An ADTRAN White Paper

Virtual Subscriber

Realistic Traffic Generation in the Lab Environment

Introduction: Broadband Networks and Application-based Testing

Broadband access networks that deliver current and future services use a wide range of architectures, devices, and technologies, especially over the "last mile" connections that provide the final link to the subscriber premises. These technologies can interact with system configurations, network protocols, and traffic patterns in non-intuitive, complex behaviors that may affect the Quality of Experience (QoE) perceived by customers, in turn affecting subscriber churn and take rates. As a result, service providers pay close attention to testing the systems they deploy, both in the lab and during initial trials.

Pre-trial testing in a lab environment is important for many reasons, including the fact that lab testing allows systems to be stressed in ways that they may not encounter in field trials. In particular, broadband traffic volume—which increases yearly at an exponential rate estimated at 20 to 40 percent or more—is usually pushed in the lab to levels projected several years into the future, while subscribers in field trials use the services at volumes reflective of current usage.

While testing with projected traffic volumes is important, the nature of the traffic generated is just as important, if not more so, to accurately characterize system performance. A stream of packets with constant size and spacing can create a flow with a defined volume, but it cannot be used to predict system behavior because (among other reasons) it lacks a feedback mechanism. A set of flows running over Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) at the transport layer may work better than a single fixed flow, but they may still not predict the QoE that results when traffic from multiple subscribers and multiple applications is aggregated over elements operating at different layers of the stack across the access network.

Some examples of the potential interactions between network systems, protocols, and traffic patterns include:

- **Passive Optical Network (PON)** systems can oversubscribe upstream bandwidth by using Dynamic Bandwidth Allocation (DBA) to allocate bandwidth in grants to Optical Network Terminals (ONTs) that need them. The time domain behavior of these grants, especially as traffic flows are initiated, can have a significant effect on TCP performance. This effect can be exacerbated by buffer sizing in the ONT.
- **G.fast Distribution Point Units (DPUs)** may serve multiple subscribers over bundled twisted pairs. Time Domain Duplexed (TDD) operation and synchronous upstream and downstream transmissions of all lines are used to avoid the effects of high levels of near-end cross-talk (NEXT). Coordinated Dynamic Time Assignment (cDTA) can optimize system performance under these conditions, but the QoE resulting from different cDTA algorithms can depend on traffic characteristics. As with DBA in the above example, any performance impact can be exacerbated by buffer sizing in the G.fast modems.
- The **DOCSIS FDX** project is investigating dynamic allocation of resource blocks to support multi-Gigabit service rates. While this functionality is not required today, the protocol needs to be designed now, due to the interaction between the changes in the available bandwidth, frequency of change and time required to do so and the higher level protocols used by the traffic.
- **Upstream RFoG** performance at the physical layer can be affected by Optical Beat Interference (OBI). The incidence of OBI is related to the statistics with which ONTs send packets concurrently at interfering wavelengths. Those statistics are dependent not only on overall traffic volumes, but also on the traffic patterns generated by different applications.

At ADTRAN, we have developed a test platform that mitigates the issues identified above by emulating the behavior of actual subscribers and applications as closely as possible. The test platform, called Virtual Subscriber, generates traffic at the application layer using multiple applications representative of those used in the field. Virtual Subscriber is described in the following sections.

Virtual Subscriber Description

The Virtual Subscriber is a set of application characteristics and subscriber behaviors implemented in software that, taken together, generate traffic emulating the behavior of an actual subscriber as closely as possible. Characteristics and behaviors are defined for each of a number of application classes, such as streaming video, Voice over IP (VoIP), or file sharing. Characteristics are defined by the application class, and behaviors are defined by the subscriber type and loading. For example, the characteristics of video streaming include transmission over TCP of the large 'chunks' of traffic typical of adaptive streaming video protocols like DASH; rate adaptation based on the rate of delivery of previous chunks and the video client receiver buffer fill level; and the range of streaming rates offered for adaptation. Subscriber behaviors for the same application include how frequently video streams are requested and the average time duration of the video streams.

The set of application classes currently emulated in Virtual Subscriber is listed below. This set is subject to refinement and expansion as new application classes emerge and as the ways in which subscribers use existing classes evolve to create meaningful distinctions between subclasses.

- **VoIP** —Interactive voice traffic between two parties.
- **Video over IP**—Interactive video/voice traffic between two parties.
- **Over the Top (OTT) Video Streaming**—This application class can be divided into a number of subclasses based on viewing duration, streaming rate, and rate adaptation. Viewing duration can be classified as short-form (under 5 minutes), medium-form (5 to 20 minutes), or long-form (over 20 minutes) [1]. Streaming rates are dependent on several factors: the quality and complexity of the original content; the different encoded versions available; and the performance of the network connection. Rate adaptation is assumed as most OTT streaming video is delivered over adaptive streaming protocols such as MPEG-DASH [2].
- **Upstream Video**—For example, video sent from a home security camera to a remote location.
- **File Sharing**—This class includes peer-to-peer sharing protocols as well as file backup and recovery and other cloud file operations. It would be possible to break these applications up into separate subclasses with different characteristics.
- **Non-video Web Access**—Web-based video access is included within the OTT streaming video class.
- **Virtual Reality (VR)**—This is modeled primarily as real time, stereo, high-quality video streamed to the subscriber, along with a relatively low-rate upstream channel for control information.
- **Gaming (excluding VR)**—While gaming bandwidth requirements can vary considerably, this class is modeled in the worst case as real time, mono video streamed to the subscriber at increasingly high quality.
- **Performance Testing**—Similar to Ookla and other network-based speed tests, this application transfers traffic in one direction at a time over a set of TCP connections and measures the resulting throughputs in each direction. Unlike other classes, this application is frequently launched deterministically to provide a performance result during a test.

Application traffic for all of the above classes is modeled in sessions, where each session represents a new instantiation of traffic (e.g., a video clip or program). Session initiation is modeled as a Poisson process with a defined Mean Time Between Sessions (MTBS) based on the application class and the overall subscriber load. The characteristics that define a session—duration, number of flows, flow rates, transport and application protocols, packet size, etc.—are also dependent on the application class and subscriber load.

Each Virtual Subscriber represents a single broadband subscription. Since residential subscribers represent households containing multiple people and devices, it is common for multiple sessions to overlap in time. For example, multiple members of the same household can stream videos at the same time, while still other members are browsing the Web and while a PC is autonomously performing file backup to the cloud. While the current set of Virtual Subscriber traffic profiles has been defined primarily for residential subscribers, the methodology can be used equally well for small- and medium-sized business subscribers so long as their behaviors are sufficiently well known to support the definition of their profiles.

The Virtual Subscriber software emulates multiple subscribers in addition to the Internet-based servers hosting the 'content' being accessed by each subscriber. Each subscriber and each application server have a dedicated network namespace, with a virtual network providing forwarding to the host machine's physical interfaces. While the performance of the system is dependent on the machine it is hosted on, testing to date with 32 subscribers on a typical desktop system has supported average aggregate loads of over 800 Mbps, with bursts as high as the physical port rate of 1 Gbps.

Figure 1 shows an example of the actual traffic volume over time generated by a single Virtual Subscriber with an average offered load of 20 Mbps. The traffic was measured over 10 msec intervals and shows the variation representative of real applications and subscriber behavior, bursting up to nearly a Gigabit per second at times. The graph cannot, of course, show the complex application behaviors or the interplay between upstream and downstream traffic that is representative of traffic in the field.

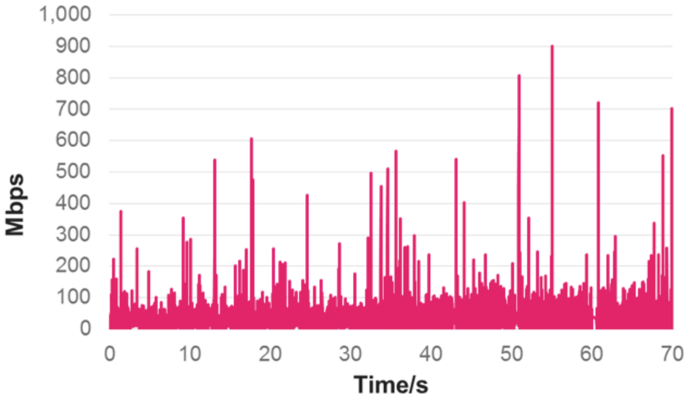

Figure 1: Variation in traffic generated by Virtual Subscriber

Traffic Modeling Trends and Forecasts

A number of sources [3, 4] have provided snapshots of actual application usage in different regions and at different times. In addition, the Cisco Visual Networking Index [5] annually forecasts regional traffic volume by application up to four years into the future. For a number of years, we have used these sources, combined with census and broadband adoption data, to generate per-subscriber traffic forecasts including estimated ranges for annualized growth. These forecasts provide an estimate of the composition of subscriber traffic by application class that can be projected out for several years.

The overall growth of subscriber traffic forecast by these projections is shown in *Figure 2*, along with service rates going back to the early 1980s. The figure, which is specific to the United States, shows several interesting trends:

- The highest widely available service rates have grown at a remarkably consistent rate of about 48 percent per year over 35 years. The biggest disruptive outlier in this trend was the introduction of Gigabit services by Google in 2013. Depending on one's definition of "widely available," we will see widely available Gigabit services sometime between the present day and 2020.
- The average downstream busy-hour traffic generated by subscribers has remained two to three orders of magnitude lower than the available service rates. From 2006 to 2012, downstream subscriber traffic grew at a Combined Annual Growth Rate (CAGR) of almost 50 percent. From 2012 on, growth has slowed considerably, maintaining an average CAGR of about 20 percent. If we start with today's average of about 1 Mbps per subscriber and bracket growth at these two rates (20 percent and 50 percent), we project downstream traffic averaging anywhere from 4.3 Mbps to 25 Mbps per subscriber in the year 2025.
- The average upstream busy-hour traffic has been steadily decreasing as a percentage of downstream traffic as other applications have given way to video, and this trend doesn't seem to be ending soon [5]. Growth has ranged from 12 to 15 percent per year, well below the downstream growth rate even at its lowest. If we take today's estimated 67 kbps and assume 15 percent growth from this point forward, we project upstream busy- hour traffic averaging slightly over 200 kbps in 2025. Even if we assume 20 percent growth, we only reach an upstream average of 288 kbps in 2025.

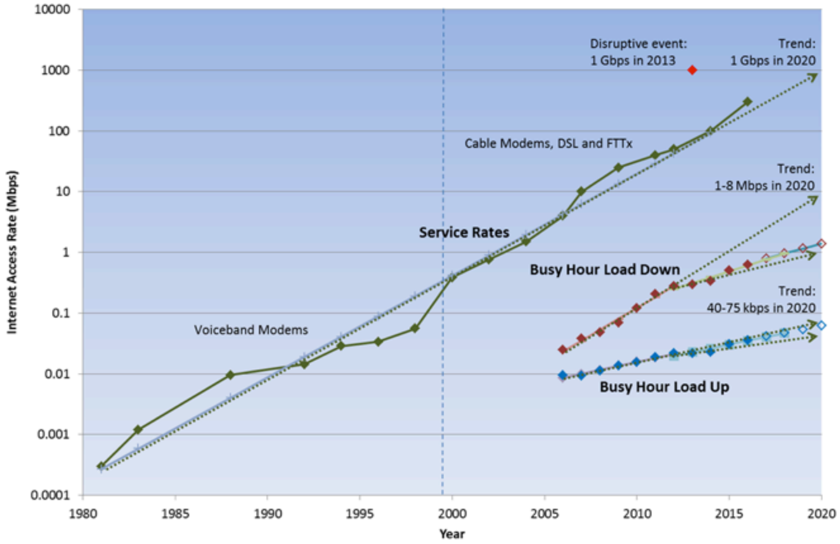

Figure 2: Service rate and traffic trends

If we attempt to break the traffic down by application class, we can generate traffic profiles similar to those shown in *Figures 3a* and *3b*. These projections are based primarily on Cisco Visual Networking Index (VNI) data until average consumer busy-hour traffic reaches several Mbps. Beyond that point, the projections become more speculative by necessity. We can, however, project that OTT video streaming will continue to drive a significant percentage of growth joined at higher traffic levels by file sharing for cloud services (especially as a percentage of upstream traffic) and by virtual reality (VR) applications. VR, in particular, has the potential to drive continued growth due to the extremely high bit rates that may be utilized to provide 8K video to each eye with a 180-degree field of vision.

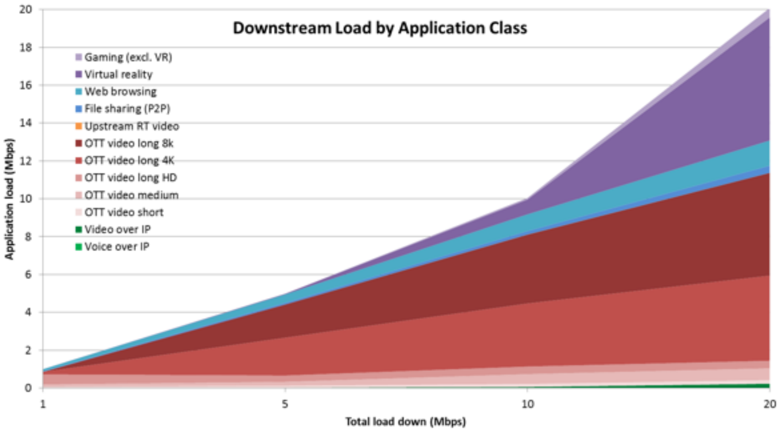

Figure 3a: Downstream traffic by application class

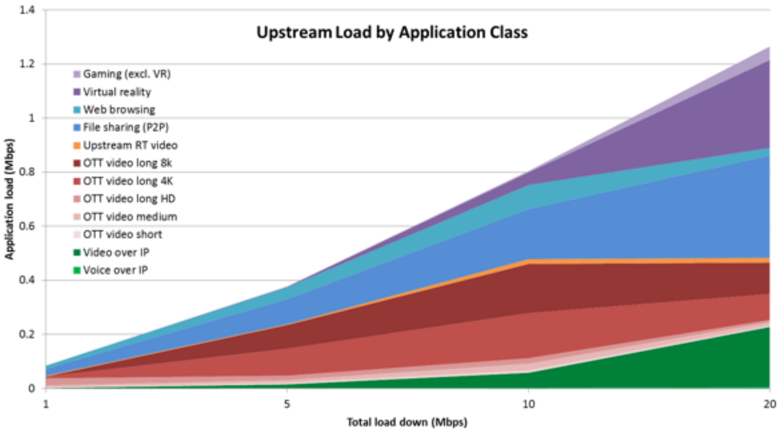

Figure 3b: Upstream traffic by application class

Conclusion

The complexities of both access network systems and the traffic carried by them demand that they are tested with the most representative traffic possible, including projections years into the future not just of traffic volume, but of the actual applications and subscriber behaviors driving that volume. ADTRAN has developed the Virtual Subscriber system for realistic traffic generation to meet these testing needs. By emulating the characteristics of a wide variety of the most commonly used applications classes along with the subscriber behavior projected to drive those applications at increasingly heavy loads, Virtual Subscriber enables testing of system behavior at a level of detail that hasn't been available to date.

This paper provides an overview of Virtual Subscriber and the application classes that are currently implemented. These application classes are expected to evolve, as new applications emerge and as subscriber behavior evolves. We also provide an overview of the trends in busy-hour traffic per subscriber in both the upstream and downstream directions and project those trends to provide ranges of expected loading going out to the year 2025. Finally, we provide some insight into how the traffic might break down by application class at different loading levels.

References

[1] https://www.ooyala.com/resources/online-video-index
[2] http://dashif.org/
[3] https://www.proceranetworks.com/
[4] https://www.sandvine.com/resources/resource-library.html
[5] http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html

ADTRAN, Inc.
901 Explorer Boulevard
Huntsville, AL 35806
256 963 8000

General Information
800 9ADTRAN
www.adtran.com/contactus

**Canada Headquarters—
Toronto, Ontario**
+1 877 923 8726
+1 905 625 2515
sales.canada@adtran.com

Canada—Montreal, Quebec
+1 877 923 8726
+1 514 940 2888
sales.canada@adtran.com

Mexico and Central America
+1 256 963 3321
+1 52 55 5280 0265 Mexico
sales.cala@adtran.com

South America
+1 256 963 3185
sales.brazil@adtran.com
sales.latam@adtran.com

TL19.1270

ADTRAN is an ISO 9001, ISO 14001, and a TL 9000 certified supplier.

ADTRAN warranty duration and entitlements vary by product and geography. For specific warranty information, visit www.adtran.com/warranty

ADTRAN products may be subject to U.S. export controls and other trade restrictions. Any export, re-export, or transfer of the products contrary to law is prohibited. For more information regarding ADTRAN's export license, please visit www.adtran.com/exportlicense