Virtual private networking over passive optical networks

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A simple and economical scheme using subcarrier multiplexed transmission enables simultaneous virtual private networks in an optical access network.

Improving optical fiber communications has traditionally focused on providing high bandwidth with reduced cost per transmitted bit. However, attention has now shifted from optical transmission to optical networking. By exploiting wavelength division multiplexing (WDM) technology, optical networks have expanded from backbone networks to metropolitan and access networks that deliver high-bandwidth services directly to users with reduced cost.

The ultimate evolution of the optical access network involves fiber-to-the-home (FTTH) technologies, which have the potential to offer a wide range of multimedia and communications services directly to consumers. Promising to be an extremely cost-effective FTTH approach, passive optical networks (PONs) share the network resources among a number of users. PONs have significant advantage over competing access technologies because the fiber infrastructure can be effectively future-proofed for upgrades. As PONs evolve, however, advanced functionalities, such as virtual private networking (VPN), need to be added to adequately develop a next-generation optical access network infrastructure.

VPNs over PONs are typically customer-owned, and they provide cost savings through remote peering and transit. Customer control allows users to change peering relationships without contacting the central office. In addition, eliminating VPN packet forwarding through routers/switches at the CO reduces costs while enabling end-to-end light paths and quality of service for high-bandwidth file transfer applications.

Establishing an access VPN in a PON is challenging because it requires several tunnels to be established among the entities involved. Apart from setting up a VPN on an existing PON, another key design challenge is to provide security for the transmitted traffic as it travels over a nonprivate network.

An optical layer VPN scheme using electronic code division multiple access (E-CDMA) has previously been demonstrated to address these VPN implementation issues. However, the bandwidth of the VPN traffic in that approach is limited by the processing gain of the E-CDMA signals, and it requires complex customer hardware. Alternatively, our research focused on a VPN scheme using radio frequency (RF) subcarrier multiplexed (SCM) transmission of the VPN traffic to achieve multiple VPNs over a PON.

Our approach for implementing VPNs is shown in Figure 1. Each optical network unit (OUN) is connected to a star coupler via two distribution fibers such that the SCM-VPN signal transmitted from an ONU on one distribution fiber is redirected back to each ONU through the second distribution fiber. Signal transmission uses low-cost Fabry-Perot laser diodes (FP-LDs) in the 1.3 µm wavelength window. Each VPN has a unique RF carrier frequency that is multiplexed with the VPN data. (As a result, several VPN transmissions can occur simultaneously.)

Electrical bandpass filters (BPFs) at the receiver separate the traffic for the different VPNs. A media access control protocol in each VPN coordinates the transmission of SCM-VPN signals. Since multiple VPN transmissions can be performed at any given time (rather than during designated time slots), there

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is no need for a burst mode receiver at each ONU. Upstream and downstream transmissions use wavelength channels in the 1.5 µm window.

Figure 2 shows our experimental setup. During transmission, 60Mb/s data was upconverted onto a 2 GHz carrier using an RF mixer. Then, the signals were directly modulated onto an FP-LD and transmitted upstream through the 2.2 km fiber. To demonstrate simultaneous VPN capability, another 60Mb/s data was modulated onto a 2.5 GHz carrier, and the resulting SCM-VPN signal was directly modulated onto another FP-LD and transmitted through the 5.6 km fiber. The transmitted SCM-VPN signals were redirected to ONU\textsubscript{1} using another 2.2 km fiber, and they were detected and fed through a BPF at 2 GHz for recovery.

A series of experiments were conducted to examine crosstalk effects, and bit error rates (BERs) for all signals were measured. Figure 3 shows the measured BER. For the SCM-VPN data, no significant penalty was observed when one source was active. With the second source active, a penalty of 0.75 dB was observed, which can be attributed to optical beat interference.

An analysis was performed to calculate the number of simultaneous VPNs in a PON with 32 ONUs. Figure 4 shows the number of simultaneous VPNs for varying data rates of the VPN signals. For the binary phase shift keyed modulation, a signal-to-noise of 12.6 dB is required to obtain a BER of $10^{-9}$. As the number of VPNs increases, the number of optical sources also increases, leading to an increased OBI for the SCM-VPN signal. The number of simultaneous VPNs decreases with increasing data rate of SCM-VPN signals, since OBI is directly proportional to the data rate of the VPN signals. The results show that eight VPNs can coexist with the data rate of 155 Mb/s.

Our research demonstrates the promise of deploying multiple simultaneous VPNs over a PON using low-cost broadband optical sources such as Fabry-Perot laser diodes. In addition to the optical layer implementation of the scheme, we are currently working toward developing an appropriate media access control protocol for transport of the SCM-VPN signals.
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References