Remote Sensing and Estimation

RLE Group
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Self-Organizing Spectrum Allocation

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This program seeks to determine as a function of link length relative to user density the approximate limits to the average communications rate (bits/second/Hz/user) that 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, numbers of antennas and data streams employed, and multipath characteristics.

This year S. Govindasamy extended his work on infinite interference-limited networks where transmitting nodes use isotropic antennas with equal power, and receiving nodes use N controllably phased antenna elements. New results include evaluation of the spectral efficiency of random interference-limited wireless networks where a small fraction of the nodes are tethered to a high-capacity fiber backbone network, a configuration that is also relevant to cellular telephone systems. Also of interest was the observation that in an OFDM network with line-of-sight propagation interferers can be nulled in range as well as in angle by phasing the receiver antennas, and that as the number of antennas at a node increases the relative variance in nodal performance declines because the dominant interferers can be nulled by using only a modest number of degrees of freedom. Separately it was found that a recently proposed hierarchical cooperation technique for maintaining spectral efficiency as user density increases could outperform TDMA only if the number of cooperating nodes exceeded 1400; therefore the domain of practicality of such hierarchical cooperation is severely limited.

K. Herring completed his 2.4-GHz urban wireless channel observation and characterization experiments, extending his prior results. The 8-channel digital software receiver in the 2.422-GHz 802.11b (WiFi) band was equipped with software and used to characterize multiple-input-multiple-output (MIMO) wireless channels around MIT and lower Cambridge. The system synchronously samples this band using up to 8 antennas at 67 MHz per channel and 12 bits accuracy. Both the adjustable 8-antenna receiver and the transmitter are independently mobile.

Experiments showed that street-level wireless losses were typically exponential along streets, depending on the fraction of the street that allowed the radiation to escape laterally rather than being trapped between parallel walls. It was found that typical losses around street corners were 40 ± 5.5 dB, implying that most dominant inter-nodal routes would involve at most one or perhaps two street corners, and that nodes placed in the center of street intersections would provide better urban coverage. Observations of path stability over periods of 300 ms to 5 seconds led to development of a new stochastic model for single-tone propagation that predicts “fatter tails” than does the Rician distribution. The corresponding physical model replaces the Rician direct path with a sum of stable sinusoids arriving with different path lengths; this stable sum then adds to a rapidly changing sum of signals that intersect cars, pedestrians, waving trees, etc. The observed fat tails result because the sum of the strong stable paths is typically Rayleigh distributed. It was also found that the power transmitted from a tall tower to surrounding urban areas typically decays as the square of distance to the rooftops, and then there is a superimposed random zero-mean Gaussian loss of ~30±8 dB??

Journal Papers

1. S. Govindasamy, D. W. Bliss, and D. H. Staelin, "Spectral efficiency in single-hop ad-hoc wireless networks with interference using adaptive antenna arrays," *IEEE Journal on Selected Areas in Communications*, *vol. 25*, No. 7, September, 2007.

2. K. Herring, J. W. Holloway, D. H. Staelin and D. W. Bliss, “Path-loss characteristics of urban wireless channels”, submitted for publication.

3. K. Herring, D. H. Staelin, and D. W. Bliss, “Time and frequency characteristics of urban wireless channels”, submitted for publication.

Conference Papers

1. S. Govindasamy, D. W. Bliss, and D. H. Staelin, "Spectral efficiency of wireless networks with multi-antenna base-stations and spatially distributed nodes", submitted to the Asilomar Conference on Signals, Systems and Computers, Pacific Grove, CA. 2008.

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 developed and delivered algorithms that calculate microwave brightness temperatures from atmospheric temperature, humidity, and hydrometeor profiles, and that retrieve precipitation, cloud liquid water content, microwave surface emissivity, and profiles of temperature and water vapor from the microwave measurements. A stochastic algorithm for infrared cloud clearing was also developed. With this algorithm, several cloud-cleared tropospheric infrared channels for the better tropical regions differ from numerical weather predictions by ~0.2K rms.

The failure of HSB in 2003 left the microwave retrieval algorithm without any ability to discriminate the altitude distribution of cloud liquid water. Although the operational infrared retrieval algorithm does sense the altitude of cloud tops, the cloud may be frozen at the top. In this final year of the contract, we developed an approach using an AIRS water-vapor profile to initialize a second-pass AMSU-A retrieval. The second-pass microwave retrieval shows some improved discrimination of liquid-water altitude compared with the first pass, which is initialized by climatology. It is hoped that this improvement will contribute to a better forward calculation for the AMSU-A channels in the retrieval software when clouds are present.

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 do not require AMSU-A data. The clear-air retrievals were provided by C. Barnet of NOAA/NESDIS. A preliminary version of these corrections is used in the currently-operational version 5 of the processing software, and in this past year, the correction coefficients were revised and improved for version 6.

The accuracy of AMSU-A temperature profiles near the surface depends on accurate modeling of the contribution of reflected down-welling sky emission to the observed brightness temperature. [1] For the ocean surface, the effect of roughness on reflection of down-welling emission is represented in the operational software by an effective zenith angle which varies with wind speed. Over all other types of surfaces the operational software models the surface scattering as Lambertian. However, our recent analysis of AMSU-A measurements over Antarctica shows that a better model for some ice-covered areas would be intermediate between specular and Lambertian scattering. [2] The average over the continent is a combination of 84% Lambertian and 16% specular reflection. We also found that the specular fraction is correlated with polarization of the ice at 37 GHz, measured by the SSM/I instrument on DMSP satellites.

Journal Articles

1. C. Mätzler and P. W. Rosenkranz, "Dependence of Brightness Temperature on Bistatic Surface Scattering: Model Functions and Applications to AMSU-A," *IEEE Transactions on Geoscience and Remote Sensing*, **45 (7)**, 2130-2138 (2007).

2. 2. P. W. Rosenkranz, "Emission and Scattering Effects in Passive Microwave Observations of Antarctica," International Geoscience and Remote Sensing Symposium, Boston, Massachusetts, July 7-11, 2008.

ATMS Contributions to Sounding Products

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This cooperative effort supports the NASA National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Program (NPP) before its launch, particularly with respect to the contributions of the Advanced Technology Microwave Sounder (ATMS) to sounding products such as global temperature and humidity profiles and precipitation. The NPP satellite mission is a critical step in ensuring the success of follow-on NPOESS satellites carrying similar instruments, and the quality of their Climate Data Records (CDR's).

The studies supporting ATMS are based on data from the Advanced Microwave Spectrometer Unit (AMSU) flying on operational NOAA weather satellites. Earlier comparisons of the AMSU millimeter-wave brightness temperatures at high scan angles with those expected based on laminar numerical weather prediction models showed that the satellite saw warmer clouds than expected in the coldest pixels. This led to the hypothesis that tall cumulonimbus clouds dominate these coldest pixels and that multistream radiative transfer models must be used in combination with non-laminar atmospheric models to predict accurately high-angle brightness. This hypothesis is now being tested.

Algorithms for generating global NPP precipitation retrieval products are being developed and tested. Initial simulations show that ATMS will generally outperform AMSU slightly in its ability to image and retrieve global precipitation [1]. Precipitation retrievals are being developed jointly with other programs; this work and its publications are summarized here under “Multi-Year Global Precipitation Statistical Studies”. This effort also involves study of instrument issues relevant to NPP mission planning.

Conference Papers

1. C. Surussavadee and D. H. Staelin, " NPOESS precipitation retrievals using the ATMS passive microwave spectrometer”, IEEE International Geoscience and Remote Sensing Meeting, Boston, Massachusetts, July 7–11, 2008.

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 continued 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.

The near-real-time MIT RLE precipitation retrieval system that became operational in August 2007 receives all passive microwave spectral image data observed by operational NOAA weather satellites and estimates surface precipitation rates (mm/h) and retrieved water paths (mm) for rain water, snow, graupel, and other constituents, as well as peak layer vertical wind speed (m/s). Each of the NOAA-15, NOAA-16, and NOAA-17 satellites observes most points on the globe twice per day, and radiance data back to 2000 has been archived. This system has been improved by reducing its sensitivity to unknown surface properties and thereby reducing the number of false detections. Progress in this joint effort is summarized here under “Multi-Year Global Precipitation Statistical Studies”.

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

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This research effort concluded this year; it contributed to the development of precipitation estimation methods using AMSU/HSB and AMSU-A/B passive microwave satellite observations. The method uses a physics-based global cloud-resolving MM5 mesoscale numerical weather prediction model running at 5-km resolution to train neural-network estimators. One important final conclusion was that although the predicted atmospheric brightness temperature spectra are quite sensitive to physical assumptions in the MM5 and radiative transfer models, the accuracy of precipitation estimates is not, provided the physical models are known [1]. This work was also supported by other NASA and NOAA programs,

Journal Articles

1. C. Surussavadee and D. H. Staelin, "Millimeter-Wave Precipitation Retrievals and Observed-versus-Simulated Radiance Distributions: Sensitivity to Assumptions", *Journal of the Atmospheric Sciences*, vol. 64, pp. 3808-3826, November, 2007.

Multi-Year Global Precipitation Statistical Studies

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This broad effort ended in September, 2007. Its major accomplishments include: 1) development and validation of the ability of opaque millimeter-wave channels 50-200 GHz to retrieve most types of global precipitation, including rainfall and snowfall rates and various hydrometeor water paths at ~15-km resolution [1, 2], 2) documentation of accomplishment (1) sufficient to provide strong support to the successful proposal to incorporate such channels in the NASA Global Precipitaion Measurement (GPM) core satellite that will extend and improve the precipitation observations of the Tropical Rainfall Measuring Mission (TRMM) equatorial satellite, 3) development of improved radiative transfer expressions for millimeter-wave propagation in clouds and precipitation 50-430 GHz based on Mie scattering tuned to DDSCAT computations for hexagonal plates and six-pointed rosettes, and consistent with AMSU observations below 190 GHz, 4) use of these expressions to evaluate the relative precipitation retrieval performance of several promising filled-aperture and synthetic-aperture millimeter-wave geostationary satellite concepts [3], and 5) preliminary establishment of a real-time precipitation retrieval system to reduce all available AMSU data from the NOAA-15, -16, and -17 satellites for wide use by researchers.

Journal Articles

1. C. Surussavadee and D. H. Staelin, "Global Millimeter-Wave Precipitation Retrievals Trained with a Cloud-Resolving Numerical Weather Prediction Model, Part I: Retrieval Design," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 46, 1, pp 99-108, 2008.

2. C. Surussavadee and D. H. Staelin, "Global Millimeter-Wave Precipitation Retrievals Trained with a Cloud-Resolving Numerical Weather Prediction Model, Part II: Performance Evaluation," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 46, 1, pp 109-118, 2008.

3. D. H. Staelin and C. Surussavadee, "Precipitation retrieval accuracies for geo-microwave sounders," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, 10, pp 3150-3159, 2007.

Conference Papers

1. C. Surussavadee and D. H. Staelin, " Global Satellite Millimeter-Wave Precipitation Retrievals Trained with a Cloud-Resolving Numerical Weather Prediction Model", IEEE International Geoscience and Remote Sensing Meeting, Barcelona, Spain, July 23–27, 2007.

2. C. Surussavadee, D. Staelin, V. Chadarong, D. McLaughlin, and D. Entekhabi, “Comparison of NOWRAD, AMSU, AMSR-E, TMI, and SSM/I Surface Precipitation Rate Retrievals over the United States Great Plains”, IEEE International Geoscience and Remote Sensing Meeting, Barcelona, Spain, July 23–27, 2007.

Study of Millimeter-Wave Satellite Precipitation Retrieval Algorithms Using MM5 Simulations

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This effort began in January 2007 and is extending prior advances in global millimeter-wave precipitation measurements. Analyses of the prior precipitation algorithm for retrieving global precipitation rates (mm/h) using the Advanced Microwave Sounding Unit (AMSU) on the operational NOAA-15/16/17/18 satellites revealed limited sensitivity to stratiform precipitation at high latitudes and occasional false detections of precipitation over some deserts and snow- or ice-covered surfaces in extremely dry climates. A less surface-sensitive version of this algorithm was recently developed that is able, for the first time, to retrieve snow and rain storms over the North Pole with reasonable accuracy, as suggested in Fig. 1, which shows rain and snow images observed 24 hours apart on June 20 and June 21, 2006. Pink indicates snow or sea ice, and dark pink indicates surface elevations too high to permit reliable retrievals. Such retrievals have previously been handicapped by the tendency of snowfall to resemble the snow on the ground below, at nearly all wavelengths. This newly demonstrated ability to map polar precipitation in combination with the changing extent of the polar ice cap could significantly improve our understanding of this climatologically fragile region and its future.

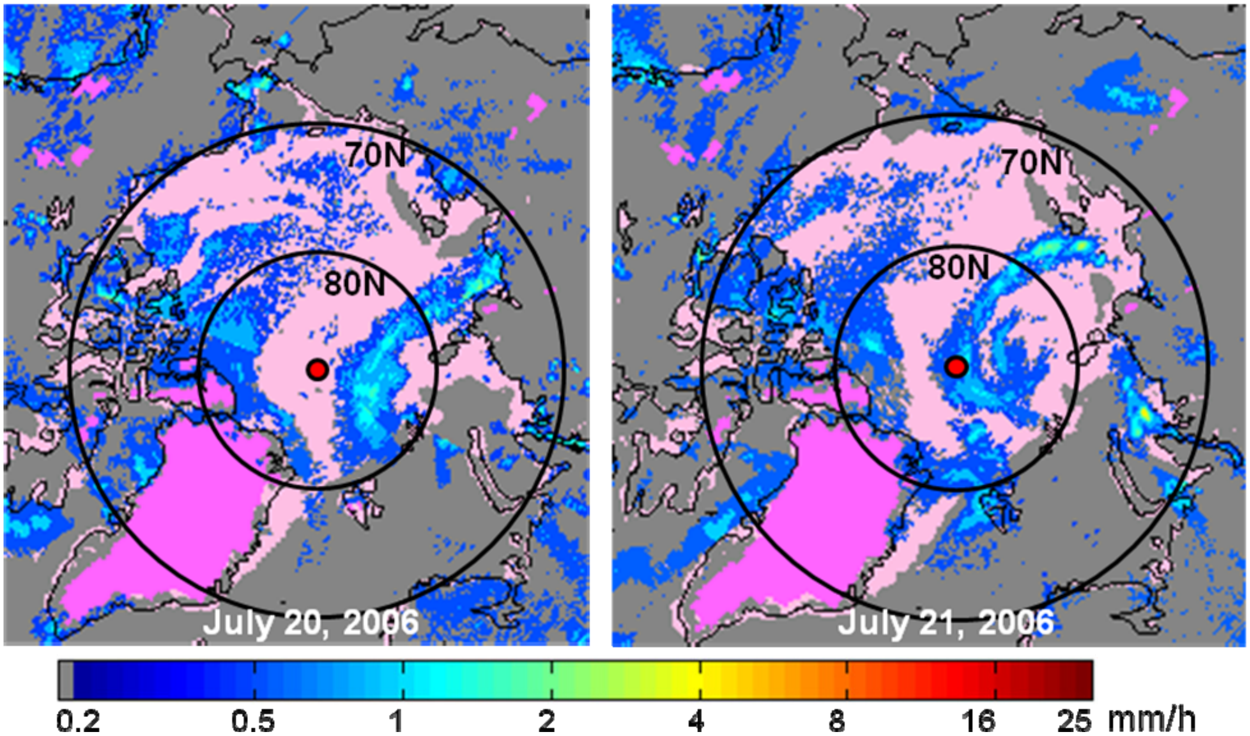

Figure 1. Precipitation rates (mm/h) retrieved over the North Pole using AMSU on the NOAA-16 operational meteorological satellite on July 20 and 21, 2006. The spatial resolution is approximately 15-20 km. Light pink represents sea ice or surface snow, and dark pink represents surface elevations to high to permit reliable retrievals.

Conference Papers

1. C. Surussavadee and D. H. Staelin, " Rain and snowfall retrievals at high latitudes using millimeter wavelengths", IEEE International Geoscience and Remote Sensing Meeting, Boston, Massachusetts, July 6-11, 2008.

Spike-timing model for neural signal processing and learning

Project Staff

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How newborns modify their brains and learn rapidly is still largely unknown. Current minimal-learning-circuit models for neocortex generally incorporate many neurons that are trained (rewarded) collectively. Multi-neuron learning circuits (MLC) are required because current single-neuron models are generally too simple for an output spike to indicate "computational success" worthy of reward. Unfortunately, multi-neuron MLCs train relatively slowly. A new model was developed in this work that shows how a single neuron could learn several complex patterns by employing trainable delays in spike propagation times, and therefore could train by itself much more rapidly. For example, a single simulated neuron using trainable delays learned in one second to recognize six digital patterns randomly selected from a corpus exceeding 10^7; it did so simply by "staring" at those patterns using neural parameters plausibly consistent with observations and inferred infant learning rates.

Although axon arbors convey spikes with all possible delays to their many synapses, in this spike-timing model only certain synapses are positioned to define a “pattern” that is recognized when those input spikes all arrive synchronously to sum and then fire that output neuron. The ~1-ms time slot of any output spike stimulated by that synchrony then conveys the input pattern identity, just as the meaning of each input spike was determined by its own exact timing. Synchrony windows of roughly one millisecond have been observed in dendrites. Each such spike-timing neuron therefore approximates a time-multiplexed logic circuit performing distinct logic functions in each time slot, and a neural circuit with even a few layers can characterize very complex arrays of recognizable patterns. The strength of each synapse is trained by spike-timing adaptive potentiation (STAP), where only those synapses excited immediately before the output spike was produced are strengthened, while others may be weakened; such behavior has also been observed.

The required spike delays within a single neuron range up to tens of milliseconds where, for example, 20-ms delays correspond to plausible 10-cm/s velocities on 2-mm-long axons. Neural models with such slow spike propagation velocities require very small neural cross-sections, which may help explain why the $\sim 10^{-14}$ m^2 cross-sections of the finest cortical axons are roughly 100 times smaller than those of the thinnest dendrites, and the total axon length per neuron is approximately ten times greater.

The first computer simulations of this model have shown that a single neuron that “stares” at an important pattern can quickly (~1 sec) learn several such patterns or digital words in sequence, each having ~10-25 bits of information, and assign them code names having ~3-4 information bits that are presented whenever the corresponding patterns or pattern classes reappear. Although a single neuron might fire at an inappropriate instant perhaps 3-10 percent of the time (roughly once per second), consensus circuits can remedy this potential problem. This simulated rate of learning is roughly consistent with nominal average infant learning rates of perhaps 10^5 bits/s, which is indicated if infants train roughly $\sim 10^{13}$ synapses in three years ($\sim 10^8$ s total); adults have perhaps 10^{14}-10^{15} synapses.

This model depends on sensory systems coding excitation strengths as pulse timing relative to a reference time with 1-ms accuracy. Recent evidence for this has been found in the retina of salamanders when excited by flashed novel images resembling visual stimuli during saccades [1]. The spike-timing model developed here should be capable of learning and then recognizing patterns represented by the relative timing of the spikes produced in response to the flashed retinal excitation of these salamanders.

Journal Articles

1. T. Gollisch and M. Meister, “Rapid Neural Coding in the Retina with Relative Spike Latencies“, Science, vol. 319, pp 1108-1111, 2008.