PONdering the Access Network

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Abstract: The access network is the connection between the telephone in your home and the local exchange. It is the first step of a customer's connection to the rest of the national telephone network. Traditionally this connection is a twisted pair of copper wires, which is adequate for telephone calls, but the wide scale introduction of the Internet is placing higher bandwidth demands on the entire network. The optical core network has a near unlimited bandwidth, and PCs are now running at gigabit speeds highlighting the 'bottle neck' caused by standard 56kbit/s or at most 512kbit/s connections over the copper lines in the current access network.

This paper will explain how this 'bottle neck' can be removed forever by the introduction of optical networking techniques into the access network.

1. Introduction

Optical access is one of the greatest remaining challenges faces by the telecommunications industry. It is a hot topic in the telecoms sector but why? What exactly is the access network? Why is it considered so important for telecoms companies to replace the existing infrastructure and what benefits does optical access offer? Answers to these questions will be given during the course of this paper and current alternative technologies will be investigated as well as passive optical networks. Research areas within passive optical networks will be identified before describing future research into the next generation systems, Super Passive Optical Networks.

2. The Access Network

The access network is the connection from the local exchange to the customer premises. It forms the first part of a link to the national telecommunications infrastructure as each local exchange is linked to a trunk exchange and acts as an interface between the customer and the core network. Figure 1 shows a simplified layout of the access network and how a customer may be connected via an overhead distribution point (DP) or via an underground distribution point (DP).

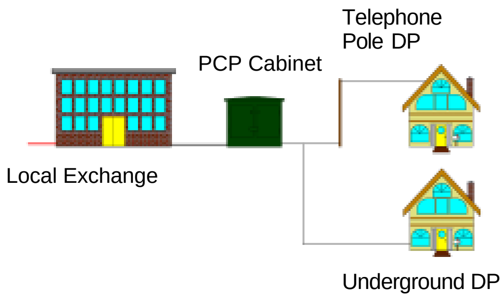

Figure 1. The Access Network

As can be seen from figure 1, the access network is fairly straight forward in principle. However, what figure 1 does not show is the scale of the access network i.e. the number of customers and connections. In the United Kingdom there are approximately 28 million customers, connected to 5600 local exchanges via 35 million lines [1]. Each line consists of a twisted pair copper wire which carries an analogue voice signal to the local exchange where it is converted to a single 64kbit/s voice channel.

3. Legacy Issues

The copper access network has become a legacy as the basic copper lines have barely changed since the days of Alexander Graham Bell, in comparison with exchange and home equipment. Equipment in the local exchange has advanced considerably since days of the human operator with the introduction of computerised switching and routing allowing faster, more reliable connections. Exchange advancements have been matched in customer premises equipment such as PCs, which have increased dramatically in operating speed with 2 GHz machine speeds being commonplace compared with 100MHz five years ago. Also people are now used to 10Mbit/s or

100Mbit/s Internet access in the office, with 1GHz Ethernet cards now commercially available. With vast increases in speed at either end of the access network and a large percentage of the population having access to office LANs, it became clear that the simple copper twisted pair was no longer adequate because regardless of the equipment operating speed, at either end, the copper access network imposes an intrinsic 'speed limit' of 56kbit/s.

In an attempt to ease this access network 'bottle neck' and satisfy bandwidth hungry customers, Asymmetric Digital Subscriber Line (ADSL) technology was introduced. An advantage of ADSL is that no changes are required to the access network infrastructure; all that is required is to install new equipment at either end. ADSL works by using the frequencies above the 4 kHz voice channel boundary as a dedicated data channel. In addition, the upstream and downstream channels are asymmetric with the majority of the bandwidth dedicated to the downstream channel. A range of downstream bit rates are available with 512kbit/s being the most common for residential customers in the UK. Although this may seem adequate at first, Services such as video require large bandwidths, which are difficult to supply via ADSL.

Very high speed DSL (VDSL) was developed as the next generation to supply customers with more bandwidth to make video and other high bandwidth services feasible. VDSL however does not share ADSL's advantage of minimal changes to the infrastructure of the access network. VDSL is able to supply higher data rates per customer by deploying fibre to a cabinet, close to the customers premises, to over come ADSL distance limits, with the final drop from the cabinet to the customer remaining as copper. Figure 2 shows the addition of a VDSL cabinet to the access network and the final copper connection. The bandwidth that VDSL delivers to a customer depends upon the details of the copper loop, but can be expected to be in the range 14-23 Mbit/s downstream[1].

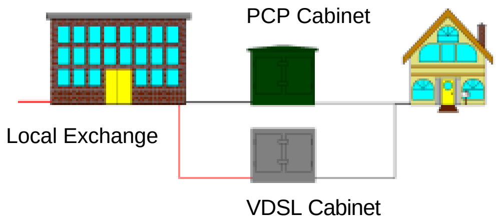

Figure 2. Fibre to the Cabinet/VDSL

4. Passive Optical Networks

An advanced alternative to VDSL is a Passive Optical Network or PON. A PON consists of a 'tree and branch' fibre optic network originating from the local exchange to the customer's premises, which only contains passive components, such passive star couplers. At the exchange side an Optical Line Terminal (OLT) is present to send data to the customer premises equipment or Optical Network Unit (ONU). The OLT also receives information transmitted from the ONUs.

An advantage of PONs over VDSL is that PONs does not require any active components to be deployed (and powered) at the cabinet. PONs are totally passive between the exchange and customer, in the same way that ADSL is.

PONs are an attractive possibility for the future access network. Average bit rates in basic PONs are currently 20Mbit/s per customer, with the ability to burst to higher bandwidths if required. In addition the design of a PON is such that it can, in principle, be upgraded by simply changing the equipment at the exchange and customer ends without changing the (fibre) local loop.

4.1 Downstream Operation

As stated previously a PON consists of an OLT connected to a number of ONUs in a tree and branch formation. In the downstream mode a PON works in a broadcast manner, a signal is transmitted from the OLT along optical fibres to a passive splitter. The transmitted signal is then divided equally among the branches of the passive

[1] 14 Mbit/s downstream and 3 Mbit/s upstream could be expected in UK with 23 Mbit/s downstream in US

splitter. Hence each ONU receives a portion of the original signal with the remainder of the signal appearing as loss, because it is shared among the other ONUs. The signal attenuation experienced by each ONU is dependant on the size of the passive splitter as each factor of 2 split, results in a signal loss of 3dB[2]. Thus a 32 way split consists of 5 split levels resulting in a 15dB[2] loss. If an extra split level was added creating a 64 way split then the loss would increase to 18dB[2], 128 way split equals 21dB[2] etc. Large losses considerably reduce the operating budget of the system and dictate the number of users in the downstream direction.

4.2 Upstream Operation

A PON also has an upstream path for communications from the ONU to the OLT. This is slightly more complicated than the broadcast operation of the downstream path because of the possibility of collisions between cells transmitted from different ONUs. To avoid this, a ranging protocol is used to determine the time difference between the OLT and the ONU. One method would be for the OLT to transmit a signal on power up to all ONUs. Each ONU would then send a reply, and the time difference between the OLT send data and receiving data could be used as a time offset unique to each ONU to avoid upstream packet collisions.

Another problem present in the upstream direction is that of noise funnelling, noise generated by each ONU is combined by the splitter, which acts as a coupler in the upstream direction, resulting in a large noise floor at the OLT receiver. Sensitivity of the receiver is reduced due to the extra noise present and special techniques may be implemented to pick out signals when these noise levels are present. A current solution employed is to turn off the laser at each ONU when not transmitting, however due to the dynamics of lasers, this solution may become impractical when very high data rates are employed as the time for laser pre-bias would be extremely small.

5. FSAN

In order to unify the access network, the G7 (Group 7) was formed in 1995 by 7 telecommunications companies and later renamed Full Service Access Networks or FSAN. The aim of FSAN is to facilitate the creation of global access network equipment standards and therefore drive down equipment costs. Since 1995 FSAN has grown with the number of members participating increasing to 21 telecoms operators plus a number of equipment vendors. FSAN has two comities, one of which is focused on the study of PONs to provide a full service access network and has published the G.983 group of seven recommendations for a Broadband PON (BPON), through the International Telecommunications Union (ITU). The other undertakes VDSL studies.

5.1 BPON

Broadband PON is the current global standard for a passive optical network. Originally called an ATM PON (APON), BPON is specified to provide either 155Mbit/s or 622Mbit/s data rates symmetrically or asymmetrically, at these rates, with a maximum number of 32 ONUs and a maximum reach of 20km [2]. In the downstream direction Time Division Multiplexing (TDM) is used to broadcast data to all ONUs. Upstream, to cope with the possibility of collisions, Time Division Multiple Access (TDMA) is used with a ranging protocol. Ranging is achieved in a similar manner to that described in section 4.2, that is on power up the time delay between the OLT and ONUs is measured and used as a time offset to ensure all upstream cells arrive at the OLT correctly [2]. The OLT remains the master in the system and ONUs can only transmit data after a 'grant' has been sent to it by the OLT. Dynamic Bandwidth Allocation (DBA), enhancement wavelength bands for future overlay services have also been incorporated along with resilience and survivability techniques.

A BPON is loss limited to 32 ONUs and eradicates noise funnelling by turning off lasers when not required to transmit data.

5.2 GPON

FSAN is also in the process of defining specifications for the next generation of PONs. This will be known as GPON because it will use downstream data rates of 1.244Gbit/s and 2.488Gbit/s whilst upstream rates may also be in the range 155Mbit/s, 622Mbit/s or higher [3]. Other changes include the use of Forward Error Correction (FEC) to provide 2 to 3dB of additional gain and the extension of the logical reach to 60km with the option to connect to 64 ONUs [3].

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[2] Plus excess loss, assumes a single N way splitter where N = 32, 64, 128

The specifics of GPON are still being argued over within FSAN. Interestingly, even with a larger number of ONUs (64) the intention is still to turn off ONU transmitters when not in use. To achieve this the proposal is to define the time allocated for laser pre-bias as 16ns instead of the last two bits of the guard time as in BPON. Effectively, FSAN have increased the laser pre-bias time from 13ns for 155Mbit/s and 3.22ns for 622Mbit/s to 16ns for all bit rates, which should ease the laser requirements and reduce costs. Changes also include a reduction in the ONU receiver sensitivity from -33dB in BPON to -25dB with a corresponding increase in the maximum launch power for the OLT transmitter. This change re-addresses the balance of the system cost shifting it towards the OLT by using a more expensive high power transmitter, the cost of which is shared between all users and then cheaper receivers at the ONU where the costs are not shared and apply only to the user [3]. The specifications for GPON are expected to be accepted by the ITU in the third quarter of 2003

6. Current Research

The objective of this engineering doctorate is to devise novel solutions for SuperPONs. A superPON is a PON with an optical amplifier included to increase the split, reach or both. This allows changes to take place in other areas of the network, for example a long reach system would enable the current SDH backhaul to be removed as it would no longer be necessary because the superPON would be able to reach customers from a Tier 1 exchange rather than an RCU site. To achieve this objective, EDFAs, SOAs, forward error correction and other technologies which have proved very successful in the core network been studied and ways of introducing them into the access network have been devised. A starting point for the introduction of these technologies has been the construction of a 2.5Gbit/s, 512 user, 40km SuperPON physical layer model which includes a single EDFA optical amplifier. This model will be developed and refined to achieve a cost effective superPON capable of reaching from a tier 1 exchange to the customer therefore simplifying the access and metro networks.

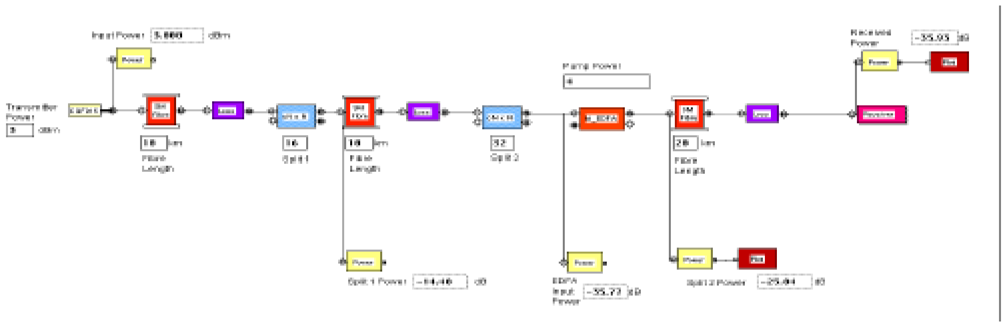

Figure 3. Upstream 2.5Gbit/s PON Model

7. Conclusion

This paper gave an overview of the access network with emphasis on how the bandwidth bottleneck caused by the current copper network can be removed by the introduction of optics, probably utilising passive optical networks. This paper explains the operation of general PON systems and introduces the work of FSAN. A description of current (BPON) and future (GPON) specifications is also provided. Areas of interest within these specifications were identified and will be explored as future research topics.

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References

[1] Loop Planning, Network Planning and Performance Course Notes, R Sutherland, 2002

[2] G.983.1 Broadband Optical Access Systems based on Passive Optical Networks, ITU-T, 10/98

[3] New Progress on GPON Studies: Service Requirements and Physical Layer Specifications, OHAN 2002 Conference Proceedings, 2002