Regular paper

Towards broadband global optical and wireless networking

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Abstract—This paper presents a novel, non-conventional approach to the future optical and wireless hybrid transport network, capable of supporting/dominant kinds of traffic, i.e., voice/real time, wireless and packet data traffic in a single transport network. The proposed model combines different technologies as connection and connectionless networks, optical cable and wireless (microwave/millimetre wave or optical wireless), being suitable for a variety of purposes and services in order to achieve global broadband networking features. Our new networking model contains an extension to wireless world in order to achieve mobility and personalisation of connection. From the networking point of view it consists of an upgrade of real-time traffic with the microwave modulated optical wave, in order to carry out conventional mobile wireless signals via optical fibres over long distances and without significant distortion. The whole available bandwidth can be fully exploited in the hybrid network. In the IP part of the network the quality of service (QoS) can be differentiated for various classes of packets and network reliability/survivability can be categorised for the whole hybrid network. This proposal combines complete and revolutionary shift to packet traffic with mooth evolutionary upgrades. We believe the model presented here is a powerful tool to trace the future evolution of telecommunications worldwide for the next 25 years.

Keywords*—*optical and wireless networking, radio-over-fibre, optical packet networks, transparent networks.

1. Introduction

Global broadband networking is a crucial requirement for the future information society, which needs a seamless personal access to broadband services, everybody to anybody, from any location to any destination, anytime. The technology of conventional connection-oriented voice networks has been developed for a hundred of years already and is in a mature state. Terabit per second transmission via optical fibre links is a reality with the use of asynchronous transfer mode/synchronous digital hierarchy (ATM/SDH) over wavelength division multiplexing (WDM) technologies. In addition, the transparent optical transmission at distances of thousands of kilometers become a reality with the advent of optical amplifiers.

Although the optical fibre communications still faces a number of technological difficulties and physical constraints with chromatic dispersion (CD), polarisation mode dispersion (PMD) and nonlinear optical interactions as classical examples, it is still the best technology to achieve terrestrial global networking. However, a serious drawback of that technology is the lack of mobility features, so in this paper a suitable combination of optical and wireless technologies is addressed and discussed.

It is worth to underline that actually the basic concept of networking is a subject of revolutionary change from classic circuit switched, connection – oriented networks to modern packet switched, connectionless transmission of data [1]. In fact this is driven by the dramatic expansion of Internet users worldwide. Therefore circuit-switched networks which work excellent for voice traffic and in general for real-time traffic are not at all a suitable solution for packet data traffic.

Packet traffic is the basis of Internet. It has a statistic nature, so at certain moments of time and network points the flow of data might be much higher that the network equipment is able to handle. This means that some data have to be stored in buffers, and if available buffer capacity is insufficient, then some data have to be sacrificed. This affects the quality of service provided by the network. This statistical phenomenon is called “burst of packets” and has provoked an effort to search for suitable means to cope with it [2]. For some applications this is not a critical situation, as the missing data can be retransmitted. But usually retransmission is not allowed for real-time voice or video services. Nevertheless, even when the networks are overprovisioned, i.e., with potential performance characteristics much better that actually needed, one could easily imagine an immense and impossible to handle data flow generated by computer viruses or malicious attacks, and a complete blocking of the network might result from that.

New technologies are being proposed to enable successful real-time service transmission through packet network [3]. However, even generally accepted, IP protocol is not so obvious as the only future platform for a converged voice/data network. In fact the main problem to be resolved is the lack of QoS guarantees for real-time traffic inherent to this approach.

In this paper we propose a combination of different technologies, such as connection and connectionless networks, optical cable and wireless (microwave/millimetre wave or optical wireless), suitable for a variety of purposes and services in order to achieve global broadband networking features. In addition to our recent proposal of a hybrid connection and connectionless networks superimposed on the top of a physical WDM layer, and on different optical wavelengths, our new network model contains an extension to wireless world in order to achieve mobility and personalisation of the connection. From the network point of view it contains an upgrade of real-time traffic with the microwave modulated optical wave, in order to carry out conventional mobile wireless via optical fibres over long distances and without a significant distortion.

The paper is organised as follows: Section 2 discusses the optical fibre communication technologies, while Section 3 addresses the relevant characteristics of the wireless mobile world. In Section 4 the hybrid optical and wireless networking basis are laid out. Conclusions and future work are summarised in Section 5.

2. Optical fibre communication technology

The transparent features of the network will be discussed in detail, pointing out that that "transparent" and "all-optical" does not mean necessarily the same [4]. The impact of optical transparency on a successful deployment of future optical packet switched networks is discussed. Actually the opacity of a network is considered as resulting from conversion to electronics only. However, an "optical opacity" is inherent to several all-optical solutions, too. Indeed, the optical transparency has to be sacrificed in future optical logic elements, e.g., for signal processing, packet switching, etc. Implementation of networking functions with photonic components is summarised and directions of future development are pointed out. Finally, a novel non-conventional approach to voice + IP network is presented in the concluding part of the paper.

2.1. Optical transparency

The advent of erbium-doped fibre amplifiers which replaced electronic regenerators in fibre transmission links in early 90s resulted in optical transparency of the links [5]. The evolution of actual telecommunication networks towards transparent networks started at that time. Transparent networks at regional and global scale with transmission speed exceeding one terabit-per-second became a reality. Such networks are commonly referred to as "terabit networks" [6].

The notion of transparency of a transmission link (not necessarily optical) is much older than optical fibre communications. Its primary meaning is that the output signal is proportional to the signal at the input of a link. Consequently, the transparency is rather an analogue feature, apparently contrary to modern digital transmission schemes.

An ideal transparency is not realisable in an optical network, since even an ideal glass fibre exhibits attenuation, chromatic dispersion of the first and higher orders, and optical nonlinearities. Moreover real fibres exhibit polarization mode dispersion (PMD), resulting from random local lack of circular symmetry of the fibre due to manufacturing imperfections and local stresses caused by cable structure. Those features of a fibre result in distortion, crosstalk, and noise in the transmitted optical signal.

Transparent photonic network insures the scaleability, i.e., possibility of future upgrades. Wavelength becomes a new degree of freedom (wavelength-switched and routed networks), and can be switched in wavelength routers and converters.

The lack of an ideal transparency requires very high wavelength precision and stability of optical sources in a dense WDM network, which considerably increases the cost of the devices. Therefore, the goal is not to loose the precious wavelength. The solution is to keep the signal in optical domain while it traverses as large part of the network as possible, and this is why transparency is a so important.

Transparent network still includes attenuation and/or amplification, and eventually wavelength conversion of signals. Transparent wavelength conversion assumes conservation of temporal signal shape, superimposed on a different wavelength.

In a way transparent networks go back to the analogue age. Transparent components of the optical network treat the passing signals in an analogue way. The transparency length is a distance over which the signal can be transmitted successfully. Transmission over longer distances requires some form of regeneration. The transparency length depends on number of factors, and it can be increased in the future, when the technology is sufficiently developed.

Moreover, the expected introduction of optically transparent fibre links to subscriber networks will allow to take advantage from WDM technology also in that area. New ways of providing access are emerging to satisfy the need for interactive broadband services. A combination of various signals (i.e., analogue or digital radio and television, interactive broadband services, Internet traffic) could then be transmitted simultaneously. The emphasis is on the possibility to transmit conventional wireless radio signal. What is really very important, is that the transparent optical networks are scaleable, i.e., provide a potential for future upgrades [7].

2.2. Optical switching and routing

Degrees of freedom of an optical network are:

– 3-D space co-ordinates;

– time (and resulting possibility of optical time domain multiplexing – OTDM);

– wavelength (WDM);

– polarization of light.

Those provide opportunities for optical switching in space, time, wavelength, and polarisation domains. In addition to that, logical on/off switching may be implemented in optical logic elements.

Optical routing can be realised as wavelength routing in a transparent way as:

- an analogue and passive solution or
- an analogue and active solution with wavelength conversion.

2.3. All-optical opacity

All-optical packet routing involves some intelligence of the router and decisions based on the information included in the packet. Therefore it is not realisable in transparent way. Even though all-optical routing concept involves optical logics, optical memory, etc., it is not optically transparent and it exploits optically opaque elements. The signal remains in optical domain, but due to digital operations the fundamental transparency condition of proportionality between output and input signals is not satisfied.
Emerging evolution directions of optical network infrastructure and its include migration:

- from circuit switched optical networks, with analogue processing of carrier frequency, i.e., in spectral domain, where the transparency is a positive characteristics;
- to a packet switched network, with direct digital processing of signals in time domain, realizing all-optical switching and in particular exploiting optically opaque all-optical routing devices.

A combination of transparency exploitation in wavelength domain and all-optical logic in time domain seems to be the most justified way of network evolution.

3. Wireless mobile world

Wireless technology has been developed during the last decade for the mobile networks. New frequency bands are exploited in view of transmission capacity and reliability, the 60 GHz band being an example. Sophisticated 3G and beyond broadband and interactive services are foreseen in many countries in the near future. European telecom companies have invested a lot of money in the UMTS licenses. Unfortunately, it is still not obvious when the investement will bring the expected revenues.
While microwave and millimeter wave links have excellent mobility characteristics that is impossible to achieve with other transmission media (wireless optical links have very poor performance compared to microwave ones), they still suffer from a number of constraints, most of them resulting from electromagnetic compatibility (EMC) requirements, in order to avoid interference and crosstalk. Also the wireless links suffer from the attenuation of signal due to air characteristics, weather, smog, and the local shape of terrain or trees and buildings. The line of sight between the transmitter and receiver is usually an essential requirement for reliable transmission. Microwave spectrum is expensive and limited. Fibre optic technology can help to transmit wireless signal superimposed on the optical wavelength, as we have proposed and analysed recently [8].

4. Hybrid optical and wireless networking

Among real time services the voice is still dominant. As videophone is concerned, this technology is not likely to be accepted widely in the near future. In fact people even prefer short message system (SMS) to spare bandwidth, time and money. Television broadcasting will never be done via public telecom networks as well.
Attempts to transmit voice over IP have an inherent difficulty to guarantee quality of service [9] – in fact nobody guarantees anything, as the basis of Internet is a "best-effort" principle. So "real-time" in fact stops to be "real" in packet traffic. Recently we have proposed to stop to care so much about voice traffic which is already an excellent developed technology, and to start to think about separate voice and data networks [10]. We propose a hybrid network in which voice is carried on dynamically allocated wavelengths, according to an instantaneous demand for real-time service traffic. Table 1 shows a comparison of main features of both types of traffic in a hybrid network [11].
Our non-conventional approach consists of voice (and other real-time services) subnetwork implemented within data traffic network. Voice is transmitted via circuit-switched subnetwork, while IP traffic travels in a packet-switched connectionless network. The two kinds of traffic are separated and interleaved in frequency (wavelength) domain, not in time domain.
The conventional mobile microwave/millimetre wave signal transmission can be included in the transparent real-time part of the network by the means of modulating the optical carrier wavelength with the mobile signal [12]. Then it can be transmitted over long distances via fibres before being detected at an optical receiver and processed further.
The network intelligence has to be located at IP routers and has to provide the real-time subnetwork including microwave transmission on a sufficient number of wavelengths [13]. This approach allows to profit fully from both SDH/ATM technology – best suited for real time-circuit switched services, and from IP protocol – developed uniquely for packet-switched traffic. Moreover, the QoS can be differentiated for various classes of services [14].

Table 1
Voice versus Internet traffic

Characteristics	Voice, real-time	Internet, data
Bandwidth	Dedicated on demand	As wide as available
Basic principle	Circuit-switched	Packet-switched
Packet length	Constant	Variable
Quality of service	Guaranteed	Best-effort
Lost packets	No retransmission	Retransmitted
Traffic	Deterministic	Statistic
Other	Instantaneous bandwidth (# of wavelengths) controlled logically in IP routers	Intelligence
	Transparent	Includes all-optical opacity
Access	Conventional twisted-pair access to public exchange offices	Broadband access to servers, e.g., via cable-TV or mobile

5. Conclusions and future work

The novel non-conventional approach to the future hybrid network retains the well-developed voice technology with transparent transmission. Voice traffic is carried via dynamically allocated wavelengths in conventional way as circuit-switched traffic. The number of wavelengths is controlled by IP layer according to the instantaneous demand for real-time traffic. All remaining wavelengths are available for the IP traffic, which becomes free of real-time restrictions and can adopt variable-packet length, no idle bits, and best-effort scheme. As a consequence, the whole available bandwidth can be fully exploited in the hybrid network. In the IP part of the network, the quality of service can be differentiated for various classes of packets and network reliability/survivability can be categorised for the whole hybrid network.

The terms "all-optical network" and "transparent network" are not equivalent. After a decade of triumph of transparent WDM transmission, evolution towards optical packet-switched networks appears to be imminent. All-optical network requires optically opaque (i.e., not transparent) optical solutions. Opaque all-optical elements have to be introduced in the all-optical packet switched network. Those optically opaque elements will perform all-optical signal processing in general, and all-optical routing functions in particular.

Voice and IP traffic have fundamentally different characteristics and requirements which should not be overlooked and have to be taken into account when designing basics of future real-time service and IP converged network. On the other hand, the future development of converged network should not lose the well developed voice traffic technology with ATM and SDH.

The approach presented here is a result of in-depth investigation of different networking principles and traffic schemes, and physical constraints that characterise the classical fixed fibre network and new mobile wireless world. This proposal substitutes the complete and revolutionary shifting to packet traffic that a number of people foresee, with a smooth evolution and network upgrade. What is really worth to note is that real time traffic provides security and network availability, conserving a number of connections even in an malicious attack occurs. So we believe the model presented here is a powerful tool to trace the future evolution of telecommunications worldwide for the next 25 years.

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