TR-400
Testing of Bonded, Multi-Pair G.fast Systems

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Executive Summary

This Broadband Forum Technical Report, TR-400, is part of the Broadband Suite. G.fast bonding uses multiple G.fast lines between two endpoints to convey an aggregate payload which is multiplexed across the multiple lines. Compared to single-line G.fast, bonding N lines of similar rates enables the transport of approximately N times the data rate, or alternatively a longer line length for the same aggregate data rate. Typically, two lines are bonded, but the number may be larger.

TR-400 provides testing methodology of multiport G.fast systems which use multi-pair bonding protocol G.998.2 amendment 4[1] (Ethernet- based multi-pair bonding). The bonded lines include G.fast specified by ITU-T Recommendations G.9700[2] and G.9701[3].

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1   Purpose and Scope

1.1   Purpose

TR-400 specifies a set of tests to be performed to assure the interoperability, functionality, and performance of the Layer 2 bonding functions. Included are tests for downstream and upstream throughput when the individual lines have equal and unequal bit-rates and cases where a bonded line is removed and restored.

1.2   Scope

TR-400 specifies the methods to test the interoperability, functionality, and performance of equipment performing G.fast bonding. These tests address the Layer 2 bonding functions only, and it is assumed that the individual G.fast transceivers also pass applicable G.fast-specific testing requirements specified in ATP-337[6]. The equipment under test includes network-end equipment (such as a DPU) and remote-end equipment (such as a network termination device or CPE). Throughout this document the term CPE is used interchangeably to describe this remote equipment.

Testing is limited to CPE devices that allow parallel initialization of the links in the bonding group and, hence, shortening of the bonding group initialization time. Specifically, the handshake operation defined in section 8 of G.998.2 amendment 2[1] shall be supported, including PME identification, and either one of the following operation options:

1. G.994.1[7]-based discovery/aggregation.
2. BACP protocol for discovery/aggregation/ link management specified in Annex C of G.998.2 amendment 2[1].

2   References & Terminology

2.1   Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found be in RFC 2119 [4].

SHALL	This word, or the term "REQUIRED", means that the definition is an absolute requirement of the specification.
SHALL NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term "RECOMMENDED", means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the term "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 inter-operate with another implementation that does include the option.

2.2   References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.

A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document	Title	Source	Year
[1] G.998.2	*Ethernet-based multi-pair bonding,* Amd 2 & 4 Annex D	ITU-T	2005
[2] G.9700	*Fast Access to Subscriber Terminals (G.fast) – Power spectrum density specification*	ITU-T	2014
[3] G.9701	*Fast Access to Subscriber Terminals (G.fast) –*	ITU-T	2014

	Physical layer specification		
[4] RFC 2119	*Key words for use in RFCs to Indicate Requirement Levels*	IETF	1997
[5] G.997.2	*Physical Layer OAM for G.fast*	ITU-T	2015
[6] ATP-337	*G.fast Certification Abstract Test Plan*	Broadband Forum	2017
[7] G.994.1	*Handshake procedures for digital subscriber line transceivers,* including all in force amendments.	ITU-T	2017

2.3 Definitions

The following terminology is used throughout this Technical Report.

Bonding group up	The bonding group is operationally up and is able to pass traffic.
Bridging	An aggregate network combining the CPE subscriber side and DPU uplink network segments without IP routing.
Customer Premises Equipment	Remote-end equipment or network termination device
Ethernet Frame size	Size of an Ethernet frame as specified in IEEE 802.3 (from the destination MAC address bytes to the Frame Check Sequence (FCS) bytes)
FASTMIX	Fast Mix is a set of Ethernet frame sizes and associated probability distributions intended to represent packet traffic typically seen on the Internet

2.4 Abbreviations

This Technical Report uses the following abbreviations:

ATP	Abstract Test Plan
CPE	Customer Premises Equipment
CV	Code Violation
DHCP	Dynamic Host Configuration Protocol
DPU	Distribution Point Unit
DUT	Device Under Test
FLR	Frame Loss Ratio
FCS	Frame Check Sequence
HON	Higher Order Node
PPPoE	Point-to-Point Protocol over Ethernet
VLAN	Virtual LAN

2.5   G.997.2 Parameters

Parameter	Section in G.997.2
CV counter (CURR/PREV_NE/FE_15/24_CV)	7.8.4

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3   Technical Report Impact

3.1   Energy Efficiency

TR-400 has no impact on energy efficiency.

3.2   Security

TR-400 has no impact on security.

3.3   Privacy

Any issues regarding privacy are not affected by TR-400.

4   Traffic Testing of Multi-Pair Bonding Systems

The bonded multi-pair G.fast technology allows the creation of a larger data pipe. The equipment behavior should allow for minimal payload loss during events such as dropped links, impulse noise events, and fluctuating noise.

4.1   Configuration

The configuration is as shown in Figure 1, with a bonding CPE connected to the G.fast over N loops of very short lengths (back to back). A traffic generator/analyzer is connected to the DPU and the CPE. The test plan requires the DPU and CPE to support a maximum Ethernet Frame Size of at least 1566-bytes.

While the bonding layer tests may be performed using any G.fast Physical Layer configuration, care must be taken to ensure errors on the physical layer do not negatively impact the test results. For example, it may be necessary to ensure the Maximum Delay and Minimum INP configuration parameters are set to appropriate values.
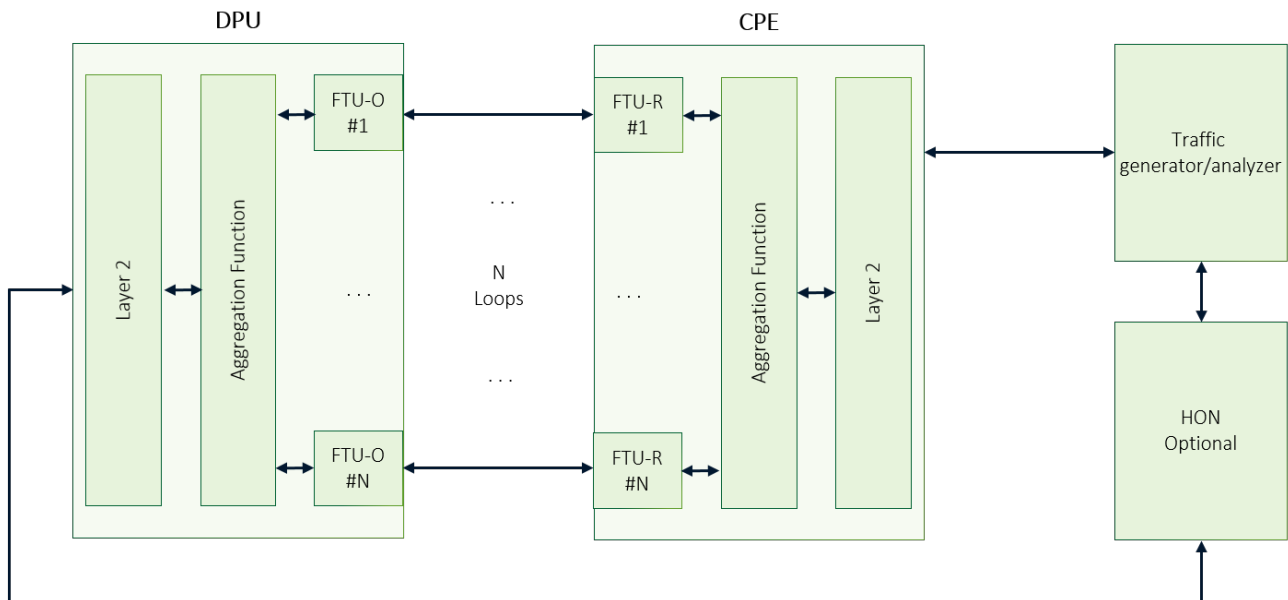

Figure 1 - Test setup for traffic testing

4.2   Traffic Setup

The frame rate to be used for a given test is determined based on the required bonded net data rate (Required_Bonded_Data_Rate) defined by Equation 1. The Required_Bonded_Data_Rate SHALL be the 90% of minimum of:

- The achievable bonded net data rate (achieved_bonded_NDR), and

- The supported bonded net data rate (supported_bonded_NDR), and
- The DPU uplink speed (DPU uplink), and
- The CPE LAN port speed (CPE_LAN).

Equation 1

$$Required\_Bonded\_Data\_Rate(\text{bits/sec}) =$$
$$0.90 \times \left(MIN(\text{achievable\_bonded\_NDR}, \text{supported\_bonded\_NDR}, \text{DPU\_uplink}, \text{CPE\_LAN}) \right)$$

The achieved_bonded_NDR (Equation 2) is calculated after multiple vectored lines are trained in parallel, by summing up the net data rates (NDR(i)) as defined in G.997.2[5] clause 7.11.1.1, where N is the number of trained lines.

Equation 2

$$\text{achieved\_bonded\_NDR}(\text{bits/sec}) = \sum_{i=1}^{N} \text{NDR}(i)$$

The supported_bonded_NDR in a particular direction SHALL be the minimum of the DPU and CPE vendor's claimed maximum bonded net data rate. The vendor's claimed maximum bonded NDR may depend on the maximum user interface rate and/or may be frame size dependent.

The frame rate associated with the Required_Bonded_Data_Rate depends on the Ethernet frame sizes and their relative probability in the mixed frame size distribution (FASTMIX) defined in Table 1. These dependencies are accounted for in determining the average frame size using Equation 3, where M is the number of frame.

Equation 3

$$\text{Average\_Frame\_Size\_of\_Mix}\left(\frac{bytes}{frame}\right) = \left\lceil \sum_{i=1}^{M} \text{frame\_probability}(i) \times \text{frame\_size}(i) \right\rceil$$

Where $\lceil x \rceil$ denotes rounding to the higher integer.

For the Frame Size Distribution in Table 1, the Average_Frame_Size_of_Mix is 1193 bytes.

Table 1 - Frame Size Distribution within Ethernet Traffic (FASTMIX)

Frame Size (bytes)	Probability
1566	0.050
1500	0.673
1024	0.088
256	0.014
64	0.175
NOTE - All Ethernet frame sizes being on the first byte of the Destination MAC Address and end on the last byte of the Frame Check Sequence (FCS).	

The frame sizes defined in Table 1 are the frame sizes for FASTMIX. The input to and output from the aggregation functions from DPU and/or CPE functionality shall include all overheads that impacts frame length (e.g., VLAN tagging and FCS).

Finally, the required frame rate used for testing is determined for a given test using Equation 4.

Equation 4

$$\text{Required\_Frame\_Rate}\left(\frac{frames}{\sec}\right) = \left\lfloor \frac{\text{Required\_Bonded\_Data\_Rate} \times \frac{1}{8}}{\text{Average\_Frame\_Size\_of\_Mix}} \right\rfloor$$

Where Required_Bonded_Data_Rate is in units of bits per second as defined by Equation 1, and specified in each specific test case for a specific direction, upstream or downstream.

The traffic configuration using the mixed Ethernet frame sizes of Table 1 is called FASTMIX in the remainder of the document.

The Ethernet/IP Traffic Generator/Analyzer shown in Figure 1 is not able to distinguish whether Ethernet frames are dropped in the DPU, the CPE, the HON, or the Ethernet switch. Hence, when verifying that no Ethernet frames are dropped in the Device Under Test (DUT) (e.g., in section Figure 1), a background Frame Loss Ratio (FLR) of 4e-7, with a minimum of 5 dropped frames, is allowed as to not fail the DUT for frames dropped outside its control.

> NOTE – An FLR of 4e-7 corresponds with about 10 dropped downstream frames and 3 dropped upstream frames when running Ethernet traffic at a 1 Gbit/s aggregate net data rate at the default 4:1 downstream:upstream split ratio for 5 minutes, with a frame size distribution as defined in Table 1. This FLR of 4e-7 accommodates the cascading of up to 4 Ethernet interfaces (as shown in Figure 1), each at an FLR of 1e-7. A minimum of 5 dropped frames is allowed for the test to be statistically relevant given the measurement time.

4.3   Basic Bonding Functionality Test

4.3.1   Purpose

The purpose of the test is to verify that the basic aggregation function (i.e., assembly and reassembly of cells/fragments) is performed successfully.
This test is executed for downstream and upstream simultaneously (i.e., with downstream and upstream traffic).

4.3.2   Test Configuration

1.   The test setup SHALL be as shown in Figure 1.
2.   Set up the loop simulators or real cable to a very short loop length (back to back).

4.3.3   Method of Procedure

1.   Configure the bonded group and place all N lines into the group.
2.   Configure the DPU to the profile line configuration allowing maximum net data rates in both directions on all N loops.
3.   Let the lines train and wait until the bonding group is up, then wait 30 seconds.
4.   Set up the traffic generator to send FASTMIX in both directions at the required frame rate (using **Equation 4**).
5.   Run traffic for 10 seconds.
6.   Run traffic for 10 minutes, record the number of downstream and upstream transmitted frames and dropped frames.
7.   Verify that no CVs occurred over the test period, if CVs occurred then repeat MoP(6) once.

4.3.4   Expected Result

The test is passed if the following pass/fail criteria are passed, otherwise the test is declared failed.
1.   If over the 10 minutes test period (MoP [6]):
   a.   The number of dropped downstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 4.2.
   b.   The number of dropped upstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 4.2.

4.4   Test for Bidirectional Frame Rate and Removal and Restoral of a Single Bonded Line to a Bonded Group

The purpose of this test is to verify bidirectional error free frame rate before and after a removal of a single bonded line out of a bonded group and a restoral to the bonded group without degradation of traffic, frame rate and minimal CVs.

4.4.1 Test Configuration

1. The test setup SHALL be as shown in Figure 1.
2. Set up the loop simulators or real cable to a very short loop length (back to back).

4.4.2 Method of Procedure

1. Configure the bonded group and place all N lines into the group.
2. Configure the DPU to the profile line configuration allowing maximum net data rates in both directions on all N loops.
3. Let the lines train and wait until the bonding group is up, then wait 30 seconds.
4. Set up the traffic generator to send FASTMIX in both directions at the required frame rate (using **Equation 4**)
5. Run traffic for 10 seconds.
6. Run traffic for 2 minutes, record the number of downstream and upstream transmitted frames and dropped frames..
7. Verify that no CVs occur over the traffic test period. If CVs occurred then rerun MoP(6), once.
8.   Remove line #1 by physically disconnecting the wire pair at either end of the line.
9.   Allow for 30 seconds to stabilize the loops and aggregation functions
10. Verify that the DPU reports that line #1 has left the bonded group.
11. Set the frame rate of both the upstream and downstream direction to the required frame rate (using **Equation 4**, with the actual net data rate of line #1 being zero).
12. Run traffic for 2 minutes, record the number of downstream, and upstream transmitted frames and dropped frames.
13. Verify that no CVs occurred over the traffic test period. If CVs occurred then rerun MoP(12), once.
14. Restore line#1.
15. Let the line train, then allow for 30 seconds to stabilize the loops and aggregation functions.
16. Verify that the DPU reports that line #1 has joined the bonded group.
17. Set the frame rate of both the upstream and downstream direction to the required frame rate (using **Equation 4**).
18. Run traffic for 2 minutes, record the number of downstream, and upstream transmitted frames and dropped frames.
19. Verify that no CVs occurred over the traffic test period. If CVs occurred then rerun MoP(18), once.
20. Repeat steps 8 to 19 (removal/restoral) for the remaining lines #2 to #N until all lines have been removed and restored to the bonding group.

4.4.3 Expected Result

The test is passed if all of the following three pass/fail criteria are passed, otherwise the test is declared failed.

1.   If over the 2 minutes test period before removal (MoP (6)):
     a. The number of dropped downstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 4.2.

      b. The number of dropped upstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 4.2.

2. If over the 2 minutes test period during disconnect (MoP [12]):
       a. The number of dropped downstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 4.2.
       b. The number of dropped upstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 4.2.

3. If over the 2 minutes test period after restoral (MoP [18]).
       a. The number of dropped downstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 4.2.
       b. The number of dropped upstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 4.2.

4.5   Frame Rate Test with Maximally Unequal Rates

The bonding standards provide the capability to bond together loops whose net rate differs by a factor of 2:1. The purpose of this test is to verify that the aggregation function can successfully bond multiple loops whose minimum versus maximum net data rates differ by a factor of 2.

4.5.1 Test Configuration

1. The test setup SHALL be as shown in Figure 1.
2. Set up the loop simulators or real cable to a very short loop length (back to back).

4.5.2 Method of Procedure

1. Configure the bonded group and place all N lines into the group.
2. Configure the DPU to the profile line configuration allowing maximum net data rates in both directions on all N loops.
3. Let the lines train and wait until the bonding group is up, then wait 30 seconds.
4. Identify the line with the lowest downstream actual net data rate, and record the rate as min_N. Reconfigure one line with a fixed net data rate equal to 50% of min_N, rounded up to the next 96kbit/s. Reconfigure the other N-1 lines with a fixed net data rate equal to min_N. Reinitialize the lines ensuring that the lowest actual net data rate of the lines is between 50% and 51% of the highest actual net data rate of the lines.
5. Let the lines retrain and wait until the bonding group is up, then wait 30 seconds.
6. Set up the traffic generator to send FASTMIX in the both directions at the required frame rate (using **Equation 4**).
7. Run traffic for 10 seconds.

8. Run traffic for 2 minutes, record the number of downstream and upstream transmitted frames and dropped frames.
9. Verify that no CVs occurred over the test period. If CVs occurred then rerun (MOP(7)), once.

4.5.3 Expected Result

The test is passed if the following pass/fail criteria is passed, otherwise the test is declared failed.
1. If over the 2 minutes test period (MoP (7)):
   a. The number of dropped downstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 4.2.
   b. The number of dropped upstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 4.2.

4.6   Bonding CPE Power Cycling Test

The purpose of the test is to verify that a bonding group retrains and traffic is picked up again after a CPE power cycle.

4.6.1 Test Configuration

1. The test setup SHALL be as shown in Figure 1.
2. Set up the loop simulators or real cable to a very small loop length (back to back).

4.6.2 Method of Procedure

1. Configure the bonded group and place all N lines into the group.
2. Configure the DPU to the profile line configuration allowing maximum net data rates in both directions on all N loops.
3. Let the lines train and wait until the bonding group is up, then wait 30 seconds.
4. Set up the traffic generator to send FASTMIX in the both directions at the required frame rate (using **Equation 4**).
5. Start the traffic generator, it continues to generate traffic until the end of the test.
6. Let traffic run for 10 seconds.
7. Run a frame loss measurement for 2 minutes, record the number of downstream and upstream transmitted frames and dropped frames.
8. Switch off the CPE's power supply.
9. Wait 20 seconds
10. Switch on the CPE's power supply
11. Let the lines retrain and wait until the bonding group is up, then wait 30 seconds.
12. Run a frame loss measurement for 2 minutes, record the number of downstream and upstream transmitted frames and dropped frames.
13. Verify that no CVs occurred over the 2 minutes test period, if CVs occurred then rerun the test, once.

4.6.3 Expected Result

The test is passed if all of the following two pass/fail criteria are passed, otherwise the test is declared failed.

1. If over the 2 minutes test period before power down (MoP (5)):
    a. The number of dropped downstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 4.2.
    b. The number of dropped upstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 4.2.
2. If over the 2 minutes test period after power on (MoP (10)):
    a. The number of dropped downstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 4.2.
    b. The number of dropped upstream (i.e., transmitted minus received) frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 4.2.

4.7   Bonding Group Train up Time Test

The purpose of the test is to verify that a bonding group which was active before disconnection of the lines can train up and reach showtime and restore traffic services in the specified time when reconnecting these lines. This test covers all configurations on the CPE for establishing a traffic path (DHCP, PPPoE, bridging). The number of lines in the bonding group shall be N=2.

4.7.1 Test Configuration

1. The test setup SHALL be as shown in Figure 1.
2. Set up the loop simulators or real cable to a very small loop length (back to back).

4.7.2 Method of Procedure

1. Configure the bonded group and place all N lines into the vectoring group of size N. All other ports on DPU shall be administratively turned off.
2. Configure the DPU to the profile line configuration allowing maximum net data rates in both directions on all N loops.
3. Let the lines train and wait until the bonding group is up, then wait 30 seconds.
4. Setup the traffic generator to send FASTMIX in both directions at a the required frame rate (using **Equation 4**) and start traffic.
5. Force all N lines in the bonding group to retrain via disconnecting and reconnecting all the links in the bonding group and starting the timer.
6. Measure the time it takes for all N lines to reach showtime and the traffic to start flowing again in both directions at the required bit rate.

4.7.3 Expected Result

The test is passed is if all N=2 lines reach showtime and the traffic passes through the group at the required bite rate within 45 seconds. Otherwise the test is declared failed.

End of Broadband Forum Technical Report TR-400