4.4 Bit Rate Trends

There has been a clear historical trend of steadily increasing bandwidth consumption for residential and business subscribers. Figure 17, which shows maximum offered Internet bandwidth of North American cable operators, is indicative of this trend. Similar curves could be also drawn for other access media, including twisted pair, as well as fiber. The observed increase is primarily motivated by both evolutionary and revolutionary end-user applications, requiring online connectivity, and attracting larger quantities of individual consumers as well as driving the bandwidth consumption per single user.

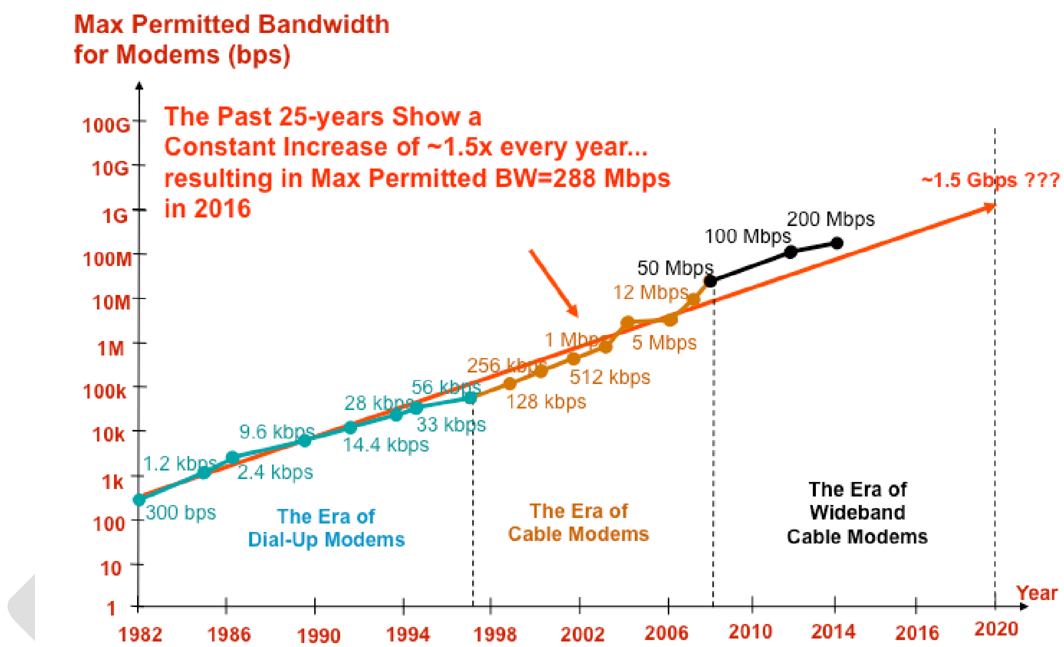

Figure 1: Maximum permitted bandwidth for cable modems [39]

Web 2.0 with its video-oriented and interactive content is one good example of a revolutionary change in the online services consumed by a large pool of users. The transition from Standard Definition (SD) to HD quality for streaming video services is an example of evolutionary change in the online services. Today (in 2014) we observe this transition as well, with some streaming platforms (for example, Netflix) beginning to offer 4K resolution content to their subscribers. It is expected that with the increasing popularity of 4K-compatible TV sets, the volume of 4K content is expected to become much larger, further increasing the average bandwidth consumption observed in the access network.

However, it is also necessary to remember that the number of simultaneous sessions established between the subscriber LAN and individual services, as well as the duration of such sessions also affect the total bandwidth consumed in the access network. In the era of dial-up modems, connections were typically made on demand, when the user needed to download and/or upload some data, resulting in short sessions, and typically very few simultaneous sessions established during such a connection. Along with the start of the era of broadband access devices and always-on network connectivity, the number and duration of individual data sessions increased substantially. Individual users started streaming data (music, video, and other content) directly off the web, rather than from local storage. There are also many more users online at any point of time, sharing a single access link and generating much more traffic on average than in the case of on-demand dial-up connections.

Various studies forecast that the average number of devices connected to the Internet (at any one time) per household can reach 5 by 2017 and 10 by 2020, comprising mostly portable personal electronic devices (tablets, smartphones, etc.) and smart home systems (home appliances, air conditioning, home security systems, etc.) [46][47]. The rapidly emerging trends for the use of cloud storage and cloud computing systems [49] only add to offered load both in downstream and upstream directions, as content is now not only consumed by devices connected to the subscriber LAN, but also generated by subscribers and uploaded to the remote cloud storage for distribution to other connected devices.

More recently, even more content is being stored in the cloud (not on local LAN storage devices), requiring more downstream bandwidth, as well as improved upload capabilities, when compared to the previous generation of access networks. The increase in quality / resolution of multimedia content stored in the cloud, as well as close integration of cloud-based storage services with newer generations of computer operating systems provides a clear view of the always-connected future, where local storage would be mostly used for caching purposes only.

The current projections, shown in Figure 17, in terms of offered load per household (in residential applications) calls for approximately 300 Mb/s around end of year 2016. If the same trend in bandwidth consumption (~1.5 increase per year, following closely Nielsen's Law [50]) be observed in the following years close to 600 Mb/s per subscriber is expected to be demanded around 2020.

In the business application space, bandwidth requirements are typically quite different when compared to residential scenarios. This is primarily due to:

- delivery of bandwidth symmetric services, where downstream and upstream bandwidth available to a connected subscriber is the same.
- delivery of guaranteed bandwidth, where the purchased amount of bandwidth is allocated exclusively to the given subscriber and not shared with other subscribers.
- more stringent frame delay and frame delay variation requirements, especially for advanced applications like cellular backhaul and fronthaul.

It is worth noting that with the rapid adoption of FTTx services, the distinction between residential and business services is quickly disappearing as far as bandwidth symmetry and quality requirements are concerned. With FTTH, it is not uncommon for operators to provide symmetric bandwidth, especially to higher subscriber tiers, to allow more streamlined usage of cloud-based services. There are also new business application products, where only part of the provisioned bandwidth is guaranteed, and the remainder is provided on a shared and best-effort basis.

The mobile cell backhaul - one of the business applications served today with EPON - has been steadily increasing bit rate requirements over the last few years. The bit rate increase is the direct result of several evolutionary changes in the cellular technology: migration from 2G to 3G and now 4G (LTE), increase in the number of mobile devices connected (on average) to a single cell tower, increase in the cell tower density per geographical area and resulting decrease in the area covered by a single cell tower to increase data rates and resulting capacity, as well as increase in data rates offered to each connected mobile device. Many studies (including [37]) demonstrate an explosive growth in the mobile traffic around the world, resulting in a steady increase in data rates per individual cell.

In order to cope with the increasing data rates served to wireless devices, cell tower operators need also to increase backhaul capacity to be able to receive data from the Internet and transmit user data to the Internet. As an example, a typical cell tower housing 3 different mobile service providers served with a third-party backhaul link aggregating traffic from all antennas on the cell tower was served with 100 Mb/s by the end of 2013. In order to cope with the increase in the mobile traffic, the very same cell tower had to be served with ~350 Mb/s circuit by the end of 2014, and it is further expected to be migrated to ~500 Mb/s circuit by the end of 2015. With the evolution towards bonding multiple LTE bands, it is likely that in 2016 the industry would see backhaul capacity grow in excess of 1 Gb/s per cell tower. Note that this trend is visible across the whole footprint of cell tower backhaul network, though might observe different timelines. For example, cell towers in large urban areas are upgraded more quickly, as their backhaul capacity is exhausted more rapidly, while cell towers in ruran areas with lower customer density will see the backhaul capacity exhaustion take more time.