An Optical Overlay Network Concept for Hard QoS Requirements

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ABSTRACT
It has long been argued that the best-effort strategy on which Internet is based will limit its use for real-time applications such as video or telephony. However, it has been shown that such services can indeed tolerate some jitter and rate variations through various error resilience and concealment techniques. Despite of that the Internet infrastructure is continuously upgraded with higher performance components, which further reduce the transmission problems; still there are certain classes of applications that undoubtedly will need new transmission paradigms. An example is the remote control of an industrial process that may require jitter levels down to a few microseconds. Another example is quantum cryptography where an optical transparent path between sender and receiver is to be established. In this paper we present a concept based on an optical overlay network infrastructure. This network concept can be applied in an incremental way and will enable the current network infrastructure to handle demands with such extreme QoS requirements.
Keywords: hybrid network, overlay, circuit-switching, real-time, hard QoS, all-optical, time-critical transmission.

1. INTRODUCTION

It is well known that packet-switched networks based on the IP protocol, are not optimal for time critical applications such as real time transmission of audio or video. This is due to the fact that these networks are unable to guarantee the arrival of the information within a prescribed time, which creates problems with variable delay, and jitter. Despite the fact that network transmission capacity increases year by year, there is no corresponding improvement in the latency reduction or in the ability to sustain a continuous information stream without disruptions. This is mostly due to the underlying transport technology based on the Internet paradigm. The result will be that, for example, interactive real time communication will not work properly creating problems in offering sufficient quality of service for applications such as HDTV-on-demand, video conferencing and interactive games. These applications require low packet delay, low jitter and low packet loss. At the same time, other industrial applications such as remote storage, high-performance computer-computer communication, and video/media production put a strong demand on bandwidth. These are just a few examples of application with the kind of performance requirements that packet-switched networks have difficulties to reach. This opens a market niche for other solutions. For example, an American network operator, the Broadwing Media Services (BMS), has established an optical network based on DTM technology (Dynamic synchronous Transfer Mode) which connects more than 40 cities. This network technology is able to fulfil the strong requirements that are mentioned above offering e.g. high-quality media services such as live HDTV transmission [1]. A similar technology is also used in several networks in the United States. The same approach was adopted in Europe by a number of companies and operators. Examples of European services using DTM are:

- European Fibre Network (FINE) which connects more than 25 cities with Washington D.C. and New York. This network is used to distribute TV content (e.g., Olympic events, European Song Contest, etc.) to providers within Europe [2].
- WDR (WestDeutsche Rundfunk) which serves 14 cities within Germany. Services include, among others, LAN2LAN, telephony, both TV and radio distribution/contribution [3].
- Norkring, a TV operator which deployed more than 600 network nodes within Norway for digital TV distribution [4].
- TeliaSonera, which is setting up a pan-European network for TV distribution and recently announced that they will offer live broadcast from New York to Stockholm with a guaranteed latency of 55 ms [7].

Apart from time-critical applications there are also other cases where a conventional IP network may not be suitable. For example, with today's technology it is difficult to protect the transmitted information against unauthorized intercepting or influence, and to securely authenticate the sender and recipient identities. DTM technology is one of the possible solutions for the problem of delivering data with hard Quality of Service (QoS) requirements. This problem is not only important from a pure academic point of view, but, as shown by the DTM example above, there are real economical incentives in finding a solution. Recently, the Swedish magazine *Ny Teknik* found that in the coming years, the demand for applications with hard QoS requirements is expected to increase as well as the price costumer will have to pay to take advantage of these services as compared to regular best-effort services [5].

This paper presents a concept for a network paradigm able to address all the issues described above. In the proposed idea the existing packet-based IP network is used as a starting point, but even if almost all services will connect to the network using IP/Ethernet, different types of transport mechanisms can be used, depending on the type of traffic carried. The considered network paradigm is based on optical fiber transmission.. As explained in the next section, we propose an additional functionality required for accommodating demands with hard QoS requirements. In particular the real-time services are separated from the existing (packet-based) infrastructure and provided via an all-optical, transparent overlay network. The existing packet-based approach, on the other hand, will still be valid for no real-time demands as well as for controlling purposes.

2. AN OPTICAL OVERLAY NETWORK

Although it is possible for large organisations, such as TV distribution companies, to set up their own fibre and/or satellite connections it is not feasible for a private user. The dedicated solutions are not easy to be integrated with the existing infrastructure, mostly due to incompatible architectures and differences in the data transfer paradigms (notably circuit-switching vs. packet switching). This fact will keep the dedicated solutions at a relatively high cost and will not allow the creation of a large user base able to influence the development of new services and applications. As an example, one could easily imagine that a circuit-switched service would be favourable for content providers (music or motion films) to distribute their content since they could then charge either per connection time or directly to the authenticated client as is commonly done in traditional telephone networks.

The idea presented in this paper aims at developing an optical overlay network that is based on the fact that the traditional telephone network has worked well for nearly a century and has been able to cope with both time critical and security sensitive information. The main reason for the high QoS offered by such an old network technology is that it is based on circuit switching. It is well known that circuit switching is the “anti-pole” of packet switching in many respects. Data is delivered in a guaranteed way (with regard to jitter and data rate), control is centralised rather than decentralised, network blocking appears on a session level rather on a data packet level etc. Although one can try to mimic features of a circuit switched network within an IP network it is our firm belief that sooner or later there will be a necessity to extend the global best-effort network with circuit services that can easily be set up by the users themselves, just as is being done in the old telephone network.

In our approach, we address the fact that most of the backbone transmission links on Internet are based on optical fibres. It is conceptually feasible to use a lot of wavelength channels by utilizing the Dense Wavelength Division Multiplexing (DWDM) technology to make room for an overlay network that is “physically” different from the IP network. Certain paths of the overlay network will be purely optical giving absolute freedom to the more demanding users with regard to modulation, coding and protocol format. In such a scenario channels with different bandwidths will co-exist and a flexible solution for handling different granularity will be required. Also, lower bandwidth channels may be transmitted over longer distances without regeneration due to less dispersion.

Contrary to DTM, in our concept it will still be possible to keep the existing infrastructure intact while the network is upgraded with the new overlay structure. This can be possible since, contrary to other hybrid structures, IP will not be a client layer on top of any other network but instead will coexist in parallel with it. The overlay network will transport time-critical data using the IP network for all control functions such as setting up and tearing down sessions. The benefit is that a fully functional IP network can be augmented with the additional overlay network without requiring any changes to the router setups of the IP network itself.

Figure 1 and Figure 2 illustrate how such an optical overlay network can be designed as a separate layer, which is linked to the underlying IP network. Figure 1 shows a conventional packet-based infrastructure, while in Figure 2 a network with the proposed overlay solution is presented. Since overlay networks do not require dealing with any administrative information, their function is simplified. This facilitates standardization, which is an important prerequisite for general acceptance and widespread deployment.

In the proposed solution all the fibres at a given node are attached to an all-optical router, which is connected to the existing IP router (Figure 2, left). The time-critical streams are assigned wavelength channels (light paths) that are routed across the network transparently without OEO conversion. These transparent streams are bypassing the IP routers (Figure 2, right) according to the instructions given by the signalling protocol, which is transported via the IP network. IP traffic is transmitted over the wavelengths passing through the hardware device to the router (Figure 2, right). Hardware in the overlay network has very limited intelligence. It is controlled entirely by information transmitted via the underlying IP network.

In contrast to the existing approaches the wavelengths with time-critical content never pass through the IP routers.

All-optical routers form a transparent circuit-switched WDM network referred to as a wavelength routed network. Transparency, however, requires taking into account degradation of the optical signal quality because the signal is not regenerated at each node. To increase flexibility, it is also desirable to have wavelength conversion capability in the network. This is possible via tuneable lasers used in modern optical switches. Tuneable lasers are now common in long-haul transport networks, and will within the next 1 – 2 years also make their entry into the larger urban networks. This will increase the volumes and will make these components cost-effective. With this technology, a flexible transparent network can be implemented.

Beside the hardware deployed at the network nodes appropriate equipment is required at the end nodes to send and receive time-critical data on separate wavelengths. The commercially available DWDM transmitters and receivers (e.g. manufactured by Cisco, Ciena and MRV) can be used for our concept to some extend. However, ultra-small band filters may be needed to detect say 10 – 100 Mb/s optical channels. Such filters don't exist at the moment and a feasibility study is required to investigate the physical limitations.

Finally, it is necessary to find a solution for the copper local loops, such that time-critical communications can take a user to the fibre network.

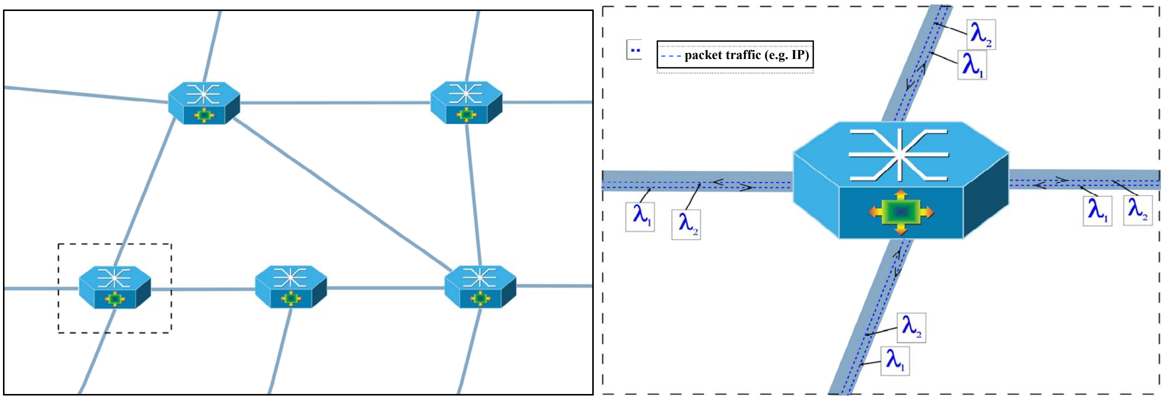

Figure 1. A conventional packet-based network infrastructure, detail (left) and close-up (right).

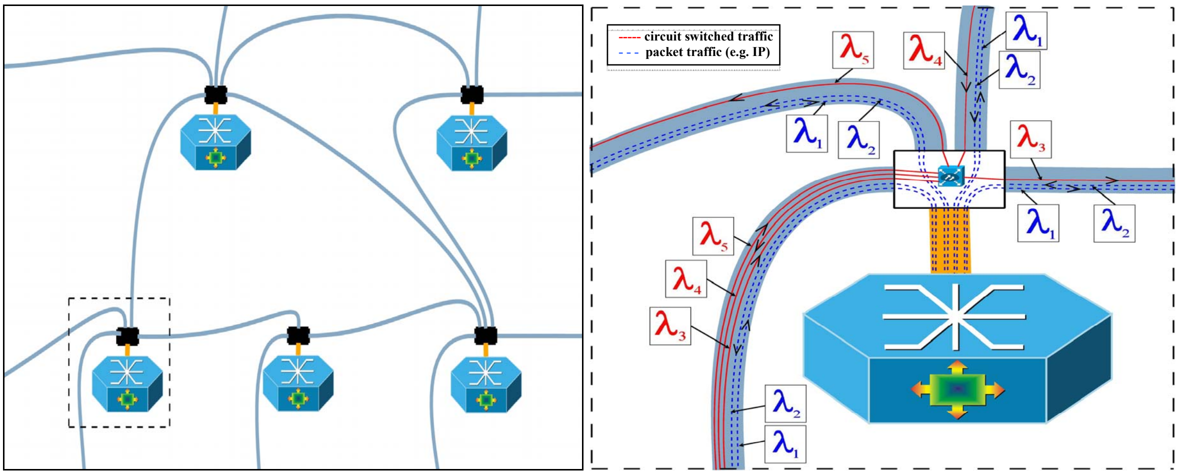

Figure 2. A network infrastructure with the proposed overly solution, detail (left) and close-up (right).

3. OPTICAL OVERLAY NETWORK APPLICATIONS AND SPECIFIC RESEARCH ISSUES

The optical overlay approach presented in Section 2 has a variety of applications and triggers a series of research issues. For example it can increase the functionality of an existing network by offering a scalable QoS solution for large and small network operators. Furthermore, the flexibility for dark fiber suppliers can be increased since dedicated links can be set up dynamically, which is both faster and cheaper than manual setup. Medical applications, such as remote surgery, the distribution of radiology images, secure transmission of patient records etc can be provided without setting up a custom made infrastructure. In this way the proposed solution can offer a major saving for hospitals, which currently use their own dark fibers. Moreover, fast and flexible encrypted transmission of data in e.g. banking sector can be provided. In quantum cryptography it is possible to offer guarantees against interception. This requires all-optical transmission. So far, it has been demonstrated that it is possible to send the encrypted information up to 100 km. HDTV-on-demand and e-cinema can be broadcasted in real time to the customers, which reduces the risk of piracy. Interactive games with extremely low tolerance for delay (< 50 ms) can be offered. Video/media production takes place mostly in the uncompressed domain, due to importance of the ultra high quality. With HDTV, the data rates are reaching up to 3 Gbps per video stream with very high requirement for low jitter, low data loss and low delays. Furthermore, our solution may enable control of machines and industrial processes where the feedback system requires a low and constant delay in order to avoid instabilities. In many process control contexts, it is important that communication is not interrupted, even for a short period. Finally, the current network performance is a major obstacle for interconnection of super computers due to the jitter and packet loss. The all-optical overlay network may be able to solve this problem.

However, the proposed approach requires a number of research issues to be solved. For example, some new components will need to be developed, such as ultra small-band filters, supporting relatively low capacity optical channels. Furthermore, the dynamically changing and dense logical topology will require an efficient control plane being able to handle multi-granular light paths with frequently changing bandwidth and holding time. The routing and wavelength assignment (RWA) algorithms will need to be fast to accommodate the dynamic setup requests. Moreover, the physical layer impairments shall be taken into account in the RWA computation in order to guarantee a sufficient optical signal quality for transparent end-to-end transmission. The dynamic scenario and the very large number of wavelength channels can result in some issues related to the control overhead. Therefore, development of efficient control overhead reduction mechanisms may be necessary.

4. CONCLUSION

We have outlined a hybrid network concept that simultaneously offers best-effort (IP) services as well as hard QoS for demanding applications. This is achieved through an overlay network that can be added incrementally to an existing IP infrastructure and without requiring changes in router set-ups. If the overlay network is made all-optical, the users are free to use any protocol and waveforms for their transmission. Applications range from real-time communication such as industrial control to quantum communication.

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