Wireless Techniques in Optical Transport

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Abstract

The field of optical communications is undergoing a transformation from analog to digital. Advanced signal processing techniques which have been widely used in wireless communications and local access loops are now being applied to long haul optical transmission networks. In this paper, we discuss the implications of such transformations and postulate a new paradigm for optical transport in future high speed optical backbone networks.

Summary

Since the beginning of fiber optic communications more than 40 years ago, the capacity of information carried in a single fiber has increased by more than 5 orders of magnitude (10^5). This vast capacity increase was mostly propelled by the tremendous advancements in fiber optic component technologies. Unlike other technologies such as wireless and DSL (digital subscription line), in which the physical layer is tightly integrated with medium access control (MAC) and IP networking layers as a single platform, fiber optic transmission system remained mostly a separate isolated transport layer which is relatively independent from upper layer equipment providing networking functions such as routing and switching. Many optical transport layer equipment companies, with special knowhow in engineering physical layer optical transmission links, have been established to produce large-capacity and high-density WDM (wavelength division multiplexing) optical transmission systems.

In a modern-day optical transport system, a short-distance client side interface with gray-optics (usually in the form of 850nm multimode fiber interface or 1310 single mode fiber interface) forms the demarcation point between the upper networking-layer equipment and the lower-layer optical transport equipment. Most of the optical transport equipment reframes the upper layer data with additional FEC (forward error correction) overhead to protect the signal for long haul transmission. The reframed signals then re-modulate WDM-compliant optics, which are multiplexed in the wavelength domain before transmission. The main function of the optical transport layer is to provide point-to-point connectivity in most fiber optic networks.

Throughout the history of fiber optic communications, simple on-off keying (OOK) with direct intensity detection has been the main modulation scheme of choice [1] (even for long haul WDM transmissions). Advanced signal processing techniques commonly adopted in other communication systems [2] have given way to the simplicity and economic benefit of OOK and direct detection for the following reasons:

(1) In the past, the abundance of bandwidths inside the optical fiber reduced the value of more bandwidth efficient modulation schemes, which would increase the cost and complexity of transceiver designs.

(2) The almost ideal low-distortion transmission link offered by the optical fiber made it unnecessary to use advanced signal processing techniques to recover transmitted signals.
(3) The extremely high data rate inside the optical fiber often outstripped the speed limit of available digital signal processing hardware.

Nevertheless, in the recent years, the landscape of optical communications is changing at an accelerating speed, from both the physical transmission viewpoint and network equipment architecture viewpoint. Such changes are made possible by the rapidly improving intelligence and integration, which are happening in the optical transport layer.

On the transmission side, the ever increasing signal baud rates are pushing against the limits of physical systems on every front: modulator and detector bandwidth, optical-signal-to-noise ratio (OSNR), chromatic dispersion (CD), polarization mode dispersion (PMD) etc. Advanced modulation using polarization multiplexing, quadrature-amplitude modulation (QAM) [3], orthogonal frequency division multiplexing (OFDM) [4] and coherent optical receiver help to reduce the signal baud rate, increase the transmission spectral efficiency and mitigate the transmission impairments. At the same time, rapid advances in mixed-signal analog and digital electronics has brought the speed of DSP within the reach of that needed for processing high-speed data carried in optical fibers. It opens the door for digital communication techniques commonly used in wireless and access loops [2] to be employed for long-haul, high-bandwidth optical transport.

The implication of such transformation is not only a quantum jump in the sheer transmission capacity and distance inside the optical fiber, but also improved functionality from a networking perspective. As an example, at a coherent receiver end, sampling of transmitted optical symbols with high-speed A/D (analog to digital) convertor (ADC) enables soft-decision FEC to be employed to reduce the OSNR requirements, allowing signals to transmit over longer distances. At the transmitter end, high-speed D/A (digital to analog) converter (DAC) allows arbitrary signal phase and amplitude to be synthesized. Thus, on a high OSNR link, one can make more efficient use of the link spectrum by packing more information onto the transmission link using a higher constellation M-QAM signal and vice versa on a low OSNR link. In a reconfigurable optical network where wavelength connections are dynamically set up on demand and add/dropped at different locations, transceivers can measure the link quality in real time and select the optimal modulation speed with the BER (bit error rate) assurance. CD and PMD no longer become limitations when coherent receivers with digital equalizer are used [5]. On the other hand, one can also combat dispersion effects by using the OFDM transmission technique [4], which breaks a high-speed serial signal into multiple densely-packed orthogonal subcarriers each transmitting at a much lower rate. An interesting use of the OFDM technique is in the optical access area where one can achieve dynamic bandwidth allocation by assigning different subcarrier groups to each individual user.

To benefit from these new physical layer capabilities, conventional approaches of separating the optical transmission layer from the upper networking layers needs to be re-examined. In the conventional approach, the optical transmission layer interfaces with the upper network layer through the gray-optics client optical interface. Besides the client optical interface, which is almost always entirely used to carry user data, there is minimal control signaling between the transmission and networking layers. Transmission layer and networking layer devices are also managed separately. This conventional architecture has the following problems:

(1) Lack of signaling between the optical layer and networking layer makes it difficult for the upper layer device to benefit from the knowledge of transmission link quality acquired by the transmission layer so that it can properly adjust the user traffic rate accordingly in the most optimal manner. The upper layer may thus be overloading or underloading the transmission link most of the time.
(2) The EO-OE conversion at the client interface creates a lot of inefficiencies in terms of space, power and cost.
(3) Managing the network layer and transmission layer separately creates a lot of system inefficiencies and duplication of network management personnel and infrastructure.

Here, we propose a new architecture paradigm which integrates the optical transmission layer as a subsystem into the upper layer networking devices, eliminating the EO-OE client interface and replacing it with a standard electrical interface, which in addition to passing the high speed user data between the transmission layer subsystem and the higher layer protocols in the host networking device, also passes a set of well-defined control and management protocol signals between the subsystem and the host mother system. Such integration is made possible by the rapid improvement in optical system integration and enhanced intelligence in the optical transmission layer.

The standard electrical interface will continue to allow separating the development efforts in the transmission layer by specialized organizations, but at the same time remove the redundancy of developing unnecessary separate management systems with inherent inefficiencies in signaling and passing information from one layer to another.

Lastly, this new integrated architecture also brings the environmental benefit of being much greener and consuming less energy by eliminating the intermediate client interface and the energy cost associated with managing a separate optical transport layer.

References

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