June 18, 2018

Notice of Ex Parte

Marlene Dortch
Office of the Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: ***Connect America Fund: Performance Measures for Connect America High-Cost Universal Service Support Recipients***
Docket No. 10-90; DA 17-1085

Dear Ms. Dortch:

On June 15, 2018, the undersigned, on behalf of NTCA–The Rural Broadband Association (NTCA) met with Jay Schwarz, Wireline Advisor to Chairman Ajit Pai, to discuss the above-captioned.

In these conversations, NTCA referenced comments that it filed in the above-captioned docket on December 6, 2017, and previous *ex parte* presentations to Wireline Competition Bureau staff.

As an overarching principle, NTCA discussed the need for performance testing obligations that recognize the characteristics of small, rural providers. These include an appropriately-sized testing pool, as described in NTCA's initial comments, as well as recognition of the costs of using CPE testing devices in the field, which include not only the CPE but also administrative costs related to deploying, connecting, testing, and then gathering back the units from the customer site over great distances in sparsely populated rural areas. NTCA explained that modems with built-in testing capabilities are not available to an extent that is sufficient to rely exclusively or even predominantly on those technologies. NTCA also discussed the impact of compliance testing on network performance and provided the attached technical papers to demonstrate wide-spread engineering recognition of the experiences described by NTCA provider members.

NTCA explained the need that testing occur at the actual subscriber location to ensure that the service measured is the service the customer receives, and to ensure that testing occurs during

windows that capture accurately, rather than obfuscate, the performance capabilities of the supported network.

NTCA also discussed, consistent with prior filings and meetings, the appropriate network segments that would be subject to performance measurement obligations. NTCA explained by way of example that network performance beyond a provider's direct interconnection with an upstream ISP is beyond the provider's control due to variables that determine the unpredictable path of traffic that is inherent to the design of the internet. Accordingly, to the extent that performance measurement obligations are intended to confirm the proper effectiveness of universal service support, that effectiveness can reasonably be measured only insofar as the measurements track performance of supported facilities; the acquisition of connections to or capacity beyond the provider's network may be necessarily informed by whether the costs of those facilities are recoverable.

Thank you for your attention to this correspondence. Pursuant to Section 1.1206 of the Commission's rules, a copy of this letter is being filed with ECFS.

Respectfully submitted,

/s/ *Joshua Seidemann*
Joshua Seidemann
Vice President of Policy

Attachments

cc: Jay Schwarz
Suzanne Yelen

Attachment 1

VantagePoint
EMPLOYEE OWNED

Broadband Speed Characteristics

June 2018

VANTAGEPNT.com 605-995-1777
2211 N Minnesota Street Mitchell SD 57301

1 Overview

There are many factors that influence the broadband speed experienced by a customer. Some of these factors are under the control of the broadband provider (such as the provisioned line rate), some are physical limitations of the network (such as the maximum supported line rates), and some are a result of the data protocols used (such as protocol overheads). Factors that limit broadband speeds are present in both the service provider's access network and the customer premises as shown in Figure 1-1. The broadband speed experienced by the customer is limited by the slowest portion of the connection which is typically in the service provider's network, but could also be in the customer premises as broadband speeds continue to increase.

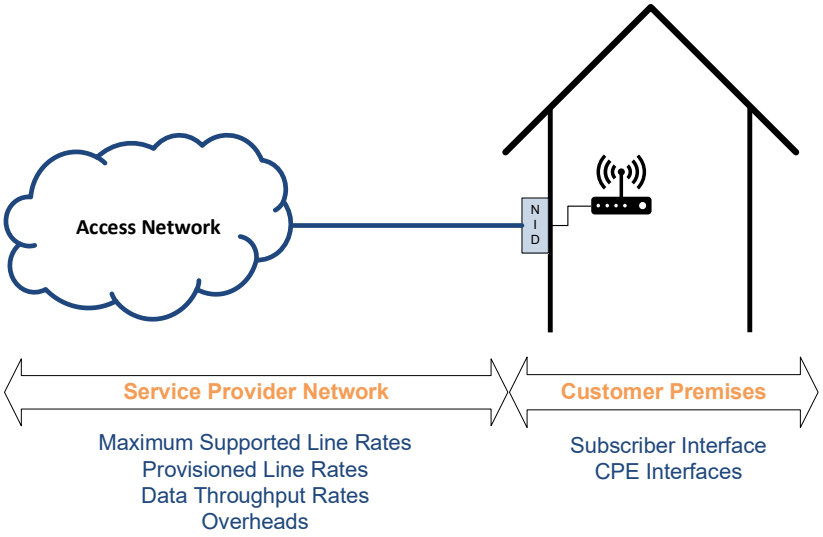

Figure 1-1: Broadband Speed Characteristics

As shown in Figure 1-2, the *provisioned line rate* is the transmission speed of the access network to the broadband subscriber. The access network could be any broadband technology including DSL, DOCSIS, Satellite, fixed wireless, or Fiber to the Premises (FTTP). The provisioned line rate includes all communications protocols and the actual subscriber data. The *data throughput rate* is the speed at which the subscriber's actual data flows over the broadband connection. The data throughput rate is always lower than the provisioned line rate since it is the speed that is remaining after accounting for the communications protocols *(overheads)*.

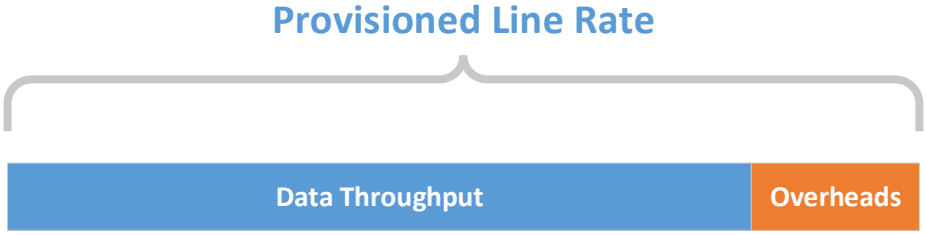

Figure 1-2: Broadband Connection Components

To account for the impact of the protocol overheads, broadband providers often provision a line rate that is higher than the broadband connection that a subscriber has ordered. As is discussed in Section 2, this higher line rate is needed if the broadband provider wants their customer to experience broadband speeds that equal or exceed what they have purchased.

Additionally, as described in Section 3, the subscriber's broadband connections are limited to the speed of their network interface and customer premises equipment (CPE) interfaces. A service provider cannot provision a higher data speed than what the equipment interface will support.

2 Protocol Overheads Can Affect Maximum Data Throughput Rates

Delivery of information almost always includes some "overheads." When mailing a letter, for example, the letter (actual information to be delivered) must be placed in an envelope that includes the sender's address, a return address, and a stamp. The letter contains the information important to the customer, but the envelope is necessary to properly deliver the letter. In data networks, the protocol overheads are similar to the envelope and include items such as the source and destination address, error correction, type of data, priority, and other information. The "envelopes" used by IP and Ethernet are called "packets" and "frames." The amount of customer data included in each packet or frame can vary, but the overheads are often a fixed size. For packets that contain less customer data (smaller packet/frame size), the protocol overheads are a larger percentage of network traffic.

In practice, Ethernet frames sizes can be between 84 bytes and 1,500 bytes or more. Figure 2-1 shows the impact of frame size on the data throughput for a 1 Gigabits per second (Gbps) broadband line rate service. For example, if the frame size is 1,514 bytes, the overheads would typically be 38 bytes for the Ethernet overhead[1] and another 20 bytes for the IP overheads. Under these conditions, the maximum throughput speed that the customer could experience would be around 960 Mbps.

[1] The 38 bytes of Ethernet overhead include: Interframe Gap, MAC Preamble & Start of Frame Delimiter, MAC Destination Address, MAC Source Address, MAC Type, Check Sequence

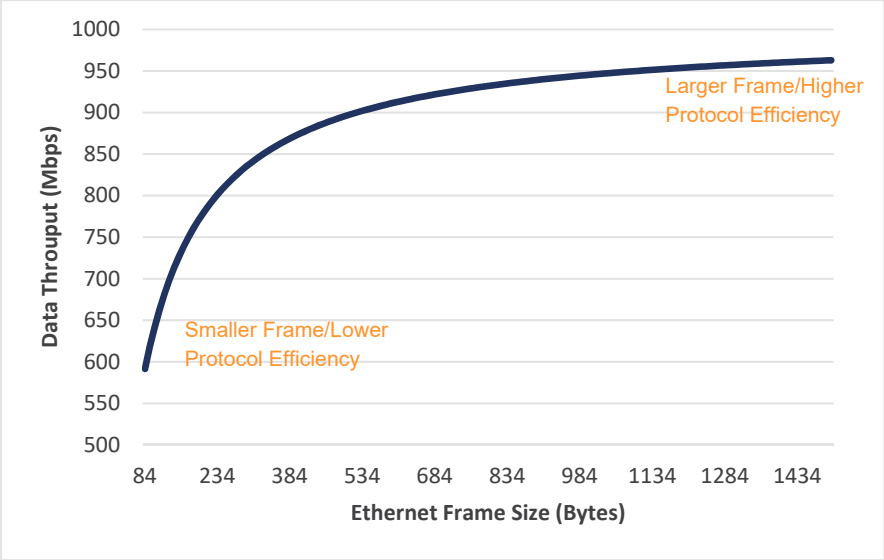

Figure 2-1: Data Throughput for a 1 Gbps Broadband Line Rate at Various Frame Sizes

Frame sizes are selected based on the type of data that is being transmitted. For applications that want to maximize data throughput, larger frames are often used due to their higher protocol efficiency. However, a single packet error in a large packet can result in a large loss of data (or large latency when the packet is retransmitted). For applications where accuracy and low latency are more important than high data throughput, such as VoIP[2], small packet sizes are often used.

To account for protocol overheads, the service provider must provision its broadband service (the provisioned line rate) to be faster than the customer's subscribed speed (the data throughput rate). This is only possible when the provider's access network can support speeds that equal or exceed the customer's subscribed rates plus the protocol overheads as shown in Figure 2-2.

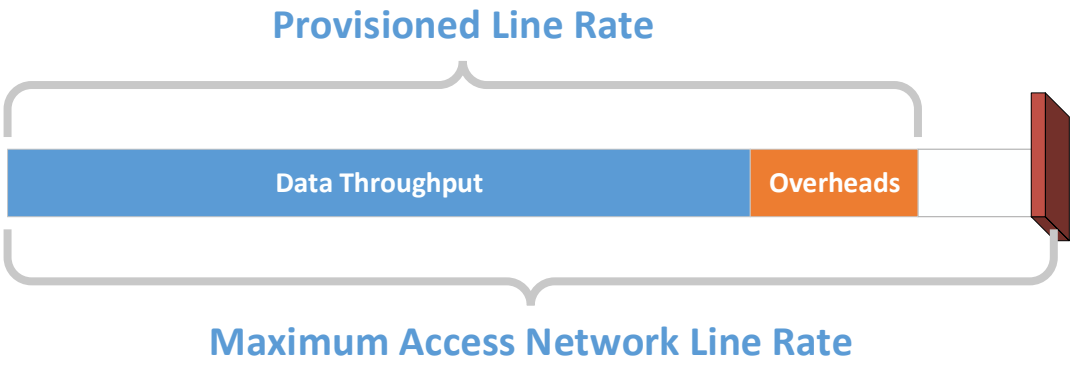

Figure 2-2: Provisioned Line Rate Compared to Maximum Line Rate

For example, assume that a subscriber orders a 25 Mbps broadband service over their provider's FTTP network. Since, the provider's network supports a maximum line rate of 1 Gbps, the provider can easily

[2] Understanding Carrier Ethernet Throughput, Am I getting the throughput I should be getting?, MEF, July 2010, pg. 10. (https://www.mef.net/Assets/White_Papers/Understanding_Carrier_Ethernet_Throughput_-_v14.pdf)

provision the subscriber's line rate to include the 25 Mbps data throughput and the additional overheads. In this example, a service provider may provision 30 Mbps downstream for the subscriber. The provider essentially "pays the tax" for the protocol overhead to give their subscriber a full 25 Mbps data throughput on their broadband connection as shown in Figure 2-3.

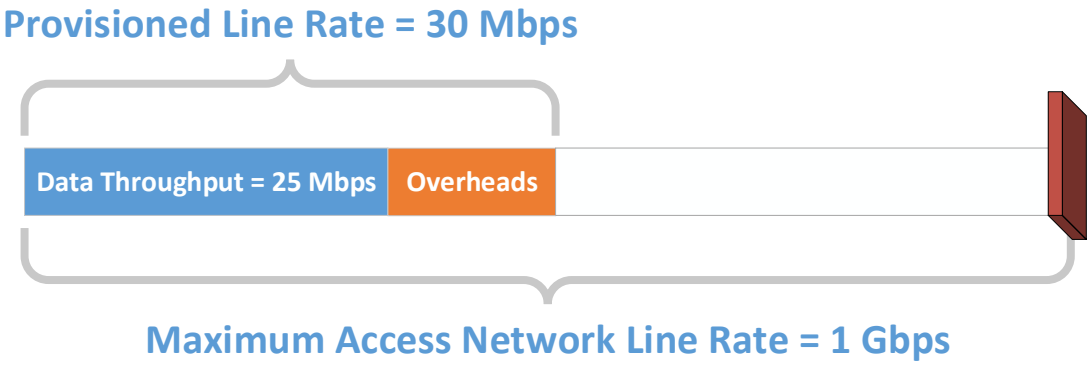

Figure 2-3: Example Showing Provider "Paying the Tax" for Protocol Overheads

Network providers can pay this protocol overhead tax for their subscribers until the broadband connection speed approaches the maximum line rate supported on the network.

Any broadband technology is subject to these relationships between the broadband line rate, overheads, and data throughput characteristics. This would include DSL, Satellite, DOCSIS, fixed wireless, and FTTP networks. Some technologies, such as FTTP, may not reach this limitation until the customer's services approach 1 Gbps (or more). Other technologies, such as DSL and satellite, reach this limitation at much lower broadband speeds.

3 Subscriber Interfaces Can Limit Maximum Broadband Rates

The interface between the provider and the customer for a broadband service is often an Ethernet interface located at the customer premises. This Ethernet interface may be on a modem, router, or Optical Network Terminal (ONT) depending upon the network technology as shown in Figure 3-1. In addition to the limitations that may be imposed on the network side described in Section 2, there may also be limitations to the broadband performance introduced by the customer's equipment.

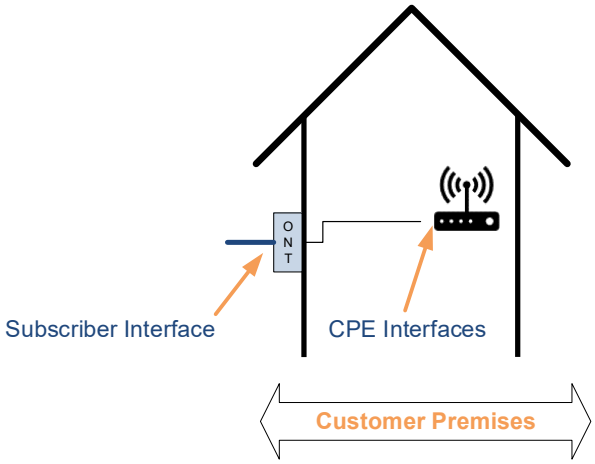

Figure 3-1: Subscriber Interfaces

A significant majority of broadband access technology deployments have 1 Gigabit Ethernet (or lower speed) subscriber interfaces. In terms of FTTP networks, the fiber optic cable infrastructure can carry tremendous bandwidth to the end users. However, the ONT subscriber interface and the CPE interfaces on the customer's home router that can only support 1 Gbps connections will be the limiting factor. Therefore, even if the broadband provider can deliver 2.4 Gbps or even 10 Gbps over their fiber network to the customer premises, the customer will be limited by the capability of the device interface (1 Gbps) between the ONT and the CPE equipment as shown in Figure 3-2.

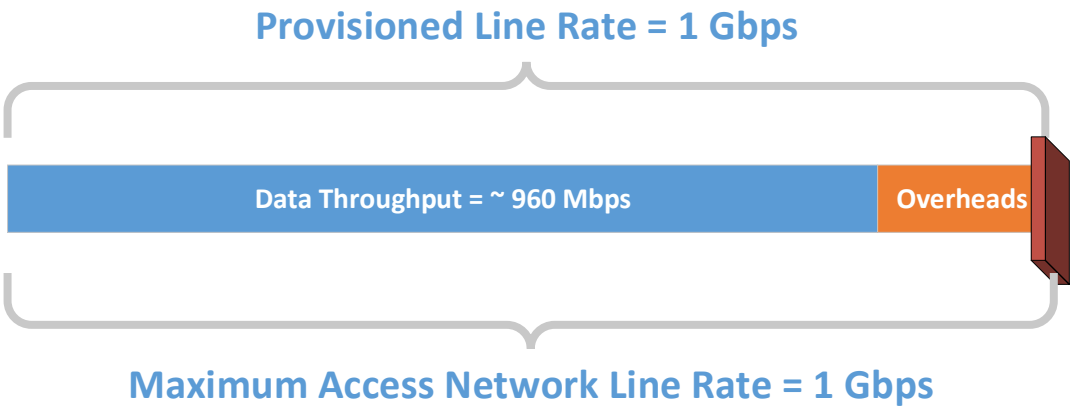

Figure 3-2: Example Showing Provider Unable to "Pay the Tax" for Protocol Overheads

About the Authors

Larry Thompson is a licensed Professional Engineer and CEO of Vantage Point Solutions. Larry has a Physics degree from William Jewell College and a Bachelor's and Master's degree in Electrical Engineering from the University of Kansas. He has been working in the telecommunications industry for more than 25 years and has helped hundreds of telecommunication companies be successful in this rapidly changing technical and regulatory environment. He has designed many wireless and wireline networks as he has assisted his clients in their transition from legacy TDM networks to broadband IP networks.

Nathan Weber is a licensed Professional Engineering and Vice President of Engineering at Vantage Point Solutions. Nathan has a Bachelor of Science degree in Electrical Engineering from South Dakota State University. He has designed and implemented many broadband wireline and wireless networks for the delivery of voice, data, and video services. Additionally, he has engineered many transport network deployments utilizing Packet Optical Transport, Carrier Ethernet Transport, DWDM, SONET, and MPLS architectures. These have included both local company and state-wide networks.

Brian Enga is a licensed Professional Engineer and part of the Senior Engineering team at Vantage Point Solutions. Brian has Bachelor's of Science degrees in Electrical Engineering and Engineering Physics from South Dakota State University. He has been working in the telecommunications industry for nearly 20 years. Brian has engineered a variety of broadband networks and has been a pioneer in deploying IP video networks.

Attachment 2

CUSTOMER ADVISORY BULLETIN

NO: CAB-16-011
DATE: Mar-16-2016
ORIG: Ben Chan
DIST: External

Throughput of Calix GPON and Active Ethernet Access Systems

CHARACTERIZATION OF DATA THROUGHPUT

OVERVIEW

Ethernet-based business services are rapidly expanding, and Calix GPON and Active Ethernet systems are being used to deliver these services to businesses, cellular towers, schools, and other institutions. Business Ethernet services frequently have service level agreements (SLAs) or other contractual performance commitments made by the service provider to the subscriber. As a result, service providers are committed to ensuring that provisioned bandwidth and actual throughput observed by the subscriber are the same.

This document summarizes tested performance on the Calix Active Ethernet (Pt-to-Pt GE) and GPON systems. The data presented is from Calix lab tests using RFC 2544 test procedures. RFC 2544 is a very rigorous system test that measures data rates using frame sizes from 64 to 1518 bytes. RFC 2544 measures the throughput by sending frames at an increasing rate, measuring the percentage of frames received, and reporting the rate at which frames are being dropped.

Calix ONTs are calibrated so that provisioned bandwidth and observed bandwidth remain as close as possible. Since RFC 2544 throughput testing is typically associated with business Ethernet services, this document is limited to bandwidths and configurations that are commonly found in business applications. Also note that E-LAN applications are not reported as a separate data set. Calix test results have found no difference in throughput in GPON systems running E-LAN versus E-LINE data services.

RFC 2544 TEST THROUGHPUT AND FRAME SIZE

An Ethernet data stream is made up of Ethernet frames and 12-byte Inter-packet Gaps (IPG) between the frames. When measuring data throughput, the RFC 2544 test includes the entire Ethernet frame except the frame Preamble. Measured throughput includes: the actual data packet and the rest of the frame overhead (address information, frame description, etc.), all the frame except the 8-byte Preamble. The 8-byte frame Preamble and the 12-byte Inter-packet Gap are not considered data and are not counted in RFC 2544 throughput measurements.

When a small frame size such as a 64-byte frame is used, non-data overhead (the Preamble and Inter-packet Gap) is also transported and accounts for a significant amount of the transported bytes. A 64 byte data frame is accompanied by 20 bytes of non-data overhead (8 bytes for the Preamble and 12 bytes for the Inter-packet Gap). Of the 84 total bytes transported for each 64-byte frame, approximately 24% of the bytes are non-data overhead.

The 20 bytes of non-data overhead does not change for a larger frame, so the percentage of non-data overhead drops rapidly as frame size increases; a 2,018-byte frame requires only 1% of the transported bytes for the Preamble and IPG. With a Calix system the provisioned rates (below the maximum line rate of 1,000 Mbps) take the non-data overhead into account and the measured data throughput matches, as close as possible, the provisioned data rate.

The Calix SOC vendor has an errata for GPON media access control that impacts downstream performance at small frame sizes. Unpredictable behavior can occur which can interrupt traffic on an Ethernet port. To address this, Calix has found it necessary to pad all downstream frames from the ONT GPON WAN interface to the ONT LAN interface to a minimum frame size of 100 bytes. The padding is not removed by the GE ONTs before the service is delivered to the customer's Ethernet port with the exception of 740GE model. This padding has no negative impact on GPON delivered service up to 500Mbps in the downstream. The effect of the 100 byte padding is to lower the measured throughput of RFC 2544 tests for packet sizes less than 100 byte frames sizes since overhead is being added. This additional padding is not done in Active Ethernet mode, so there is no effect on the measured throughput of RFC 2544 for Pt-to-Pt applications.

The following charts show the RFC 2544 test data for the E7 platform with the latest generation of Calix premises products, which includes: 700GE, 836GE RSG, 760GX, 844G/854G GigaCenters, 812G/813G GigaHubs, and 801G GigaPoint. The GigaCenters do not yet support Active Ethernet, so they are listed only with GPON tables. RFC 2544 testing only requires frame sizes up to 1518, but we have included frame sizes out to 2018 on the Calix ONTs, since they support these large frame sizes. Currently 2048 frame size is not supported on the GigaCenters. Test results are shown in the white area of the charts. Measured data throughput rates (excluding non-data overhead: Preamble and IPG) are found by locating the data frame size in the left hand column and matching it with the Provisioned Data Rate. The result is the measured data throughput in Mbps.

Calix premises products support auto-detect technology that enables these devices to be used as either GPON or Active Ethernet (Pt-to-Pt GE) ONTs. The GigaCenters will support auto-detect in future hardware versions. Residential internet services are best effort and can be offered up to Gigabit rates over both GPON and Active Ethernet.

Business services require committed information rates. Therefore, Calix recommends business services be limited to 500 Mbps over GPON and that higher rate services for businesses be offered over Pt-to-Pt GE (Active Ethernet).

E7 GPON WITH 700GE/836GE BRIDGED - DOWNSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.2	50.9	93.2	251.1	476.7	691.5 Throughput above 500 Mbps is limited by padding Calix adds to frames below 100 bytes	929.6
128	10.2	50.9	98.6	250.7	506.0	864.9	1000.0
256	10.2	50.9	99.3	255.8	503.6	927.5	1000.0
512	10.2	50.9	96.2	251.9	502.3	962.4	1000.0
1024	10.2	50.9	98.1	249.8	505.0	980.8	1000.0
1280	10.2	50.9	98.5	250.8	506.9	984.6	1000.0
1518	10.2	50.9	98.7	251.4	508.1	987.0	1000.0
2018	10.2	50.9	99.0	252.2	502.8	990.2	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 700GE/836GE BRIDGED - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.5	47.5	93.6	234.8	338.1	343.5	581.6
128	9.8	49.1	92.6	244.6	487.8	633.8	768.9
256	10.0	50.0	99.3	249.3	497.0	927.5	1000.0
512	10.1	50.5	96.2	251.9	502.3	962.4	1000.0
1024	10.1	50.7	98.1	249.8	505.0	980.8	1000.0
1280	10.1	50.7	98.5	250.8	506.9	984.6	1000.0
1518	10.2	50.8	98.7	251.4	501.2	987.0	1000.0
2018	10.2	50.8	99.0	252.2	502.8	990.1	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*
*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 700GE/836GE ROUTED - DOWNSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.5	52.3	93.2	236.4	394.9	727.3 Throughput above 500 Mbps is limited by padding Calix adds to frames below 100 bytes	965.4
128	11.1	55.5	98.6	250.7	500.0	864.9	1000.0
256	11.1	55.5	99.3	255.8	503.6	927.5	1000.0
512	11.1	55.5	96.2	251.9	502.3	962.4	1000.0
1024	11.1	55.5	98.1	249.8	498.1	980.8	1000.0
1280	11.1	55.5	98.5	250.8	500.0	984.6	1000.0
1518	11.1	55.5	98.7	251.4	501.2	987.0	1000.0
2018	11.1	55.5	99.0	252.2	502.8	990.2	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 700GE/836GE ROUTED - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.0	45.0	77.3	77.3	77.3	77.3 Throughput above 500 Mbps is limited by padding Calix adds to frames below 100 bytes	315.3
128	9.5	47.6	92.6	232.4	475.7	627.7	762.8
256	9.9	49.2	92.8	242.8	490.6	653.6	726.1
512	10.0	50.1	96.2	245.1	495.5	739.1	776.7
1024	10.1	50.5	98.1	249.8	505.0	856.7	875.9
1280	10.1	50.6	98.5	250.8	500.0	860.0	875.4
1518	10.1	50.6	98.7	251.4	501.2	980.1	993.1
2018	10.1	50.7	99.0	252.2	502.8	983.2	993.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*
*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 844G/854G BRIDGED - DOWNSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.0	50.0	97.6	247.6	499.4	761.9	1000.0
128	10.0	50.0	98.6	244.6	493.9	864.9	1000.0
256	10.0	50.0	99.3	249.3	497.1	927.5	1000.0
512	10.0	50.0	96.2	245.1	495.5	962.4	1000.0
1024	10.0	50.0	98.1	249.8	498.0	980.8	1000.0
1280	10.0	50.0	98.5	243.8	500.0	984.6	1000.0
1518	10.0	50.0	98.7	244.4	494.3	987.0	1000.0

E7 GPON WITH 844G/854G BRIDGED - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.6	47.8	92.3	236.9	472.6	681.6	919.7
128	9.9	49.6	98.6	244.6	493.9	864.9	1000.0
256	10.0	50.0	99.3	249.3	497.1	927.5	1000.0
512	10.0	50.0	96.2	245.1	495.5	962.4	1000.0
1024	10.0	50.0	98.1	249.8	498.1	980.8	1000.0
1280	10.0	50.0	98.5	250.0	500.0	984.6	1000.0
1518	10.0	50.0	98.7	244.4	494.3	987.0	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*
*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 844G/854G ROUTED - DOWNSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	11.6	57.9	104.4	262.0	522.8	767.3	1000.0
128	11.6	57.9	104.7	256.8	524.3	846.6	981.8
256	11.6	57.9	99.3	262.3	523.2	927.5	1000.0
512	11.6	57.9	103.0	258.6	522.6	942.1	979.7
1024	11.6	57.9	105.0	256.7	518.8	980.8	1000.0
1280	11.6	57.9	98.5	257.7	520.8	984.6	1000.0
1518	11.6	57.9	98.7	258.3	522.0	987.0	1000.0

E7 GPON WITH 844G/854G ROUTED - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.0	45.2	86.9	220.8	451.2	676.2	914.3
128	9.6	48.1	92.6	238.5	475.7	840.6	975.7
256	9.8	49.2	92.8	242.8	490.6	908.0	980.5
512	9.9	49.6	96.2	245.1	495.5	948.9	986.5
1024	10.0	49.8	98.1	249.0	498.1	974.0	993.1
1280	10.0	49.8	98.5	243.8	493.1	977.7	993.1
1518	10.0	49.9	98.7	244.4	480.3	980.1	993.1

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*
*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 812G/813G BRIDGED - DOWNSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.0	50.0	97.6	247.6	499.4	724.4	962.5
128	10.0	50.0	98.6	244.6	493.9	864.9	1000.0
256	10.0	50.0	99.3	249.3	497.1	927.5	1000.0
512	10.0	50.0	96.2	245.1	495.5	962.4	1000.0
1024	10.0	50.0	98.1	249.8	498.1	980.8	1000.0
1280	10.0	50.0	98.5	243.8	500.0	984.6	1000.0
1518	10.0	50.0	98.7	244.4	494.3	987.0	1000.0

E7 GPON WITH 812G/813G BRIDGED - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.3	45.5	86.9	215.5	451.2	724.4	962.5
128	10.0	49.9	98.6	244.6	493.9	864.9	1000.0
256	10.0	50.0	99.3	249.3	497.1	927.5	1000.0
512	10.0	50.0	96.2	245.1	495.5	962.4	1000.0
1024	10.0	50.0	98.1	249.8	498.1	980.8	1000.0
1280	10.0	50.0	98.5	243.8	500.0	984.6	1000.0
1518	10.0	50.0	98.7	244.4	494.3	987.0	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*
*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 812G/813G ROUTED - DOWNSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.7	53.3	97.6	253.0	510.1	724.4	962.5
128	10.3	51.6	98.6	250.7	512.2	834.5	969.6
256	10.2	50.8	99.3	249.3	503.6	927.5	1000.0
512	10.1	50.4	96.2	251.9	502.3	962.4	1000.0
1024	10.0	50.2	98.1	249.8	498.1	980.8	1000.0
1280	10.0	50.2	98.5	250.8	500.0	984.6	1000.0
1518	10.0	50.1	98.7	244.4	501.2	987.0	1000.0

E7 GPON WITH 812G/813G ROUTED - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.3	45.5	86.9	215.5	435.1	724.4	962.5
128	10.0	49.9	98.6	244.6	493.9	864.8	1000.0
256	10.0	50.0	99.3	249.3	497.1	927.5	1000.0
512	10.0	50.0	96.2	245.1	495.5	962.4	1000.0
1024	10.0	50.0	98.1	249.8	498.1	980.8	1000.0
1280	10.0	50.0	98.5	243.8	500.0	984.6	1000.0
1518	10.0	50.0	98.7	244.4	494.3	987.0	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*
*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 801G BRIDGED - DOWNSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Premble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.0	50.0	97.6	247.6	499.4	724.4	962.5
128	10.0	50.0	98.6	244.6	493.9	864.9	1000.0
256	10.0	50.0	99.3	249.3	497.1	927.5	1000.0
512	10.0	50.0	96.2	245.1	495.5	962.4	1000.0
1024	10.0	50.0	98.1	249.8	498.1	980.8	1000.0
1280	10.0	50.0	98.5	243.8	500.0	984.6	1000.0
1518	10.0	50.0	98.7	244.4	494.3	987.0	1000.0

E7 GPON WITH 801 BRIDGED - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.3	45.5	86.9	220.8	424.4	724.4	962.5
128	10.0	49.9	98.7	244.6	493.9	864.8	1000.0
256	10.0	50.0	99.3	249.3	497.1	927.5	1000.0
512	10.0	50.0	96.2	245.1	495.5	962.4	1000.0
1024	10.0	50.0	98.1	249.8	498.1	980.8	1000.0
1280	10.0	50.0	98.5	243.9	500.0	984.6	1000.0
1518	10.0	50.0	98.7	244.4	494.3	987.0	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*
*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 760GX - DOWNSTREAM

	10	50	100	250	500	1000*	Line Rate**
Frame Size (bytes)	Data Rate Without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.6	47.9	93.2	236.4	476.7	691.5	929.6
128	10.2	50.9	98.6	250.7	506.1	840.5	975.7
256	10.2	50.9	99.3	249.3	503.6	908.0	980.4
512	10.2	50.9	96.2	251.9	502.3	948.9	986.5
1024	10.2	50.9	98.1	249.8	505.0	973.9	993.1
1280	10.2	50.9	98.5	250.8	506.9	977.7	993.1
1518	10.2	50.9	98.7	251.4	508.1	980.0	993.0
2018	10.2	50.9	99.0	252.2	502.8	983.2	993.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 GPON WITH 760GX - UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	9.6	47.9	93.6	234.8	473.9	620.6	858.7
128	9.9	49.6	98.6	244.6	493.9	840.6	975.7
256	10.0	50.1	99.3	249.3	503.6	908.0	980.4
512	10.1	50.1	96.2	251.9	502.3	948.9	986.5
1024	10.1	50.1	98.1	249.8	498.1	973.9	993.1
1280	10.1	50.1	98.5	250.8	500.0	977.7	993.1
1518	10.1	50.1	98.7	251.4	501.2	980.1	993.2
2018	10.1	50.1	99.0	245.2	502.8	983.2	993.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 ACTIVE ETHERNET WITH 700GE AND 836GE RSG - DOWNSTREAM

	10	50	100	250	500	1000*	Line Rate**
Frame Size	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	11.0	53.9	103.0	269.0	536.9	756.5	994.7
128	11.0	53.9	104.7	268.9	536.5	864.9	1000.0
256	10.7	52.3	99.3	255.8	516.7	927.5	1000.0
512	10.8	53.1	103.0	265.4	529.3	962.4	1000.0
1024	10.9	53.5	105.0	263.6	532.6	980.8	1000.0
1280	10.9	53.6	105.4	264.6	534.6	984.6	1000.0
1518	10.9	53.7	105.7	265.5	535.9	987.0	1000.0
2018	10.9	54.0	106.0	266.1	537.6	990.2	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 ACTIVE ETHERNET WITH 700GE AND 836GE RSG – UPSTREAM

	10	50	100	250	500	1000*	Line Rate**
Frame Size	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	11.0	53.9	103.0	269.0	536.9	756.5	994.6
128	11.0	53.9	104.7	268.9	536.5	864.9	1000.0
256	10.7	52.3	99.3	255.8	516.7	927.5	1000.0
512	10.8	53.1	103.0	265.4	529.3	962.4	1000.0
1024	10.9	53.5	105.0	263.6	532.6	980.8	1000.0
1280	10.9	53.6	105.4	264.6	534.6	984.6	1000.0
1518	10.9	53.7	105.7	265.5	535.9	987.0	1000.0
2018	11.0	54.0	106.0	266.1	537.6	990.2	1000.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 ACTIVE ETHERNET WITH 760GX - DOWNSTREAM

	10	50	100	250	500	1000*	Line Rate**
Frame Size (bytes)	Data Rate Without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.6	52.6	103.0	258.3	520.8	724.4	962.5
128	10.6	52.6	104.7	256.8	524.3	840.5	975.7
256	10.6	52.6	99.3	262.3	523.2	908.0	980.4
512	10.6	52.6	103.0	258.6	522.6	948.9	986.5
1024	10.6	52.6	105.0	256.7	518.8	973.9	993.1
1280	10.6	52.6	98.5	257.7	520.8	977.7	993.1
1518	10.6	52.6	98.7	258.3	522.0	980.1	993.0
2018	10.6	52.6	99.0	259.1	523.7	983.2	993.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

E7 ACTIVE ETHERNET WITH 760GX- UPSTREAM

Frame Size (bytes)	10	50	100	250	500	1000*	Line Rate**
	Data Rate without Preamble and IPG					Data Rate without Preamble and IPG	Data + Preamble + IPG
64	10.3	51.3	97.6	253.0	510.1	708.3	946.4
128	10.3	49.6	98.6	244.6	493.9	840.6	975.7
256	10.3	50.1	99.3	249.3	503.6	908.0	980.4
512	10.3	50.1	96.2	251.9	502.3	948.9	986.5
1024	10.3	50.1	98.1	249.8	498.1	973.9	993.1
1280	10.3	50.1	98.5	250.8	500.0	977.7	993.1
1518	10.3	50.1	98.7	251.4	501.2	980.1	993.2
2018	10.3	50.1	99.0	245.2	502.8	983.2	993.0

** RFC 2544 acknowledges that data throughput cannot equal the 1,000 Mbps maximum system line rate due to the frame Preamble and Inter-packet Gap (non-data overhead). As in the other data rate columns the actual data rate throughput for a 1,000 Mbps provisioned service is listed in this column.*

*** The Line Rate column lists the actual throughput PLUS the additional non-data overhead (Preamble and IPG) required for that frame size. This provides a total throughput to compare to the Maximum Line Rate of 1,000 Mbps.*

CONCLUSION

Calix has tested the data throughput of the E7 platform with the Calix premises portfolio using rigorous RFC 2544 test methods to ensure that throughput measurements match provisioned rates.

ADDENDUM

The table below is from Agilent's White Paper *RFC 2544 Testing of Ethernet Services in Telecom Networks*, November 15, 2004

Line Rate Data Throughput -without Preamble and Inter-Packet Gaps (IPG)

Frame Size	10 Mbps	100 Mbps	1000 Mbps
64 byte	7.62 Mbps	76.19 Mbps	761.90 Mbps
128 byte	8.65 Mbps	86.49 Mbps	864.86 Mbps
256 byte	9.27 Mbps	92.75 Mbps	927.54 Mbps
512 byte	9.62 Mbps	96.24 Mbps	962.40 Mbps
1024 byte	9.81 Mbps	98.08 Mbps	980.84 Mbps
1280 byte	9.84 Mbps	98.46 Mbps	984.61 Mbps
1518 byte	9.87 Mbps	98.69 Mbps	986.99 Mbps

PETALUMA HEADQUARTERS 1035 N. McDowell Blvd. Petaluma, CA 94954 Phone: 707.766.3000

INFORMATION Web: www.calix.com

TECHNICAL SUPPORT Email: tech.support@calix.com Phone: 877.766.3500

ORDER MANAGEMENT Email: order.management@calix.com Phone: 877.766.3500 FAX: 707.283.3771