Quality of Service for the Last Mile

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Abstract

As broadband access to the Internet is expected to become widely available to customers over the last-mile, the need for providing Quality of Service (QoS) classifications over last-mile links is keenly felt. This report deals with a broad set of last-mile technologies from the perspective of their respective abilities to support QoS. A brief overview of the QoS characteristics, standards defined, and unresolved issues with respect to each last mile technology is presented.

1 Introduction

The Internet is literally bursting at the seams today. There has been a tremendous increase in bandwidth availability in the backbone networks in recent years. This has resulted in a situation where the *last-mile* from the customer premises to the local Internet Service Provider (ISP) is now being identified as the bottleneck [1] in providing broadband internet access to residences and to the Small Office/Home Office (SOHO) segment. As broadband Internet access over the last mile becomes available in the future, it is natural that ISP's would endeavor to provide Quality of Service (QoS) guarantees [2] to their customers. This report provides

- a brief overview of each last-mile technology and its
- support (or lack of it) for providing QoS and the
- QoS characteristics, issues and standards for each link technology.

The last-mile technologies that are currently in use or are being deployed can be classified broadly based on potential bandwidth availability into low speed links, broadband wireless access, and optic-fiber based links.

2 Low Speed Link Technologies

An evolutionary approach is adopted to discuss the QoS characteristics of relatively low speed access technologies to highlight the limitations and advantages of each one.

2.1 56 Kbps Dial-up Link

The V.34 and V.90 specifications [2] for dial-up modem based links over existing telecom infrastructure have inherent limitations in providing bandwidth guarantees. The analog modem uses the 0-3.5 kHz voice channel for data transmission, which theoretically allows a downstream bit rate up to 56 Kbps and upstream rate of 33.6 Kbps. Both the customer and the ISP are connected to a possibly digital circuit-switched Public Switched Telephone Network (PSTN) over analog modem based links in V.34. The V.90 modem allows some speed-up by replacing the analog loop between the ISP and the PSTN by a digital loop. These and an unpredictable jitter due to *retraining* (a process by which the modem periodically adjusts the bit-rate based on the line quality.) and possible jitter and latency due to compression and error correction make the dial-up link "unsuitable for guaranteed service and unreliable for controlled load service [2]."

2.2 Digital Subscriber Line (DSL) Technologies

The DSL based technologies offer higher speeds for the last-mile customer to access the ISP by terminating the link at the local exchange. This was proposed by the telecom industry to provide high-speed access without disturbing the existing infrastructure.

2.2.1 Integrated Services Digital Network (ISDN)

In ISDN, the analog loop from the customer to the local exchange is terminated at the PSTN end where an ISDN signaling entity and an ISDN Network Terminal (NT) aid in establishing and tearing down the connection. The NT is connected through the circuit switched core to an ISP's packet switched backbone network. An ISDN link consists of one signaling channel of 64 Kbps and 23 (in the USA) bearer channels, each offering 64 Kbps. It is sufficient to note that ISDN bit-rates are fairly predictable, since the channels are either setup or not. Therefore a QoS enabled IP service [2] can be setup over ISDN after handling the issue of unpredictable payload expansion when PPP is used.

2.2.2 Asynchronous Digital Subscriber Line

Several variations of the DSL technology have evolved from after ISDN, Very High Speed DSL (VDSL), High Speed DSL (HDSL) and Asynchronous DSL (ADSL). Among these, ADSL is the most popular one. ADSL offers higher bit rates than ISDN, upto a maximum of 9 Mbps downstream and 640 Kbps upstream. This technology is based on the assumption that a packet or cell transport service is available upto the local exchange. ADSL "simply provides the last hop [2] to a customer site" from the DSL Access Module (DSL-AM) and uses frequencies above those used by ISDN and the voice channel, which can, therefore, coexist with ADSL [5].

2.2.2.1 ATM over ADSL

ATM is strongly favored [5] to be used over ADSL links, since it offers fine-grained traffic classification, and little unique consideration for ADSL is required from ATM's point of view. The use of ATM over ADSL would also enable the customer to use the end-to-end service architecture offered by the wide area ATM network. The ADSL channels can be divided into several logical channels with different VPI/VCI values and "virtual circuits can be established between the customer site and endpoints anywhere on the ATM backbone network [2]." The use of PPP over ATM over ADSL is gaining popularity.

However, the impact of the asymmetry of ADSL data traffic on higher layer protocols like ATM and TCP/IP is under study and is beyond the scope of this report.

2.2.3 G.Lite

The difficulty in deploying the splitter at the customer site required for ADSL lead to the development of G.Lite [3], which is a splitterless version of ADSL. The G.Lite modem performs a *fast-retrain* procedure when it detects a telephone device, to operate at a lower bit-rate. When the telephone device goes "on-hook" again, the modem reverts back to the bit-rate in use when the telephone device went "off-hook". This fast-retrain procedure can adversely impact higher layer protocol functionality.

Due to this reason, it is not recommended that guaranteed bit rate services be offered over G.Lite. A service that provides some sort of feedback to prevent congestion and buffer overflow when the telephone device goes "off-hook" is required, like the ATM Available Bit Rate (ABR) service. However, a practical limitation exists in that there is no widespread deployment of ABR. Hence the suggested alternative is to use large buffers at either ends of the G.Lite modem pair.

2.3 Cable Modem

An alternative to the telecom network based internet service over the last-mile is the cable modem. The cable industry proposed the popular Data over Cable Service Interface Specification (DOCSIS) standard [6], overtaking an effort by the IEEE to define a standard for ATM over cable modem. DOCSIS supports Ethernet like framing for packet transport between the Cable Modem Termination System (CMTS) and the Cable Modem (CM). The CMTS regulates the upstream traffic by implementing a form of Time Division Multiple Access (TDMA) among the CM's. CM's are assigned minislots and they can transmit data upstream directly to the CMTS, and the assignment of the minislots is "directly and dynamically regulated" by the CMTS [2]. Bandwidth allocations are controlled by the CMTS by the dynamic assignment of these minislots to each of the CM's. Downstream traffic consists of the CMTS transmitting onto a shared medium. DOCSIS has an interesting provision to support multiple QoS classes. The CMTS models this requirement as a distributed scheduler, where each CM is modeled as a queue feeding onto the upstream link. Each CM is assigned a unique Service ID (SID) and minislot assignments are made on a per-SID basis. CM's that require multiple traffic classes are provided with unique SID's, one for each class of traffic. The temporal requirement of each queue is handled during minislot provisioning for the respective SID. A CM informs the CMTS about jitter sensitive traffic, so that rigid allocation of minislots can be made [2]. Several technical issues like security and authentication have not been rigidly defined by DOCSIS, and it remains to be seen how DOCSIS based Cable Modems are implemented in reality.

2.4 Direct Satellite

Current "Direct to Home- Satellite Internet Connectivity" utilizes geo-stationary satellites that are 22,000 miles above the surface of the earth. The latency due to the 44,000-mile round-trip time discourages any attempts at providing QoS over this link. However, caching of frequently used websites and other information is being experimented with to reduce this latency [7]. DOCSIS like TDMA could be used to regulate access to the shared medium among users.

Another option being explored is that of providing high speed internet access to residences using the Low Earth Orbit (LEO) satellites (e.g. the Iridium constellation). If and when this technology is deployed widely, implementing QoS over it could be explored.

3 Fiber Based Technologies

This section describes a few Fiber related last mile technologies and their QoS characteristics. Fibers, i.e. Optical Fibers have a large frequency spectrum and hence have huge bandwidth capabilities. This bandwidth can be divided among many users and the resultant bandwidth available to the end-users will be more than that offered by most other technologies today. The fiber-based technologies that are discussed here are the Hybrid Fiber Co-axial (HFC) and the Fiber To The Home/Building/Curb/Cabinet/Remote (FTTx).

3.1 Hybrid Fiber Co-axial (HFC)

The Hybrid Fiber Co-axial is a technology that tries to provide Internet access utilizing the existing cable television network. It combines the huge bandwidth of the fiber optic network with the shared nature of the co-axial network.

3.2 Frequency Spectrum of HFC

The Frequency Spectrum of HFC is divided in an asymmetric nature. It is asymmetric in the sense that the available upstream bandwidth (traffic from the node) is less than the available downstream bandwidth. The available bandwidth is divided into channels and data rate available in each channel depends upon the type of digital modulation technique used. Quadrature Amplitude Modulation (QAM) and the Vestigial Side Band (VSB) modulation are the most commonly used modulation techniques.

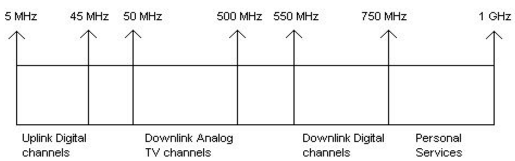

Fig. 3.1 Frequency Spectrum of HFC [13]

The frequency spectrum ranges from 0 to 1 GHz. In this range, the 50MHz to 500MHz spectrum is allocated to the downlink analog TV channels. The allocated upstream frequency is between 5 MHz and 45 MHz. This is divided into channels, with each channel having a bandwidth of 1MHz to 3 MHz. Depending upon the type of digital modulation technique used, the bandwidth available in each channel will be between 2 to 10 Mbps. The allocated downstream frequency is between 550 MHz to 750 MHz. This is divided into channels of about 6 MHz each, with each channel allowing a data rate of 30 to 40 MHz.

3.3 Architecture of HFC

The HFC architecture is tree based, and is of point-to-multipoint type. It has a *Headend* (which is the root of the

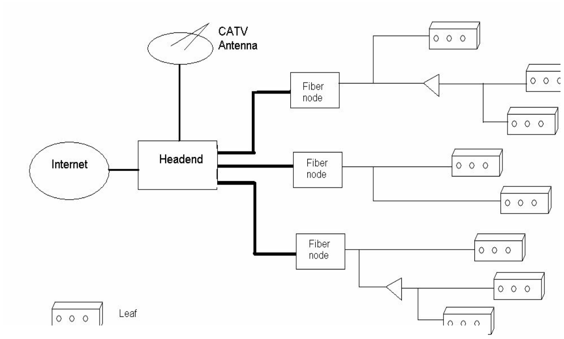

Fig. 3.2 HFC Architecture [13]

tree), Fiber Nodes (leaves), Fiber Trunks, Co-axial cables and Amplifiers. Also every computer that is connected to the network has a cable modem through which digital signals are converted to analog signals and vice-versa. The Headend is the interface between the access network and the external network. The bandwidth allocation for various nodes is carried out at the Headend. It also takes care of providing different services over the same network and ensures data security. The Fiber Nodes convert the optical signals into electrical signals. They may also include powering subsystems to distribute power to the telephonic equipment connected downstream.

3.4 Quality of Service In HFC

The Quality of Service in HFC is dependent upon the bandwidth that is allocated to each user. The downstream bandwidth is not a constraint due to the quantity available. Thus it can be said that the Quality of Service depends mainly upon the upstream bandwidth that is allocated to each user.

3.4.1 Upstream Bandwidth Allocation

The upstream bandwidth allocation is negotiated between the Headend and the terminals. An active terminal sends to the Headend its bandwidth requirement in an upstream frame. A bandwidth allocation algorithm is executed in the Headend. This algorithm allocates the bandwidth based on many factors, like the available bandwidth, number of users, type of service etc. Once the decision has been made, the user who had requested for the bandwidth is informed about the status of the request. The main limitation of this method is that it is prone to collisions. Collisions occur when two users request for bandwidth using the same upstream frame. There are many algorithms that have been proposed for bandwidth allocation and related issues. In the following section one such popular algorithm is described.

3.4.2 A Dynamic Reservation Protocol for Integrating CBR/VBR/ABR Traffic over 802.14 HFC Networks[11]

In this protocol, upstream bandwidth is slotted and framed. Each slot has a 48-byte payload and a 6-byte header. A 48-byte payload is used, as it is compatible with the ATM, so that the packet can be sent through the ATM network just by changing its header. Also whenever a slot is not being used for carrying data, it can be used as mini-slots by dividing into slots of eight bytes each. These mini slots can be used to send control messages, thus preventing the wastage of an entire slot for the same. The protocol behaves in a different manner when different services are simultaneously present, as opposed to when each service is independently serviced. In the following paragraph, the behavior of the protocol for different services is discussed.

For a CBR service, the node requests for the bandwidth and as CBR is given the highest preference, these requests are given the highest priority. When the type of traffic is VBR, statistical multiplexing is done. VBR sources generate data in bursts. These data are buffered and sent when bandwidth is allocated to that particular source. The bandwidth allocation is done as described earlier. For ABR type of sources, the requests are received by the Headend and stored in a queue. The requests are processed in a FIFO process. When CBR and ABR sources need to be serviced at the same time, the protocol behaves in a slightly different manner. The CBR sources as mentioned earlier, are given the highest priority. For deciding between the VBR and ABR sources, the headend maintains a flag and the decisions are based on the flag. The flag is set when there is a request from a VBR source. When there are no requests from VBR sources, the flag is reset. The following is the set of conditions, based on which the decisions are made.

- If the flag is set, the upstream slots are assigned to the VBR sources only.
- If the flag is not set, and the data request (ABR) queue is not empty, the slots are allocated to the ABR sources.
- If the flag is not set, and the data request queue is empty, the slot is converted into mini-slots.

Thus this protocol provides dynamic bandwidth allocations as the slots are converted to mini-slots. Simulations have proved that this protocol could be more effective than the existing 802.14 MAC layer protocols

3.5 Fiber To The Home/Building/Curb/Cabinet / Remote (FTTx)

The FTTx is a new technology, consisting predominantly of fiber cable, with the last part consisting of metallic fiber. The metallic fiber may be either a T1/Ethernet/ ISDN/POTS/ ADSL/ VDSL service, and the bandwidth that is available is dependent upon this metallic link.

3.5.1 FTTx Architecture

The preferred architecture is the double star Passive Optical Network (PON). When an optical power splitter splits the fiber signal among many Optical Network Terminators (ONTs), the network is said to be a Passive Optical Network.

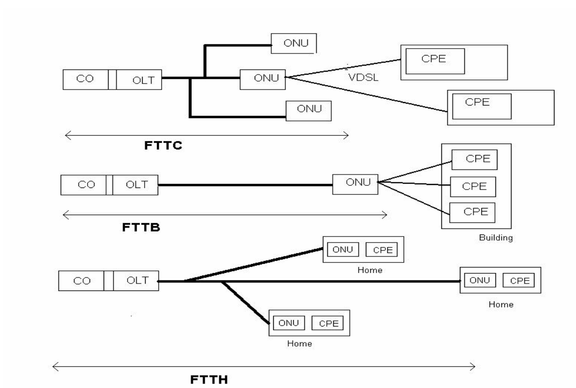

Fig. 3.3 FTTx Architectures

In the FTTx, the downstream bandwidth allocation is done through Time Division Multiplexing (TDM), whereas the upstream division uses Time Division Multiple Access (TDMA). In the FTTX technologies, multiple services are integrated using either pass-band system or by base-band system. If TDM is used, then it is called base-band system and if sub carrier multiplexing is used, the system is said to be of pass-band type.

4 Quality of Service in Broadband Wireless Networks

Broadband Wireless Networks today, operate at two major frequency bands, namely the unlicensed 2.5 GHz range and the millimeter wave range at 28 GHz (38 GHz in Europe). The former is termed as Multipoint Multichannel Distribution Service (MMDS) technology whereas the latter is referred to as Local Multipoint Distribution Services (LMDS). As these technologies are becoming increasingly popular, the focus has shifted to the assurance of Quality of Service for these systems. The following section of this paper deals with the major issues that have to be dealt with, for assuring QoS over a wireless link. This report restricts itself to fixed wireless systems. Mobile systems are not considered in the analysis.

4.1 General Air Channel Issues

Wireless links complicate the issues of assuring Quality of Service in the network. In wire-line networks employing fiber as medium of transport, error rates are inherently low and QoS parameters are defined based on queue management at routers and switches. Packet losses are rare and primary losses are due to congestion of traffic in the network. But in wireless networks the air medium serves to attenuate and cause loss of packets. Errors induced by the various noise components in air medium also serve to compound the problem. Error Coding bits consume a lot of bandwidth, thereby reducing the total bandwidth available to the rest of the users. There is a need for retransmission issues to be resolved at the link layer because a misinterpretation of packet losses as network congestion by TCP results in unwanted retransmissions and reduced throughput. A uniform system performance statistic for QoS assurance in the air medium is difficult as the remote units receiving signals may or may not experience among other problems, fading, diffraction, and multi-path and co-channel interference [14]. Most of the QoS enforcement and policy decisions, therefore, have to be made at the Base Station, and a particular level of unpredictability has to be taken into consideration while defining Service Level Agreements for wireless links.

4.2 Link Layer Issues

TCP transport scheme assumes a lot of importance in wireless links with TCP/IP protocol implementation, where packet loss, rather than network congestion in air channel triggers retransmission in the network. This translates into a need for an Error Correction/Retransmission scheme at the link layer. Forward Error Correction (FEC) and ARQ (Automatic Repeat Request) are two such means to restrict the loss accounting policy to a function of the link layer. But these systems have their disadvantages due to bandwidth reduction and increase in delay [14]. One other common issue in wireless networks is the problem of varying Round Tri Times (RTT's) in asymmetric traffic conditions. When the difference in uplink and downlink capacities is high, the variance in Round Trip Time as estimated by TCP is also high. TCP does not adapt well to highly varying RTT's due to which the timeouts are also increased. This further reduces the throughput of the network [14].

4.3 Access Technologies

The wireless access schemes used to allocate bandwidth to the user are

- Time Division Multiplexing
- Frequency Division Multiplexing

4.3.1 Time Division Multiple Access

In Time Division Multiplexing, the bandwidth is allocated by means of slots to individual users where the resources are available to the user for his/her slot time. The allocation of slots is a contentious issue and standards are being developed to address it. When the number of slots is less than the number of users, there is a need to arbiter the allocation of slots among users. For this purpose, proposals based on Packet Reservation Multiple Access (PRMA) and Distributed Queuing Request Update Multiple Access (DQRUMA) has been submitted to the standards committee [15]. The DAVIC and DOCSIS proposals initially recommended for IEEE 802.14 networks have been suggested for broadband wireless networks with suitable modifications. TDM can support many users at the same time but cannot assure bandwidth at all times.

4.3.2 Frequency Division Multiple Access

Frequency Division Multiplexing works on the principle of allocating permanent bands for each user. This way, users are assured of bandwidth all the time. The disadvantage of this scheme is that it cannot support many users and there is also loss of bandwidth due to guard bands between individual frequency bands.

There are hybrid system implementations where the channel allocation is Frequency Division Duplexing with uplink and downlink being the two channels and within each channel, TDM used as multiple access technique. Vendors are developing systems that have Dynamic Bandwidth Allocation capabilities to ensure minimal loss of bandwidth and QoS adherence at the cost of added complexity of equipment.

4.4 Broadband Wireless Technologies

The two major fixed broadband wireless systems that have been implemented in the United States are MMDS and LMDS. While MMDS is in the unlicensed 2.5GHz range, LMDS uses licensed spectrum at 28GHz. Both the schemes have their merits and demerits that have to be carefully analyzed before any kind of SLA is entered upon for QoS assurance.

4.4.1 Multipoint Multichannel Distribution Services (MMDS)

MMDS was initially envisaged to provide digital television broadcasting to towns and cities. It can provide up to 33 concurrent channels for Digital television broadcasting at 6MHz per channel. But today it has evolved into a broadband wireless access technology that can provide up to 10Mbps of data to the customer at remote locations [16] .It is also popular due to the fact that it operates in unlicensed spectrum. The problem with unlicensed band is that there is a lot of interference in this part of the spectrum, reducing the dependability on performance of network. Wireless LAN's, Siemens 2.4GHz cordless telephone sets, Bluetooth devices and microwave ovens all operate in the same band thereby acting as active interferers to MMDS systems. MMDS does not require Line of Sight and can travel up to a distance of 30 miles. Hence user coverage is more and license fee can be avoided.

4.4.2 Local Multipoint Distribution Services (LMDS)

LMDS is a licensed fixed broadband wireless technology that operates at 28GHz. It is primarily a Line of Sight, short-range system that operates within 5 miles from the hub unit. LMDS requires meticulous planning for network topology design that has to take into account vegetation, weather conditions etc. This is because at 28 GHz, attenuation is fast and severe and can lead to network outages. Once properly planned, LMDS offers huge amounts of bandwidth to users, and revenues to Service Providers. It is scalable and easy to deploy. Interference at 28 GHz is minimal and it is more of rain fade and attenuation that has to be accounted for rather than co-channel interference.

Virginia Tech owns the LMDS Spectrum for parts of Virginia, Tennessee and North Carolina [17]. The Blacksburg deployment of LMDS is a case study for the kinds of services that can be offered over the LMDS Network. The current range of LMDS equipment do not support different classes of service and it is still a practice to provide only dedicated bandwidth in terms of T1's to paying customers. As the rollout increases, there will be need to arbiter among users for network bandwidth, and also to setup different classes of service based on individual requirements and financial considerations.

4.5 Current Trends in QoS for Wireless Broadband Access Systems

The next generation of LMDS equipment has some kind of Quality of Service assurance embedded in the device. But the extent of QoS that can be provided is still negligible, compared to what wire-line systems can offer. In fact, most LMDS vendors use ATM as the protocol of choice and try to maintain ATM QoS over the air channel. To account for the unpredictability of air channel, wireless engineers are working to develop and implement a robust air channel model in the devices. Independent QoS device vendors are looking at placing QoS boxes between the routers and WAN interface at Base station and the antenna and Indoor Data Unit (IDU) at the remote station that perform the necessary shaping, policing and QoS policy maintenance tasks.

5 Conclusion

This paper describes the various last mile technologies that are currently in use or are on the verge of widespread deployment. It further details the various bottlenecks of each technology and the common issues that have to be resolved to assure Quality of Service. It also highlights the current QoS assurances over these technologies and the future possibilities. An ideal extension to this paper would be a thorough analysis on the bottlenecks and means to alleviate them. With last mile becoming an attractive segment for service providers, there is tremendous scope, economic viability and opportunity for future work.

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