Communication Sciences and Engineering

19. Optical Propagation and Communication

Academic and Research Staff

Prof. J.H. Shapiro, Dr. R.H. Rediker, Dr. P. Kumar

Graduate Students

P.L. Bogler, R.S. Bondurant, F. Hakimi, M.W. Maeda, M.B. Mark, P.L. Mesite, T.T. Nguyen, J. Ocenasek, R.P. Schloss, P.D. Shapiro, E.A. Swanson, A.H. Tewfik, H.V. Tran, S.S. Wagner, A.K. Wong

The central theme of our programs has been to advance the understanding of optical and quasi-optical communication, radar, and sensing systems. Broadly speaking, this has entailed: developing system-analytic models for important optical propagation, detection, and communication scenarios; using these models to derive the fundamental limits on system performance; and identifying, and establishing through experimentation the feasibility of, techniques and devices which can be used to approach these performance limits.

19.1 Atmospheric Optical Communication Systems for Network Environments

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Jeffrey H. Shapiro, Trung T. Nguyen, Hai V. Tran, Albert K. Wong

A local computer network is prototypically a high-bandwidth (1–10 Mbps) geographically compact (0.1–10 km diameter) packet-switched network that employs coaxial cable or fiber optics as its transmission medium. These networks interconnect host computers within a single company, often within a single building. They are distinguished from long-haul packet networks in that the high-bandwidth, short delay, low-cost transmission media employed in local networks permit simplified protocols and control strategies.

Atmospheric optical communication links are a natural choice for certain high-bandwidth short-haul terrestrial transmission applications in which cable rights-of-way are unobtainable, or frequent link and network reconfiguration is necessary. Such systems will experience occasional outages due to local adverse weather conditions, but, via the results of our prior work,[1,2] low-visibility atmospheric optical communication links can now be analyzed with some confidence. It turns out that exploitation of scattered light can permit useful link operation beyond the limit set by extinction of the direct beam. However, although technology development can help extend scattered-light operating range, true all-weather capability at high data rates over kilometer or longer path lengths cannot be guaranteed.

The natural advantages of atmospheric optical links make them attractive candidates for such local network applications as bridges between buildings containing cable networks, and temporary quick-connects for new outlying hosts for which cable runs are unavailable. Whether these advantages will lead to widespread usage of atmospheric optical communication in local computer networks is uncertain at this time. There is a substantial gap that exists between link-understanding and network-understanding of atmospheric optical communications. In particular, high-level network protocols are designed to provide 100% reliability message transmission end-to-end through the network. Thus, in designing and implementing atmospheric optical links for such networks appropriate compromises must be established between the physical link design and low-level protocol design to best provide fairly reliable packet transmission for the high-level protocols to act upon. We have undertaken a combined analytical and experimental effort to attack these network problems. A brief summary of the status of these efforts follows.

Theory

The analysis of computer networks is generally carried out within a layered architecture model. Our purpose for analysis is to study how a local area network, employing one or more atmospheric optical links, is affected by the weather-dependent performance of these optical links.[3] Thus far, we have examined the trade-off between the delay created by an optical link making an unannounced transmission rate reduction to maintain reliable data communication in deteriorating visibility conditions versus the increased fraction of weather conditions in which operation is made possible by this rate reduction. We have also proposed and analyzed several state control procedures under which an optical link's transmission rate can be adjusted and communicated to the remainder of the network without creating a state-oscillation problem. Such a problem occurs when the optical nodes oscillate between states, sending their constantly changing status to the rest of the network at a rate much faster than the rate at which the network can make use of this information.

The preceding work addresses issues arising at the lowest layers of the hierarchy, namely, the physical layer (delay due to unannounced rate reduction), and the data link layer (state control procedure). We have begun blocking out the key issues to be studied at the higher layers.

Experiment

A major component of our research program is to experimentally probe the utility of atmospheric optical communication links in local area networks. Toward that end, we have constructed[3,4] a pair of optical transceivers capable of digital transmission at a rate up to 10 Mbps over line-of-sight paths as long as 1 km in weather conditions down to optical thickness 3. Initial laboratory tests of the equipment were performed using video terminals and a pair of specially constructed transmission rate converters. Building-to-building communication tests are now underway using the recently acquired LSI 11/23 computer to generate long sequences of packets for transmission to a remote video terminal via the link and one of our transmission rate converters.

In addition to the preceding communication link tests, we have been in contact with members of the

M.I.T. Laboratory for Computer Science regarding the future use of the optical links in network experiments.

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19.2 Two-Photon Coherent State Light

U.S. Navy - Office of Naval Research (Contract N00014-81-K-0662)

Jeffrey H. Shapiro, Prem Kumar, Roy S. Bondurant, Mari W. Maeda, Josef Ocenasek, Stuart S. Wagner

Recent work has highlighted the applications of two-photon coherent states (TCS), also known as squeezed states, in optical communications and precision measurements. These states have non-classical noise statistics, and their predicted generation schemes include degenerate parametric amplification (DPA), degenerate four-wave mixing (DFWM), the free-electron laser, and multi-photon optical bistability. The preceding generation schemes have been analyzed to varying degrees of approximation, but no experimental observation of TCS has been reported as of yet. We are engaged in a program to: generate and verify the quantum noise behavior of TCS light; and analyze the physics and applications of such light. Our recent progress is summarized below.

TCS Generation and Detection

Two-photon coherent states are in essence minimum uncertainty states for the quadrature components of the electromagnetic field possessing an asymmetric noise division between the quadratures. To detect them, one seeks to demonstrate their non-classical behavior. To generate them, one seeks interactions which mix annihilation operators and creation operators.

Our approach is to generate TCS light via pulsed DFWM,[1] and to exhibit its anti-bunching behavior via photon counting.[2] An initial experiment of this type with sodium vapor as the DFWM medium was performed,[3-5] with negative results. Basically, a combination of experimental difficulties prevented DFWM/photon counting operation in the regime wherein non-classical behavior should prevail. Additional analysis[3,5,6] has clarified pump and loss issues in DFWM TCS generation. Work is now proceeding toward a continuous-wave homodyne detection experiment.

TCS Applications

The main thrust of our TCS applications research has been in the area of phase sensing. We showed in[7] how multi-mode TCS permit arbitrarily high accuracy to be achieved in simultaneous amplitude and phase measurements made via optical heterodyne detection. In[8] we demonstrate how the preceding heterodyne apparatus could be used to greatly exceed the standard quantum limit on phase sensing gravity-wave interferometers.

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19.3 Atmospheric Propagation Effects on Infrared Radars

U.S. Army Research Office - Durham (Contract DAAG29-80-K-0022)

Jeffrey H. Shapiro, Martin B. Mark, Paula L. Mesite, Ahmed H. Tewfik

Compact coherent laser radars have the potential for greatly improved angle, range, and velocity resolution relative to their microwave radar counterparts. This program is aimed at obtaining a quantitative understanding of target reflection and atmospheric propagation effects on the performance of compact coherent laser radars through a combination of theory and experiments. Under a collaboration arrangement with the Opto-Radar Systems Group at the M.I.T. Lincoln Laboratory, the experimental portions of the research are being carried out on the compact CO_2-laser radars under development there. During the past year our work has focused on experiments using the 2-D Doppler imager radar, and analyses of 3-D imaging systems, as described below.

Doppler-Radar Measurements

Two important features of Doppler radar operation are hard-target speckle and clutter. We have found[1,2] that target-returns from a moving flame-sprayed aluminum calibration plate do show the expected speckle behavior in the Doppler radar's far field, but evidence an as yet unaccounted for reduction of the speckle fluctuations in the radar's near field. Work is continuing on the latter case. In tree-clutter measurements[1,2] we have shown that observed spectra obey a micro-motion/macro-motion decomposition that we had previously proposed. Amplitude statistics for clutter returns are being investigated.

High Time-Bandwidth Radars

We have been studying,[2,3] analytically, the use of high time-bandwidth (TW) waveforms for 3-D imaging. In particular, we have been concerned with the effects of range-spread speckle targets on the range accuracy of such systems.

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19.4 Fiber-Coupled External-Cavity Semiconductor High Power Laser

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Robert H. Rediker, Robert P. Schloss, Farhad Hakimi

The external-cavity laser has been operated with all five semiconductor gain elements lasing simultaneously and being controlled by the external cavity. The wavelength of lasing of each gain element has been controlled by controlling the temperature of its heat sink to 0.5×10^{-3} °C. Lasing has been obtained with various spatial filters in the focal plane between the two lenses which focus the collimated beam from the laser and recollimate the beam so it is incident on the end mirror of the cavity. These spatial filters include a 200 μm pinhole, a 100 μm pinhole and a 170 μm slit.

The insertion of the spatial filters perturb the lasing wavelengths of the various gain elements differently, requiring re-adjustment of parameters to put the lasing wavelengths again in coincidence. The external-cavity has not lased when the spatial filter which contains thirteen 3 μm slits on 10.5 μm centers is used. This spatial filter is the diffraction pattern of the gain elements radiation if these elements are emitting in coherence. It is believed this latter spatial filter has also perturbed the wavelength at which the various gain elements would lase and, of course, stable interference is not possible for different wavelength gain-elements. Without lasing of the individual elements there is no systematic way to re-establish coincident wavelengths. Frequency-selective etalons are now being incorporated into the cavity to eliminate the wavelength perturbation. It is believed that once the gain elements have locked together that the perturbation issue will no longer exist.