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ERROR-CORRECTION CODING

ANNUAL REPORT

Prepared
by

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Submitted
to

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Period Covered
June 1, 1995 - July 31, 1996

Introduction

This report is concerned with the work that was conducted under the Grant NAGW4013 which was awarded to the Department of Computer Science at Southern University by the Office of Space Communications, NASA, for the period June 1, 1995 to May 31, 1996. The value of the grant was $200,000. Because the grant was actually awarded in October 1995, a no-cost extension of the period to August 31, 1996 was granted by NASA. While the scope of the grant was rather broad, a principal part of it is a specific task on error-correcting coding (described below) assigned by NASA. The report describes the progress made towards the completion of that task as well as other significant developments in the Department of Computer Science in the area of Telecommunications and Data Networks.

The team was organized as follows: Dr. Erold W. Hinds, Professor and Chair, Department of Computer Science, Southern University (SU), Principal Investigator; Dr. Ibibia Dabipi, Professor, Department of Electrical Engineering (SU), Researcher; Drs. T. R. N. Rao, Z. L. Loflin Chair Professor of Computer Science, Gui-Liang Feng, Assistant Professor of Computer Science, Guna S. Seetharaman, Assistant Professor of Computer Engineering, The Center for Advanced Computer Studies, University of Southwestern Louisiana (USL); Mr. James Smith, Program Manager; Mrs. Muriel Johnson, Resource Coordinator; Ms. Angela Jenkins, Graduate Student (SU), Research Assistant; Miss Yolanda Whitlock, Undergraduate Student (SU), Research Assistant, and Miss Kendra Elliott, Undergraduate Student (SU), Research Assistant, Miss Michelle Johnson, Undergraduate Student (SU), Research Assistant. The graduate students from USL who also contributed to this project include: Dr. Xinwen Wu, post-doctoral, Mathematics, Messrs. Wenji Jin and Zhiyuan Li, students for the Master's degree in computer science. Dr. Victor Lawrence, Director, Digital Communications Research Laboratory, Lucent Technologies (formerly AT&T Bell Labs) acted as a consultant to the project. The participation by the team from USL was accomplished via a sub-contract funded by the grant.

Southern University provided support for this research project by making available the release time for faculty. In addition, it provided the necessary office space and a limited amount of office equipment to support this project. Other valuable resources provided by the university were word processors, software systems, telecommunication equipment as well as access to telephones and facilities associated with public data networks including the Internet.

Project Specific Research - $200,000 (1995-1996)

The research team worked on the task entitled "Improved Space Link Performance via Concatenated Forward-Error-Correction Coding". A description follows:

The proposed research consists of investigating the use of modulation block codes as the inner code of concatenated coding system in order to improve the overall

communications performance. This study will identify and analyze candidate codes that will complement the performance of the overall coding system which uses the interleaved RS (255,223) code as the outer code. The investigation should consider the use of 8-PSK and 16-PSK modulation in order to provide the coding redundancy (and inner-code error correction) without increasing the effective irradiated power (EIRP) or signal bandwidth relative to a QPSK (i.e., 4-PSK) reference system.

To complement the RS codes most effectively, assume that the coded modulation block contains 8k bits of information (k is small integer; not abbreviation for kilo) which is synchronized with the RS code so that a decoded modulation block consists of k RS-symbols. The investigation should presume that some form of maximum-likelihood decoding is performed on the modulation blocks so as to obtain both a "best-guess" of RS symbols and also a performance metric (e.g., log likelihood ratio) providing a statistical estimate of the decoding reliability. (Note: the development of the decoder is not a part of the proposed research topic.) Since practical high-speed implementations of the candidate codes are important, the investigation should be limited to codes with k<6.

In addition, the project team conducted research in Data Compression Algorithms.

In conducting the research the SU team had another major goal. The NASA grant called for the enhancement of the computer science program infrastructure through meaningful association and interaction with universities such as the University of Southwestern Louisiana and New Mexico State University. During 1996 the department accomplished:

* the establishment of two joint faculty appointments between the Computer Science Departments at SU and USL. This program is funded by the National Science Foundation through the Louisiana Board of Regents and goes into effect in the Fall 1996.

* the acquisition of educational grants from major corporations such as AT&T, Xerox, Proctor & Gamble, Bellcore, and Exxon.

Activities

In response to the above task assignment required by NASA, the principal investigator held technical discussions with Mr. Warner Miller and Dr. James Morakis, Goddard Space Center, Technical Consultants, Dr. Daniel J. Costello, Jr., Professor and Chairman, Electrical Engineering, Notre Dame University, and Dr. Shu Lin, Professor, Department of Electrical Engineering, University of Hawai'i at Manoa, on various aspects of the above problem. These very fruitful discussions formed the basis for the proposed technical co-operations with the appropriate departments of Southern University and Notre Dame University. Two graduates have expressed interest in pursuing doctoral degree at Notre Dame University.

June 95 - August 95: The Principal Investigator participated in technical discussions with Mr. Warner Miller, and Dr. Jim Morakis, Goddard Space Center, Maryland. These discussions concentrated on those technical problems of interest to NASA which were to be researched by the Southern Team. There was also an agreement that an infrastructure needed to be established at Southern to conduct the research.

Southern University identified a graduate student (Ms. Angelle Jenkins) and two undergraduate students (Ms. Yolanda Whitlock and Ms. Kendra Elliott) to be part of the program as research assistants.

The Principal Investigator developed and implemented two new courses, Digital Data Networks and Digital Communications and added them to the Computer Science curriculum.

January - May 1996: Dr. Ibibia Dabipi (Electrical Engineering) joined the project and began research on Turbo Codes and Trellis Coded Modulation. The research assistants (Jenkins, Elliott, Whitlock) established, managed and maintained the new UNIX-based and networked computer laboratory. Ms. Jenkins expanded her knowledge of Data Communications and Error Correcting Coding. In May 1996, Ms. Jenkins gave a tutorial on coding theory to her Data Networks class. The S.U. team hosted a one-day NASA Research Review Meeting in February, 1996. This meeting was held on the Baton Rouge Campus and 17 NASA researchers attended. Five presentations were given.

Results

The results achieved by the project team on the NASA task were accomplished by the principal investigator and the USL team of researchers over the period January 15, 1996 to July 31, 1996. Research on the NASA task was given a great impetus with the introduction of the research team from USL. The USL program report is attached.

Two accompanying results of the work associated with the grant are worth of note: (a) the completion of the first draft of notes for two courses in Data Networks and Coding Theory for both the undergraduate and graduate programs in computer science. The class on Coding Theory is scheduled for the Spring 1997 semester and the course on Data Networks was given to 10 graduate students in Spring 1996. These notes also provided the basis for a proposed textbook entitled "Digital Communications - Theory and Practice" to be published next year. The book will place a major emphasis on the latest results on error-correcting coding and data compression. (b) The research students played a major role in establishing and maintaining a laboratory of 30 networked computers which were donated by Intel Corporation. The laboratory, which is used by faculty and students for research and classroom instruction, was established in January 1996 and has full Internet access. The students participated in the planning, installation, software maintenance, and provided the overall management of the laboratory. This was a great achievement for students who had a limited background in data networking or communications.

Planned Accomplishments for 1996-1997

The research team associated with this continuation of the grant will consist of:

Southern University

- Dr. Erold W. Hinds (Principal Investigator)
- Dr. John Dyer (Researcher)
- Miss Angelle Jenkins (Graduate Student)
- Miss Kendra Elliott (Undergraduate Student)
- Mr. Jim Smith (Program Manager)

University of Southwestern Louisiana (Subcontract)

- Dr. T.R.N. Rao (Researcher)
- Dr. G. L. Feng (Researcher)

Networks, Inc. (Subcontract)

The Southern and the USL teams will concentrate on three(3) main areas:

(1) Developing and testing the efficiency of new algorithms for lossless data compression.

(2) Developing new efficient codes from the recent work in algebraic geometric coding theory.

(3) Study the properties of "Turbo Codes" with a view towards better understanding and explaining their properties.

(4) Participate in the Protocol Testing Project at New Mexico State University through Networks, Inc.

Statement of 1996-1997 Tasks

With the development of new advanced instruments for remote sensing applications, sensor data will be generated at a rate that not only requires increased onboard processing and storage capability, but imposes demands on the space to ground communication link and ground data management-communication system.

Data compression and error control codes provide viable means to alleviate these demands. Two types of data compression have been studied by many researchers in the area os information theory: a lossless technique that guarantees full reconstruction of the data and a lossy technique which generally gives higher data compaction ratio but incurs some distortion in the reconstructed data. To satisfy the many science disciplines which NASA supports, lossless data compression becomes a primary focus for the technology development. Recently, Yeh and Miler have shown significant research results in this area using the *Rice algorithm*. The result has been tested for following various applications: (1) Landsat-D Thematic Mapper over Sierra Nevada at 30m ground resolution in band 1 with wavelength region of 0.45-0.52 *u*; (2) Soft X-ray telescope (SXT) image, in the wave length region of 3-60 Angsrom, acquired on Solar A Mission launched in '91; (3) Acousto-Optical Spectrometer (AOS) data, representative of what has been acquired on the Sub-millimeter Wave Astronomy Satellite (SWAS) launched '95. Two traces of 1450 data are in the upper graph and the expanded view in the lower graph; (4) Magnetic Resonance Imaging (MRI) data over the human brain area; (5) Seismic trace acquired in Japan. The compression results show that the extended Rice algorithm is well adapted to various types of sensor data.

On the other hand, while transmitting the data obtained by any lossless data compression, it is very important to sue some error-control code. For a long time, convolutional codes have been widely used in satellite telecommunications. To more efficiently transform the data obtained by Rice algorithm, it is required to meet the *a posteriori probability* (APP) for each decoded bit. A relevant algorithm for this purpose has been proposed by Bahl et al. This algorithm minimizes the bit error probability in the decoding linear block and convolutional codes and meets the APP for each decoded bit. However, recent results on iterative decoding of *Turbo codes*, which have achieved low error probabilities at rates well beyond R_0, turn conventional wisdom on its head and suggest fundamentally new techniques.

During the past several months of this research, the following approaches have been developed: (1) a new lossless data compression algorithm, which is much better than the extended Rice algorithm for various types of sensor data, (2) a new approach to determine the generalized Hamming weights of the algebraic-geometric codes defined by a large class of curves in high-dimensional spaces, (3) some efficient improved geometric Goppa codes for disk memory systems and high-speed mass memory systems, (4) a tree based approach for data compression using dynamic programming. We strongly believe that the research on lossless data compression and error-correcting codes has now reached a stage of very exciting prospects for many commercial, government and defense applications.

We acknowledge that some of our previous research contributions have been achieved with the support of the grant from the NASA. At this time we seek continued support for our investigations in the research of improved space link performance via concatenated

forward error correction coding. The main problems which we propose for further investigations are more concretely presented below.

(1) A new Rice-like data compression algorithm for remote-sensing and other applications has been developed. Some simulations have shown that the results were much better than that by the extended Rice algorithm for some cases. In the next period, we would like to test the performance of the new algorithm on various test imagery. On the other hand, we also would like to improve the Rice-like data compression algorithm by developing a modified Huffman code, which has minimal expected average length and is quasi-uniquely decodable. Quasi-uniquely decodable means that any subset of the ordered codeword sequence can be uniquely decodable. For example, let *abcdefghijk* be an ordered codeword sequence and *a, b, c, d, e, f, g, h, i, j, k* are all codewords. *bdghk* is a subset of this ordered codeword sequence. Obviously, the condition of prefix is stronger than the condition of quasi-uniquely decodable. Thus, the Rice-like algorithm can be improved by using the modified Huffman code. To analyze and test the performance of the improved Rice-like algorithm are also proposed.

(2) It is well-known that the expected code length cannot be less than the entropy of the type of source symbol sequence. However, some technologies can be used to change the entropy of the type of source symbol sequence. for example, let *a, b, c, d, e, f, g, h* be a source symbol. set. Let *cdebbgdefgfabacb* be an original character sequence (a source symbol sequence). The entropy of this type is 2.952820. If we decode a as 000, b as 001, and so on. The symbol sequence is encoded in a binary sequence. We add (modulo two) a known binary sequence to the sequence. Then we get a new binary sequence. Decoding the new binary sequence, we get a new symbol sequence *dhddhgfhdffdghdd*, whose entropy is 1.849602. We are very interested in this preliminary result, because there may be a new lossless data compression algorithm. We propose to investigate a new lossless data compression algorithm by changing the original binary sequence. This technique can be used in combination with Huffman coding or arithmetic coding to obtain a new efficient universal lossless data compression method. On the other hand, the research may result in a new lossless data compression with some cryptographic properties.

(3) We propose to develop a class of fixed-byte error protection codes, that are suitable for the data obtained by the extended Rice algorithm. The data is divided into two segments. The data in one segment is the J sample sequence of the most significant ***n-k*** bits samples extracted from the original data. For the data in this part, it is required to be error free. The data in the other segment is the corresponding sequence of the k least significant bit samples of the original data. For the data in this segment, a small error rate is tolerated.

(4) From the performance of *Turbo codes*, we propose to investigate a new encoding and decoding scheme that should greatly enhance the likelihood of detecting any single or multiple bit errors that may occur during transmission and reception of information. The proposed scheme must attain a target bit error rate of 10^{-15} to 10^{-17}, with acceptable implementation overhead.

Network, Inc. Team

Background

The NASA Tracking and Data Relay Satellite System (TDRSS) is a national resource that was built at considerable government investment. Even with the superior tracking coverage afforded by TDRSS, there are several obstacles to the effective use of this resource. Almost 90% of new NASA spacecraft are NOT planning to use the TDRSS multiple access system. Obviously, there is an urgent need for improved techniques and equipment that will improve the ability of TDRSS to serve the user community.

There are two major areas of improvement needed: (1) increased effective, highly reliable, space-to-ground data rates and (2) automatic (data driven) routing and distribution of data and commands. The former involves the use of improved coding techniques, in particular turbo codes, while the latter focuses on the use of the INTERNET for access to satellite data. With this concept, each satellite would appear as a node if the INTERNET.

Statement of Work

The contractor shall advise Southern University of promising areas of research in coding and TCP/IP protocols and suggest experiments that will demonstrate increased utility of the TDRSS as well as complement similar activities by other research organizations in these areas.

The contractor shall suggest and facilitate use of NASA spacecraft that have completed their prime mission and are available to be used as test vehicles. There include the Extreme Ultraviolet Explorer (EUVE. The Cosmic Background Explorer (COBE), the Upper Atmosphere Research Satellite (USRS) and DOD spacecraft.

The contractor shall facilitate use by Southern University of the NASA Tracking and Data Relay Satellite Ground Station, Las Cruces, NM, and any other required NASA facilities necessary to carry out the experiments. In this regard, the contractor shall arrange for the necessary scheduled events via the NASA Network Control Center, Greenbelt, MD.

The contractor shall facilitate the electronic exchange of information and foster collaboration between Southern University and other organizations that are engaged in related coding and TCP/IP research, such as; New Mexico State University, The University of Hawaii, Purdue University and the Jet Propulsion Laboratory.

The contractor shall assist Southern University in preparation of reports and presentations to NASA headquarters and field centers and will participate in those reviews as required.

Period of Performance

The period of performance shall be for one year, commencing on September 1, 1996 and completing on August 10, 1997.

Reports

The contractor shall provide comprehensive monthly status reports.