TCPOpenResponseTime, equal to the current time value.

Error Condition -If the connection could not be opened or a timeout has occurred, then set DiagnosticsState to Error_NoResponse and terminate the test.

   - Send a CWD command to change to the directory to the directory in the UploadURL.

   Note: The client is not always required to send a CWD command prior to sending the STOR command in cases where the upload is performed in the home directory of the anonymous login.

8. Upon receiving a CWD response:
   - If a new directory change notification was received, send a STOR command to request uploading (storing) a file using the file name value specified in UploadURL.
   - When the STOR command is sent set ROMTime to the current time value.

Error Condition -If the CWD fails or times out set the DiagnosticsState to Error_NoCWD _and terminate the test.

9. Upon receiving a STOR command response:
   - If the client receives a “ready for transfer” notification, record the current

value of the Ethernet bytes sent on the Interface, to be used has reference later in TotalBytesSent calculation.

- Begin file upload over the FTP data connection, set BOMTime to the current time value.

Error Condition -If an error code is returned by the server and/or a timeout has occurred prior to receiving a “ready for transfer” notification then set the DiagnosticsState to Error_NoSTOR and terminate the test.

10. Upon completing the file upload:
    - If the client receives a “transfer complete” notification. set EOMTime to the current time value.
    - Record the current value of the Ethernet bytes sent on the Interface and calculate the TotalBytesSent using previous value sampled at BOM Time.

Error Condition – If and error code is returned by the server and/or a timeout has occurred prior to receiving a “transfer complete” notification, then set the DiagnosticsState to Error_NoTransferComplete and terminate the test.

11. Once the EOMTime is set, close the connections (FTP data and control) to the server.
    - Set the DiagnosticsState to Completed.

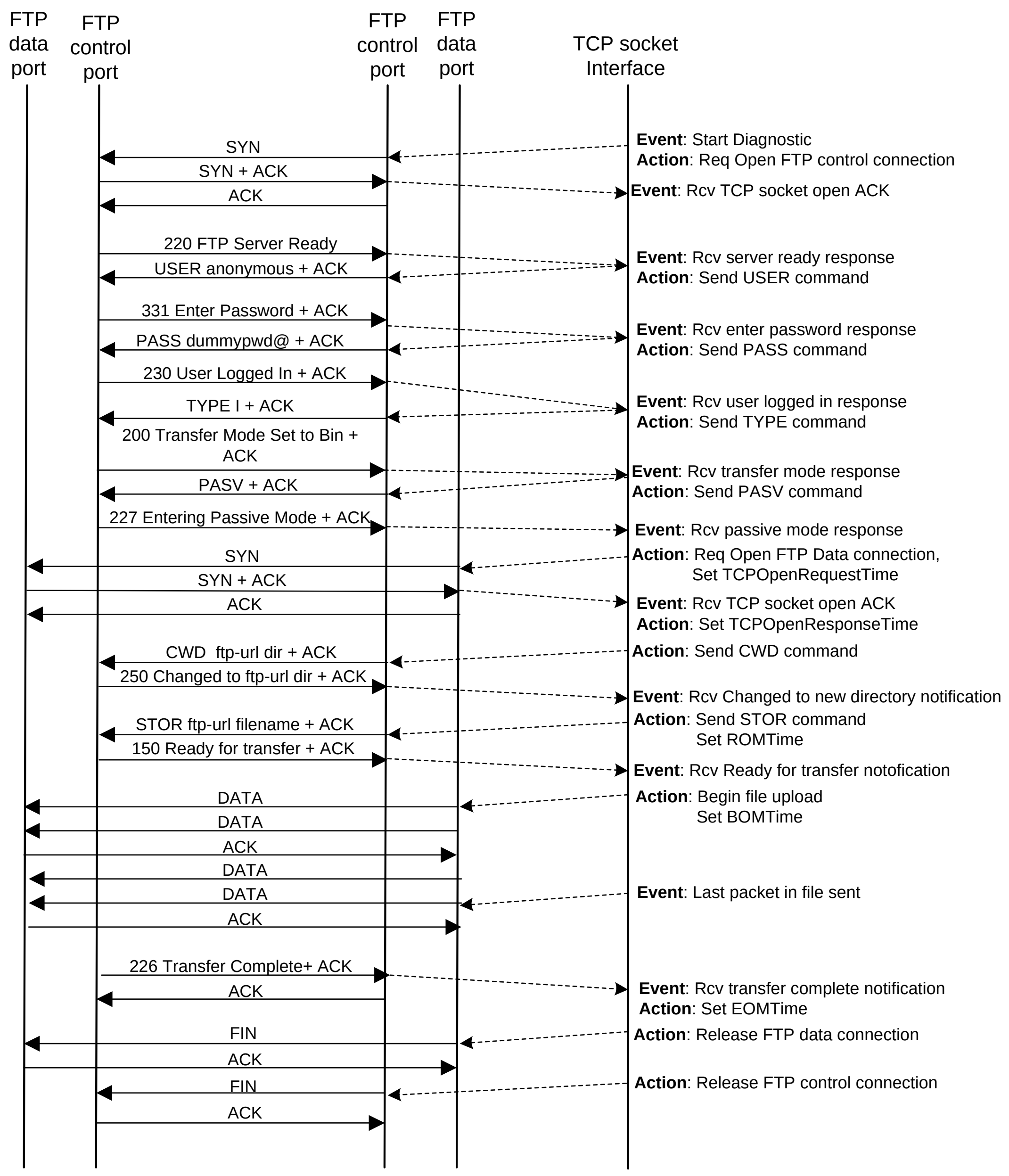

FTP data port
FTP control port
FTP control port
FTP data port
TCP socket Interface
SYN
SYN + ACK
ACK
220 FTP Server Ready
USER anonymous + ACK
331 Enter Password + ACK
PASS dummypwd@ + ACK
230 User Logged In + ACK
TYPE I + ACK
200 Transfer Mode Set to Bin + ACK
PASV + ACK
227 Entering Passive Mode + ACK
SYN
SYN + ACK
ACK
CWD ftp-url dir + ACK
250 Changed to ftp-url dir + ACK
STOR ftp-url filename + ACK
150 Ready for transfer + ACK
DATA
DATA
ACK
DATA
DATA
ACK
226 Transfer Complete+ ACK
ACK
FIN
ACK
FIN
ACK
Event: Start Diagnostic
Action: Req Open FTP control connection
Event: Rcv TCP socket open ACK
Event: Rcv server ready response
Action: Send USER command
Event: Rcv enter password response
Action: Send PASS command
Event: Rcv user logged in response
Action: Send TYPE command
Event: Rcv transfer mode response
Action: Send PASV command
Event: Rcv passive mode response
Action: Req Open FTP Data connection, Set TCPOpenRequestTime
Event: Rcv TCP socket open ACK
Action: Set TCPOpenResponseTime
Action: Send CWD command
Event: Rcv Changed to new directory notification
Action: Send STOR command Set ROMTime
Event: Rcv Ready for transfer notofication
Action: Begin file upload Set BOMTime
Event: Last packet in file sent
Event: Rcv transfer complete notification
Action: Set EOMTime
Action: Release FTP data connection
Action: Release FTP control connection

Figure 5 UploadDiagnostics utilizing FTP transport

A.4 DownloadDiagnostics utilizing HTTP transport

The DownloadDiagnostics test is being used to test the streaming capabilities and responses of the CPE and the WAN connection. The measurements are made during the download process, the ‘files’ that are Downloaded are arbitrary, and are only temporary. There are no storage requirements on the CPE for the downloaded files. The file received is a stream of arbitrary bytes of a specified length. There is no bound on file size.

The HTTP [2] server response to the HTTP Get includes the first TCP block of the file and either the HTTP header with the total file size or chunked encoding.

The CPE counts the number of file bytes received successfully. The CPE is not required to retain the file in memory.

Once the CPE has successfully received the number of file bytes specified in the HTTP response or chunked header the HTTP connection is closed.

HTTP implementation notes:

- Pipelining is not supported.
- The CPE counts the number of bytes received on the Interface for the duration of the test.
- HTTP authentication is not supported.
- HTTP headers may be 1.0 or 1.1. HTTPS is not supported.

Table 12 Statistics and Protocol layer reference for HTTP DownloadDiagnostics

Above Socket (HTTP)	Socket Layer	Below Socket
EOMTime	ROMTime	TotalBytesReceived (Ethernet)
	BOMTime	EthernetPriority (Ethernet)
	TCPOpenRequestTime	DSCP setting (IP)
	TCPOpenResponseTime	
	TestBytesReceived	

For the DownloadDiagnostics test utilizing HTTP transport, the HTTP client emulates an HTTP Get (download transaction) to an HTTP URL as specified by DownloadURL. A sequence of events and corresponding actions are described below, reference Figure 6.

1. Open a TCP socket for the HTTP connection.
    - Set TCPOpenRequestTime to the current time.

2. When the TCP Ack is received for the HTTP connection:
    - Set TCPOpenResponseTime to the current time.

Error Condition -If the connection could not be opened or a timeout has occurred, then set the DiagnosticsState to the Error_InitConnectionFailed and terminate the test.

- Send a GET command to request the contents of the file.
- Set the ROMTime to the current timestamp value.

3. Upon receiving the first packet of data and HTTP successful response:
   - Set BOMTime equal to the current time value.
   - Record the current value of the Ethernet bytes received on the Interface, to be used has reference later in TotalBytesReceived calculation.

Note: The content length field may return in the first packet of data (which also includes the server HTTP response code) and may be used to determine the number of bytes to count to indicate the file download is complete. If the response uses chunked encoding the chucked header is used to determine file size.

Error Condition - If a HTTP successful response code was not received from the server in response to the GET command or a timeout has occurred, then set DiagnosticsState to the Error_NoResponse and terminate the test.

4. Upon receiving the last packet of data in the file:
   - Set EOMTime equal to the current time value.
   - Record the current value of the Ethernet bytes received on the Interface, and calculate the TotalBytesReceived using previous value sampled at BOM Time.

Note: The last segment of file data has been received once a number of bytes received is equal to content length as determined from the step #3 above, or an EOF character sequence has been detected.

Error Condition - If the number of bytes received did not match the bytes expected or, a timeout has occurred, then set DiagnosticsState to Error_TransferFailed state and terminate the test.

5. Once the EOMTime is recorded, the HTTP client then simply waits for the server to close the connection or sends a TCP RESET flag if a timeout period TBD is exceeded. However, at this stage the test can be deemed successful and set DiagnosticsState to the Completed state.

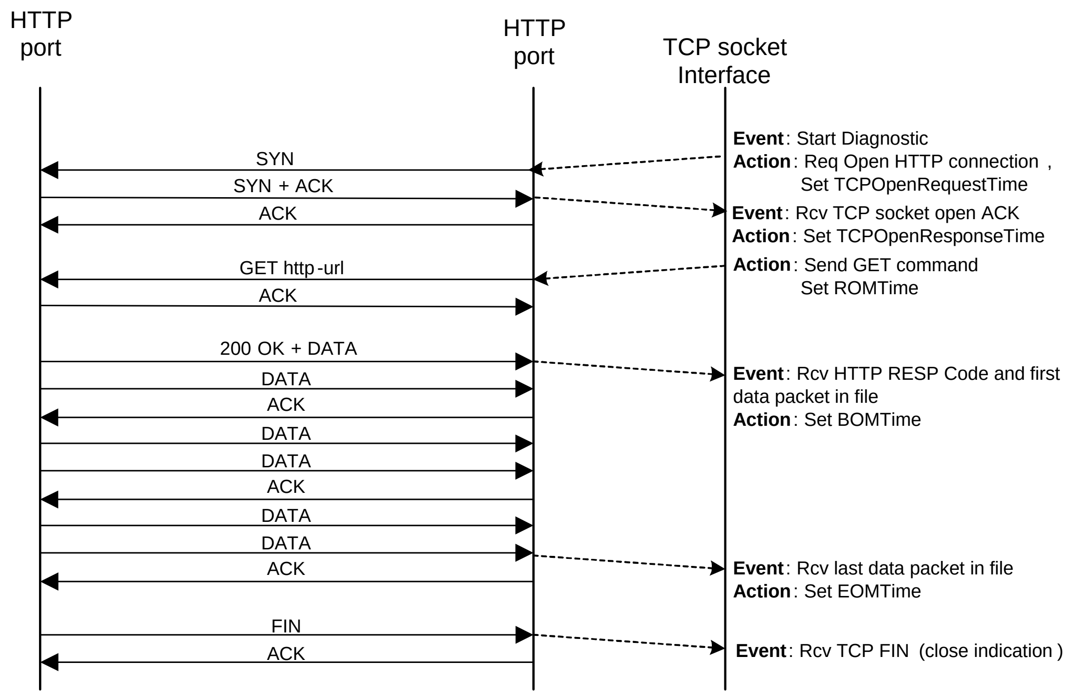

HTTP port
HTTP port
TCP socket Interface
SYN
SYN + ACK
ACK
GET http-url
ACK
200 OK + DATA
DATA
ACK
DATA
DATA
ACK
DATA
DATA
ACK
FIN
ACK
Event: Start Diagnostic
Action: Req Open HTTP connection, Set TCPOpenRequestTime
Event: Rcv TCP socket open ACK
Action: Set TCPOpenResponseTime
Action: Send GET command Set ROMTime
Event: Rcv HTTP RESP Code and first data packet in file
Action: Set BOMTime
Event: Rcv last data packet in file
Action: Set EOMTime
Event: Rcv TCP FIN (close indication)

Figure 6 DownloadDiagnostics utilizing HTTP transport

A.5 UploadDiagnostics utilizing HTTP transport

The UploadDiagnostics test is being used to test the streaming capabilities and responses of the CPE and the WAN connection. The measurements are made during the upload process, the 'files' that are Uploaded are arbitrary byte patterns or streams. There are no file storage requirements on the CPE for the uploaded files. The CPE sends a file of size TestFileLength (actual value in each byte sent is arbitrary).

The HTTP [2] server responds to the HTTP put with a successful response when the file has completed the Upload, this will indicate a successful test. If the 200 OK is not received, or the TCP socket is torn down, the test will fail. The CPE may use chunked encoding.

The CPE counts the number of bytes sent on the Interface for the duration of the test.

HTTP Implementation notes:

- Pipelining is not supported.
- HTTP authentication is not supported.
- HTTP headers may be 1.0 or 1.1. HTTPS is not supported.

Table 13 Statistics and Protocol layer reference for HTTP UploadDiagnostics

Above Socket (HTTP)	Socket Layer	Below Socket
EOMTime	ROMTime	TotalBytesSent (Ethernet)
	BOMTime	EthernetPriority (Ethernet)
	TCPOpenRequestTime	DSCP setting (IP)
	TCPOpenResponseTime	

For the UploadDiagnostics test utilizing the HTTP transport, the HTTP client emulates an HTTP upload (PUT) transaction to an HTTP server with filename as specified by UploadURL. A sequence of events and corresponding actions for the HTTP Upload are described below, reference of Figure 7.

1. Open a TCP socket for the HTTP connection.
   - Set TCPOpenRequestTime to the current time.

2. Upon receiving indication that the HTTP connection response:
   - If the response was successfully established, set TCPOpenResponseTime to the current time.

Error Condition -If the connection could not be opened or a timeout has occurred, then set DiagnosticsState to Error_InitConnectionFailed and terminate the test.

- Send a PUT command to request the sending of a file with filename specified in UploadURL. Set ROMTime to the current time value.

3. Upon sending data the first unit of data (i.e. TCP segment) to the server:
   - Set BOMTime to the current time value.
   - Record the current value of the Ethernet bytes sent on the Interface, to be used has reference later in TotalBytesSent calculation.

4. Upon completing the file upload :
   - When the client receives a HTTP successful response code from the server indicating the put was successfully performed set EOMTime to the current time value.
   - Record the current value of the Ethernet bytes sent on the Interface, and calculate the TotalBytesSent using previous value sampled at BOM Time.

Error Condition -If an HTTP successful response is not returned by the server and/or a timeout has occurred prior to receiving HTTP response code, then set DiagnosticsState to Error_NoResponse and terminate the test.

5. Once the EOMTime is recorded, the HTTP client then initiates the connection release. At this stage the test can be deemed successful and set DiagnosticsState to Completed.

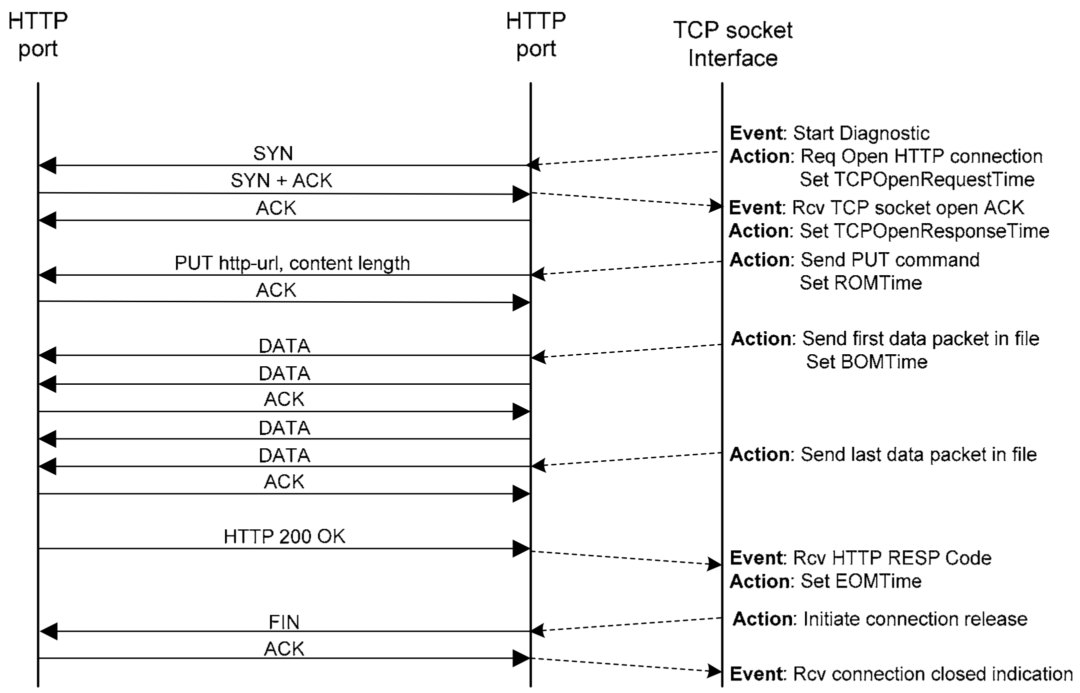

HTTP port
HTTP port
TCP socket Interface
SYN
SYN + ACK
ACK
PUT http-url, content length
ACK
DATA
DATA
ACK
DATA
DATA
ACK
HTTP 200 OK
FIN
ACK
Event: Start Diagnostic
Action: Req Open HTTP connection
Set TCPOpenRequestTime
Event: Rcv TCP socket open ACK
Action: Set TCPOpenResponseTime
Action: Send PUT command
Set ROMTime
Action: Send first data packet in file
Set BOMTime
Action: Send last data packet in file
Event: Rcv HTTP RESP Code
Action: Set EOMTime
Action: Initiate connection release
Event: Rcv connection closed indication

Figure 7 UploadDiagnostics utilizing HTTP transport

Appendix B: Test results

B.1 UploadDiagnostics and DownloadDiagnostics Test Results

Once a CPE throughput test is successfully completed there are several Active Monitoring performance metrics of particular interest that are implied in the object parameters.

Currently Jitter and delay are only measured by the UDP Echo Plus test.

Results may vary on CPE due to varying TCP implementations.

Table 14 Diagnostics Test Results

Metric	Description	Calculation
Test Connection Handshake Round Trip Time	Represents the round trip time incurred during the 3-way handshake of the TCP connection established to perform the throughput test	TCPOpenResponseTime – TCPOpenRequestTime
Test Transaction Response Time	The response time from the test beginning to end.	EOMTime – ROMTime
Test Transaction Request Round Trip Time	This is an application level round trip time measure (defined from transaction request time to the arrival of the first response packet at the client).	BOMTime - ROMTime
Test Transaction Response Throughput	The throughput measure output from the test.	Upload test = 8 * TestFileLength[3] / (EOMTime - BOMTime) Download test = 8 * TestBytesReceived[4] / (EOMTime - BOMTime)
Test Line Interface Throughput	The throughput measured on the WAN interface during the test activity period. This will show if other applications were using bandwidth resources while the test was run, when compared to Test Transaction Response Throughput.	Upload test = 8 * (TotalBytesSent) / (EOMTime - BOMTime) Download test = 8 * (TotalBytesReceived) / (EOMTime - BOMTime)

B.2 Asymmetrical Considerations

Today's broadband access networks are typically dimensioned asymmetrically to support currently deployed Internet services. The proposed test suites in this document are designed for both symmetric and asymmetric type networks.
However in the asymmetric case, there are extreme cases where the upstream capacity is not sufficient for Active Monitoring. In these cases, the returned TCP acknowledgement

[3] Note that TestFileLength does not include the HTTP header overhead bytes
[4] Note that TestBytesReceived does include the HTTP header overhead bytes

packets (ACK) from the CPE client cannot be returned reliably. Implementation guidance is provided in [7] in order to increase accuracy of the test performed.

k = (Downstream Bottleneck Rate)/(MTU * 8) / (Upstream Bottleneck Rate/(Ack Packet Size*8)

This equation is derived by assuming the client will use the Maximum Segment Size (MSS) when at all possible for forwarding data to the CPE client and ACKs returned from the client to server have a zero payload size resulting in a line packet size of Ack Packet Size in bytes (e.g. typically 64 bytes on Ethernet). If delayed ACKs are used (i.e. only ACK every other packet), as is typically the case in current TCP implementations, then the downstream is rate limited when K > .5 so we want K <= .5 (for the delayed ACK case).