Overview of Optical Local Access Networks
Development and Design Challenges

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Abstract: Local access network technologies tend to take advantage of the potentially huge capabilities of fiber communication to deliver faster and more various services to end users. There has been considerable research effort in implementing access networks optically. These optical access technologies were developed particularly under certain circumstances, each of which has its own application domain. This paper reviews critically the existing optical technologies in terms of advantages and limitations. The intention of implementing optical access network also reveals some critical challenges. Through a case study, the paper analyzes the feasibility of designing an optical access network that avoids the common challenges and limitations in the optical field, hence concludes that the key issue when designing an optical access control protocol is the good utilization of the available bandwidth with simplicity of implementation.

Keywords: Optical Networking, Access Networks

1. Introduction

Optical networks have been developing for many years. Fibers used to merely function as a dumb optical layer transporting optical signals. As the layered network architecture has developed, the optical transport network tends to support a wider variety of functionalities. The trend of the optical transport network development is to provide an intelligent platform to support various types of services. The flexibility can be provided by the introduction of optical packet switching (OPS) which enables highly-reconfigurable, efficient and low cost data transmission [1, 2].

Nowadays, local access network technologies also tend to take advantage of the potentially huge capabilities of fiber communication to deliver faster and more various services to end users. Considerable research effort has been put in implementing access networks optically. There have been some productive cases such as Hybrid Fiber-Coax (HFC), Optical Ethernet (OE), Radio over Fiber (RoF), and Passive Optical Networks (PON), of all which will be reviewed in this paper. These technologies were developed under certain circumstances; each of them has their own benefits and limitations.

In terms of network design and deployment of optical access networks there are many restrictions and challenges that have to be faced despite so many appealing features of the optical fibers. As an advanced networking concept, optical access network still has lots of technical aspects which need to be explored and improved. With the restrictions of the available optical devices, the design of optical access networks should avoid the pitfalls in the optical domain and make the maximum utilization of the existing networking capability with low cost and simplicity, in order to realize the implementation in short term.

Section 2 addresses the needs for the implementation of optical local access networking and describes its benefits. Section 3 overviews the current development of optical local access networks, and reviews each individual technology as mentioned, of which both advantages and disadvantages will be summarized at the end of the subsection. Section 4 analyzes the design challenges for the optical networks. Section 5 uses a case study to indicate suggestions for the design and implementation of optical local access networks. Section 6 summarizes and concludes the paper.

2. Benefits of Optical Local access Networking

The demand for greater capacity is encouraging a new breed of technologies designed to make networks faster, more reliable, and more scalable than ever before. Optical technology meets the aforementioned needs because of its capabilities. Firstly, fiber optics can provide huge bandwidth of up to 50 Tb/s [3]. Some forms of multiplexing can be employed to effectively exploit the bandwidth of the optical medium, e.g. Wavelength Division Multiplexing (WDM) [4]. Secondly, optical fiber offers bit rate transparency and service transparency given that the optical switching technology is implemented where there is no electronic processing in the data path and the data can ideally pass through without any limitation on bit rate or protocol format. Thirdly, optical layer agility provides a unique opportunity for nodal scalability. By using wavelength division technologies (i.e. WDM), more users are allowed through each port and high bandwidth lightpaths are provided for users, although the number of wavelengths that can be contained is still limited.

The access network has consistently been regarded as a bottleneck in the provisioning of data communication services. Optical fiber has been largely deployed in the backbone core network as a major transmission medium which is engaged with data transportation in the domain of gigabits per second [3]. As far as the end workstations are concerned, users can currently benefit from several GHz of central processing unit (CPU) speed by the year 2009. Despite the high speed processing capacity of the core network and end user interface devices, local access networks such as broadband service providers are presently operating at the speed of between 2~100 Mb/s per site [4]. Presently, considerable measurements have been taken to attempt to overcome the bottleneck problem of access networks. With the arrival of broadband Internet, Voice over IP, TV over Asynchronous Digital Subscriber Loop (ADSL), high-quality video telephony, data transfer, and such like, the
demand for bandwidth keeps growing rapidly, which has forced carriers to choose quickly among competing access technologies: Digital Subscriber Line (DSL), Ethernet, Wireless LAN, Cable Modem, etc. All of these offer customers with high-bandwidth access services. Optical access offers additional possibilities compared to DSL technologies. The main inconvenience of broadband through the copper wire is that transfer rates depend directly on the distance between the hub and the end user. Besides, advanced digital video services require guaranteed bit rates to all subscribers concurrently. Figure 1 shows that only fiber offers the 100 Mb/s symmetric performance or higher bandwidth without distance or interference constraints [5].

Fiber communication network supports many applications transcending the typical limits of copper; the fiber provides perennial networks with upgradeable bandwidths. It could be a matter either of dedicated optical links or of networks servicing both home and corporate customers, by sharing the resources of one single fiber.

These implications all indicate that fiber is the only viable solution as it offers a practical opportunity in terms of bandwidth. By taking optical fiber as close to the users as possible, it will in future become possible to draw the maximum benefit from optics and thereby obtain an extensive increase in bandwidth. When the demand for bandwidth exceeds the offered capacity, optical access will bring technological progress into existing services. The following outlines the benefits of optical access networks.

- **High capacity.** With bandwidth of up to several gigabits per second in the access network, all optical data paths with ultra-high capacity can be provided, with 100+ Mb/s guaranteed per subscriber [3].
- **New services.** Optical access will enable existing services to evolve thanks to the transparency characteristics of optical networks. Bandwidths of several dozen or hundreds of Mb/s will open the way to a whole range of new services. The field of very high data transfer rates could thereby develop to a great extent.
- **Cost-effective.** The cost to install an optical access network is the same as traditional fiber, but the operational cost to run an all fiber network can be 50% or less [5]. Much larger quantities of data across the link can be accommodated, routed, switched and processed, meaning reduced average operational expense per user compared to the present mode of operation.

- **Smooth evolution.** It will be easy to transit from traditional services formats, such as Plain Old Telephone Service (POTS) and Cable Television (CaTV) to IP-based services, e.g. VoIP and video. Optical access platform will be optimized for broadband services. Many vendors and service providers endeavor to provide smooth transition from narrowband to data broadband networks using optical technologies.

### 3. Current Optical Access Technologies

Optical local access networks show appealing merits by permitting end users to access the network via the entire optical data paths. Recent advances in optical access network have produced several successful technologies. In this section, four optical technologies are discussed: hybrid fiber-copper, optical Ethernet, radio over fiber, and passive optical network.

#### 3.1 Hybrid Fiber-Coax

HFC uses cheaper, coaxial cables as well as higher capacity optical fibers to provide video, voice telephony, data and other interactive services [6]. HFC finds its origins in CaTV networks. In the 1980s, a breakthrough in the CaTV network came when fiber optic cables were used to replace trunks. The traditional CaTV network provided one-way analogue signals to the subscriber. Recently it has been made possible for two-way systems over cable. Physically, coaxial cables are capable of transmitting in both directions but the unidirectional amplifiers that were required to amplify signals were unable to transmit in both directions. The use of optical fibers in the traditional CaTV network meant that there was a higher quality of service and by upgrading the existing amplifiers within the feeder part of the network, two-way communication was possible. This technology was adopted very quickly as it merely replaced trunks with fiber optic cables and there was no need to change the already existing coaxial networks to the homes. The ever-increasing need for bandwidth amongst Internet users quickly created a market for this high bandwidth, yet affordable technology. This new generation of cable network is now used for both Internet and cable television.

As shown in Figure 2, HFC networks employ fibers in the video trunk section from the master headend (HE) to the primary hubs (PH), and from the primary hubs to the secondary hubs (SH). From the secondary hubs the fiber connects to an optical access node (OAN). Some projects have deployed 8~16 channel WDM systems over the fiber portion of the HFC networks to provide video-on-demand service capabilities with targeted narrowcasting [7]. At OAN nodes, optoelectronics conversion of video plus data signals are performed, and the video broadcast plus cable modem-based data are delivered over the coax cable bus architecture to the customers’ premises. Each OAN may serve typically 500-1000 homes, but since the total access bandwidth is shared by the total number of users connected to the optical node, the future trend is to have a smaller node serving, for example 50-100 homes per node to increase the bandwidth per user. This is sometime called fiber mini-node and
requires a ‘fiber-deep’ architecture and many more optical access nodes [7].

![Diagram of CaTV operator’s HFC network](image)

**Figure 2.** Schematic of CaTV operator’s HFC network

**Advantages:**
- Reliable, immune to noise and almost non-existent attenuation.
- Bandwidth is increased from traditional CaTV network (330 MHz) to 750 MHz [7].
- Has ability to adapt to new services such as voice, data or video without changing existing operational parameters.
- Lighter weight and thinner than copper cables with the same bandwidth.
- Much more difficult to tap information from undetected; immune to electromagnetic interference from radio signals, car ignition systems, lightning etc.
- No need to dial-up or tie up a phone line as it uses a separate connection, Cable Internet has constant connectivity.

**Disadvantages:**
- Costly to rural subscribers due to long cables required.
- Optical fibers require additional training of personnel and expensive precision splicing and measurement equipment.
- Signal quality is reduced as more subscribers use the network.

### 3.2 Optical Ethernet

Ethernet is currently the dominant LAN technology which occupies over 90% of the entire market in the world, thanks to its simplicity and low cost [8]. It is now standardized at 10 Mb/s, 100 Mb/s, 1 Gb/s and 10 Gb/s. As Ethernet is highly adaptable to higher bandwidths and switching technologies, it utilizes optical fiber to distribute high data rate service to end users. OE means Ethernet directly over fiber. Ethernet in the First Mile (EFM) is an IEEE 802 standards project which promises to complete the ‘Ethernet Everywhere’ picture by embracing the access network (see Figure 3). Single and dual fiber solutions are under discussion at 100 Mb/s and 1 Gb/s rates. 10 Gb/s Ethernet is intended only for full duplex fiber environments. IEEE 802.3 is the standard for Ethernet. Extensions are as below:

- IEEE 802.3z 1-Gigabit Ethernet: An established standard for 1,000-Mb/s Ethernet technology and products. It’s used today in dark-fiber metro Ethernet cores and will play an ongoing role in metro Ethernet access.
- IEEE 802.3ae 10-Gigabit Ethernet: A standard of mid-2002 for the metropolitan Ethernet cores and access. Three major versions were defined: 10GBase-R LAN serial, 10GBase-W WAN serial, 10GBase-X WWDM.
- IEEE 802.3ah Ethernet in the First Mile: A standard of 2003, which is designed to provide 1-Gb/s and 10/100-M/s Ethernet in fiber and copper-pair access networks.
- IEEE 802.3av 10-Gigabit Ethernet: Next generation PHY for Ethernet Passive Optical Networks (EPON) that delivers triple-play services of voice, video and high speed data access, was approved in September 2009.
- IEEE 802.3ba 40-Gigabit and 100-Gigabit Ethernet: Provides extensive support for Optical Transport Networks, expected to be ratified in the second quarter of 2010.

**Figure 3.** Ethernet in the First Mile

Since 10 Gigabit Ethernet is a full-duplex only technology, there is no collision domain, so Carrier Sense Multiplexing Access/Collision Detection (CSMA/CD) protocol [9] is not needed like other Ethernet technologies. In every other respect, 10 Gigabit Ethernet matches the original Ethernet model. An Ethernet-optimized infrastructure is taking place in the metropolitan area and many metropolitan areas are currently the focus of intense network development intending to deliver optical Ethernet services.

**Advantages:**
- Cost-effective, Gigabit-level connections between access gear and service provider in native Ethernet format.
- Simple access to the metropolitan optical infrastructure.
- Metropolitan-based interconnection over dark fiber (i.e. 10 ~ 40 km) [8].

**Disadvantages:**
- Not a switched technology, which means no intelligence of highly-configurable system control and network management.

### 3.3 Radio over Fiber

RoF is also known as Wireless Fiber or Fiber Wireless (FiWi). Generally in wireless communication systems there is a tradeoff between coverage and capacity. As mobile communication systems seek to increase capacity, and wireless data systems seek to increase coverage, they will both move towards convergence. RoF technology entails the
use of optical fiber links to distribute RF signals from a central location (i.e. headend) to Remote Antenna Units or Radio Access Units (RAUs). In narrowband communication systems and Wireless LANs, RF signal processing functions such as frequency up-conversion, carrier modulation, and multiplexing, are performed at the Base Station or the Radio Access Point, and immediately fed into the antenna [10]. RoF makes it possible to centralize the RF signal processing functions in one shared location (headend), and then to use optical fiber, which offers low signal loss to distribute the RF signals to the RAUs, as shown in Figure 4. By doing so, RAUs are simplified significantly, as they only need to perform optoelectronic conversion and amplification functions. The centralization of RF signal processing functions enables equipment sharing, dynamic allocation of resources, and simplified system operation and maintenance. RoF distribution systems can readily be used for indoor distribution of wireless signals of both mobile and data communication systems.

**Figure 4.** The concept of radio over fiber system

Advantages:
- Multi-service operation. Depending on the microwave generation technique, the RoF distribution system can be made signal-format transparent, which offers system operational flexibility.
- Dynamic resource allocation. Allocating capacity dynamically as need arises can be achieved by assigning optical wavelengths through WDM technologies.
- Large bandwidth. This enables high speed signal processing that may be more difficult or impossible to do in electronic systems. Some of the demanding microwave functions such as filtering, mixing, up-and down-conversion, can be implemented in the optical domain [10].
- Immunity to radio frequency interference. This is a very attractive property of optical fiber communications, especially for microwave transmission. This is so because signals are transmitted in the form of light through the fiber.
- Easy installation and maintenance. In RoF systems, complex and expensive equipment is kept at the headend, thereby making the RAUs simpler.
- Reduced power consumption. Reduced power consumption is a consequence of having simple RAUs with reduced equipment.

Disadvantages:
- Since RoF involves analogue modulation, and detection of light, it is fundamentally an analogue transmission system. Therefore, signal impairments such as noise and distortion, which are important in analogue communication systems, are important in RoF systems as well. In Single Mode Fiber based RoF, systems, chromatic dispersion may limit the fiber link lengths and may also cause phase de-correlation leading to increased RF carrier phase noise. In Multi-Mode Fiber based RoF systems, modal dispersion severely limits the available link bandwidth and distance. It must be stated that although the RoF transmission system itself is analogue, the radio system being distributed need not be analogue as well, but it may be digital, such as Wireless Local Area Network and Universal Mobile Telecommunications System.

### 3.4 Passive Optical Networks

PON is a point-to-multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises (up to 256) [11]. PON configuration reduces the amount of fiber and central office equipment required compared with point to point architectures. As shown in Figure 5, depending on where the PON terminates, the system can be called Fiber-to-the-x (FTTx), where x can be: C (Curb), B (Building), H (Home) or Cab (Cabinet). PON can use single or multiple fibers for upstream and downstream traffic, with or without WDM. Downstream signals are broadcast to each premise sharing a fiber. Upstream signals are combined using a multiple access protocol, invariably Time Division Multiple Access (TDMA). Encryption is used to prevent eavesdropping. The principle of PON is to share equipment and the feeder fibers among as many optical transport networks as possible. With PON, operators would aim to remove electrical equipment in the access network, which has requirements for electrical power and active parts. PON brings the optical network closer to end-users, providing more and cheaper bandwidth for households. Extensive research has been carried out in this area. There are a few versions of PONs being studied – ATM based PON (APON), Broadband PON (BPON), Ethernet based PON (EPON), Gigabit PON (GPON), and WDM-PON.

**Figure 5.** PON architecture
Advantages

- ATM based PON (APON): was the first PON system which uses ATM as its bearer protocol. Later it was renamed to BPON, because from the name APON, people assumed that only ATM services could be provided to end users, which was not the case. Now the name BPON reflects the offering of broadband services, including Ethernet access, video distribution, and high-speed leased line services. APON system has typical ATM-like performance including small overhead, high scalability with short delays and reliable operation [12].
- Broadband PON (BPON): the presently used name for APON which is based on ITU-T recommendations G.983.1 [13], G.983.2 [14] and G.983.3 [15].
- Ethernet based PON (EPON): is IP efficient and low cost PON, based on Ethernet technology. It supports voice transport together with data transport. EPON is scalable, but not so efficient in voice transfer [16].
- Gigabit PON (GPON): is an ITU-T recommendation for PON service requirements for speeds over 1 Gb/s. GPON provides high bit rate support enabling the transport of multiple services in native formats and with high efficiency. It is the native PON and stands as a foundation for new PONs, not based on APON [13]. In addition, GPON supports ITU-T standard Generic Framing Procedure mapping and provides the best efficiency in voice and data transportation, especially Time Division Multiplexing.
- WDM-PON: the name DWDM- or WDM-PON is used for PONs, where multiple wavelengths are used. This requires the use of more expensive optical equipment, but enables higher bandwidth [17]. Coarse WDM (CWDM) in PON is more likely implemented in near term than Dense WDM (DWDM).

One important factor in PONs is the variety of architectures and topologies which can be used in the network. With this flexibility, PONs can be implemented almost everywhere easily. However, the physical tree, logical star topology seems to be the most suitable for PONs. Scalability and security issues are also important. Bursts in traffic can be balanced and bandwidth increased easily. Furthermore, when all downstream traffic is sent to everyone in the network, like it is in TDMA PON system, encryption mechanisms are necessary to provide the minimum-security.

Disadvantages

- Another major disadvantage to PON is its inflexibility. If a 1x4 splitter is used to serve four homes, hooking up a fifth customer requires pulling a new strand of fiber all the way from the upstream splitter, or re-designing the network to accommodate a larger splitter near the customer premises without violating the 256 split maximum allowed. Unfortunately, changing any splitter in the network requires all downstream customers to come offline while the work is done.
- Although PON solution allows competition between various providers, it can only scale to a few providers, and may entail duplicating infrastructure. In exchange, space and reduced cost are not guaranteed.

4. Design Challenges

Despite the appealing features of fiber optics, optical access still contains some technical issues that need to be improved in time. This section overviews some typical problems or challenges that have concerned telecommunication engineers for a long time, such as optical issues, limited number of available wavelengths, lack of optical memory, and electronic vs. optical control.

4.1 Optical Transmission Issues

Dispersion brings impairment to the optical transmission. There are four main types of dispersion in fiber communication systems: modal dispersion, material dispersion, waveguide dispersion and polarization mode dispersion (PMD). Modal dispersion is the dominant source of dispersion in multimode fibers. In multi-mode fiber, the core of the fiber is much larger than the wavelength of light and a ray can take multiple paths of differing lengths down the fiber, effectively spreading an optical pulse in time. Material dispersion is caused by the fact that the index of the medium refraction changes with wavelength. Even if there were no material dispersion, there would still be some pulse spreading due to waveguide dispersion. The index change across waveguide means that different wavelengths have different delays. PMD is actually a form of material dispersion [19]. One of the orthogonal polarization modes may travel faster than the other, hence causing dispersion of the optical pulse. Besides dispersion, there are some other elements that compromise the quality of the optical transmission, e.g. environmental factors, optical power, etc. All the above optical transmission issues need to be considered for long or medium distance transmission.

4.2 Limited Number of Available Wavelengths

Most researches towards applying OPS into local area networks are based on WDM which offers an attractive solution to increasing bandwidth without disturbing the
existing embedded fiber. By multiplexing several relatively
cosely spaced wavelengths over a single, installed
multimode network, the aggregate bandwidth can be
increased by the multiplexing factor. Although WDM is a
very promising technology, there is an increasing awareness
of its limitations. WDM networks with a high number of
nodes and covering a large area will be limited by the
availability of the network elements. Currently many WDM
technologies use wavelength as individual lightpath to
switch and forward data, which requires quite a few
wavelengths. For instance, an optical switch may use
wavelengths as identification of input/output ports.
However, the number of wavelengths per fiber is determined
by the technology and is fixed. There are a very limited
number of available wavelengths per fiber. Even wavelength
conversion will not provide any significant reduction in the
number of wavelengths [20]. If a single fiber does not
suffice to carry existing traffic on a link, more fibers on that
link need to be deployed. Hence in network design, it is a
common requirement to minimize the number of
wavelengths necessary to carry all demands.

4.3 Lack of Optical Memory

Memory is the inevitable component for the network to be
engaged with the data switching and forwarding. Data need
to be stored temporarily or permanently in the memory to be
accessed for the data servicing purposes. Unfortunately, at
present there are no practical optical Random Access
Memory (RAM) elements available from which to build
even small memories in spite of significant research [21]. So
far three main options are commonly felt to offer alternative
possibilities – photonic crystals, fiber delay line (FDL) and
wavelength conversions, although they all offer very
restricted flexibility.

Photonic crystals are currently a topic of research. Buffering
may be achieved by slowing down the optical signal using a
control light source to vary the dispersion characteristic of
the medium. Many believe the technique may play the role
of an optical buffer in all-optical signal processing systems
of the future. On the other hand, many believe that
fundamental restrictions limit its usefulness. At present,
only 10 bits of storage can be cascaded [22].

FDL offers one means of buffering. Combined with the use
of multiple wavelengths, such a delay line permits multiple
packets to be simultaneously buffered in the same fiber [23].

FDL components have been demonstrated in laboratories,
but have some major limitations. First of all, FDLs cannot
store a packet indefinitely, and once a packet has entered an
FDL, it cannot be retrieved until it emerges on the other side.

Secondly, it introduces quality degradation of the optical
signals. During the recirculation losses accumulate,
especially in the delay line tap for insertion and removal of
packets. Thirdly, FDLs can be bulky and expensive. Finally,
it is a limitation that using delay lines as a buffer naturally
leads to the consideration of “slotted” systems: either ATM
style packets with labels, or synchronous TDM. In the
general case we need to deal with the variability in the slot
arrival time compared to the packet switching time. With a
slot synchronizer a variable delay of up to one slot time in
increments of some quantum of time based on the degree of
bit level synchronization is required. However this leads to
another drawback: multi-stages of loss and noise are injected
even before the packet reaches the main FDL buffer.

4.4 Electronic Control or Optical Control?

In OPS networks, optical packet header contains destination,
routing and other control information of the data packets. In
some schemes, packet headers are referred as control
messages. The processing of optical packet headers
composes the physical structure of optical network control
plane. Today optical networks in the world are under
electronic control which is considered to be a bottleneck due
to its much slower speed compared to the optical capacity.
The ideal approach to optically extract and process header
information is most desirable.

Nowadays, all-optical header processing is an active research
area, and considerable progress has been made in some
critical functions. Research in this area can be divided into
two categories: single wavelength based and multi-
wavelength based. Single wavelength based techniques
usually utilize Fiber Bragg Grating (FBG) correlators [24].
Multi-wavelength based techniques are called all-optical
label swapping in which case the unique header is
represented in dimensions of both wavelength and time.
Different permutation of several wavelengths carrying data
bits can create a number of unique labels based on
recognition in special devices, e.g. Multi-section FBGs or
Waveguide Tapped Delay Line are used. Both techniques are
immature and require specially designed optical devices.

So far, the lack of fast, scalable, and robust optical bit-level
processing technologies means that all-optical networking is
still in the future, and electronic processing of the header
remains the only practical approach. Currently most optical
network with electronic control requires Optical-to-
Electronic-to-Optical (O-E-O) conversions, which adds
additional complexity and cost to the network construction.

4.5 Complexity of Wavelength Conversion

Wavelength conversion has often been proposed as an
alternative to optical buffers: at the point of contention
where two packets wish to travel on the same output link at
the same time, simply ensure they are on different
wavelengths. A single FDL can also hold multiple packets if
they are on different wavelengths, while requiring that the
tap on the FDL is able to add and remove specific
wavelengths [20]. Although this option offers flexible
resource allocation, it does require an expensive and delicate
wavelength converter of which the performance and
availability are yet to be improved, as well as efficient and
effective wavelength allocation algorithm which is restricted
by the number of available wavelengths. The lack of an
efficient way to store information in the optical domain
represents a major difficulty in the design of OPS nodes.
Some researchers have focused on ways of emulating optical
RAM capabilities by various means.

4.6 Cost and Complexity

An ordinary point-to-point WDM network is expensive due
to its switching cost of sending all the pass-through traffic,
which often involves the use of delicate optical devices and
configurations. Many of these optical devices remain in the research stage. Enormous research work is ongoing to improve device availability and performance.

5. Case Study – SOAPS Project

Current optical access networks cannot completely take advantage of the capabilities of the state-of-the-art OPS technology, due to the challenges described in the previous chapter. Efficient and low-cost solutions are needed to facilitate highly-configurable optical local access area networking in the near future. A realistic approach to design optical access network is to avoid those limitations by utilizing the existing optical devices and techniques or those may become available in the short term, rather than to attempt to solve these restrictions and problems in the design and deployment of futuristic networks.

Smoothed Optical ATD Packet switching project (SOAPS) is such an example which complies with that concept. Papers [25 ~ 28] contain the majority of the research results of this project. ATD is the abbreviation for Asynchronous Time Division, which is derived from Asynchronous Transfer Mode (ATM) [29]. The project was co-funded by Department of Trade and Industry and EPSRC in UK, and was finished in 2007. It aims to deliver an evolutionary bridge towards future all-optical network by employing an appropriate mix of electronics and optics linked with an original protocol design. Table 1 shows the originalities of SOAPS project in terms of facing the design challenges mentioned in the previous chapter. Figure 6 shows the network scenario of SOAPS project.

![Figure 6. SOAPS network architecture](image)

<table>
<thead>
<tr>
<th>Design Challenges</th>
<th>Solutions by SOAPS</th>
</tr>
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<tbody>
<tr>
<td>Optical Transmission Issues</td>
<td>CWDM technology is used, which keeps the optical transmission problem to the minimum.</td>
</tr>
<tr>
<td>Limited Number of Available Wavelengths</td>
<td>The design of the optical packet format only requires two wavelengths. One for control messages and one for data.</td>
</tr>
<tr>
<td>Lack of Optical Memory</td>
<td>The advanced scheduling scheme allocates the network resources prior to the data transmission. Hence there is no need for optical memory in the switches.</td>
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### Table I. The originalities of SOAPS project

<table>
<thead>
<tr>
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<th>SOAPS Project</th>
<th>Other Existing Optical Access Technologies</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Optical packet switching</td>
<td>Mostly optical circuit switching; Wavelength as lightpath;</td>
</tr>
<tr>
<td></td>
<td>New packet format design;</td>
<td>Mostly in-band control</td>
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<tr>
<td></td>
<td>Out-of-band control;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CWDM</td>
<td>Mostly DWDM;</td>
</tr>
<tr>
<td></td>
<td>Need fewer wavelengths;</td>
<td>Wavelength is network resource;</td>
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<td></td>
<td>Time slot is network resource;</td>
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<tr>
<td></td>
<td>Active resource reservation</td>
<td>Passive or no resource reservation</td>
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<tr>
<td></td>
<td>with scheduling in advance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centralized control</td>
<td>Distributed (except for PONs)</td>
</tr>
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<td></td>
<td>Protocol transparency</td>
<td>Protocol Transparency</td>
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</table>

Coarse WDM (CWDM) is employed in the network, unlike most other research projects that use Dense WDM (DWDM) as the multiplexing technology. One wavelength is reserved as the control channel, and user data are striped into the rest waveband; hence out-of-band management is facilitated. The successful exchange of control messages enables the resource allocation in advance; hence optical switches perform collision-free transmissions without the need for optical buffering and optical header processing [25]. Electronic buffers are deployed at edge networks. Data packets will be buffered electronically until a lightpath is established [26]. While the data transmission is under centralized control, congestion relief is distributed to the edge systems [26 ~ 28].

Network modeling and simulations were carried out to evaluate network performance when varying different parameters. Figure 7 shows a result that was obtained in the project deliverable [26], which indicates stable network performance with high network throughput. The statistics were based on the modeling of a four-node 100m LAN engaged with FTP application. The fibre data rate is set to 10 Gb/s, and the control channel is set to 100 Mb/s. The application has uniformly distributed inter-request time, which can be configured to set the traffic intensity. Table 2 compares the SOAPS network with other existing optical access networks, in terms of explicit characteristics of optical access technologies.

Low-cost and simplicity are important characteristics of this project, which are accomplished by the employment of simple optical switch architecture, elimination of optical buffering and optical header processing and O-E-O conversion, etc.
This study would not have been possible without the author’s scholarship granted by University of Essex and its Electronic Systems Engineering Department.

6. Conclusions

Optical local access networks show appealing merits by permitting end users to access the network via the entire optical data paths. The ongoing research about optical local access networks has created various technologies. Some of them evolve from the legacy networking system, e.g. HFC, OE. Some new technologies like RoF, PON, etc, try to open a new era by taking advantage of versatile photonic devices and unique optical characteristics. All the endeavors lead to productive results, although each of them has its own disadvantages and limitations. The challenges that network engineers and researchers have to face when designing optical networks include lack of optical buffers, limited available wavelengths, complexity of wavelength conversions, optical transmission issues, optical control feasibility, cost and complexity, etc. A realistic design approach is to avoid those limitations rather than to solve them. This concept was exercised in SOAPS project. Network engineers should seek to take advantage of optical components and technologies that exist or will be available in the short term, so that efficient and low-cost solutions can facilitate highly-configurable packet switching in the optical local access area networks.

Acknowledgement

The case study was based on the author’s PhD project which was supervised by Dr. David Hunter and Prof. Ian D. Henning in University of Essex, UK. This study would not

<table>
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<tbody>
<tr>
<td>Electronic control</td>
<td>Electronic control requires O-E-O conversion (except for PONs);</td>
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<tr>
<td>No O-E-O conversion</td>
<td>Various research on optical header processing;</td>
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<tr>
<td>No optical header processing</td>
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<tr>
<td>Collision-free</td>
<td>Possible packet loss</td>
</tr>
<tr>
<td>No optical buffer in the hub;</td>
<td>FDL is in use in some cases;</td>
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<td>Electronic buffer in the edge;</td>
<td>Demands for optical buffer;</td>
</tr>
<tr>
<td>Easy to implement; Low cost;</td>
<td>Can be complex and expensive</td>
</tr>
<tr>
<td>Short term implementation</td>
<td>Some are already commercialized.</td>
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</table>

Table II. SOAPS vs. other existing optical access technologies

Figure 7. TCP performance of SOAPS network [26]

References


