Remote Sensing and Estimation

RLE Group
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Self-Organizing Spectrum Allocation

Sponsor
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This program seeks to determine approximate limits to the average communications bit rate per Hz per user, as a function of link length relative to user density, which can be exchanged between pairs of wireless mobile users randomly distributed over a two-dimensional plane. Of primary interest is the dependence of those bit-rate limits upon coding, number of antennas employed, and multipath characteristics.

S. Govindasamy has shown that in an infinite interference-limited network where transmitting nodes use single antennas with equal power and receiving nodes use N antenna elements, the average link spectral efficiency (b/s/Hz/link) grows logarithmically with N and linearly with the path-loss-exponent α, where received signal power P decays with distance r as $r^{-\alpha}$. The variance of link spectral efficiencies decays as 1/N.

We have also found that if all transmitting nodes have M < N antenna elements and no channel-state information, then transmitting equal-power, independent streams from the optimum number of antennas at each node can improve the average link spectral efficiency in the network several-fold over the optimum selfish strategy of transmitting equal-power independent streams from every antenna element. The optimum number of transmit antennas is approximately proportional to the number of receive antennas and inversely proportional to both nodal density and the square of the nominal link length. For these results we assumed each node transmits equal power simultaneously in the same interference-limited frequency band (i.e. without Medium Access Control). Portions of this work have been presented [1,2] and submitted for publication [3].

This year an 8-channel digital software receiver was completed by Keith Herring and Jack Holloway. It operates in the third 22-Mhz channel of the 802.11b (WiFi) standard which is centered at 2.422Ghz. The system synchronously samples this band using up to 8 antennas at 67 Mhz per channel and 12 bits accuracy. The data passes to 128-KB memories, one per channel, from which all channels can be simultaneously downloaded to a single 200-GB disk on the order of one second before being filled again. The channels have system noise temperatures near 600K, and dynamic ranges of ~70 dB. Passive 8-pole filters reduce out-of-band interference prior to the first amplifiers. Receiver operation is controlled by a 700-Mhz Pentium-III computer that houses a NI-6534 DAQ card and issues commands to programmed FPGAs serving each channel.

Preliminary propagation data has been observed using Netgear WiFi routers that broadcast arbitrary known pseudo-random waveforms. Experiments conducted on the roof of Building 26 suggest stable path characteristics and strong multipath that decays approximately exponentially with distance; the 1/e distance is ~1 km for signals reflected primarily within the Alumni pool courtyard. Strong nulls in frequency occur with spacings of ~500 Khz. These measurements will be substantially elaborated and expanded to more of Cambridge and Boston in the coming year, and will include passive studies as well.

Conference Papers

1. S. Govindasamy, F. Antic, D. W. Bliss, and D. H. Staelin, "The Performance of Linear Multiple-Antenna Receivers with Interferers Distributed on a Plane," 2006 IEEE Workshop on Signal Processing Advances in Wireless Communications, New York, New York, June 5–8 2005.

2. S. Govindasamy and D. H. Staelin, "Linear MMSE Receivers for Random CDMA in Wireless Networks With Equal Transmit Powers," 39th Asilomar Conference on Signals, Systems and Computers, Pacific Grove, California, October 30–November 2, 2005.

3. S. Govindasamy, D. W. Bliss, and D. H. Staelin, "Interference Mitigation in Single-Hop Ad-Hoc Wireless Networks Using Antenna Arrays," submitted for publication.

AIRS/AMSU/HSB Algorithm Refinement

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The Aqua satellite of NASA's Earth Observing System was launched May 4, 2002. Its instrument complement includes a 2378-channel infrared imaging spectrometer, AIRS, and a 19-channel microwave imaging spectrometer, AMSU-A plus HSB, which are treated as a single facility for the purpose of retrieving profiles of atmospheric parameters such as temperature and moisture. The 4-channel 150-200 GHz HSB failed on February 5, 2003, but AIRS and the 23-90 GHz AMSU-A are still operating. We have developed and delivered algorithms for the purpose of calculating microwave brightness temperatures and for retrieving precipitation, cloud liquid water content [1], microwave surface emissivity [2], and first-guess profiles of temperature and water vapor from the microwave channels. The latter two profiles constitute the retrieval product in overcast fields of view and are used to initialize the cloud-clearing of infrared channels. A stochastic algorithm for infrared cloud clearing has also been developed [3,6], and the thesis by C. Cho [6] further deals with compensation for AIRS noisy channels and scan-line miscalibration. Several cloud-cleared tropospheric channels for the better tropical regions differ from numerical weather predictions by ~0.2K rms.

To obtain consistency between the different instruments (i.e. AMSU-A and AIRS) it is necessary to make adjustments for antenna sidelobes and possible forward-model errors. We derived these corrections by comparison of AMSU-A measurements to brightness temperatures calculated from AIRS retrievals in very clear air, which did not require AMSU-A data as a starting point. (The clear-air retrievals were provided by C. Barnet of NOAA/NESDIS.) These newly-derived corrections will be used in version 5 of the operational processing software.

The accuracy of AMSU-A temperature profiles near the surface depends on accurate modeling of the contribution of reflected downwelling sky emission to the observed brightness temperature. For the ocean surface, the effect of down-welling emission is represented by an effective zenith angle, which varies with wind speed [2]. Over all other types of surfaces, the current operational software models the surface scattering as Lambertian. However, there are indications in AMSU-A measurements over Antarctica that a better model for some ice-covered areas would be intermediate between specular and Lambertian scattering. An effort is in progress to derive from the Antarctic measurements a parameter characterizing the degree to which the surface is Lambertian [4,5].

Journal Articles

1. P. W. Rosenkranz, “Cloud Liquid-Water Profile Retrieval Algorithm and Validation,” *Journal of Geophysical Research*, **111**, D09S08, doi:10.1029/2005JD005832 (2006).

2. P. W. Rosenkranz and C. D. Barnet, “Microwave Radiative Transfer Model Validation,” *Journal of Geophysical Research*, **111**, D09S07, doi:10.1029/2005JD006008 (2006).

3. C. Cho and D. H. Staelin, "Cloud clearing of AIRS hyperspectral infrared radiances using stochastic methods,” *Journal of Geophysical Research*, **111**, D09S18, doi:10.1029/ 2005JD006013 (2006).

4. C. Mätzler and P. W. Rosenkranz, "Dependence of Brightness Temperature on Bistatic Scattering: Theoretical Basis," submitted to *IEEE Transactions on Geoscience and Remote Sensing*.

Conference Papers

C. Mätzler and P. W. Rosenkranz, "Dependence of Brightness Temperature on Bistatic Scattering With Applications to Antarctica," 9th Specialist Meeting on Microwave Radiometry and Remote Sensing Applications, San Juan, Puerto Rico, February 28–March 3, 2006.

Theses

C. Cho, *Anomaly Detection and Compensation for Hyperspectral Imagery,* Ph.D. diss., Department of Electrical Engineering and Computer Science, MIT, August 2005.

ATMS Contributions to Sounding Products

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The NPOESS Preparatory Project (NPP) is developing a satellite designed to ensure that the next generation of U.S. weather satellites will meet NASA's needs for climate data records. We provide advice on design and testing of instruments, in particular the Advanced Technology Microwave Sounder (ATMS), and on geophysical-parameter retrieval algorithms, particularly with respect to effects produced by clouds and by surface emissivity and roughness. These activities draw on experience with satellite and aircraft instruments such as AIRS, AMSU-A/B, HSB, NAST-M, and NAST-I.

This year, we provided advice on ATMS instrument issues involving instrument alignments, ATMS sidelobes, and Gunn-diode oscillators. The stochastic cloud clearing algorithm developed by Cho was transferred to Lincoln Laboratory and others for evaluation and possible use in NPP. The microwave first-guess retrieval algorithm developed for AMSU/HSB was modified for ATMS and was provided to other NPP investigators. The rapid transmittance algorithm was modified to include absorption by ozone, which has a significant influence on ATMS channels at 166 and 183.3±1 GHz.

NPOESS Program Science Team Support

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This program supports Lincoln Laboratory and NOAA Integrated Program Office efforts to develop a National Polar Orbiting Environmental Satellite System (NPOESS). The NPOESS Sounding Operational Algorithm Team (SOAT) is being supported through membership and participation by Prof. Staelin, and Instrument, algorithm, and calibration/validation issues are being addressed. The main scientific efforts involved documentation and transfer to Lincoln Laboratory of the hyperspectral infrared cloud-clearing algorithm [1,4] and development and evaluation of improved rain rate and hydrometeor path retrieval algorithms using millimeter-wave spectra observed by current NOAA and NASA satellites. Both efforts are also separately supported by NASA. Prior work with the NPOESS Aircraft Sounder Testbed (NAST) was also presented [2].

The hyperspectral cloud-clearing algorithm estimates the cloud-cleared radiance spectrum for 3x3 sets of 15-km fields of view of the Atmospheric Infrared Sounder (AIRS) on the NASA Aqua satellite. AIRS observes 2378 channels in the 3.7-15.4 micron spectral band. The rms differences between the cloud-cleared 4- and 15-micron carbon-dioxide channels and the corresponding numerical weather prediction model radiances were ~0.2-0.3K for 60 selected channels having peak sensitivities to tropospheric temperature at altitudes ranging down to the surface for the best 28 percent of all soundings selected using the same AIRS data [1].

To establish a physical basis for development of surface precipitation rate retrieval algorithms a numerical weather prediction model (MM5) was coupled to a radiative transfer algorithm suitable for use in precipitation at millimeter wavelengths. The sensitivities of neural-network retrieval algorithms to physical assumptions inherent in the MM5 model were evaluated [3].

Journal Articles

C. Cho and D. H. Staelin, "Cloud clearing of AIRS hyperspectral infrared radiances using stochastic methods," *Journal of Geophysical Research*, **111**, D09S18, doi:10.1029/ 2005JD006013 (2006).

Conference Papers

W. L. Smith, D. K. Zhou, X. Liu, A. M. Larar, S. A. Mango, D. H. Staelin, H. E. Revercomb, and P. W. Rosenkranz, "NPOESS Risk Reduction, NAST for CrIMSS," American Meteorological Society Annual Meeting, Atlanta, Georgia, January 29–February 2, 2006.

C. Surussavadee and D. H. Staelin, "AMSU millimeter-wave precipitation retrievals trained with MM5 simulations: sensitivity to physical assumptions," to be presented at the 2006 IEEE International Geoscience and Remote Sensing Meeting, Denver, Colorado, July 29–August 5, 2006.

Theses

C. Cho, *Anomaly Detection and Compensation for Hyperspectral Imagery,* Ph.D. diss., Department of Electrical Engineering and Computer Science, MIT, August 2005.

Retrievals and Global Studies of Precipitation Rate and Cloud-Base Pressure

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This year development of precipitation estimation methods using AMSU/HSB and AMSU-A/B passive microwave satellite observations trained with NEXRAD data was concluded and documented in the doctoral thesis of F. W. Chen. The method employs 13 channels 23-190 GHz near water vapor and oxygen resonances. These frequencies have been observed globally by four polar orbiting satellites with 15- and 50-km resolution. Comparisons with passive microwave observations by AMSR-E over ocean permitted adjustment of the NEXRAD-trained precipitation-rate retrievals for those higher latitudes not observed by NEXRAD, which is an extensive 3-cm wavelength doppler radar network deployed over the continental United States. AMSR-E is another imaging microwave spectrometer that uses lower more transparent frequencies and is more sensitive to the absorption characteristics of precipitation, unlike AMSU which relies more on the scattering signatures of glaciated precipitation cells. AMSU accuracies compare favorably with those of NEXRAD, as evidenced by the ability of AMSU to detect degradation in NEXRAD soundings at low rain rates when the radar range exceeds ~110 km. At these greater distances

NEXRAD sounds higher in the atmosphere and consistently performs well only for rain cells that reach high altitudes.

We recently overcame the limitations inherent in use of localized ground-radar training data by retraining the retrieval algorithm using the physics-based global cloud-resolving MM5 mesoscale numerical weather prediction model running at 5-km resolution. For validation purposes 122 global storms distributed over the year were selected, each covering $\sim 10^7$ km^2 and each being observed by 20-channel Advanced Microwave Sounding Units (AMSUs) on various NOAA polar orbiting satellites. For these storms it was found that histograms of brightness temperatures predicted using MM5 and a radiative transfer program based on a rapid algorithm [1] and Mie scattering, agreed well with those observed by AMSU for the same storms [2] despite being reasonably sensitive to a wide variety of assumptions made within MM5 and within the radiative transfer program that converts MM5 state information into predicted AMSU brightness temperatures. It was also found that retrievals of surface precipitation rates and of water paths (mm) for snow, graupel (~hail), cloud ice, and rain water were usefully accurate, where this retrieval accuracy was found to be relatively insensitive to the same range of model assumptions noted above [3].

Having validated the radiative transfer algorithm using MM5 and AMSU data, retrieval algorithms for surface precipitation rate and the water path equivalents for snow, graupel, cloud ice, and rainwater were then extended to AMSU, for which the angle of incidence, microwave polarization, and surface characteristics were incorporated. Attractive retrieval accuracies were again predicted, similar to those obtained for instruments viewing nadir. This work was also supported by other NASA and NOAA programs.

Journal Articles

1. P. W. Rosenkranz, "Radiative transfer solution using initial values in a scattering and absorbing atmosphere with surface reflection," *IEEE Transactions on Geoscience and Remote Sensing,* **40(8)**, 1889–1892 (2002).

2. C. Surussavadee and D. H. Staelin, "Comparison of AMSU Millimeter-Wave Satellite Observations, MM5/TBSCAT Predicted Radiances, and Electromagnetic Models for Hydrometeors," *IEEE Transactions on Geoscience and Remote Sensing*, in press, 2006.

3. C. Surussavadee and D. H. Staelin, "Millimeter-Wave Precipitation Observations versus Simulations: Sensitivity to Assumptions," *Journal of Geophysical Research*, submitted, 2006.

Multi-Year Global Precipitation Statistical Studies

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This effort supports preparations for the NASA Global Precipitation Measurement (GPM) mission, which involves development of satellites and algorithms for monitoring global precipitation for climate and related purposes. Such precipitation and violent storms are among the key variables that might be affected by global warning.

One project is exploring the potential performance of geostationary satellites that could monitor precipitation at ~15-60-minute intervals at millimeter and sub-millimeter wavelengths located in various oxygen and water vapor absorption bands. Such microwave spectrometers would image the visible earth from geostationary orbit with ~15-25 km resolution and retrieve surface precipitation rates and the water paths (mm) of snow, graupel, cloud ice, and rain water. Two types of such instruments are being analyzed, those incorporating Cassegrain antennas with a nutating subreflector, and aperture synthesis systems incorporating hundreds of small millimeter-wave receivers and hundreds of thousands of correlators. The former readily incorporates many wavelengths and can operate at sub-millimeter wavelengths that offer higher spatial resolution, while the latter avoids mechanical scanning and can provide more frequent observations. The radiative transfer models and retrieval techniques being developed in related programs are being used to develop retrieval methods and predict the relative performance of such alternative geostationary systems. The unexpected result was that relatively modest systems, perhaps using a 1.2-meter diameter parabolic antenna, might enable hurricanes such as the one that destroyed much of New Orleans to be continuously monitored, thus potentially improving detailed forecasts.

A second project is reconciling surface precipitation rates retrieved using AMSU data with those obtained using the operational NEXRAD radar system, the operational SSM/I passive microwave spectrometer on the military DSMP satellites, and the somewhat similar TMI instrument on the NASA TRMM satellite. Preliminary results suggest that one widely used radar precipitation product may be more sensitive to snow aloft than to surface precipitation itself; fortunately snow aloft and surface precipitation rates are reasonably well correlated.

Conference Papers

C. Surussavadee and D. H. Staelin, "Precipitation Retrieval Accuracies for Geo-Microwave Sounders", to be presented at the 2006 IEEE International Geoscience and Remote Sensing Meeting, Denver, Colorado, July 29–August 5, 2006.