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COMMUNICATION TECHNIQUES IN STRESSED ENVIRONMENTS

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FINAL TECHNICAL REPORT

1 July 1988 - 30 September 1991

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PAPERS PROCESSED/SUBMITTED/PUBLISHED[1]

Publications - Victor Li

- Ming Yin and Victor O.K. Li, "Throughput of Single-Hop Unslotted CDMA Networks with Fixed Packet Lengths", *Proceedings MILCOM 88*, San Diego, CA, October 1988. (15 reprints 1/89)

A B S T R A C T

The throughput analysis of unslotted CDMA system requires the joint distribution of bit errors for all bits in a packet. In this paper, we present a recursive method to compute the joint distribution of bit errors for single hop unslotted CDMA networks with deterministic packet lengths. A special case, the L-Channel model, is analyzed in detail. Its complexity is shown to be $O(M^3)$ where M is the number of bits per packet. We also analyze the throughput improvement by using a channel sensing protocol.

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- Rong-Feng Chang and Victor O.K. Li, "Performance Analysis of Mobile Packet Radio Networks", *Proceedings IEEE INFOCOM*, Ottawa, Canada, April 1989. (15 reprints 1/89)

A B S T R A C T

A model is proposed for analyzing the performance of a Mobile Packet Radio Network. In this network a node is allowed to move around with a random velocity. Hence the distribution of the number of nodes in one's transmission circle is dependent on the mobility of the nodes. We develop a queueing model to evaluate this distribution and the effects of node mobility on system performance. This effect cannot be obtained by the classical two-dimensional Poisson model. It is found that an optimal power radius is dependent on the node mobility.

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- Rong-Feng Chang and Victor O.K. Li, "Local Access Algorithms in Hierarchical Mobile Packet Radio Networks," *Proceedings, INFOCOM '90*, San Francisco, CA, June 1990. (15 reprints 6/90)

A B S T R A C T

[1]A number of published manuscripts acknowledged support from the previous ARO contract DAAG29-85-K-0116

In this paper, we present two local access algorithms in a hierarchical mobile packet radio network where each user transmits with a fixed or an adjustable transmission radius, respectively. We develop a model for analyzing these two access schemes and show that the network can achieve better performance if each node uses an adjustable transmission radius. Previous research assumed a static two-dimensional Poisson model to describe the distribution of users, and cannot fully characterize the effect of user mobility. Our proposed model accounts for this effect.

Publications - Andreas Polydoros

- S. Hinedi and A. Polydoros, "DS/LPI Autocorrelation Detection in Noise Plus Random-Tone Interference", *Proceedings MILCOM 88*, San Diego, CA, October 1988. (15 reprints 1/89)

A B S T R A C T

We present and analyze a frequency-noncoherent, two-lag autocorrelation statistic for the wideband detection of random BPSK signals in noise plus random multi-tone interference. It is shown that this detector is quite robust to the presence or absence of interference and its specific parameter values, contrary to an energy detector. The rule assumes knowledge of the data rate and the active scenario under H_0. The purpose of the paper is to promote the real-time autocorrelation domain and its samples (lags) as a viable approach for detecting random signals in dense environments.

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- Char-Dir Chung & Andreas Polydoros, "Epoch Synchronization of Random FH Signals in Broadband Noise", *Proceedings MILCOM '90*, pp. 38.1.1-5. (15 reprints 12/90)

A B S T R A C T

We present an epoch-synchronization scheme of random FH signals in broadband noise, which operates on the power-samples of the real-time autocorrelation function of the received waveform. The scheme takes advantage of the fact that power sampling in the correlation domain suppresses frequency and phase dependence, but preserves timing information, in order to construct a maximum-likelihood epoch estimation algorithm where the hopping pattern need not be known. The conditional mean and variance of this estimator are derived analytically and confirmed by simulation.

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- Char-Dir Chung & Andreas Polydoros, "On the Detection and Parameter Estimation of Random FH Signals" Autocorrelation Technique", *Proceedings MILCOM '91.* (15 reprints 11/91)

ABSTRACT

In this paper, a multiple-hop-observation autocorrelation (MHAC) processing is modeled to intercept the random frequency-hopping (FH) signals in broadband noise. It is shown that the power-sampling in the MHAC domain suppresses frequency and phase dependence, contrary to spectral-domain processing; moreover, timing (or epoch) information becomes insignificant as a large number of hops is processed. On the other hand, the hop rate information is preserved. This is the feature of MHAC power-sampling processing. Operating on the feature of MHAC samples of the received signal, a hop-rate estimation scheme and multi-hop detection scheme are developed and analyzed. The proposed detection scheme does not depend on the knowledge of the signal parameters, such as signal power, hop transition times, hopping frequencies and phases, and hop rate, while its detection performance does depend on the hop rate. The performance comparison of this detector and radiometer, the time-domain energy-based detector, is obtained. The hop-rate estimator is an approximate maximum-likelihood (ML) estimator based on the power sum of the MHAC samples. In composing this estimator, the only crucial requirement is that the uncertainty region of the signal's hop rate needs to be known a priori. The conditional mean and variance of this estimator are derived analytically and confirmed by simulation.

Assuming known hop rate, a simplified autocorrelation (AC) processing, single-hop-observation autocorrelation (SHAC) processing, is also modeled for synchronizing the hop transition times of the random FH signals. Operating on the SHAC power samples, an epoch-synchronization scheme is developed. The scheme takes advantage of the fact that power sampling in the SHAC domain suppresses frequency and phase dependence, but preserves timing information, in order to construct an approximate maximum-likelihood epoch estimation algorithm where the hopping pattern need not be known. To improve the estimation performance, a multiple-hop-combining ML epoch estimator is also shown. Its estimation performance is also analyzed and confirmed by simulation.

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- Char-Dir Chung & Andreas Polydoros, "Generalized Likelihood-Ratio Detection of Frequency-Hopping Signals in Broadband Noise," *Proceedings MILCOM '91.* (15 reprints 11/91)

ABSTRACT

A noncoherent receiver that detects multiple-hop frequency-hopping (FH) signals is developed based on the generalized likelihood-ratio test (GLRT) theory. Hop rate, hop transition times, and the set of candidate carrier frequencies are assumed known throughout the paper. The proposed receiver has a simple architecture and consists of a bank of envelope filters, a maximum operator, an accumulator, and a threshold device. For large number of the the observed signal hops, this receiver is analyzed on the basis of a Central-Limit Theorem (CLT) argument. A simple formula that relates the detection probability, the false alarm

probability, and the signal-to-noise ratio is found adequate for performance measure. This CLT-based analysis is justified by simulation. We also evaluate the detection performance of this proposed receiver in terms of the relationship of the detection probability and per-hop signal-to-noise ratio for several sets of false alarm probabilities, numbers of the signal hops being observed, and numbers of the candidate frequency slots. The detection performance comparison with the conventional detectors is also obtained.

Publications - Robert Scholtz

- Charles N. Franz and Robert A. Scholtz, "The Calibration of Distorted Airborne Imaging Arrays Using Coherent Observations of Radar Clutter", *Proceedings of the International Conference on Radar*, Paris, France, April 20-24, 1989. (15 reprints 1/89)

A B S T R A C T

Unknown geometric distortion can degrade the radiation pattern of an antenna array. It introduces electrical path-length errors which destroy the required phase relationship between the signals that are coherently combined in the beamforming process. If these errors exceed the carrier wavelength, they will not be compensated using conventional postprocessing autofocus techniques. This report summarizes the results of an investigation of coherent land-clutter-based calibration techniques which compensate the effects of this distortion in airborne arrays. It is noted that these techniques do not apply to the calibration of synthetic arrays.

It is assumed that the array operates in diffuse clutter for which it may not be possible to range gate a dominant scatterer. Consequently, coherent processing is invoked to form range-doppler cells which emulate the characteristics of an ideal point source. With existing techniques, the synthetic arrays which are formed in this process must provide resolution that is much finer than that of the real array. This study develops techniques which enable this requirement to be relaxed. This is achieved by processing additional dimensions of the clutter which are correlated with the parameters that must be estimated in the calibration. The use of this additional information is seen to provide a fivefold reduction in synthetic array length for realistic design parameters. The approach of the investigation is to model the clutter observations, apply classical estimation theory techniques, and then evaluate the performance of the resulting estimators.

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- Seok-Ho Kim and Robert A. Scholtz, "An Optimum Generalized Cross- Spectrum Symbol-Rate Detector", accepted by the *IEEE Transactions on Communications.* (1 preprint 6/90)

ABSTRACT

Optimal design of a pre-correlation filtering system for use in cross-spectrum symbol-rate detectors in the presence of additive Gaussian noise is described. The design generalizes practical cross-spectrum symbol-rate detectors, and derives the necessary condition which achieves the maximum processed signal-to-noise ratio as an integer multiple of the symbol rate. The resultant optimum condition is a function of the transfer functions of pre-correlation filters and fixed signal model parameters. As a by-product, the performance measure applicable to any quadrature amplitude modulation format is derived, including the effect of self-noise and inter-symbol interference. An algorithm for realizing pre-correlation filters that satisfy the optimum condition, with the constraints such as causality and stability, is also given.

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- Dong-In Kim and Robert A. Scholtz, "Multiple Capture in a Centralized Packet Radio System with Common Direct-Sequence Spread-Spectrum Modulation", *Proceedings of the Fifteenth Biennial Symposium on Communications*, June 3-9, 1990. (15 reprints 6/90)

ABSTRACT

In this paper a multiple capture model is presented in a centralized packet radio system with common direct-sequence spread-spectrum modulation. Basic equations for the multiple capture probability and throughput performance are derived at the central receiver. At the link-level, we evaluate the expected number of packets captured at the receiver and the maximum number of simultaneous transmissions supportable at a specified data bit-error rate and probability of packet capture. Using the Block Oriented Systems Simulator (BOSS), simulations were carried out for the DS/BPSK packet radio system, and results from the simulation are compared with theoretical evaluations of the multiple capture probability. It is shown that the multiple capture model has significantly higher system throughput than a single capture model.

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- Arie Reichman & Robert A. Scholtz, "Joint Phase Estimation and Data Decoding for TCM Systems," submitted to *1991 International Symposium on Communication Theory and Applications.* (Summary published)

ABSTRACT

In order to obtain the accurate phase estimate that is necessary to process trellis-coded modulation (TCM) in a receiver, several methods for jointly estimating the data sequence

and the phase ar e proposed. The process of phase acqusition and tracking can be embedded in Viterbi demodulator for TCM, without increasing the number of states or tran sitions.

Several *ad hoc* approaches can be constructed, depending on the nature of the phase process to be tracked, e.g., constant unknown phase, constant unknown frequency, phase diffusion process, etc. All are based on the following idea: Each state s_n at time n in the Viterbi algorithm of the trellis-code demodulator is augmented by a complex number $\hat{z}(s_n)$ that is a decision-directed estimate, based on the transmitted symbols that lead to the state s_n of $e^{i\phi_n}$, where ϕ_n is the phase of the carrier at time n.

It is a low-complexity phase tracking algorithm of this type, the phase-information-bearing complex numbers are recursively updated for each state sequence tracked by the trellis-code demodulator. Some of these simple schemes can be shown to produce optimum estimates of the true complex phase e^{ϕ_n} at the true state in the trellis decoder.

These phase-tracking schemes can be made adaptive to phase variations by inserting a forgetting factor in the complex phase estimator, e.g., $\hat{z}(s_{n+1}) = w(s_{n+1}, s_n) + \lambda\hat{z}(s_n)$, $|\lambda| < 1$, where $\hat{z}(s_n)$ denotes the complex phase estimate that is based on the transmitted waveform that drives the trellis code demodulator to state s_n, $w(s_{n+1}, s_n)$ is the estimate of the current complex phase based on the transmitted waveform that corresponds to the state transition to s_{n+1} from s_n, and λ is the forgetting factor. The structure just described arises naturally in the linear minimum-mean-square estimation of $e^{i\phi_n}$ from noisy samples of the same process when ϕ_n is a diffusion process and the noise is additive and white. In this case optimal forgetting factor values can be specified for any signal-to-noise ratio and phase-increment standard deviation.

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- R.E. Peile and R.A. Scholtz, "Adaptive Channel/Code Matching Using Hidden Markov Chains," *Proceedings Twenty-Fourth Asilomar Conference on Signals, Systems and Computers*, November 5-7, 1990. (15 reprints 12/90)

A B S T R A C T

Presently, a communication system designer is faced with a large variety of commercially available coding techniques. With regard to the choice, the standard advice is to "know thy channel" and pick a code accordingly. This conventional wisdom ignores the practical point that few system designers know their channel perfectly, or that a single system-wide stationary channel may not be approximately knowable *a priori* or may not even exist! Given the diversity and uncertainty of possible channel conditions, the logical design approach is to select a family of codes capable of meeting the majority of situations in which communication is required. Current coding technology can provide a family of codes, working at practical data rates, implemented in a small package. Concatenated codes, composed of the above types of hardware, are well-suited for harsh channels. A concatenated code consists of two codes in series, with the code whose encoder and decoder are nearest the channel being known as the *inner* code and the remaining code being the *outer* code. Inner codes are typically

either short binary codes or a convolutional codes, while for sound technical reasons, the outer code is nearly always a RS code. Consequently, the range of concatenated codes available for selection, even using the above present day equipment, is large.

The design approach of selecting a family of codes raises a control issue: How is the most suitable member of the family selected when the equipment is in operation. It is important to note that adaptive coding works in a different fashion on different channels. Some channels are noisy but statistically stationary, i.e., their characteristics are not time-varying. For such channels adaptive coding amounts to an automatic configuration upon activation, and this might even be done manually. However, manual selection can be difficu't on *real* channels, even for experts, and hence for efficiency and ease of use, automation is desirable and, in some arenas, essential.

Other channels are not stationary and the quality worsens and improves with time, e.g., the notorious HF skywave propagation media. In this environment, an adaptive coding algorithm must constantly check and adjust the strength of the code. In such extreme circumstances, a fixed code will not be even approximately suitable; if the code were chosen to match one of the many "worst case" conditions, it will be extrava gently redundant for the benevolent periods of high channel quality. Conversely, if a code is su ited for the channel's good periods, it will collapse during the periods of low channel quality. Neither extreme is acceptable and the code must be changed automatically in reaction to varying conditions.

If a decoder is working, it can accumulate enough information to determine when adaptation is necessary simply by monitoring its own performance, e.g., the numbers and relative *locations* of errors that it corrects or detects, and the occurrences of *impossible-to-decode* situations in the decoder. It should then be able to tell if the channel tends to produce error bursts or errors that are purely random, and estimate the necessary probabilities associated with these effects. This may not be the most accurate way to make adaptation decisions because it ignores other sources of channel quality information that might be present elsewhere in the receiver, but it is simply conceptually and has the virtue of design modularity and transportability. In this paper, we will explore a method by which a decoder monitors its own performance, estimates a channel model, assesses its quality, and if desirable, initiates changes in the coding system.

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- Dong-In Kim and Robert A. Scholtz, "A Random Spreading Code Assignment Scheme for Centralized Spread-Spectrum Packet Radio Networks," *Proceedings MILCOM '91.* (15 reprints 11/91)

ABSTRACT

This paper presents a random spreading code assignment scheme for enhancing channel efficiency in centralized spread-spectrum packet radio networks which employ a multiple capture receiver for each code channel. Compared to the common code case, this approach requires modest increase in receiver complexity, but the number of distinct spreading codes

being used is considerably less than the number of radios in the network. The capture and throughput performance of the random assignment scheme is evaluated for a proper set of codes, and compared with the theoretical results from the common code scheme. It is shown that the use of random assignment scheme with more than one code results in a higher performance gain, and most of this gain can be achieved with just two distinct spreading codes.

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- In-Kyung Kim and Robert A. Scholtz, "Adaptive Threshold Control Scheme in a Centralized Packet Radio Network with Common Direct-Sequence Spread-Spectrum Modulation," *Proceedings 25th Annual Asilomar Conference on Signals, Systems, and Computers*, November 4-6, 1991, Pacific Grove, CA. (15 reprints 11/91)

A B S T R A C T

This paper describes an automatic threshold control scheme for the detection of a header which is a frame synchronization word in a centralized packet radio network in which all communicators employ a common direct-sequence spread-spectrum modulation format.

This scheme yields a false-alarm probability which is nearly invariant to the changes in the number of actual transmissions in the channel, and a detection efficiency essentially free of loss with respect to the ideal detection when the multiple access noise level is known to the receiver.

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- Ranjan K. Mallik, Robert A. Scholtz and George P. Papavassilopoulos, "On the steady state solution of a two-by-two dynamic jamming game with cumulative power constraints," *Proceedings 25th Annual Asilomar Conference on Signals, Systems, and Computers*, November 4-6, 1991, Pacific Grove, CA. (15 reprints 11/91)

A B S T R A C T

The process of jamming can be modelled as a two-person zero-sum non-cooperative dynamic game played between a communicator and a jammer over a number of discrete time instants. The simplest case is when, at each instant, the communicator and jammer randomize their strategies between idleness and transmission. The payoff (throughput) matrix is then two-by-two, with one variable throughput. The cost is the average payoff summed over time, to be optimized subject to cumulative power constraints. We find an analytical steady-state solution for the game played over an infinite time duration. Results show that when the throughput is lower than a threshold, the optimal strategies are mixed, and the cost increment constant; otherwise the strategies are pure, with the cost increment exhibiting oscillatory behavior.

Publications - Charles Weber

- Yu Teh Su and Charles L. Weber, "A Class of Sequential Tests and Its Applications", [2] accepted for publication in the *IEEE Transactions on Communications*, 1989. (1 preprint 7/89)

A B S T R A C T

Two iterated algorithms to evaluate the performance of a class of sequential tests are porposed. The goal is equivalent to computing the distribution function of the first passage time for a random walk to cross a one-sided barrier. Limitations on both algorithms are studied, and associated methods to eliminate those limitations when possible are derived. These algorithms are then applied to a PN code acquisition system and a range-sampled Radar searching problem. Related computational problems are discussed and numerical results are given.

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- Tao Chen and Charles L. Weber, "Bit Error Rate Simulation of Non-linear Digital Systems via Conditional Importance Sampling," submitted for presentation to *Globecom '89*. This paper was presented at the *1990 Information Theory Symposium* in San Diego, CA. (1 preprint 7/89)

A B S T R A C T

A new variation of *importance sampling*, designated as *conditional importance sampling*, or CIS, is proposed for the simulation of bit error rate in nonlinear digital communication systems. *Monte Carlo* simulations are simple and tractable in simulating the bit error rate, but is prohibitively slow when errors are rare. *Importance sampling* is a variation of *Monte Carlo* to increase the simulation speed by altering the input density functions and weighting the output to have an unbiased estimator. Earlier research concentrated on fixed amount of bias in the input noise pdf for every simulation trial. We extend the biasing to the phase error pdf, and, to utilize more of the knowledge we have about the system, we suggest the *conditional importance sampling*. That is, biasing the probability density functions of some input variables according to the values of other ones. The estimator variances of CIS are evaluated for some simple systems, and the resulting improvements over standard *Monte Carlo* are significant.

[2] This paper, supported in part by a previous ARO Contract, was presented at the MILCOM '84 Conference, Los Angeles, CA, October 21-24, 1984

Publications - James R. Yee

- Song-Chyau Liang and James R. Yee, "A Gateway Allocation Algorithm for Interconnecting Existing Data Networks", *Proc. IEEE INFOCOM*, April 1989. (1 preprint 1/89)

A B S T R A C T

This paper considers the problem of interconnecting two virtual circuit networks. More specifically, the problem is to determine (i) which nodes (one from each network) should be connected by gateways and (ii) the routing assignments to minimize the routing costs subject to a limitation on the cost of the gateways. This problem is NP-hard. We formulate the problem as a linear combinatorial optimization problem. We propose a two phase algorithm to obtain good solutions. The first phase is a greedy heuristic algorithm. The second phase is an algorithm based upon Lagrangian relaxation with the subgradient method. This method has been implemented. In our computational experiments, the method determines gateway locations to interconnect networks (of various sizes) that are within a few percent of an optimal solution in a few minutes of CPU time.

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- Ming-Jeng Lee and James R. Yee, "An Efficient Near-Optimal Algorithm for the Joint Traffic and Trunk Routing Problem in Self-Planning Networks," *Proc. INFOCOM 89*, and submitted to *J. on Selected Areas on Communications.* (1 preprint 1/89)

A B S T R A C T

A *self-planning network* can adjust its configuration and routing according to the current traffic conditions. The joint problem of determining the best configuration and routing assignment is a fundamental problem in the design of a self-planning network. In this paper, we first formulate the configuration and routing problem (or the *joint trunk and traffic routing problem*) as a mixed integer nonlinear minimization problem. Then we prove certain properties about the problem structure. These properties lead to an efficient algorithm that can determine a near-optimal solution. This algorithm is used to find the best configuration and routing assignment for several networks. We also compute a lower bound in order to evaluate the quality of the solution. Computational experiments confirm that the algorithm is effective and efficient.

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- James R. Yee, "Optimal Distributed Routing Algorithms for Datagram Communication Networks." *Proceedings of the Allerton Conference on Communications, Control, and Computing*, 1989. (1 preprint 1/90)

A B S T R A C T

We consider the problem of routing in a communication network with datagram service. Relationships among four optimality conditions are presented. Two distributed algorithms are derived. The main idea underlying the construction of these algorithms is the use of a vector of step sizes. This results in an algorithm with better descent properties than those in the literature.

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- James R. Yee and Feng-Min Shiao, "On Calculating High Throughputs in Multi-Hop Slotted ALOHA Packet Radio Networks." *Proceedings IEEE INFOCOM '90* (15 reprints 7/90)

A B S T R A C T

In this paper, we investigate the problem of determining routing assignments in slotted ALOHA packet radio networks to maximize the end-to-end throughput. It is assumed that the networks have an arbitrary topology and the relative traffic requirements matrix is arbitrary. We formulate the problem as a nonlinear programming problem. Unfortunately, the problem is not a convex program which explains why the development of an algorithm to find global optimal solutions has been so elusive. We develop a heuristic algorithm based upon ideas from resource directive decomposition. We apply our heuristic to several standard problems. The numerical results show that our method compares favorably to other methods in the literature.

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- James R. Yee and Yeong-Sung Lin, "A Routing Algorithm for Virtual Circuit Data Networks with Multiple Traffic Types." submitted to *Networks*. (1 preprint 1/90)

A B S T R A C T

In this paper the routing problem in virtual circuit networks is considered. In virtual circuit networks, all of the packets in a session are transmitted over exactly one path established between the origin and the destination. For each origin-destination pair, it is assumed that there are multiple sessions and different types of sessions (data, video, voice and file transfer). We consider the problem of choosing a path for each session so as to minimize the average packet delay in the network. We formulate this problem as a nonlinear multicommodity flow problem with integer decision variables.

An iterative scheme which is similar to local search is developed to solve this problem. In each iteration, we apply Lagrangean Relaxation and a multiplier adjustment procedure to solve a restricted problem. In computational experiments our algorithm determines solutions that are within 1% of an optimal solution in minutes of CPU time for networks with 26 to 61 nodes. In addition, we show that our proposed algorithm is better both theoretically and computationally than the $K(0)$-ordering, single-path routing and the round-off Frank-Wolfe heuristics.

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- Feng-Min Shiao and James R. Yee, "On Determining the Transmission Range for Multi-Hop Slotted ALOHA Packet Radio Networks", *Proceedings MILCOM 90*, Monterey, CA, October 1990. (15 reprints 6/90)

A B S T R A C T

In this paper, we investigate the problem of determining the transmission range for stations and the routing assignments in slotted ALOHA packet radio networks to maximize the end-to-end throughput. It is assumed that the location of the nodes and the relative traffic requirements matrix are arbitrary. We formulate the problem as a non-linear programming problem. We show that the problem can be solved by solving a polynomial number of routing problems. Our solution procedure is used to solve the joint transmission range and routing problem for several typical packet radio networks.

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- James R. Yee and Yeong-Sung Lin, "A Routing Algorithm for Virtual Circuit Data Networks with Multiple Traffic Types." to appear *Networks*. (1 preprint 1/90, 1 revised preprint 6/90)

A B S T R A C T

In virtual circuit networks, all of the packets in a session are transmitted over exactly one path established between the origin and the destination. For each origin-destination pair, it is assumed that there are multiple sessions. We consider the problem of choosing a path for each session so as to minimize the average packet delay in the network. We formulate this problem as a nonlinear multicommodity flow problem with integer decision variables.

An Iterative scheme which is similar to local search is developed to solve this problem. In each iteration, we apply Lagrangean Relaxation and a multiplier adjustment procedure to solve a restricted problem. We show that the Lagrangean dual problem can be solved exactly by solving a convex program. In computational experiments our algorithm determines solutions that are within 1% of an optimal solution in minutes of CPU time for networks with 26 to 61 nodes. In addition, we show that our proposed algorithm is better both theoretically and computationally than the K(0)-ordering, single-path routing and the round-off Frank-Wolfe heuristics.

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- Ming-Jeng Lee and James R. Yee, "Minimax Routing in ATM Networks", submitted for presentation at *IEEE GLOBECOM '90.* (15 reprints 12/90)

A B S T R A C T

Asynchronous Transfer Mode (ATM) networks has been adopted by the CCITT as the transport network in which broadband iSDN will be based. In this paper, we formulate the problem of routing cells in an ATM network as an optimization problem. The objective is to minimize the largest cell loss probability. The constraints correspond to a multicommodity network flow problem with gains. An algorithm to determine a global optimal flow assignment is presented. The minimax routing algorithm was implemented and tested on several sample networks. The computational experiments show that the algorithm is computationally efficient.

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- Yeong-Sung Lin and James R. Yee, "Models and Algorithms for Routing and Flow Control in Virtual Circuit Networks," submitted for presentation at *IEEE GLOBECOM '90.* (This paper was not presented.) (1 preprint 6/90)

A B S T R A C T

In this paper, the joint routing and flow control problem in virtual circuit networks is considered. In virtual circuit networks, all of the packets in a session are transmitted over exactly one path established between the origin and the destination. We consider the problem of choosing a path and adjusting the input rate for each origin-destination pair in the network. In the first model we minimize the average number of packets in the network plus a throughput limitation cost. In the second model, we maximize the allocation to the most poorly treated user(s) subject to link utilization constraints. The third model, which is a variation of the second model, has an additional constraint which limits the average number of packets in the network. These joint routing and flow control problems are formulated as mixed integer programming problems.

The emphasis of this work is to develop near-optimal algorithms to solve these three optimization problems and to investigate the performance trade-offs of the three models. The basic approach in this work is Lagrangean Relaxation which has been a common and successful technique in solving many difficult combinatorial optimization problems. In computational experiments, our algorithms determine the solutions that are within a few percent of an optimal solution in minutes of CPU time for networks with 26 to 61 nodes.

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- Song-Chyau Liang & James R. Yee, A Model and Algorithm for Interconnecting Two WANS", *Proc. IEEE SMC Conf.* November 1990. (15 reprints 12/90)

A B S T R A C T

In this paper, we consider the problem of determining which gateways to use to interconnect existing data networks to minimize a linear combination of the average internet and

intranet packet delays subject to a cost constraint on the amount to be spent to establish the gateways. This problem is formulated as a nonlinear combinatorial optimization problem. When the gateway locations are fixed, the resulting routing problem is not a convex programming problem. This is unexpected since the routing problem in datagram networks is usually formulated as a convex program. We develop an algorithm to solve this problem and report computational experience.

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- Ming-Jeng Lee & James R. Yee, "A Topology and Discrete Capacity Assignment Algorithm for Reconfigurable Networks", submitted to *Operations Research.* (1 preprint 12/90)

A B S T R A C T

A *reconfigurable network* is a circuit-switched network where the effective topology and capacities can be dynamically adapted to changes in the traffic requirements or to change sin the structure of the network due to failures. The application of reconfigurable networks considered in this paper is data communications. We formulated the joint topology, capacity and routing problem in a reconfigurable network as a nonlinear mixed integer programming problem. To solve this problem, we present an algorithm which is a partial branch and bound algorithm. The reduced gradient method is used to solve the problem with the integrality constraints relaxed. In the computational experiments, the algorithm found good solutions and lower bounds in a few minutes of CPU time. In addition, the reduction in the minimal delay due to the reconfiguration capability can be as large as 66%.

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- James R. Yee and Feng-Min Shiao, "An Algorithm to Find Global Optimal Routing Assignments for a Class of PRNs", *Int. Conf. on Comm. 91.* (15 reprints 11/91)

A B S T R A C T

We investigate the problem of determining routing assignments and transmission probabilities to maximize the end-to-end throughput in a slotted Aloha packet radio network. Due to interference from the neighbors of a receiver, this optimization problem is inherently nonconvex. By restricting the transmission probability of each node to be the same, we show that a global optimal solution can be found by solving a series of linear programs. Dantzig-Wolfe decomposition is applied to solve the LPs. The numerical examples show that the proposed method is effective in determining the network capacity.

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- James R. Yee and Ming-Jeng Lee, "A Branch and Bound Design Algorithm for Reconfigurable Networks", *Int. Conf. on Comm. 91.* (15 reprints 11/91)

A B S T R A C T

A *reconfigurable network* is a circuit-switched network where the effective topology and capacities can be dynamically adapted to changes in the traffic requirements or to changes in the structure of the network due to failures. The application of reconfigurable networks considered in this paper is data communications. We formulated the joint topology, capacity and routing problem in a reconfigurable network as a nunlinear mixed integer programming problem. To solve this problem, we present an algorithm which is a partial branch and bound algorithm. The reduced gradient method is used to solve the problem with the integrality constraints relaxed. In the computational experiments, the algorithm found good solutions and lower bounds in a few minutes of CPU time. In addition, the reduction in the minimal delay due to the reconfiguration capability can be as large as 66%.

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- Song-Chyau Liang & James R. Yee, "Algorithms for Interconnecting Ethernets with Multi-Port Bridges," submitted to the *IEEE Transactions on Computers.* (1 preprint 12/90)

A B S T R A C T

In this paper, we consider the problem of determining which bridges and which LAN-bridge connections to establish to interconnect a set of Ethernets. The objective is to minimize the cost. The configuration is required to be a spanning tree and obey a degree constraint on each connected bridge. This combinatorial optimization problem is a degree-constrained Steiner tree problem. We develop a second order greedy algorithm to find an initial feasible solution. We propose a composite solution procedure based on two different Lagrangian relaxations. The results of computational experiments with the algorithm are reported. The algorithms were applied to interconnect a set of Ethernets at USC. We find a configuration for the USC Ethernets that cost 20% ($30K) less than the cost of the current configuration.

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- James R. Yee & Song-Chyau Liang, "A Second-Order Greedy Algorithm for Interconnecting Ethernets," *Int. Conf. on Comm. 91.* (15 reprints 11/91)

A B S T R A C T

In this paper, we consider the problem of determining which bridges and which LAN-bridge connections to establish to interconnect a set of Ethernets. The objective is to minimize the cost. The configuration is required to be a spanning tree and obey a degree constraint on each bridge. This combinatorial optimization problem is a degree-constrained Steiner tree problem. We develop an efficient second order greedy algorithm to find a feasible solution to this problem. The results of computational experiments with the algorithm are reported. The algorithms were applied to interconnect a set of Ethernets at USC. We find a configuration for the USC Ethernets that costs 20% less than the cost of the current configuration.

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- Song-Chyau Liang & James R. Yee, "Locating Internet Gateways to Minimize Nonlinear Congestion Costs", revised version to appear in the *IEEE Transactions on Communications.* (1 revised preprint 12/90)

A B S T R A C T

In this paper, we investigate the impact of the locations of the gateways on the performance of the internet. We consider the problem of determining (i) the routing assignments for the intranet and internet traffic and (ii) the number of gateways and their locations to interconnect existing data networks to minimize a linear comb ination of the average internet and intranet packet delays subject to a cost constraint on the amount to b e spent to establish the gateways. The joint routing and topological design problem is important in the design of internets and should be solved before networks are artually interconnected. The problem is formulated as a nonlinear combinatorial optimization problem. When the gateway locations are fixed, the resulting routing problem is not a convex programming problem. This is unexpected since the routing problem in datagram networks is usually formulated as a convex program. We develop an algorithm based upon Lagrangian relaxation to solve this problem. In the computational experiments, the algorithm was shown to be effective in interconnecting (i) two WANs and (ii) two grid networks. The experiments also showed that the algorithm finds better feasible solutions than an exchange heuristic.

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- Yeong-Sun Lin & James R. Yee, "A New Multiplier Adjustment Procedure for the Distributed Computation of Routing Assignments in Virtual Circuit Data Networks," submitted to *ORSA, J. on Computing.* (1 preprint 12/90)

A B S T R A C T

In this paper, the routing problem in virtual circuit network is considered. In virtual circuit networks, all of the packets in a session are transmitted over exactly one path established between the origin and the destination. We consider the problem of choosing a

path for each origin-destination pair so as to minimize the average number of packets in the network. We consider the formulation of this problem as a nonlinear multicommodity flow problem with integer decision variables.

The emphasis of this work is to develop a distributed algorithm to solve this optimization problem. The basic approach is Lagrangean Relaxation. We introduce a new multiplier update rule which facilitates the solution of the nonlinear integer programming problem using distributed computation. In computational experiments, our proposed distributed algorithm determines solutions that are within 1% of an optimal solution in minutes of CPU time for networks with 26 to 61 nodes. In addition, the proposed multiplier adjustment procedure provides better bounds and is less sensitive to the algorithm parameters than the subgradient method. An analysis of the com munication delays of the control messages needed to support a distributed implementation is given.

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- Ming-Jeng Lee & James R. Yee,"An Algorithm for Optimal Minimax Routing in ATM Networks," submitted to *IEEE J. Selected Areas of Communications.* (1 preprint 7/91)

A B S T R A C T

Asynchronous Transfer Mode (ATM) networks has been adopted by the CCITT as the transport network in which broadband ISDN will be based. In this paper, we formulate the problem of routing cells in an ATM network as an optimization problem. The objective is to minimize the largest cell loss probability. The constraints correspond to a multicommodity network flow problem with gains. An algorithm to determine a global optimal flow assignment is presented. The minimax routing algorithm was implemented and tested on several sample networks. The computational experiments show that the algorithm is computationally efficient.

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- James R. Yee and Ming-Jeng Lee, "Convergence of an Iterative Method for ATM Networks," submitted to *IEEE Trans. on Information Theory.* (1 preprint 7/91)

A B S T R A C T

In this paper, we present a flow model for evaluating the performance of a network of ATM switches. The performance measures used include the link and end-to-end cell loss probabilities as well as the link (nodal) and end-to-end cell delays. In the model, the routing assignments are assumed to be given. The assumed form of routing assignments may be used to represent either virtual circuit or datagram service. Due to the nonlinear relationship between cell losses and offered flows, the flow model is a system of nonlinear equations. We develop a sufficient condition for the existence of a unique solution to the nonlinear system of equations. We present an iterative method and prove that it converges to a unique fixed

point provided the sufficient condition is satisfied. The unique fixed point corresponds to the unique solution to the flow model. We applied the iterative method to evaluate the performance of a 61-node wide area ATM network. Four typical routing strategies were compared with respect to the end-to-end delays and throughputs. In this example, 99% of the end-to-end delay was due to the propagation delay.

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- James R. Yee and Ming-Jeng Lee, "A Design Algorithm for Reconfigurable ATM Networks," to be submitted for publication. (1 preprint 7/91)

A B S T R A C T

In this paper, we propose to use the reconfiguration capability in ATM networks to reduce ATM cell losses. The reconfiguration capability can be achieved by restricting ATM cells of an origin-destination pair to use certain channels in a physical link. We formulate the joint topology, discrete capacity and routing problem in a reconfigurable ATM network as a nonlinear mixed integer programming problem. Our model has three improvements over the model proposed by Gerla, Suruagy Monteiro and Pazos. First, we include cell losses in the model. The flow model is thus more realistic. Second, instead of using queue length in an M/M/1 system to approximate cell loses, we directly use total cell losses as the objective function. Third, we represent capacity variables as integer variables rather than continuous variables. This more accurately reflects the fact that link capacities are divided into channels of 150 Mbps. We prove that the joint topology, discrete capacity and routing problem with integrality constraints relaxed can be simplified to a convex programming problem. This provides us a method to compute a lower bound on the problem. An algorithm is developed to solve the nonlinear mixed integer programming problem. In the computational experiments, the proposed algorithm determined a good feasible solution in a few minutes on SUN SPARCsystem 400. We show that the reconfiguration capability decreases the total cell losses by more than 50%. We also identified some problem parameters that affect the effectiveness of using reconfiguration capability to reduce ATM cell losses.

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- James R. Yee and Feng-Min Shiao, "An Optimization-Based Method for Determining the Capacity of a Multi-Hop Slotted Aloha PRM," submitted to the *IEEE Transactions on Communications.* (1 preprint 7/91)

A B S T R A C T

We investigate the problem of jointly determining transmission range, routing assignments and transmission probabilities to maximize the end-to-end throughput in multi-hop slotted ALOHA packet radio networks. It is assumed that the node locations and the traffic requirements are arbitrary. This problem is formulated as an optimization problem. We

show that this problem can be reduced to solving a polynomial number of routing problems. Due to interference from the neighbors of a receiver, the routing problem is inherently non-convex. By restricting the transmission probability of each node to be the same, we show that a global optimal solution can be found by solving a series of linear programs. We apply Dantzig-Wolfe decomposition to solve the linear programs. The numerical examples show that the proposed method is significantly better than previous approaches for determining the network capacity.

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- James R. Yee and Yeong-Sung Lin, "The Effect of Control Message Delays on the Convergence of a Distributed Routing Algorithm for Virtual Circuit Networks," submitted to *GLOBECOM '91.* (1 preprint 7/91) (This paper was not presented.)

A B S T R A C T

In this paper, we investigate the performance of our previously proposed distributed routing algorithm for virtual circuit networks. The emphasis of this paper is two fold. First, an analysis of the communication delays of the control messages needed to support the distributed routing algorithm is given. The results show that the communication delays dominate the computation time. In addition, the speedup of the distributed algorithm over a centralized algorithm with respect to computation time is approximately equal to the number of nodes in the network divided by the largest outdegree of the network. Second, our multiplier adjustment procedure used in the previously proposed algorithm is compared with two subgradient-based methods. It is shown that our new multiplier adjustment procedure is more stable and finds slightly better bounds than the other two multiplier update rules for most of the computational experiments.

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- James R. Yee and Ming-Jeng Lee, "A Flow Model for Performance Evaluation of ATM Networks," submitted to *GLOBECOM '91.* (1 preprint 7/91) (This paper was not presented.)

A B S T R A C T

In this paper, we present a flow model for evaluating the performance of a network of ATM switches. The performance measures used include the link and end-to-end cell loss probabilities as well as the link (nodal) and end-to-end cell delays. In the model, the routing assignments are assumed to be given. The assumed form of routing assignments may be used to represent either virtual circuit or datagram service. Due to the nonlinear relationship between cell losses and offered flows, the flow model is a system of nonlinear equations. We present a sufficient condition for the existence of a unique solution to the nonlinear system of equations. We then present an iterative method which converges to

a unique fixed point provided the sufficient condition is satisfied. The unique fixed point corresponds to the unique solution to the flow model. We applied the iterative method to evaluate the performance of a 61-node wide area ATM network. Four typical routing strategies were compared with respect to the end-to-end delays and throughputs. In this example, 99% of the end-to-end delay was due to the propagation delay.

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- James R. Yee and Ming-Jeng Lee, "A Convergence Proof for an Iterative Method for ATM Networks," submitted to *INFOCOM '92.* (1 preprint 7/91)

A B S T R A C T

In this paper, we present a flow model for evaluating the performance of a network of ATM switches. The performance measures used include the link (nodal) and end-to-end cell loss probabilities as well as the link (nodal) and end-to-end cell delays. In the model, the routing assignments are assumed to be given. The assumed form of routing assignments may be used to represent either virtual circuit or datagram service. Due to the nonlinear relationship between cell losses and offered flows, the flow model is a system of nonlinear equations. We develop a sufficient condition for the existence of a unique solution to the nonlinear system of equations. We present an iterative method and prove that it converges to a unique fixed point provided the sufficient condition is satisfied. The unique fixed point corresponds to the unique solution to the flow model.

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- Song-Chyau Liang and James R. Yee, "An Algorithm for Configuring/Expanding a Distributed Computer System," submitted to *IEEE Transactions on Parallel and Distributed Systems.* (1 preprint 7/91)

A B S T R A C T

In this paper, we consider the joint problem of determining which new bridges and LAN-bridge connections to establish to extend the connection of Ethernets and determining which new file servers to add to enhance the performance of a distributed computer system (DCS). We formulate this system expansion problem as a nonlinear combinatorial optimization problem. The initial system configuration problem of a DCS is a special application of this model. The objective is to minimize the configuration cost. The topology of extended LANs is required to be a spanning tree and obey a degree constraint on each bridge. The average file access response time is required to be within a maximum limit accepted to users. We develop a procedure based on Lagrangian relaxation and the subgradient method to obtain lower bound on the optimal configuration cost. We propose optimization based heuristic to find good feasible solution. Application of the algorithms provides low-cost configurations for both system installation and system expansion of a DCS. The results of computational experiments with the algorithms are reported. We find a tradeoff between the configuration cost versus the average response time for configurating and/or expanding a DCS.

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- Feng-Min Shiao and James R. Yee, "Optimal Routing and Transmission Probabilities in Multi-Hop Spread-Spectrum Networks," *Proceedings of the Internation Symposium on Communications*, December 1991. (15 reprints 11/91)

ABSTRACT

In this paper, we study the problem of jointly determining the transmission probabilities and routing assignments to maximize the end-to-end throuhput for a variety of spread spectrum packet radio n etworks (PRNs). We formulate this problem as an optimization problem. It is shown that our optimization model applies to PRNs where the access protocol is (i) common code direct sequence, (ii) transmitter oriented direct sequence, (iii) common code frequency hopping, (iv) transmitte oriented frequency hopping, (v) FM sustem with capture or (vi) ordinary slotted Aloha. We show that our previous solution procedure can be used for PRNs with any of these access protocols.

Ph.D. THESES

- **Ching Chuang**, On Power Spectral Densities of Modulated and Coded Digital Signals via Ergodic Markov Modeling, Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute, Report *CSI-88-07-01*, May 1988. (1 copy 1/89)

A B S T R A C T

Several methods have been proposed for the calculation of the spectral characteristics of modulated and coded digital signals. However, little attention has been given to the appropriate algebraic structure of the general modulation and encoding formats. Since, in digital communication, these schemes may generally be represented by a finite state synchronous sequential machine, a generalized method for evaluating power spectral density can be achieved by expressing their characteristics through ergodic Markov modeling, which is the first and most important step in this method.

One primary thrust of this paper is to rigorously derive the mathematical theory of discrete and continuous spectral components of ergodic Markovian models. The existence problem is proved by using the concepts of: (i) the generalized function for the discrete component; (ii) Jordan decomposition of the transition matrix for the continuous component. From these concepts closed-form expression for the power spectral density is developed. It is shown that an eigenvalue equal to one and of multiplicity one belongs to all of the ergodic Markov transition matrices; in addition it has no effect in the spectral computations. Furthermore, zero is the only multiple eigenvalue of the transition matrices for most of the schemes. The general theory becomes particularly simple due to above results.

The general conclusions are applied to PCM formats and convolutional codes for both independent and correlated input. Properties of the transition matrix of Markov models are studied and used in deriving the general form of spectral densities. The condition of not having spectral line components is considered. Also, the variation of continuous spectral density with various input statistics, format structures, and transmitted waveforms are then discussed and computed.

Charles Weber's efforts on behalf of this thesis research, were supported in part by ARO.

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- **Nikolaos-John B. Pronios**, "On the Performance of Slotted-Random Access Networks Under Jamming", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute, Report *CSI-88-07-04*, July, 1988. (1 copy 1/89)

A B S T R A C T

In this thesis, we study the performance of slotted, monohop networks of unbuffered users, with ALOHA-type access protocol, spread and unspread, in the presence of noise and jamming. Jamming is introduced on the physical level and the throughput/delay (link level) performance of the network is studied.

The basic problem is the effective use of the finite average jamming power. The jamming effectiveness is determined through the decrease of the average throughput and/or the increased average delay of the network. In the same framework, user countermeasures by use of different spreading/coding and/or access parameters can be determined. The jamming is ***uniformly*** distributed among the users and different scenarios are examined, depending on the side information available to the jammer.

The jammer is initially assumed to have no side information regarding the channel and the system's state. Three different jammer models are examined for this case, with the jamming action been decided in a probabilistically prescribed manner always under the finite average power constraint.

The scenario where the jammer has information about the (unobservable) system's state is then examined, followed by the scenario where the jammer has information about the (observable) channel's state. Optimal choices for jamming are made, always under the finite jamming power constraint, from a class of stationary policies for these dynamic jamming procedures. Furthermore, a heuristic algorithm determining (for some cases) the optimal jamming policy is presented.

In addition, approximate methods are developed for throughput/delay performance evaluation of this type of networks. These methods are using diffusion processes for the approximation of the performance characteristics. These approximate methods can also be used for the study of systems under jamming, and are shown to be accurate for a large range of values of the parameters involved.

Andreas Polydoros' efforts on behalf of this thesis research, were supported in part by ARO.

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- **Kurt Kosbar**, "Open and Closed Loop Delay Estimation with Applications to Pseudonoise Code Tracking", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute, Report *CSI-88-08-11*, August 1988. (1 copy 1/89)

A B S T R A C T

Time delay estimation of a signal corrupted by an additive white Gaussian channel is examined. The primary case of interest is when the desired signal is a deterministic, discontinuous function. The work is devided into two areas, namely open-loop and closed-loop estimation.

In the open loop section, a number of previous bounds on the mean square error (MSE) of unbiased estimates are put into perspective. A discussion is included ont he inapplicability of the Cramer-Rao bound for discontinuous waveforms. A new bound on the MSE of maximum likelihood estimators is derived by combining concepts developed by many other authors. It is most useful for periodic square pulses and pseudonoise (PN) codes typically used in direct sequence spread spectrum communications. It is significantly tighter than previous bounds at moderate signal to noise ratios when the pulse width is much less than the period of the signal, or the observation time.

The closed loop section extends analysis began by Layland in 1969. It was possible to find the cross correlation function that minimizes the MSE of a first order correlation loop for arbitrary transmitted signals. The result is not in closed form, however it was still possible to gain insight by examining special cases. The most significant result of this section is that the optimal cross correlation function is not in general the derivative of the transmitted signal. In the case of discontinuous signals, there is a substantial difference between open-loop bounds and conventional first order correlation loops, such as early/late delay-locked loops (DLL). DLLs have a MSE that decays with the reciprocal of the signal to noise ratio, hwereas open loop bounds on the discontinuous signals suggest that the MSE can decay with the square of the reciprocal of the signal to noise ratio. This finding suggests that first order, early/late DI Ls are suboptimal tracking devices. A modified tracking loop structure is suggested that approximates maximum likelihood estimation more accurately than conventional DLLs.

Andreas Polydoros' efforts on behalf of this thesis research, were supported in part by ARO.

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- **Chih-Ping Wang**, "The Precedence-Assignment Model for Distributed Database Concurrency Control Algorithms," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute, Report *CSI-88-08-05*, August 1988. (1 copy 1/89)

A B S T R A C T

The purpose of this thesis is to study the design of efficient concurrency control algorithms for distributed databases. We introduced the precedence-assignment model (PAM) to analyze distributed concurrency control algorithms by their precedence assignment and precedence enforcement functions. We found that most concurrency control algorithms, and specifically, two phase locking (2PL), timestanp ordering (T/O), and the optimistic method

(OP), can be described by this model.

Under PAM, the design of distributed concurrency control algorithms can be viewed as a trade-off between the cost of precedence assignment and the cost of precedence enforcement. We observed that due to the simplicty and low cost of their precedence assignment method, most concurrency control algorithms suffer from higher precedence enforcement expense – the probabilities of deadlocks and restarts are high and the duration of transaction blocking is long. Therefore, we advocate research on more sophisticated precedence -agreement algorithms and a unified concurrency control scheme.

The precedence-agreement algorithms (PA) is a deadlock free, restart free distributed concurrency control algorithm. Our smulation results showed the superiority of PA over 2PL, and T/O. The performance of PA can be further improved by allowing transaction sites to "guess" the decisions at data sites. We applied an analytical method to study the optimal guessing strategy.

We next proposed and analyzed an adaptive concurrency control system which is an integration of 2PL, T/O, and PA. This system dynamically assigns different concurrency control algorithms to different transactions. Thus performance can be optimized.

Finally, we extended the PAM to analyze replicate database concurrency control algorithms.

Victor Li's efforts on behalf of this thesis research, were supported in part by ARO.

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- **Robert Ward White**, "Performance of Fast Frequency Hopped MFSK Spread Spectrum Communication in the Presence of AWGN and Tone Jamming", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-05-06*, May 1989. (1 copy 7/89)

A B S T R A C T

In this dissertation, three methods are considered to determine the performance of fast frequency hopped MFSK spread spectrum communication in the presence of tone jamming. The three methods are a direct method, a characteristic function method and a discrete method with an A/D converter. A square-law receiver is used for all cases with post detection summing over the hops.

Different cases are considered for the different methods. For the direct method the binary case (i.e., $M = 2$) with two hops per symbol (i.e. $h = 2$) is considered with no Additive White Gaussian Noise (AWGN). An expression for Bit Error Rate (BER) is developed and

plotted for several cases.

For the characteristic function method an expression is found for the binary case, but for an arbitrary number of hops per symbol (i.e. arbitrary h) and with the presence of AWGN in addition to the tone jamming. The expression is numerically evaluated and plotted for several cases. As is expected, multiple hops per symbol degrade performance for this case.

To improve performance, a limiter is added to the receiver prior to summing over the hops. The form of the limiter used is an A/D converter. The A/D converter also allows calculations to be performed in the discrete domain. For this method, larger values of M and h are allowed. The channel is AWGN with tone jamming. For a variety of cases, performance is evaluated and plotted. The diversity due to multiple hops per symbol is shown to improve performance with the use of a limiter. It is also whon that the clipping point of the A/D converter can be selected to give near optimum performance over a wide range of jammer levels (i.e. E_b/N_J).

Charles Weber's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Charles N. Franz**, "The Callibration of Distorted Airborne Antenna Arrays Using Synthetic-Aperture-Radar Principles" Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-05-03*, May 1989. (1 copy 7/89)

A B S T R A C T

Unknown geometric distortion can degrade the radiation pattern of an antenna array. It introduces electrical-path-length errors which destroy the required phase relationship between the signals that are coherently combined in the beam-forming process. If these errors exceed the carrier wavelength, they will not be compensated using conventional postprocessing autofocus techniques. This report summarizes the results of an investigation of coherent land-clutter-based calibration techniques which compensate the effects of this distortion in airborne arrays. It is noted that these techniques do not apply to the calibration of synthetic arrays.

It is assumed that the array operates in diffuse clutter for which it may not be possible to range gate a dominant scatterer. Consequently, coherent processing is invoked to form range-doppler cells which each emulate the characteristics of an ideal point source. With existing techniques, the synthetic arrays which are formed in this process must provide resolution that is much finer than that of the real array. This study develops techniques which enable this requirement to be relaxed. This is achieved by processing additional dimensions of the clutter which are correlated with the parameters that must be estimated in the calibration.

The use of this additional information is seen to provide a fivefold reduction in synthetic array length for realistic design parameters. The approach of the investigation is to model the clutter observations, apply classical estimation theory techniques, and then evaluate the performance of the resulting estimators.

Robert Scholtz's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Char-Dir Chung**, "Multi-Hop Frequency-Hopping Detection," Ph.D. Dissertation, University of Southern California. Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-06-04*, August 1989. (1 copy 7/89)

A B S T R A C T

The detection of a multi-hop certain low probability of intercept/frequency hopping (LPI/FH) signal with unknown signal parameters such as hop rate, timing reference, set of candidate carrier frequencies, set of carrier phases, hopping pattern, and signal power immersed in additive white Gaussian noise (AWGN) is considered. From an interceptor's viewpoint, the tolerable assumptions made herein are (1) noise level is known in advance; (2) the spread spectral band wherein the transmitted signal might exist is known; (3) minimum noncoherent orthogonal spacing in the setup of the set of candidate carrier frequencies is adopted by the transmitter; (4) each hop carrier phase and hop carrier frequency are fixed; (5) the transmitted signal's envelope is a constant; and (6) a priori knowledge of the possible hop rates is available. Since the environment under consideration is a noncooperative one, our goal is to design detection algorithms which offer both highly detectability and less signal-parameter-sensitive performance in the statistical sense from the spectral technique. Neyman Pearson criterion is employed as the design criterion.

Since large implementational complexity is encountered in building up the spectral measurement extraction device, the bank of inphase and quadriphase matched filters, DFT (Discrete Fourier Transform) spectrum analyzers have been extensively used instead in real world application. However, still insufficient is the study on the statistical comparison on the output statistics generated from two mechanisms under general conditions of timing and frequency mismatch between mechanism-set parameters and transmitted signal parameters. In the dissertation, a thorough study on the issue is also pursued.

With the use of a bank of inphase and quadriphase matched filter or the DFT spectrum analyzers, spectral measurements in time domain and correlation domain of the received signal can be extracted to assemble the proposed spectral algorithms – Enveloped Maximal algorithms, Complex Envelope Maximal algorithms, Correlation-Domain Complex Envelope Maximal algorithms, and Sequential Spectral Maximal algorithms. Performance analysis and simulation results confirm that detectability-enhanced and less signal-parameter-sensitive

detection performance with respect to the unknown signal parameters can be obtained by the proposed algorithms compared to those of the previously-designed detection algorithms which were designed either in an ad hoc way or under some crucial assumption on the signal parameters.

Andreas Polydoros' on behalf of this thesis research, were supported in part by ARO.

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- **Yu-Cheun Jou**, "Design of Switchable Pseudonoise Sequence Generator and its VLSI Implementation," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-06-01*, August 1989. (1 copy 7/89)

A B S T R A C T

A flexible bent-sequence generator is useful in the practical anti-jamming direct-sequence spread-spectrum multiple-access communications. Different sequences can be obtained by switching the feedback connections and the initial contents of the shift register and also by using different nonlinear binary functions within the generator. In this thesis we discuss the mechanism used to select proper feedback connections of the shift register and the algorithms used to compute related parameters. we also describe a criterion for choosing the class of nonlinear functions and alternative ways of specifying any of them. VLSI circuits of a 40-stage switchable bent sequence generator are designed using a hierarchical method. The operation of this generator and various algorithms for the computation of control signal inputs to the chip are also presented.

Robert Scholtz's efforts on behalf of this thesis research, were supported in part by ARO.

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- **Rong-Feng Chang**, "Performance Analysis of Mobile Packet Radio Networks,", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-07-06*, August 1989. (1 copy 1/90)

A B S T R A C T

The purpose of this dissertation is to study the effect of node mobility on the performance of mobile packet radio networks. Both the fully distributed and the hierarchical architecture are taken into consideration. To account for the effect of node mobility on the system performance, we first develop a queueing model to evaluate the distribution of the number of nodes in a transmission region.

Various routing algorithms are proposed and analyzed for the fully distributed and the hierarchical network. In the hierarchical network, two local access schemes, in which a network node uses a fixed power radius or an adjustable power radius, are investigated and evaluated.

To compare the network performance of these two architectures, we use the end-to-end throughput as the performance measure. The results are shown that the hierarchical network outperforms the fully distributed network for most scenarios.

Victor Li's efforts in behalf of this thesis research, were supported in part by ARO. Rong-Feng Chang was a part-time research assistant, supported by ARO since September of 1988.

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- **Ching-Liang Huang**, "Crash Recovery in Replicated Database Systems,", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-12-04*, October 1989. (1 copy 1/90)

A B S T R A C T

The purpose of this thesis is to study the crash recovery problem in replicated database systems. A replicated database is a distributed database where some of the data items have more than one copy stored in the system. The major reason for using replicated data is to increase data availability. By storing critical data at multiple sites, the system can operate even when some of the sites have failed. Another reason for data replication is to improve performance. By storing copies of data in sites where they are frequently accessed, the need for expensive remote access can be reduced. Even though data replication provides these two benefits, it also introduces a new problem – the problem of preserving the consistency and maintaining the availability of replicated databases in the face of failures, which include site crashes, timing failures, line failures, and network partitionings. This problem can be decomposed into two subproblems: (1) replication control problem: ensuring one-copy serializability among all transactions committed, and (2) atomic commitment problem: ensuring atomic commitment of each transaction executed. This thesis is on the investigation of both of these subproblems.

On the replication control problem, we first propose a replication control protocol, called the missing-partition dynamic voting scheme. The protocol is a dynamic voting scheme which dynamically adjusts vote assignment of data items in response to failures and recoveries. By adjusting vote assignment dynamically, the protocol maintains higher data availability than the static voting scheme. Furthermore, unlike existing dynamic voting schemes, it supports inexpensive read operations which access one copy, rather than all copies, of each data item read.

Based on the missing-partition dynamic voting scheme, a regeneration-based multiversion dynamic voting scheme is then designed. Like the missing-partition dynamic voting scheme,

the new scheme supports inexpensive read operations which access one copy, rather than all copies, of each data item read. Furthermore, by incorporating the concept of regeneration and keeping multiple versions for each data item in the database, higher data availability is maintained. To support data regeneration, a replicated directory architecture for the proposed scheme is designed that not only supports regeneration of replicated data items, but also provides inexpensive, high availability directory services, which help maintain database availability.

Even though voting schemes have been proposed for quite a long time, no literature has discussed the problem of reinitialization in these schemes. After developing two dynamic voting schemes, we then identify the reinitialization problem of voting schemes and propose solutions for the static voting scheme, existing dynamic voting schemes, and the two newly developed schemes.

On the atomic commitment problem, we develop a quorum-based commit and termination protocol for replicated databases which guarantees atomic commitment in the face of arbitrary concurrent site failures, timing failures, link failures, and network partitionings. By taking voting replication control protocol into consideration in the design, the protocol maintains higher data availability than existing ones as was shown in our simulation results.

Victor Li's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Lawrence Charles Pond**, "On the Performance Analysis and Media Access of Distributed Mobile Multi-Hop Packet Radio Networks", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-08-03*, August 1989. (1 copy 1/90)

A B S T R A C T

Investigated in this research is the particular class of packet radio networks in which the users are mobile, the topology requires multi-hop routing, the radio transmissions are broadcast, and the network control is distributed. These networks are interesting because of their intrinsic characteristics of rapid and convenient deployment, self-organization, mobility, adaptivity, and survivability. The network operational scenario considered is deployment of the network into a relative compact geographical area in which the radio propagation and frequency spectrum usage environment is severe. The traffic considered is short messages which require bounded forwarding delay.

A distributed media access protocol is developed for this class of packet radio networks. The protocol constructs virtual circuits, using time division multiple access, by making dedicated, non-contention time-slot assignments along the minimum hop source to destination

path. The protocol features time-slot selection that assures bounded forwarding delay once a virtual circuit is established. Distributed routing and flow control are investigated and analyzed.

Analytical tools are developed to determine, for the media access protocol, the virtual circuit setup time, the virtual circuit duration, the network capacity, and the network setup time as a function of the number of users, the network area, and the transmission range of the users. These tools are applied to analyze the important trade between the capacity of the network and the responsiveness of the network to change.

The basic media access protocol is extended with several advanced networking techniques. Adaptive signalling channel policies are developed that increase the network responsiveness without the requisite decrease in network capacity. A hierarchical architecture is developed that provides increased responsiveness and capacity over flat networks. Finally, priority service policies are developed that provide preferential service according to session priority.

Victor Li's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Shiow-Chen Shyu**, "Design and Performance of Locking Algorithms for Distributed Databases," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-12-06*, December 1989. (1 copy 6/90)

A B S T R A C T

Numerous performance models have been proposed for locking algorithms in centralized database systems, but few have been developed for distributed ones. Existing results on distributed locking usually ignore the deadlock problem so as to simplify the analysis. In this thesis, a new performance model for static locking in distributed database systems is developed. A queueing model is used to approximate static locking in distributed database systems without deadlocks. Then a random graph model is proposed to find the deadlock probability and restart probability of each transaction. Finally, the above two models are integrated, so that given the transaction arrival rate, the response time and the effective throughput can be calculated. The results are very general, so they can be applied to other systems with deadlocks. The analytical results are vbalidated by simulation results.

The deadlock problem is intrinsic to locking systems. Efficient resolving deadlocks is crucial to the performance of locking systems. From the simulation, we verify that most deadlocks are of length two and that the deadlock probability is very small. However, we found that although deadlock does not occur often, once it occurs, the system performance drops dramatically, unless it is resolved quickly. This is because the resource held by the deadlocked transactions are not released and this further blocks more transactions. Therefore, an efficient abortion-free deadlock detection/resolution algorithm (ABF) is proposed in

this thesis. The most important feature of ABF is that when a deadlock cycle is detected, it is resolved by reordering the wait-for-relations between pairs of transactions. Therefore, no transaction abortions are necessary to resolve the better fairness. The correctness of this abortion-free algorithm is proved. We also develop a performance model, based on our random graph model, to study the transaction response time of a database system using ABF with a system using existing deadlock detection/resolution algorithms. The algorithm ABF is then extended to .. tinguish Read/Write locks and transaction classes.

Victor Li's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Seok-Ho Kim**, "An Optimum Filter Design For a Cross-Spectrum Symbol-Rate Detector" Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-05-02*, May 1990. (1 copy 6/90)

A B S T R A C T

In this dissertation, several optimum symbol-rate detectors for low input signal-to-noise ration (SNR) situations have been derived under totally different scenarios using a multiple composite hypotheses testing. Beginning with the structures of optimum symbol-rate detectors and the ad hoc symbol-rate detectors, we motivate the optimal design of a pre-correlation filtering system for use in a cross-spectrum symbol-rate detector, which consists of two radio-frequency pre-correlation filters, a multiplier and a narrow bandpass filter. The design generalizes practical cross-spectrum symbol-rate detectors, and derives the necessary condition which maximizes the performance measure, i.e., the processed signal-to-noise ratio at a predetermined integer multiple of the *a priori* known symbol rate, for binary phase shift keyed signalling. The resultant optimum condition depends on the transfer functions of pre-correlation filters and fixed signal model parameters. As a by-product, the performance measure applicable to any quadrature amplitude modulation format is derived, including the effects of self-noise and inter-symbol interference. An algorithm for realizing pre-correlation filters that satisfy the optimum condition, with the constraints such as causality and stability, is presented.

Robert Scholtz's efforts in behalf of this thesis research, were supported in part by ARO. Seok-Ho Kim was a research assistant supported by ARO.

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- **Youngky Kim**, "Signal Classification Based on Spectral Correlations", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-90-05-05*, April 1990. (1 copy 6/90)

A B S T R A C T

Signal classification is an intermediate step between signal detection and data demodulation. It is useful for signal confirmation, interference identification and selection of the proper demodulation scheme. A general signal classification algorithm is developed in spectral domain, and applied to a modulation classification problem.

Signal classification problem is formulated as a hypothesis testing problem, i.e., for different hypotheses, the signal has different statistical characteristics. It has been agreed that the likelihood function characterizes a signal completely in a decision theoretic point of view. The likelihood function for the additive white Gaussian channel is expressed in spectral domain to establish a bridge between spectral analysis and hypothesis testing problem. It shows that the nth order spectral correlation characterizes the nth order property of the signal. Instead of developing the optimum algorithm which utilizes all order spectral correlations, a sub-optimum algorithm, called *F-SPCR algorithm*, is developed, which thoroughly utilizes the second order spectral correlation property of a signal. During developing the algorithm, only a binary signal classification is considered for the ideal, the unknown carrier phase, and epoch environments. But, more complicated scenarios are considered in application stage. As a benchmark, a simple classifier, called *single cycle classifier*, is also developed, which makes a decision based on a pure sinusoidal generated by a cross correlator. Both classifier can be applied whenever the received signal has different second order spectral correlations for different hypotheses. Emphasis is placed on low SNR.

The developed algorithms are applied to the SQPSK vs. 2^kPSK classification problem. As an upper bound, the exact likelihood ratio test are obtained and evaluated for the ideal environment. Performance improvement from the simple single cycle classifier to the F-SPCR classifier, and performance degradation due to ignorance of the carrier phase and epoch, are described. Further considerations are taken for i) and unknown signal and noise power environment, ii) a tone jamming environment, and iii) an unknown baud time environment: i) a SNR and signal power estimator is developed and applied together with the signal classifier, ii) tone jamming free classifiers which are not affected by the tone jamming, are developed, and iii) the effects of baud time error to the classifier are discussed.

Charles Weber's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Khiem Van Le**, "Reliability Issues in Communication Networks with Dependent Failures and Multimode Components" Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-90-07-01*, August 1990. (1 copy 6/90)

A B S T R A C T

Network reliability has been extensively studies, usually with two simplifying but unrealistic assumptions. The first assumption is that failures are statistically independent, and the second is that each component has only two modes, fully working or fully failed. This dissertation considers the reliability issues of communication networks in the light of dependent failures and multimode compone ts. The Cause-based Multimode model (CBMM)

is proposed as a general and flexible modeling framework to take into account failure dependencies and component degradations. An efficient approach to analyze reliability and performability) is to approximate the measure by enumerating and analyzing only the most probable network states. To use that approach in the framework of the CBMM, algorithms to enumerate the states by decreasing probability have been devised. For reliability analysis, the proposed Path-based approach exploits some general properties of real systems to further reduce the time and memory requirements by up to orders of magnitude. The approach presents the same advantages as the most probable state approximation, that is, it can handle general reliability criteria, and gives an upper bound of the approximation error. The tools developed are applied to the problem of survivability enhancement, with reliability as a measure of survivability, i.e. the problem is to find a minimum-cost set of links to be added to an existing network so as to satisfy a given reliability constraint. The solution method combines a Cost Ordered Enumeration with a heuristic. The heuristic eliminates the least promising links to drastically reduce the number of candidate enhancements. Tests on randomly generated networks show that (i) the method finds the optimum in most cases, and (ii) the heuristic has a reasonable computation time for networks of practical size. One can assess the quality of the solution with the lower bound of the optimal cost given by the Cost Ordered Enumeration.

Victor Li's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Thomas Ketseoglou**, "Coding Adaptivity Issues in Spread-Spectrum Random-Access Networks', Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-90-08-03*, August 1990. (1 copy 12/90)

A B S T R A C T

We address the problem of adaptive coding in Spread-Spectrum Random-Access slotted networks. First, we investigate decoding methods with code combining. We show the high potential of this techniques, as well as, its decoding simplicity. Next, we consider adaptive receiver operation in Spread-Spectrum Random Access Networks. We apply the code combining technique in Direct-Sequence and Frequency-Hopping Spread-Spectrum Random Access Networks. Incremental-redundancy transmission, a hybrid type-II ARQ adaptive protocol is also examined for Freqeuncy-Hopping Systems. We show that high gains are obtained if this type of adaptive receiver operation is applied in Spread-Spectrum Random-Access Networks. Finally, we consider an adaptive transmission method, in which the coding rage is changed in accordance with each packet status. Our results indicate that no gains are obtainable by this. Thus, our conclusion is in favor of systems with adaptive receiver operation as these systems are more effective than ones with adaptive transmitter operation.

Andreas Polydoros' efforts in behalf of this thesis research, were supported in part by ARO.

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- **Arr-Mien Chou**, "Fair Channel Access Algorithms in Multihop Packet Radio Networks," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-90-12-03*, December 1990. (1 copy 12/90)

A B S T R A C T

In this dissertation we study the fairness performance of time-division channel access protocols (TCAPs) in multihop packet radio networks with multiple reception capacity. The goal of a TCAP is to activate the network, that is, to assure that every node in the network will receive a successful transmission from each of its neighbor nodes. Both collision-free and collision-allowed TCAPs are considered. Several collision-free TCAPs which are fairer, in terms of some defined fairness measures, than existing ones are developed. Several collision-allowed TCAPs which are faster, in terms of time required to activate the network, than existing ones are developed. Some properties of general TCAPs , both collision-free and collision-allowed, are proved. One distributed TCAP which satisfies the network traffic requirements, in the long run, is developed.

Dr. Victor Li's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Dong-In Kim**, "On the Performance of Common Spreading Code CDMA Packet Radio Systems with Multiple Capture Capability," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-90-11-01*, November 1990. (1 copy 12/90)

A B S T R A C T

In this thesis we present a multiple capture model for common spreading code CDMA packet radio systems, in which a finite number of mobile radios communicate with a single central receiver in a slotted random-access mode. Three basic approaches to multiple capture, namely, coherent, differential, and envelope header detection, are considered at the central receiver.

The problem of multiple header detection is addressed in the presence of multi-user interference. Our approach is to find good header sequences which can be received with small probability of false alarm and a high probability of correct detection. We use Chernoff bounds to derive the probabilities of false alarm and missed detection of the header, and then determine a proper randomization time that minimizes these bounds for several system parameters.

Basic equations for the multiple capture probability and throughput performance are derived at the central receiver. At the link-level, we evaluate two key design parameters in common spreading code systems, namely, the expected number of packets captured at the

receiver and the allowable number of simultaneous transmissions that are supportable at a specified data bit-error rate and probability of packet capture.

Using the Block Oriented Systems Simulator (BOSS), simulations were carried out for the central receivers with coherent, differential, and envelope header detection, and results from the simulations are compared with theoretical evaluations of the multiple capture probability. It is shown that for a threshold approximation to the probability of data packet success, the multiple capture model significantly improves system throughput.

A random spreading code assignment scheme for enhancing channel efficiency is presented in centralized spread-spectrum packet radio networks which employ a multiple capture receiver. Compared to the common code case, this approach requires modest increase in receiver complexity, but the number of discinct spreading codes being used is considerably less than the number of radios in the network. The capture and throughput performance of the random assignment scheme is evaluated for various sets of codes, and compared with the theoretical results from the common code scheme.

Dr. Robert Scholtz's efforts in behalf of this thesis research, were supported in part by ARO. Dong-In Kim was a research assistant supported in part by ARO.

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- **Ming-Jeng Lee**, "Design Algorithms for Reconfigurable Networks", Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-91-03-01*, March 91. (1 copy 7/91)

A B S T R A C T

This dissertation addresses four interrelated problems. In the first problem, we consider the joint problem of topological design, discrete capacity assignment and routing in traditional reconfigurable networks which transmit data packets. In the optimization model, the two types of constraints are (i) capacity constraints that describe all possible logical configurations and (ii) traditional flow conservation con straints. The objective is to minimize the average packet delay. We developed a partial branch and bound algorithm to solve the problem. It is shown that reconfiguration capability may reduce average packet delay by more than 66%. In the second problem, we consider a flow model for Asynchronous Transfer Mode 9ATM) networks. We show that the flows and losses of ATM cells in an ATM network can be represented by a nonlinear system of equations. We then provide a sufficient condition to guarantee that the nonlinear system of equations has a unique solution and this unique solution can b e determined by our porposed iterativ e method. With the solution, end-to-end cell loss probabilities and end-to-end delays can be computed. In the third problem, we consider the routing problem in ATM networks where the objective is to minimize the largest link cell loss probability. We develop an algorithm to determine a global optimal solution to the problem. So far, this is the only formulation of the routing problem in ATM networks for which determining a global optimal solution is computationally tractable. In the fourth problem, we consider a design problem for reconfigurable ATM networks. We

first show how the reconfiguration capability can be implemented in ATM switches. We formulate the topological design, capacity assignment and routing problem in reconfigurable ATM networks. The objective is to minimize total ATM cell losses. We develop an algorithm to solve this problem. In the computational experiments, the average cell loss probabilities were reduced by more than 50% by reconfiguration capability.

Dr. James Yee's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Tao Chen**, "Bit Error Rate Simulation of Digital Communication Systems using Conditional Importance Sampling," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-91-05-03*, May 1991. (1 copy 7/91)

A B S T R A C T

A new version of *importance sampling*, designated as conditional importance sampling, or CIS, is proposed for the simulation of bit error rate in nonlinear digital communication systems. *Monte Carlo* simulations are simple and tractable in simulating the bit error rate, but are prohibitively slow when errors are rare. *Importance sampling* is a variation of *Monte Carlo* which increases the simulation speed by altering the input density functions and weighting the output to have an unbiased estimator. Earlier research concentrated on a fixed amount of bias in the input noise probability density function, or pdf, for every simulation trial. In order to better control the bias, we suggest CIS, which is an adaptive scheme that biases the pdf's of some input random variables according to the realizations of other random sources. By doing so, it reduces the uncertainty about the error causing region in the input space and lower the dimension of the biasing problem and enables us to apply proper biasing settings obtained on simpler systems. The estimator variances of CIS are evaluated for some systems, and the resulting improvements over standard *Monte Carlo* and regular (unconditional) *importance sampling* are significant. This is also confirmed by simulation results.

Dr. Charles Weber's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Chung-Yu Hwang**, "Advanced Methods for Digital Modulation Classification," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-91-05-07*, May 1991. (1 copy 11/91)

A B S T R A C T

In this dissertation we address the problem of constructing classifiers of digital modulation signals including QAM, OQPOSK and MFSK and detectors of the CPM signals by likelihood approach and other heuristic approaches.

In likelihood approach for the QAM and OQPSK classification, we start from the log-likelihood functions (LLF's) of such signals in additive white Gaussian noise 9AWGN). We first assume known symbol timing and carrier frequency, and we then relax the timing assumption by introducing a staggered structure, which averages over the symbol timing ambiguity. In order to make the resultant classification rules easier to implement and to reduce complexity, we make some reasonable simplifications on the theoretical rules to obtain certain suboptimal versions. We also show that such rules attain good performance in medium-to-low SNR environments. The second approach for the QAM classification is based on some specific properties of the targeted signals. We then suggest M^{th}-law classifiers, which raise the signal to the M^{th} power and detects the energy around the M^{th} multiple of the carrier frequency, to classify QAM signals and a DAM (Delay-and-Multiply) classifier to classify OQPSK and QPSK. We compare the performance of the classifiers based on these two approaches. It is shown that a particular suboptimal version of the LF rules for the QAM classification, which we call the q_p classifier, is closely related to the M^{th}-law rule, both in terms of implementation and performance.

In the classification of MFSK, we also start with the likelihood approach. We derive the MFSK log-likelihood functionslf to accomplish the optimal rule and then come to three suboptimal rules from the complexity-reduction of the optimal rule. We also point out that the Gram-Schmidt process is a useful tool to classification of the nonorthogonal spacing multiple-tone modulation schemes. Two examples are studied, classification of BPSK and BFSK and detection of the nonorthogonal BFSK signals where the detection problem can be treated as a special case of the classification problem such that one of the hypothesis is the null hypothesis. For the continuous phase FSK or CPM scheme, we construct the detection rules, which can be extended to the classification rules, by three different approaches. One of the approaches applied to the MSK signal achieves the optim um by a modified Viterbi Algorithm, called Average Viterbi Algorithm.

Dr. Andreas Polydoros' efforts in behalf of this thesis research, were supported in part by ARO.

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- **Abhijit Choudhury**, "Deflection Routing in High-Speed Networks," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-91-08-04*, August 1991. (1 copy 11/91)

A B S T R A C T

The rapid development of fiber-optic technology has generated a lot of interest in designing high-speed communication networks for the future. The design of efficient routing and flow control techniques is imperative for the efficient utilization of the large b andwidth that fiber-optic technology places at our disposal.

In this dissertation, we undertake a study of *deflection routing*, which is a novel distributed scheme that has been suggested for networks with regular topology like the Manhattan Street Network, the Shuffle Exchange Network and the ShuffleNet. We develop an accurate analytic model to study both unbuffered and buffered versions of this routing scheme under a uniform traffil model. This model allows us to estimate performance measures like average probability of deflection, average throughput and average network delay. Simulation results agree very closely with those obtained from this model. Next, we study the effect of various contention resolution rules on the performance of deflection routing. A new livelock-free contention resolution rule, based on distance to the destination and number of deflections suffered by a packet, is proposed. The previous model is then extended to compare the performance of deflection routing when using different contention resolution rules. An iterative technique for evaluating the network delay distribution is formulated. Deflection routing causes packets to arrive out of sequence at the destination. The receiver uses a reassembly buffer to store packets until the packet with the missing sequence number is received. If the packets are too far out of sequence, the receiver may run out of memory and be forced to drop packets. The effect of using a finite reassembly buffer on the performance of deflection routing is discussed next. This study helps us identify the range of input rates where the network should be operated for acceptable performance in terms of network delay and packet loss. Finally, we discuss various structural properties of graphs which decide their merit as hosts to the deflection routing scheme. A comparative study of several regular networks is undertaken in order to understand the effect of the different topological characteristics on the performance of deflection routing.

Dr. Victor Li's efforts in behalf of this thesis research, were supported in part by ARO.

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- **Cheng-Shong Wu,** "Design and Analysis of Multiple Access Protocols in Packet Radio Networks," Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-91-08-03*, August 1991. (1 copy 11/91)

A B S T R A C T

Packet radio is a communication technology which applies packet switching to the domain of broadcast radio. A packet radio network (PRN) is a network which uses packet radio for communication between the network users. Due to its broadcast nature, PRN is easy to deploy and reconfiture; it is also particularly suitable for mobile users. In addition, packet switching makes PRN efficient for unpredictable and bursty traffic in computer communications.

In order to utilize the common radio medium more efficiently, it is necessary to coordinate the transmissions of the users. In a packet radio network, this coordination is implemented by means of a multiple access protocol. The ALOHA and Carrier Sense Multiple Access (CSMA) protocols have been proposed for packet radio networks (PRN). However, Carrier

Sense Multiple Access With Collision Detection (CSMA/CD) which gives superior performance and has been successfully applied in local area networks cannot be readily applied in PRN since the locally generated signals will overwhelm a remote transmission, rendering it impossible to tell whether a collision has occurred or not. In addition, CSMA and CSMA/CD suffer from the "hidden node" problem in a multihop PRN. In this thesis, we develop the Receiver-Initiated Busy-Tone Multiple Access (RI-BTMA) protocol to resolve these difficulties. Both fully connected and multihop networks are studied. The busy tone serves as an acknowledgement and prevents conflicting transmissions from other nodes, including "hidden nodes".

Next, we will try to analyze the performance of the proposed mutiple access protocol. The major difficulty involved in the delay analysis of multiple access protocols is the mutual interference between the user queues. We have developed two models to resolve this difficulty: the System Queue model for fully connected networks and the Interrupted Link Queue model for multi-hop networks.

In the system queue approach, a single Markov chain considering all packets in the system is formulated. Based on the statistically identical behavior of each user, we distribute the packets in the system to every user with equaluser, we distribute the packets in the system to every user with equal probability. A recursive method is introduced to solve the Markov chain efficiently. Though the system queue model is a simple and efficient method to calculate the performance of multiaccess protocol, it does not apply to the multihop scenario. To make our research complete, we developed the Interrupted Link Queue model for multihop networks. In particular, we model each link as a single queue and use an interruption source to capture the effect of interference and dependency between different users and then formulate an embedded Markov chain for the queue. This model can be used to analyze not only RI-BTMA but also other multiple access protocols. The results show that our proposed RI-BTMA protocol outperforms other protocols.

Dr. Victor Li's efforts in behalf of this thesis research, were supported in part by ARO. Cheng-Shong Wu was a research assistant support in part by ARO.

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- **Monisha Ghosh**, "An Optimal Approach to Blind Equalization" ,Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-91-12-01*, December 1991. (1 copy 11/91)

A B S T R A C T

This dissertation introduces blind equalization techniques that are motivated by the search for *optimal* approaches to the blind equalization problem. Hence, we depart from the traditional approach of using a finite-impulse-response 9FIR) filter with adaptable tap coefficients as the equalizer, since this structure attempts to identify the *inverse* of the unknown channel. With this structure, no matter what the cost function used to adapt the tap coefficients, or whether the equalizer is blind or trained, channels which have deep nulls

in their frequency response will not be adequately equalized. In such cases, the solution is to perform channel identification (as opposed to channel inverse estimation), followed by maximum-likelihood sequence estimation. The attraction of FIR structures over maximum-likelihood estimators is that the former approach is much easier to implement. Hence, much of the study of blind equalizers has revolved around formulating suitable cost functions that can be used to adapt FIR filters.

In this dissertation, we develop optimal and suboptimal maximum-likelihood based estimators that perform channel and data estimation in a blind environment, i.e., without the help of a training sequence. While this approach is more computationally intensive than channel-inverse identification using a FIR filter and a suitable cost function like the Sato cost function, the performance on channels having deep nulls in their frequency response is clearly superiof. Moreover, the estimators developed give a lower bound on attainable performance of any blind equalizer. Simulation results demonstrate that the performance obtained by the optimal approaches developed in this dissertation are comparable to those obtained in a known channel environment.

Dr. Charles Weber's efforts in behalf of this thesis research, were supported in part by ARO. Monisha Ghosh was a research assistant who received partial support from ARO.

COMMUNICATION SCIENCES INSTITUTE
ANNUAL RESEARCH REVIEW
Wednesday, February 8, 1989
Room 1, Davidson Conference Center
University of Southern California
A G E N D A

8:15 A.M.	Registration	
9:00 A.M.	Lloyd Griffiths Assoc. Dean Eng.	Welcoming Remarks
9:10 A.M.	Robert Scholtz Director CSI	CSI Events
9:20 A.M.	Lloyd Welch	"Markov Signal Generation and Signal Analysis"
9:50 A.M.	Zhen Zhang	"Information Storage Problems"
10:20 A.M.	COFFEE BREAK	
10:40 A.M.	Discussion	"The Gigabit Network Research Activities at USC" John Silvester - USC Organizer Robert Gagliardi - USC Dale Harris - Pacific Bell Vinton Cerf - CNRI
12 NOON	LUNCH	Garden Court, Commons
1:20 P.M.	Irving Reed	"Simple Decoding of the Golay Code"
1:50 P.M.	Robert Peile	"New Directions in Equalization of Band Limited Channels"
2:20 P.M.	COFFEE BREAK	
2:40 P.M.	William Lindsey	Selected Topics in Communication
3:10 P.M.	Charles Weber	Progress on the Modulation Characterization Project

3:40 P.M.	POSTER SESSION	(Until 5:40 P.M.)
	Khaled Biyari	Performance of Digital Communication Systems Employing Quadratic-Form Receivers over Time-Varying Channels
	Rong-Feng Chang	Hierarchical Routing in Mobile Radio Network
	Char-Dir Chung	Multi-Hop Frequency-Hopping Detection
	Michael Fitz	Open Loop Phase Estimator Structures and Analysis
	Elke Hendon	CFAR Sidelobe Canceler for Radar
	Chihping Hsu	Soft Decision Syndrome Decoding of Convolutional Codes
	Yu-Cheun Jou	Switchable Pseudonoise Sequence Generator Design
	Dong-In Kim	Performance Considerations for Common-Signal Spread-Spectrum Radio with Multiple Capture Capability
	Youngky Kim	Modulation Classification for Phase-Modulated Signals
	Shankar Krishnan	Adaptive Error Correction Using Neural Nets
	Ming-Jeng Lee	A Near-Optimal Design Algorithm for Self-Planning Networks
	Song-Chyau Liang	Gateway Allocation for Connecting Existing Networks
	Yeong-Sung Lin	A Distributed Routing Algorithm for Virtual Circuit Networks
	Yeeman Lo	Space-Time System Architecture for Optical Neural Computer
	Michael Rude	Linearly-Constrained Adaptive Filtering of Constant-Modulus Signals
	Syu-Je Wang	Throughput/Delay and Stability Analysis of Multihop Slotted ALOHA Networks
	Thomas Wei	Cooperative Optical Beam Tracking Analysis
	Xiaoli Yu	A Multiple Channel Detection Algorithm Using Reference Optical Images
4:00 P.M.	CSI Faculty Meeting	with Lewis Franks, Director, Networking and Communications, National Science Foundation - Davidson Conference Center, Room 223
4:15 P.M.	CSI Advisory Board	Meeting at Davidson Conference Center, Room 222
6:00 P.M.	MIXER	Faculty Center
7:00 P.M.	BANQUET	Faculty Center

COMMUNICATION SCIENCES INSTITUTE
ANNUAL RESEARCH REVIEW
Wednesday, February 8, 1989
ATTENDEES

Frank Amoroso *Hughes*	Ellwyn Berlekamp *Cyclotomics*	Jack Bricker *Hughes*	Vinton Cerf *CNRI*
Frank Chethik *Ford Aerospace*	Eric Clelland *McDonnell Douglas*	James Dupree *TRW*	Lewis Franks *NSF*
Ken Fredricks *Motorola*	John Garnett *NSA*	James Gault *ARO*	Dennis Hall *TRW*
Dale Harris *Pacbell*	T.C. Huang *Aerospace*	Keith Hurbut *Aerospace*	Gaylord Huth *Axiomatix*
David Isaacs *Applied Systems*	Thomas Kolze *TRW*	Walter Kroy *Douglas Aircraft*	James La Frieda *Aerospace*
Robert Leyendecker *U.S.Army*	Benjamin Lipshuetz *GTE*	Kuo-Hui Liu *Pacbell*	John Maul *Aerospace*
Jerry Michaelson *Signal Proc. Tech.*	John Olsen *Hughes*	Peter Pawlowski *TRW*	Roger Peterson *Motorola*
Alexander Polman *Hughes*	William Sander *ARO*	San Shanmugan *U of Kansas*	James Spilker *Stanford Telecomm.*
Steve Stearns *Tech. Comm. Intl.*	Dan Sullivan *TRW*	Charles Wheatley *Qualcomm.*	Fletcher Wicker *Aerospace*
Eliza Wojtaszek *Rand*	Robert Word *Tech. Comm. Intl.*	Marvin Wunderlich *NSA*	Chin Yuan *Pacbell*
Joseph Yuen *JPL*			

Communication Sciences Institute
RESEARCH REVIEW
Davidson Conference Center, Room 1
University of Southern California
Wednesday, February 7, 1990

8:30 am REGISTRATION

9:00 am Lloyd Griffiths — Welcoming Remarks

9:10 am Robert Scholtz — Communication Sciences Institute Overview

9:20 am Irving Reed — *Optimal Adaptive Detection of Optical Targets in Clutter from Multiple Frequency-Band Data*

9:50 am Jim Yee — *Locating Internet Gateways*

10:20 am BREAK

10:40 am Panel Session: Robert Peile (chairman), K. Sam Shanmugan (U. Kansas, Comdisco Systems), Edward Lee (U.C. Berkeley), Paul Feintuch (Hughes Aircraft Co.) — *The Future of Digital Signal Processing — A Basis for University/Industry Cooperation?*

12:00 noon LUNCH, Center Ballroom, University Hilton

1:30 pm Guest speaker: Andrew J. Viterbi, Cofounder and Chief Technical Officer, Qualcomm, Inc. — *A Spread Spectrum Approach to Multiple Access for Digital Cellular Radio*

2:00 pm Vijay Kumar — *Nonbinary Sequence Sets (Better than Gold!)*

2:30 pm BREAK

2:50 pm Eberhardt Rechtin — *Experiences Teaching System Architecture*

3:20 pm Andreas Polydoros — *Narrowband Interference Effects in a Spread-Spectrum Packet Radio Network*

3:50 pm Poster Session

K. Biyari — *Binary Communication over Random Channels: A Unified Theory*

S. Boztas — *Four-phase Linear Recurring Sequences with Good Correlation Properties*

T. Chen — *Communication System Simulations via Conditional Importance Sampling*

A.M. Chou — *Collision-Free Channel-Access Protocols for Mobile Multihop Packet Radio Networks*

K. Hathaway — *Error Performance of Optical Processing Systems*

C.Y. Hwang — *Classification of FSK Sequences*

D.I. Kim — *Multiple Capture in Spread-Spectrum Networks*

D.K. Kim — *Demodulation Error Statistics over Rayleigh and Rician Correlated Channels*

S.H. Kim — *An Optimal Filter Design for a Cross-Spectrum Symbol-Rate Detector*

Y. Kim — *Modulation Characterization Based on Spectral Correlation*

S.C. Liang — *Locating Internetwork Gateways to Minimize Nonlinear Congestion Costs*

A. Lin — *On the Performance of an ATM Switch with a Multichannel Transmission Group*

A. Patapoutian — *A (d,k) Error-Correcting Code for Magnetic Recording*

S. Rajput — *Codesigned Receiver for ISI Channels*

M. Rude — *An Untrained, Fractionally-Spaced Equalizer for Co-Channel Interference Environments*

F.M. Shiao — *On Maximizing Throughputs in Multi-Hop Slotted Aloha Packet Radio Networks*

M.T. Shih — *A VLSI Design for a Systolic Viterbi Decoder*

H. Song — *On Tuscan Squares*

C.Y. Tseng — *On the Implementation of Adaptive Filters with Adjustable Linear Constraints*

M.Z. Win — *Design and Demonstration of an Optical Phase-Locked Loop (OPLL) for Free-Space Optical Communications*

S.W. Yin — *Algebraic Decoding of the (32,16,8) Quadratic Residue Code*

S. Yu — *A Detection Algorithm for an Optical Moving Target*

G. Zunich — *A Non-Linear Robust Technique for Adaptive Arrays*

4:15 pm CSI Advisory Board Meeting, Room 222

5:30 pm MIXER, Faculty Center

6:30 pm BANQUET, Faculty Center

Attendees - 1990 CSI Review

Keith Hurlbut Aerospace	Diana Johnson Aerospace	James La Frieda Aerospace
Sumner Matsunaga Aerospace	John Maul Aerospace	Jerry D. Michaelson Aerospace
Fletcher Wicker Aerospace	Herbert Wintroub Aerospace	Art Yamada Aerospace
William Sander ARO	Gaylord Huth Axiomatix	Frank Chethik Ford Aerospace
Robert Kwan Ford Aerospace	Phillip Fire GTE	Cynthia Woverton GTE
Stan Aks Hughes	Paul Feintuch Hughes	James A. Kivett Hughes
Jon Leonard Hughes	John Olsen Hughes	Alexander Polman Hughes
William Sagey Hughes	Joseph Yuen JPL	Patrick Wong Lockheed
Eric Clelland McDonnel Douglas	David Borth Motorola	Marc Brack Motorola
James Mikulski Motorola	Ray Waddoups Motorola	Dan Sullivan None
Dale Harris Pacbell	Andrew Viterbi Qualcomm	Ed Bedrosian Rand
James Spilker Stanford Telecomm.	Steve Stearns TCI	Dennis Hall TRW
Peter Joseph TRW	Eric Wiswell TRW	Edward Lee UC Berkeley
Sam Shanmugan U of Kansas	Spyros Magliveras U of Nebraska	

TECHNICAL WORKSHOP

Dr. Robert Scholtz organized a technical workshop "Advanced Communication Processing Techniques", sponsored by the U.S. Army Researth Office under Grant DAAL03-89-G-0016. The workshop was held May 14-17, 1989 in Ruidoso, New Mexico. The program is as follows:

Session 1 - Modulation Characterization

Charles L. Weber Introduction

Bart Rice Automatic and Interactive Signal Classification

Mark Wickert Modulation Characterization Using Rate-Tone Generation Systems

Steve Stearns Statistical Pattern Recognition versus Model-Based Approaches to Signal Classification

Edgar Satorius Application of Neural Networks to Signal Sorting

Bart Rice Interactive and Automatic Signal Analysis

Session 2 - Communication Channels

William C. Lindsey Introduction

Phillip Bello Radio Frequency Channels

Kenneth Wilson Optical Channels

Paul Sass Wideband Channel Measurement Experience

Allan Schneider Delay Spread Estimation for Time Invariant Random Media

Session 3 - Current Issues in Equalization

Dennis Hall Introduction

John Proakis Overview of Adaptive Equalization

John Treichler Adaptive IIR Equalization, Frequency Domain Adaptive Filters

John Cioffi Algorithms for Multipath, Multitone Equalizers

Brian Agee Blind Adaptive Signal Restoration

Session 4 - Adaptive Coding

Robert Peile Introduction

Vedat Eyuboglu Coding and Equalization

Allen Levesque Error Control for the HF Channel

Robert Peile Adaptive Channel Modelling Using Hidden Markov Chains

Seymour Stein Systems Perspectives

Session 5 - Wrap-Up

Robert Scholtz Introduction

Marvin Simon New Ideas on Differential Detection with Multiple Symbol Memory

Paul Sass Issues in Tactical Networks

Dennis Hall Overview and Comments

Robert Peile Overview and Comments

William Lindsey Overview and Comments

Charles Weber Overview and Comments

Herman Bustamante 1105B Communication Subsystem for Satellite Channels

PERSONNEL SUPPORTED

FACULTY

Robert Scholtz	Principal Investigator
Andreas Polydoros	Co-Principal Investigator
Lloyd Griffiths	Senior Investigator
Victor Li	Senior Investigator
Charles Weber	Senior Investigator
James Yee	Senior Investigator
Arie Reichman	Research Associate 8/31/90
Raimundo Sampaio-Neto	Research Associate since 11/90

RESEARCH ASSISTANTS

Sujata Banerjee	Full-time Sept. 88, Part-time Sept. 90	
Rong Feng Chang	Part-time, Aug. 88-Oct. 89	Graduated with Ph.D. 12/91
Shih-Fu Chang	Part-time, Sept. 88-Jan. 89	
David Feldman	Full-time, Sept. 89-Jan. 90	
Monisha Ghosh	Part-time, Sept. 88-May 90	Graduated with Ph.D. 8/91
Irfan Khan	Part-time, Sept. 88, Full-time Sept. 90-July 91	
Dong-In Kim	Full-time, Sept. 88	Graduated with Ph.D. 11/90
Inkyung Kim	Full-time, Feb. 90-July 91	
Seok-Ho Kim	Full-time, Sept. 88-Feb. 90	Graduated with Ph.D.5/90
Song-Chyau Liang	Part-time, June 90-July 91	
Ranjan Mallik	Full-time, Sept. 89-July 91	
K. Ramakrishnan	Part-time, Sept. 88-July 91	
Stephen Sek	Part-time, Sept. 88- Dec. 89	Graduate with M.S. 12/89
Gopa Sen	Part-time, September 90-July 91	
Pablo Valle	Part-time, September 90-July 91	
Wei-Chun Wang	Part-time, June 90-Aug.90	
Cheng-Shong Wu	Part-time, Aug. 88	Graduated with Ph.D. 8/91

EQUIPMENT PURCHASES

As indicated in the first year's budget and approved by separate letter from ARO, we have used our first-year equipment budget for the purchase of a SUN 3/60 workstation, 8 mB extra RAM, 300 mB hard disk, ethernet connection, etc., and named it CSIARO on the USC.edu net. In addition to the standard language package available to us, we have added common LISP, BOSS (block oriented system simulator), Mathematica, and MatLab. We have made use of this computer as a research tool on contract tasks for ARO.

A SUN 3/80 workstation was purchased with our second-year equipment budget. It is networked to our CSI network and the machine is named JIMMIE.

Additionally, in May of 1991, we requested the use of unexpended travel funds to upgrade two of our existing SUN 3 machines to IPC Sparcstations. The upgrade of 2 of our machines was made possible following this approval. SUN Microsystems has announced its intentions to discontinue support of the SUN 3 series.

TRAVEL

- Dr. Robert Scholtz travelled to San Diego, CA, October 23-25, 1988, to attend technical sessions at *MILCOM 88.*
- Dr. Robert Scholtz travelled to Pacific Grove, CA, October 30-November 3, 1988, to attend the *Asilomar Conference on Signals, Systems and Computers.*
- Dr. Andreas Polydoros travelled to Pacific Grove, CA, October 30-November 3, 1988, to attend the *Asilomar Conference on Signals, Systems and Computers.*
- Dr. James Yee travelled to Ottawa, Ontario Canada April 24-27, 1989, to attend and deliver 2 technical presentations at *IEEE INFOCOM '89.*
- Dr. Victor Li travelled to Ottawa, Ontario Canada April 24-27, 1989, to attend and deliver 2 technical presentations at *IEEE INFOCOM '89.*
- Dr. Robert Scholtz travelled to Ruidoso, NM, to coordinate the *CSI Workshop* "Advanced Communication Processing Techniques", May 14-17, 1989.
- Dr. Charles Weber travelled to Ruidoso, NM, to chair the session on *Modulation Characterization* at the *CSI Workshop* May 14-17, 1989.
- Dr. Andreas Polydoros travelled to Ruidoso, NM, to attend the *CSI Workshop* "Advanced Communication Processing Techniques", May 14-17, 1989.
- Dr. Victor Li travelled to Boston, Massachusetts, June 10-13, 1989, to attend and deliver technical presentations at *IEEE ICC '89.*
- Dr. James Yee travelled to Champaign, Illinois, September 26-28, 1989, to attend the *Allerton Conference* and present a technical paper. While there he visited with technical personnel at Northwestern University.
- Dr. Robert Scholtz travelled to Pacific Grove, CA, to attend the *Asilomar Conference on Signals, Systems and Computers,* October 30 - November 1, 1989.

- Dr. Robert Scholtz travelled to Rio Piedras, Puerto Rico, January 8-12, 1990, to attend, participate, and give and invited presentation at the *Workshop on Applications of Algebraic Geometry.*

- Dr. Robert Scholtz travelled to San Diego, CA, January 14-16, 1990, to attend, participate and chair a session at the *IEEE International Symposium on Information Theory.*

- Dr. Robert Scholtz travelled to Kingston, Ontario, Canada, June 3-9, to attend, present a paper and chair a session at the *Fifteenth Biennial Symposium on Communications.*

- Dr. Victor Li travelled to San Francisco, CA, June 5-7, 1990, to attend, participate, and present 2 technical papers at *IEEE INFOCOM '90.*

- Dr. Arie Reichman (visiting Research Associate) travelled to Ojai, CA, June 24-27, 1990, to attend and participate in the *IEEE Communication Theory Workshop.*

- Dr. Robert Scholtz travelled to Ojai, CA, June 24-27, 1990, to attend and participate in the *IEEE Communication Theory Workshop.*

- Dr. Charles Weber travelled to Monterey, CA, October 1-2, 1990 to attend, participate and present a paper at *MILCOM '90.*

- Dr. James Yee travelled to Monterey, CA, October 1-2, 1990 to attend, participate and present a paper at *MILCOM '90.*

- Dr. Robert Scholtz travelled to Pacific Grove, CA., November 4-7, 1990, to attend as Session Chairman and Speaker the *Twnety Fourth Annual Asilomar Conference on Signals, Systems and Computers.*

- Dr. James Yee travelled to San Diego, CA, December 2-5, 1990, to attend, participate and present technical papers at *GLOBECOM 90.*

- Dr. Charles Weber travelled to Phoenix, Arizona, March 28, 1991, to attend and present a joint paper with Monisha Ghosh at the *Phoenix International Conference on Computers and Communications.*

- Dr. Victor Li travelled to Raleigh, NC, and Ft. Lauderdale, FLA, April 8-16, 1991, to attend *INFOCOM '91*, and to visit ARO in connection with continuing research.

- Dr. Robert Scholtz travelled to Montebello, Canada, May 21-23, 1991, to attend and present a technical talk at the *Spread Spectrum Workshop* as an invited speaker.

- Dr. Andreas Polydoros travelled to Toronto and Montebello, Canada, May 14-24, 1991, to attend *ICASSP '91* and the *Spread Spectrum Workshop* as an invited speaker.

- Dr. James Yee travelled to Denter, Colorado, June 24-26, 1991, to attend and present technical papers at *ICC '91.*

- Dr. Victor Li travelled to Denter, Colorado, June 24-26, 1991, to attend and present technical papers at *ICC '91.*

- Dr. Robert Scholtz travelled to Crieff, Scotland, September 8-13, 1991 to attend the *First International Symposium on Communication Theory and Applications*, where he delivered a technical paper and chaired a session. Funds from ARO partially covered his travel costs. His trip report follows.

Trip Report
International Symposium on Communication Theory and Applications
Crief, Scotland. September 8-13, 1991
from *R.A. Scholtz*

This meeting was sponsored by the Royal Society and organized by Hull-Warwick Communications Research Group (a total of about 30 students and faculty) and the USSR Academy of Sciences. The next meeting is planned for Crete in 1993.

The meeting was attended by approximately 80 researchers, including 10 from the USSR, 3 each from Brazil, Italy, and the USA, 2 each from Australia and Iran and one each from Germany, India, Israel, South Africa, Spain, and Switzerland. The remainder were from Great Britain, including a large contingent from the Hull-Warwick Group.

The Soviet contingent presented 9 papers, all but one related to coding theory. The most well known of this group, R.R. Varshamov, presented a paper that was not originally on the agenda, and which did not make the original proceedings (although it will apparently be made available for a later publication of selected papers from the symposium), the topic being cryptography. Roughly speaking, in Varshamov's system, information was block-encoded into a linear subspace and a key-controlled vector from the null-space of the code was added to it. P.G. Farrell asked a question concerning how the code was used in practice and how secure it was if the same key was used several times, and the question was not given a direct answer. Later in the week, Varshamov continued the presentation, indicating that the system also could correct one or two transmission errors and that the word length was adjustable.

The Soviet's remaining papers were on code/modulation design (4), codes for fiber-optic communications (1), sequence design (2), remote sensing receivers (1).

Much of the work reported at this symposium, especially from the UK and USSR, has been aimed at combined code and modulation design, i.e., designs used Euclidean distance (not Hamming distance) as a code design criterion. Most were aimed at producing PSK signal formats, and a few papers (e.g., Mittelholzer, Khachtrain) were aimed at generalizing coding theory from fields to rings in order to have a natural mapping to PSK formats. The UK researchers, led by P. Farrell, are exploring block-coded modulation (as opposed to trellis-coded modulation), dragging the age-old controversy over the choice between convolutional and block codes to the coded modulation domain. The adaptive coding schemes presented were relatively standard (Honary and Darnell reviewed many of their prior works; Bate and Honary reported on an incremental redundancy scheme for convolutional codes).

I had a nice discussion with Ernst M. Gabidulin, Head of the Department of Radio Engineering at the Moscow Institute of Physics and Technology. He is involved in a proposal to hold the IEEE Information Theory Workshop in Moscow at the end of May in 1993. We briefly discussed his current interests, including the construction of a radio navigation receiver that could operate on both GPS and on the Soviet system's signals, and security in communication networks. He has developed a public key system similar to that suggested by McEliece. While McEliece's design is based on Goppa codes, Gabidulin's design is based on codes with maximum rank distance (see his paper in *Problems of Information Transmission*, July 1985, Russian Original Vol. 21, No. 1, Jan.-Mar. 1985). Gabidulin's presentation at the conference concerned some results on PSK-sequences with perfect periodic correlation. He indicated that the crosscorrelations of these sets was very close to the Welch-Sidelnikov bound.

Several other sequence design efforts were presented at the symposium, especially in the poster sessions, mostly by students in the Hull-Warwick research group. Most were relatively simplistic or questionable, e.g., a frequency hop set design that did not consider random phases on individual hops and did not use a Hamming correlation design criteria. Either the authors were thinking coherent hopping or were using the wrong channel model. The application of these sequences was not discussed.

A more interesting paper entitled "New Pseudorandom Sequences Derived from Reflections in Enclosures" by A.T.H. Al-Dabbagh and M. Darnell hints at the use of chaotic carrier generators in communications, although I am not sure that their thinking has progressed to this application of their computerized random number generator.

L.H. Khachatrian of the USSR was not able to talk on "An Algorithm for the Generation of DeBruijn Sequences," but his paper is in the Proceedings, and his results may be new.

Most of the remainder of the papers covered a variety of topics related to commercial applications (e.g., cellular and mobile radio, lightwave communications), implementation considerations, and channel characterization. The bulk of this work was British and European.