Illuminating the Last Mile?

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***Abstract*— The next leap in the communications market may be the extension of optical technology to access networks. Advanced fibre optical access equipment has been developed in the last decade and today trial tests are on the way and insular deployment has begun. The access network, the last mile, has not encountered any major changes of technology for a century. However, current advancements in technology indicate that *Fibre to the Home* could be widely deployed in coming years. This paper identifies challenges and reports on open questions in this area. It concludes that many open issues relate to economical, political and social issues rather than technical challenges.**

I. Introduction

Today, practically every household in Australia uses electricity and the way it is provided is usually transparent to the user. From a consumer perspective, there are no obvious limitations to the amount of power they can purchase[1]. A customer can use almost any practical number of appliances without reaching the limitations of the grid. It is expected that every dwelling has sockets and that power is available 24 hours a day and seven days a week. In the future, the same basic assumptions will be expected of the Internet, or more generally, of integrated information/services networks providing access to voice, data, video, TV, gaming etc. It is expected that connectivity and information delivery will become a commodity, much like the electrical grid, the road or water systems.

Many technical issues are currently being addressed to enable advances for the consumer domain. However, the question of last mile access seems to be less a technological and more a business, political and strategic decision; for example: What business model can be used? Who owns the network? Who is prepared to make long-term investments?

Copper line access has been used in the local loop since the dawn of telephony and there has been no principal change in technology for fixed line access in a century. However, innovations and great changes can be seen in the wireless access domain. The mobile boom had an earth shattering impact on the *Information and Communication Technology* (ICT) industry, as well as to society in general. Another area where advancement leaps have changed industry and society is in the area of Internet development.

The *Internet* evolved from a research and scientific network into a public entertainment and business media with increasing traffic requirements. As part of this development, telecommunication companies and service providers are currently migrating all network transport technology towards an integrated all *Internet Protocol* (IP) network. The main focus in these all IP environments is client services. Due to these major changes in the consumer domain of the ICT industry in recent years we have seen tremendous growth in network traffic.

In the core network, this growth has been accommodated by optical networking technologies such as *Synchronous Optical NETwork* SONET and *Synchronous Digital Hierarchy* SDH. Current architectures include point-to-point *Wavelength Division Multiplexed* (WDM) networks that connect IP routers and advances include *Automatically Switched Optical Network* ASON, *Optical Burst Switching* (OBS), and in the future, possibly *Optical Packet Switching* (OPS).

Current access network technology includes dialup and DSL (and Cable) access for households and dedicated lines and DSL for business users. Emerging *Fibre to the Home* (FTTH) technologies promise a change in access technology which has been discussed for a long time[2]. If these changes involve the digging of trenches and the rollout of fibre cables to dwellings this change in access media may last for a long period - "so we better get it right" since it may be a long time until the next major change. Wireless access alternatives are also being discussed. By a rule of thumb, wireless access is, by a factor 10 to 20, slower than wired line access - until now. But this may dramatically change with the almost unlimited bandwidth promise of fibre optics. However, wireless access technology could be a viable alternative in some deployment areas and for certain services, such as data services for rural areas.

There has been much activity in analysing and investigating viable broadband access technologies. For example, the *Digital Rivers* research initiative [2] investigated technological, economical and political issues influencing broadband infrastructure development in the Pittsburgh region. Whereas, some results are specific to the region of the United States, many conclusions can be adopted to a general problem set. A European perspective developed by the *Techno-Economics of IP Optimised Networks and Services* (TONIC) project, is discussed by the Communication Magazine article [3] which investigates the economics of fixed broadband access network strategies. The study uses a techno-economical model to eval-

[1]Obviously there are capacity limitations to household connections, but usually the demand lies below this limit.

[2]British Telecom invented the technology in 1982 and had early *Passive Optical Network* PON trials in Bishop's Stortford in 1987 [1].

uate different scenarios for network technology deployment. An Australian outlook is given by a CommsWorld article [4] describing a Queensland FTTH trial. The article comments on economical issues of fibre deployment in Australia.

This paper is organised as follows: Section II introduces drivers of optical access, Section III reports on current technology and Section IV outlines open issues that have to be addressed to illuminate the last mile.

II. The Need to Close the Gap

The requirement to close the capacity gap has many drivers; relevant topics include political motivation, as well as applications that need broadband access.

The American President, George W. Bush, said in Albuquerque, NM, on the 26 March 2004 "This country needs a national goal for broadband technology ... universal, affordable access for broadband technology by 2007." The former Australian Minister for Communications, Information Technology and the Arts, the Hon Daryl Williams AM QC MP, released on the 13 July 2004 *Australia's Strategic Framework for the Information Economy 2004 - 2006: Opportunities and Challenges for the Information Age*. The policy document outlines a strategic framework that states: "An *information economy* is one where information, knowledge and education are major inputs to business and social activity. It is not a separate *new* economy-it is an economy in which the rapid development and diffusion of ICT-based innovation is transforming all sectors and all aspects of society." Out of this context arises the need for broadband connectivity for households in Australia, which is also recognised by the *The National Broadband Strategy* [5].

There seems to be strong political interest in building an information economy, but major business drivers are applications and services using the information infrastructure. A number of possible broadband applications are identified in [2]. These include: *Electronic Commerce*, *Video and Audio Conferencing*, *Web Broadcasting*, *Distant Education and Training*, *Internet Telephony*, *Telecommuting and Remote Office Applications*, *Entertainment*, *Remote Monitoring, Sensing and Control* and *Telemedicine and Telenursing*. FTTH can also supply cable television-like services in digital *High Definition TV* (HDTV).

One major theme that is common to almost all applications (except HDTV) is that useful usage from an end-user/residential customer perspective requires ADSL speed connections and for business and application providers speeds of OC-3 and higher, are required. No single application can be identified as the *killer app* which needs extensive bandwidth, and more importantly combines this need with the will of customers to pay for higher charges[3]. This will impact on the will of entrepreneurs to invest in optical access technology. One could think of additional bandwidth hungry applications, but to convince the customers to pay more, new services have to be enabled. For example, the access network could be used as a cable TV substitute. The combination of these FTTH applications is often referred to as "triple play" which indicates video, Internet, and voice. To a large extent, customer uptake depends on motivating factors. A report by the U.S Department of Commerce: *A Nation Online: How Americans Are Expanding Their Use of the Internet* [7] gives interesting insight into online usage patterns.

There is a strong political will to enable broadband access for private and business users. For the moment, the outlined application set requires ADSL access speed for private households and additional services, such as cable TV which requires higher bandwidth. The next section outlines proposed access technologies in more detail.

[3]Content sharing and peer to peer networking has been a good candidate for a killer app. For some links in the Sprint network content sharing and media traffic is now the dominant traffic type, which some links having content-sharing loads of 80% [6]. However, most customers are not prepared to spend more money on their Internet access than they currently do [7].

III. (Optical) Access Network

A. Available Technology

Currently DSL and cable networks are common broadband access solutions. The next leap in this area is the extension of fibre to the customer's premise. Two general solutions are being proposed for *Optical Access Networks* (OANs): *home run architectures*, i.e. fibre connects the exchange and the customer's premise and *star architectures* (passive and active) which utilise intermediate splitter nodes, located in between the customer and the exchange.

Depending on the point of termination, fibre access can be categorised by *Fibre to the Cabinet* (FTTCab), *Fibre to the Curb* (FTTC), *Fibre to the Building* (FTTB), *Fibre to the Premise* (FTTP) and *Fibre to the Home (Office)*. Solutions that do not extend to the customer's premise use *Very-high-speed Digital Subscriber Lines* (VDSLs) to closes this gap by using the existing copper infrastructure.

B. Deployment

The type of deployment is important to analyse the feasibility of optical access technology.

1) Areas: Deployment areas can be identified with various granularity levels: Dense urban, urban and suburban are used in [2] and urban, suburban, small town, rural, remotely rural are used in [3]. It is evident that deployment in highly populated areas is more efficient. The Digital Rivers project reports that *Passive Optical Network* (PON) architectures are the most economical, particularly for a lower level of penetration. Home run fibre becomes more effective for high level of penetration. It gives estimates on deployment cost per home served, but does not evaluate the overall profitability. Deployment costs for small towns/rural areas are about twice the cost of deployment costs of urban/suburban areas. Remote rural deployment is more than three times more expensive than urban deployment.

The TONIC study reports that the choice of technology (ATM/Ethernet) has only marginal relevance for profitability. It concludes that for suburban areas FTTCab is too expensive (heavy infrastructure investments), however for urban and dense urban deployment FTTCab is profitable. FTTH is only

profitable in dense urban areas with a large number of potential customers.

2) Scenarios: Deployment scenarios include green field deployment and the replacement of existing telephone/communication equipment. Greenfield deployment will become increasingly viable since the equipment is readily available and the prices are expected to drop further. However, many issues outlined in Section IV apply to greenfield deployments.

C. Passive Optical Networks

Out of the different star architectures, the passive optical variants have revived much attention. The ITU-T G.983 series of standards is known as *Broadband PON* (BPON). It uses Asynchronous Transfer Mode (ATM) as its bearer protocol and is also known as *ATM based PON* (APON). The original APON standard is being enhanced to support protection, dynamic bandwidth assignment etc. *Ethernet based PON* (EPON) uses extensions to IEEE 802.3 Media Access Control to support optical fibre (and unshielded twisted pair). This is also known as *Ethernet in the First Mile* (EFM) - IEEE 802.3ah. Standards for PONs are driven by two major bodies: *Full Service Access Networks* (FSAN)/ITU-T for BPON/APON & GPON and *Ethernet in the First Mile Alliance* (EFMA)/IEEE for EPON.

The major advantage of PONs is that no active electronics have to be located between the customer's premises and the optical carrier exchange. Wavelengths are divided by passive splitters and are shared by a number of end-users (e.g. 32 homes in [4]). PON can use three active devices: *Optical Line Terminals* (OLT), that terminate the *Optical Distribution Network* (ODN) at the optical exchange, *Optical Network Unit* (ONU) and *Optical Network Termination* (ONT) that converts the optical signals to electrical signals. ONTs are located on, ONUs are located outside the customer premise and VDSL transmits the electrical signals to the customer premise.

The popularity of PONs is reflected in the large number of publications in the area. Examples include: [8] describes wavelength division multiplexing, dynamic bandwidth assignment and survivable networking additions to the BPON standard, [9] introduces a optimisation model to select the best technology and evolutionary path at a minimum cost for high speed Internet access, [10] discusses design and cost performance of WDM-PONs in multistage architectures, [11] investigates dynamic bandwidth allocation for QoS over Ethernet PONs, [12] studies relative costs of WDM rings and PONs for metro optical packet networks and [13] introduces EPONs.

IV. Open Issues

There are a number of open issues that are related to FTTH. In the last decade, many technical problems of optical access have been solved and recent advances have driven the equipment cost down, current open questions relate, but are not limited to, economical, political and social issues.

A. Business Model

Business cases and business models for FTTH deployment are not yet set. Telstra's FTTH trial is a trial for business models and requirements necessary "to make it work" as outlined in [4]. A similar trial in Western Australia by Western Power deployed fibre with electricity cables in Perth suburbs and was not successful due to the lack of customers interest/acceptance [14].

B. New Services

Besides the delivery of the *triple play* and well-known services such as cable TV etc., on demand service provisioning is possible. For example, if more than one telephone line is required for a limited time at the premises, lines can be activated on the fly. Almost all services that are delivered could be implemented with on-demand features. This is possible since they are already deployed and need only to be activated.

C. Technology

As mentioned earlier, the last mile access medium has not been changed in the last century. Therefore, if the medium is changed, future upgrades should be possible and not being limited by the current deployment. This leads to questions such as: Will the asymmetric traffic assumption be valid in the future? Is the upgrade path of PON deployment feasible and sustainable? Are passive or active solutions more viable?

D. Regulatory/ Customer Requirements

There are several requirements for the existing telephony network that have to be adapted for optical networks. For example: Can optical access networks provide economical lifelines?[4]. Are lifelines still required?

Another issue in this area relates to the ownership of the network. Should optical networks be deployed by Telcos or are they essential infrastructure, such as the road networks with unlimited/limited access for everybody? Should optical access network be regulated? Do operators need a carrier licence?[5] How can competition be enabled for last mile access?[6]

E. Nature of Data

The nature of network data has dramatically changed during the evolution of the Internet, with changes continuing in the future. Current "shaping" applications include: peer-to-peer and increasingly *Voice over IP*. Future applications might comprise online gaming etc. Open questions include: How will the traffic patterns change? What kind of usage patterns can be expected? Where should data caches be located? What new peer services may evolve? What are future requirements?

[4]Lifeline refers to the requirement that telephone handsets have to be powered by the exchange, so they operate also under power failures. This requirement is already violated by some cordless home phones.

[5]During the deployment of pay TV in Australia, network access and regulatory intervention has been a hot topic. Similar issues may arise and will have to be resolved by the *Australian Competition and Consumer Commission* (ACCC) - e.g. [15].

[6]Competition in FTTH is also discussed in [2]. Facilities-based competition for FTTH is unlikely; service-level competition depends on the technology.

Fibre optics deliver almost unlimited speed connections, but how much is required to overcome the bottleneck situation?

V. Conclusion

There are a number of unsolved issues that relate to FTTH deployment and most of these issues are not of a technical nature. Currently, no single killer application can be identified that requires optical access networks for home or private use. However, business could greatly benefit from the practically unlimited bandwidth promise of fibre access networks. Furthermore, additional services, such as cable HDTV can increase the value to customers. The cost between different optical technologies in the local loop appears to be comparable, so it is possible to select the most beneficial technology.

FTTH deployment is not a new topic and has been discussed for more than a decade. However, for the first time drivers are strong enough and equipment prices have reached realistic levels. In particular greenfield deployment appears to become increasingly viable. Issues like ownership, licence requirements and business models have to be resolved. For dense urban areas the last mile appears bright, in other areas the light might only shine as far as the curb.

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