Advanced Optical Fiber Communication Systems

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Our research is focused on four aspects of advanced optical fiber communication systems: dynamic wavelength division multiplexing (WDM) networks, linewidth-insensitive coherent optical analog links, video distribution systems using direct frequency modulation of semiconductor lasers, and impact of fiber nonlinearities on optical communication systems. In the area of WDM networks, we investigated, designed, and are currently implementing a coherent optical network with a total throughput of 12 Gbit/s. In the study of coherent optical analog links, we analyzed two linewidth-insensitive schemes that could overcome the impact of phase noise of semiconductor laser diodes. In the area of video distribution systems, we investigated the performance of novel systems using direct frequency modulation of semiconductor lasers for subcarrier-multiplexed video distribution. In the area of fiber nonlinearities, we evaluated the performance of optical WDM systems in the presence of four-wave mixing, and are analyzing the impact of stimulated Brillouin scattering on such networks.

Dynamic wavelength division multiplexing (WDM) networks

Dynamically reconfigurable WDM optical networks have the potential of achieving higher throughput, higher reliability and lower latency as compared to both single-wavelength networks and to WDM networks with fixed wavelength assignment. Our work is concerned with the study, design and implementation of broadband dynamically reconfigurable WDM optical networks.

In the current reporting period, we investigated a network based on a passive optical star architecture. The network uses WDM to transmit multiple data channels over a single fiber and therefore makes more efficient use of the available fiber bandwidth. Future high speed networks will be required to support a wide range of data rates for diverse applications such as e-mail, video conferencing, and digital HDTV. A WDM network that would efficiently support these demanding traffic requirement would ideally be implemented using fast wavelength packet switching. However, with the slow laser tuning speed of today's technology, this would not be possible. We showed that future traffic requirements could be met by providing every node in the network with an access to both a fixed tuned low-speed packet network and a tunable high speed circuit interconnect operating over the same physical fiber. The fixed-tuned network eliminates the need for fast wavelength packet switching, while the tunable circuit switched network still offers the user a network with a potential throughput in the Tbit/s range.

In this current reporting period the experimental work has also been started. This work is aimed at the realization of a prototype two-node network which will be later expanded to four nodes. The two-node prototype is designed to demonstrate that the network can deliver a throughput of 3 Gbit/s per node, for a total four-node throughput of 12 Gbit/s. The experimental part of this effort is supported by other sponsors.

A proper reconfiguration algorithm is needed for dynamic WDM systems. It should dynamically allocate WDM channels based on the communication needs of the stations. Ideally, this should be a distributed algorithm with low overhead. The design and evaluation of such algorithms are currently in progress in conjunction with the network experiment.

In addition to the experimental network project, we are also investigating novel modulation formats for coherent WDM networks. We performed a theoretical study of an advanced coherent optical transmission scheme based on continuous modulation of the polarization state in the fiber, continuous polarization shift keying (CPOLSK). The results show that CPOLSK has a bandwidth efficiency nearly two times greater than that of minimum-shift keying (MSK).

Linewidth-insensitive coherent optical analog links

There is currently much interest in the use of fiber to transport high dynamic range analog signals from antennas to remote signal processing sites. Due to their superior size, weight, ruggedness and reliability, laser diodes are the preferred sources for such links. The use of coherent detection techniques may provide enhanced analog link performance over conventional direct-detection links if the impact of laser diode phase noise can be overcome.

Our theoretical effort has concentrated on achieving high dynamic range coherent optical analog links that are insensitive to phase noise. One technique for achieving this goal is the embedded carrier phase noise cancellation. In the receiver, the unmodulated carrier is mixed with the signal, resulting in cancellation of phase noise. Our initial results indicate that the lowest signal frequency must be much larger than the linewidth to achieve appreciable phase noise cancellation. Ongoing analysis is aimed at establishing the noise penalty associated with various combinations of filter characteristics, laser linewidths, and signal bandwidths. This analysis will also consider the impact of laser and FM discriminator nonlinearity on the dynamic range of the link.

Further we theoretically analyzed another linewidth-insensitive scheme: the AM (amplitude modulation) -WIRNA (WIdeband-Rectifier-NArrowband filter) heterodyne system. By appropriate filtering and squaring at the receiver, the effect of laser phase noise is minimized. We analyzed the impact of the phase noise and of the shot noise for a system with ideal filtering and squaring, and with the bandpass filter (BPF) bandwidth larger than the laser linewidth. The output signal power and the signal-to-noise ratio (SNR) were evaluated. The system was shown to be tolerant to modest values of laser linewidth and additive noise. The output SNR was shown to be nearly independent from the BPF bandwidth. The AM-WIRNA heterodyne approach is therefore a promising candidate for analog optical communication links using semiconductor lasers.

Video distribution systems using direct frequency modulation of semiconductor lasers

We investigated the potential of direct frequency modulation of semiconductor lasers for the transmission of subcarrier-multiplexed (SCM) amplitude-modulated vestigial sideband (AM-VSB) and frequency-modulated (FM) analog video channels. Direct FM of the optical transmitter gives the advantage of FM enhancement at the cost of increased per-channel bandwidth requirements. It also avoids the necessity of using a lossy external modulator at the transmitter. We have found theoretically that the FM video format is highly resistant to linewidth-induced degradation. However, the AM video format is highly susceptible to the linewidth-induced degradation. The effects of receiver noise and the relative-intensity noise have also been investigated. We are currently investigating the effects of demodulation-induced nonlinearities on FM systems.

Impact of fiber nonlinearities on optical communication systems

We have evaluated the performance of optical WDM systems in the presence of four-wave mixing (FWM). The nonlinear FWM process limits the maximum optical power that can be launched into fibers, and the shot noise limits the minimum power at the receiver. We have evaluated the link budget defined as the ratio of the maximum transmitter power to the minimum optical power at the receiver, and derived the maximum transmission distance.

We have also proposed and investigated FWM noise reduction method using Manchester coding. The performance of NRZ (non-return-to-zero) and Manchester coding in both ASK (amplitude-shift keying) and DPSK (differential phase-shift keying) modulated systems was evaluated. The effect of fiber dispersion on FWM noise was also investigated. Our analysis showed that Manchester coding improves ASK systems more significantly than DPSK systems, and that systems utilizing dispersion-shifted fiber are more seriously impaired by FWM noise than those utilizing nondispersion-shifted fibers.

Another potentially limiting nonlinear effect is stimulated Brillouin scattering (SBS). SBS process tends to reflect back the launched optical power exceeding a certain threshold, and also induces excess noise in the transmitted signals. We are currently analyzing the impact of SBS process theoretically, and are planning to set up an experimental investigation.

We have also studied a nonlinear interaction between two copropagating optical modes and an acoustical wave in dual-mode optical fibers. This interaction leads to so-called three-wave envelope soliton (TWES). Our results showed that the group velocity of TWES can be controlled by adjusting the power of one of the optical modes.