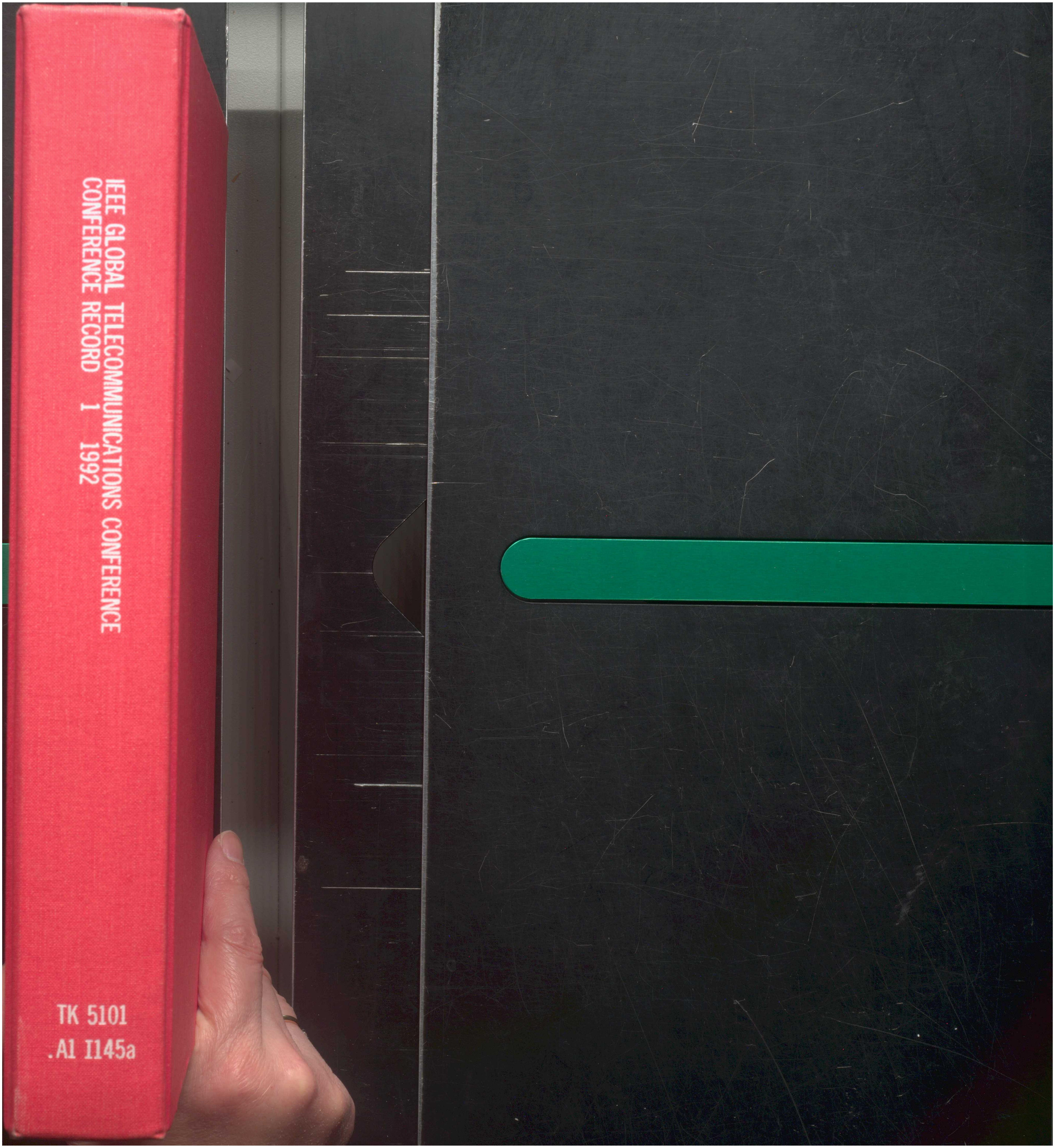
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DECEMBER 6-9, 1992

ORLANDO

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Including a *Communications Theory* Mini-Conference

Technical Program
Conference Record

Vol 1 of 3

Volume	Day	Sessions	Pages
1	MONDAY	1-18	1 - 648
2	TUESDAY	19-36B	649 -1254
3	WEDNESDAY	37-54	1255 -1920

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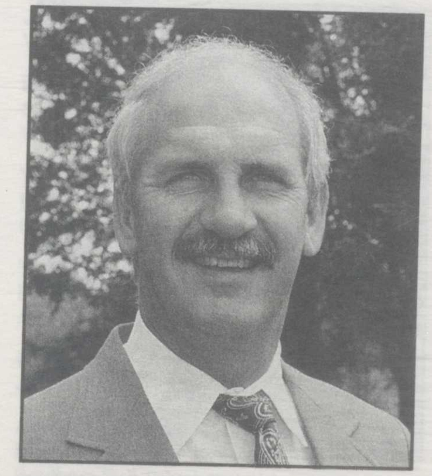
Greetings from the General Chairman



Escape to the land of sunshine and balmy breezes for a look into the future of telecommunications at GLOBECOM '92, December 6-9, at the Buena Vista Palace, Orlando, Florida. This year's conference promises an excellent technical program for attendees from all points of the globe. Members of the IEEE Communications Society in particular will make GLOBECOM '92 a focal point of their meeting year, providing a valuable opportunity to make contacts in this arena. Join us in Orlando, the southern gateway to growth and technical innovation.

The heart of GLOBECOM '92 is, as always, its comprehensive technical program, which includes several tutorials and workshops in addition to 54 technical sessions. The technical sessions will run from Monday, December 7, through Wednesday, December 9. An additional attraction will be the debut of the Communication Theory Mini-Conference (CTMC), which highlights developing theoretical issues. The CTMC is sponsored by the Communication Theory Committee of COMSOC in cooperation with Commission-C of U.R.S.I. and the IEEE Information Theory Society. Sessions will run from the afternoon of Monday, December 7, through the morning of Wednesday, December 9.

Exhibits are shaping up nicely as December draws near, leaving us with 25 exhibitors at program printing. This will include several international exhibitors. The Great Hall East/West/Center will be the location of the General Chairman's Reception.

A taste of the offerings of Central Florida is provided in a varied social events program which includes educational tours, exclusive shopping, and an evening of fantasy and amusement. Kennedy Space Center is the site of an exciting tour of America's space program. If we're especially lucky, a shuttle launch may even be scheduled during the days of the conference. Shopping among quaint boutiques and galleries awaits you on Florida's very own Park Avenue, and in the evening you can be a guest at the Medieval games of 11th century Europe.

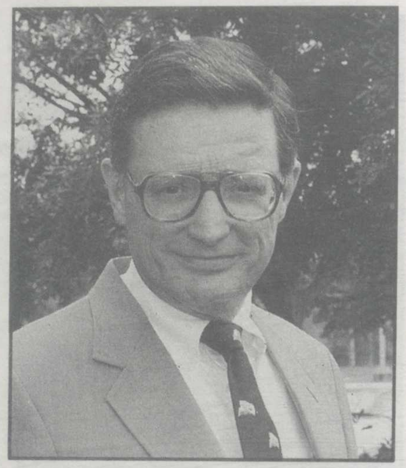
Outdoor activities are as popular and plentiful as the Florida sun. Golf, tennis, sailing, and much more are available within and around the hotel and the rest of the WALT DISNEY WORLD Resort. Be a part of the Disney magic at the MAGIC KINGDOM Park, watch movies in the making at the Disney/MGM Studios Theme Park, or take a trip 'round the World at EPCOT Center.

As the multinational market continues to evolve, GLOBECOM '92 provides a forum for discussion of the challenges and opportunities it will bring to our industry. Thus the theme, "Communication for Global Users," which demonstrates our objective: Bringing together industry leaders to assess worldwide communications trends. Please join us in December to further explore the future of telecommunications.

Ronald J. Kandell
General Chairman GLOBECOM'92

Technical Program Chairman's Message

There is no doubt that the last few decades have brought tremendous developments in telecommunications, however none of us can begin to predict the scope of the advances to be achieved by the turn of the century. There is one certainty: These advances will be driven more by the global business needs of communications users and service providers than they ever have been in the past! Thus, the Technical Program Committee has used the GLOBECOM '92 theme, "Communication for Global Users" to spotlight the impact of global user needs on advancing technologies.



A Monday morning session combining the Keynote Address and the Opening Plenary launches the technical program. Keynote speaker Gerd Tenzer of the Deutsche Bundespost will discuss the challenges of modernizing the (formerly) East German telecommunications network. The Opening Plenary which follows highlights residential and small business market needs from the perspective of telecommunications and cable TV companies, and an outlook on consumer products. In addition the Opening Plenary will feature an international panel of speakers presenting their views on technologies and architectures needed for customer markets in the years 1996 and beyond.

"Communication for Global Users" is evident throughout the entire three days of the technical program of GLOBECOM '92. Approximately 50% of the technical papers have been contributed from the international community. The number of sessions on subjects such as Personal Communications Services demonstrates interest in services and user needs. A special, and I believe spirited panel session will be held on Monday afternoon, with panelists representing the financial community, a cable company, a satellite vendor and a local exchange carrier, discussing the topic of "Competition in the Local Loop."

In addition to the technical sessions, two lunch time panels are included in the program. On Tuesday, a panel will discuss the hot topic of "Personal Communications Network-TDMA or CDMA." On Wednesday, a panel of international speakers will present the latest in the Europe '92 initiative and how the evolution of the Common Market is unfolding. Sunday afternoon through Thursday, five tutorials and five workshops will be offered on a wide variety of topics.

Additionally, a Mini-Conference, sponsored by the Communications Theory Committee, will be held in parallel with the main conference and will offer four sessions beginning on Monday afternoon and ending on Wednesday morning.

This exciting technical program results from the dedication and hard work of many individuals. I want to thank all of the members of the GLOBECOM '92 Technical Program Committee, the technical program session organizers and chairs, the Regional Representatives, the hundreds of international reviewers and of course, the authors. All have teamed to create and shape this excellent technical program.

On behalf of the Technical Program Committee, I invite you to GLOBECOM '92.

David P. Worrall

Technical Program Committee Chairman

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GLOBECOM '92

Program Schedule Overview

▭ = Mini-Conference Sessions

▦ = Special Sessions

Sunday, December 6

2:00 pm - 5:00 pm

- Tutorial 1: *Emerald* — Broadband Service Requirements: A User Perspective
- Tutorial 2: *Diamond* — Information Networking Architecture

6:00 pm - 9:00 pm

- General Chairman's Reception — *Great Hall East/West/Center*

Registration:

Sun.	Dec. 6	2 pm - 7 pm
Mon.	Dec. 7	7 am - 8 pm
Tues.	Dec. 8	7 am - 6 pm
Wed.	Dec. 9	8 am - 5 pm
Thurs.	Dec. 10	8 am - 10 am

Exhibits:

Sun.	Dec. 6	6 pm - 9 pm
Mon.	Dec. 7	9 am - 5 pm
Tues.	Dec. 8	9 am - 5 pm
Wed.	Dec. 9	9 am - 12 pm

"No Smoking Allowed Except in Designated Area"

Monday, December 7

8:00 am - 8:45 am

- KEYNOTE ADDRESS — *Great Hall East/West* — "Modernizing the East German Telecommunications Network"

9:00 am - 12:00 pm

- PS-1 *Great Hall East/West* — Exploring Technologies and Architectures for Customer Markets for the Years 1996 & 2000
- 1 *Scotland B* — Wireless Data Network in PCS
- 2 *Scotland A* — Coding and Equalization for Digital Subscriber Loops
- 3 *England* — Advances in Digital Mobile Networks
- 4 *Scotland C* — Quality Management Strategies (Panel)
- 5 *Ireland B* — ATM Switching Experiments and Future Research
- 6 *Ireland A* — Evolution and Experiences of Subscriber Access Systems
- 7 *Diamond* — Interconnections Within High-Speed Systems
- 8A *Ireland C* — Networking For Multimedia Applications
- 8B *Ireland C* — Advances in Image Processing
- 9A *Emerald* — Application of Object-Oriented Technology to Telecommunications Systems
- 9B *Emerald* — Users' Tools For Services and Network Management
- Tutorial 3: *Sapphire* — Broadband Applications: Strategic Benefit for Industry

12:15 pm - 1:45 pm

- Awards Luncheon — *Great Hall North* — "Vital Communications Link: Apollo 13 Rescue" — Fred W. Haise

2:00 pm - 5:00 pm

- SP-1 *Great Hall East* — Competition in the Local Loop (Panel)
- 10 *Ireland B* — Integrated Data/Voice/Video Transport in ATM Networks
- 11 *Ireland C* — Synchronization
- 12 *Ireland A* — Network Element Initial Verification Tools and Methods
- 13 *Emerald* — Advanced Satellite Communication Systems and Techniques
- 14 *Diamond* — DSP in Communications
- 15 *England* — Broadband Switching Systems
- 16 *Scotland B* — Emerging Software Technologies for Services Support
- 17 *Scotland C* — Network Planning, Management and Interconnection
- 18 *Scotland A* — Advances in the Theory and Practice of Fault Tolerance with Applications to Information Networks
- CTMC 1 - *Great Hall West* — Channel Equalization
- Tutorial 4: *Sapphire* — ISO 9000 Quality Management Standards and Their Impact on Global Businesses

Social Events: Monday

Monday Afternoon, 1:30 pm
INNOVATION IN ACTION: BEHIND THE SCENES AT THE WALT DISNEY WORLD RESORT

Monday evening, 7:00 pm
Evening at Medieval Times

Tuesday, December 8

9:00 am - 12:00 pm

- 19 *Ireland A* — Key Technologies for the Americas and Related Standards (Panel)
- 20A *Scotland B* — Wireless Personal Radio Systems: Techniques & Applications
- 20B *Scotland B* — Topics in Personal Communication Systems and Services
- 21 *Diamond* — ISO 9000 Series Standards: A New Way of Doing Business (Panel)
- 22 *Emerald* — Satellite Technologies
- 23 *Scotland A* — Hypermedia/CSCW and Its Applications
- 24 *Ireland B* — Dynamic Phenomena in Communication Networks
- 25 *Ireland C* — Advances in SONET/SDH Implementations
- 26 *England* — Spread Spectrum Systems Multiple Access For Personal Radio Communication System
- 27 *Scotland C* — Advances in Modulation, Coding/Decoding for Fading Channels
- CTMC 2 - *Great Hall West* — Mobile Communications
- Tutorial 5: *Sapphire* — Network Intrusion Detection

12:15 pm - 1:45 pm

- LP-1 TDMA or CDMA: *Great Hall North* — The Solution for Microcellular PCNs (Panel)

2:00 pm - 5:00 pm

- 28 *Ireland B* — Packet Network Services and Applications
- 29A *Ireland C* — Mobile Communication for Developing Countries
- 29B *Ireland C* — Cellular Communications in Latin America: Experience and Future Developments
- 30 *Ireland A* — Distributed Architectures for Operating Telecommunications Networks
- 31 *Scotland B* — 802.6, SMDS and FDDI MAN/WAN Experiences
- 32A Diamond — Signal Processing and Coding for Recording Channels
- 32B *Diamond* — Coding for Video and High Definition Television
- 33 *Emerald* — OSI/CMISE - Operations System to Network Element Interface Protocol of Choice
- 34A *England* — Experimental Studies of Protocols and Traffic Measurements for Broadband Networks
- 34B *England* — Signaling Systems for Broadband ISDN
- 35 *Scotland A* — Gigabit Computer Networks
- 36A *Scotland C* — MANs & WANs
- 36B *Scotland C* — Knowledge-Based Network Management
- CTMC 3 - *Great Hall West* — Multi-User Communications Using Spread Spectrum Technology
- Workshop 1 - *Sapphire* — Software Interoperability Across Suppliers and Releases

6:00 pm - 7:00 pm

- Pre-Banquet Reception — *Great Hall Assembly*

7:00 pm - 10:00 pm

- Conference Banquet — *Great Hall North/Center* — "A TRIP into the Future" — John W. Seazholtz

Social Events: Tuesday

Tuesday (all day), 9:00 am
Winter Park Shopping Tour

Wednesday, December 9

9:00 am - 12:00 pm

- 37 *Emerald* — VLSI and Communications
- 38 *Ireland A* — Neural Networks for Communications and Signal Processing
- 39 *England* — Wireless Local Area Communications
- 40 *Ireland C* — Transport Protocols for Video & Multimedia
- 41 *Ireland B* — Radio Resource Management in Personal Communications Systems
- 42A *Diamond* — Next Generation Undersea Communications Systems
- 42B *Diamond* — Techniques for Modeling Large High-Speed Networks
- 43 *Scotland A* — Switching Software, Architecture & Performance
- 44 *Scotland B* — Teletraffic Analysis and Performance Evaluation of B-ISDN
- 45 *Scotland C* — Modernizing Telecommunications Networks: Accent on Eastern Europe
- CTMC 4 - *Great Hall North* — Bandwidth Efficient Modulation and Coding (Co-Sponsored by U.R.S.I. Commission C)
- Workshop 2 - *Sapphire* — Powering for Fiber in the Loop Systems

12:15 pm - 1:45 pm

- LP-2 *Great Hall Center* — EUROPE '93: The Common Market for Telecommunications (Lunchtime Panel)

2:00 pm - 5:00 pm

- 46 *Scotland A* — Optical Switching
- 47 *Scotland B* — High-Speed LANs & MANs
- 48 *Scotland C* — Trends in Field Reliability and Performance Analysis
- 49 *Diamond* — Advances in Standardization of Low-Rate Signal Processing
- 50 *Ireland A* — Operations of CCS Networks and ISDN in the 90's
- 51 *Ireland B* — Coding and Modulation
- 52 *England* — Modeling and Simulation of Wireless PCN Channels
- 53 *Emerald* — Microwave Radio Systems for Future Telecommunications Networks
- 54 *Ireland C* — Next Generation Lightwave System

Social Events: Wednesday

Wednesday (all day), 8:30 am
Kennedy Space Center Tour

Thursday, December 10

9:00 am - 12:00 pm

- Workshop 3 - *Westminster* — User Oriented Telecommunications Network Management

9:00 am - 5:00 pm

- Workshop 4 - *Senate/Gallery* — 20/30 GHz Space Satellite Technology
- Workshop 5 - *Outback Veranda* — Networking of Personal Communications Applications

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Future Conferences

1993

Optical Fiber Communications Conference, San Jose Convention Center, San Jose, CA
Feb. 21-26
Info: Monica Malouf
Optical Society of America.
2010 Massachusetts Avenue, N.W.,
Washington, DC 20036
Tel: (202) 223-0920; FAX (202) 416-6100

Phoenix Conference on Computers and Communications, Wyndham Paradise Valley Resort, Scottsdale, AZ
March 24-26
Info: Mr. James Weeldreyer
Honeywell
16404 N. Black Canyon Highway
Phoenix, AZ 85023
Tel: (602) 436-4813: FAX (602) 436-4848

INFOCOM '93 Hotel Nikko, San Fransico, CA
March 28-April 1
Info: Mike Hluchyj
Motorola Codex, MS C2-15
20 Cabot Blvd.
Mansfield, MA 02048
Tel: (617) 821-7952; FAX (617) 821-4218

ICC '93 Centre International de Conferences de Geneve, Geneva, Switzerland
May 23-26
Info: Peter Leuthold
Insitut fuer Kommunikationstechnik,
ETH-Zentrum,
CH-8092 Zurich, Switzerland
Tel: 41-1-256-2788; FAX 41-1-262-0943

ISSLS '93, Vancouver, BC, Canada
October 4-8
Info: Shahid Hussain
BC Tel
3777 Kingsway
Burnaby, BC V5H327 Canada
Tel:(604) 432-2151; FAX(604) 434-6616

Second International Conference on Universal Personal Communications, Ottawa, Canada
October 12-14
Info: Celia Desmond
Bell Canada
800 Bay Street, 4th Floor
Toronto, Canada M5G 2E1
Tel: (416) 353-4080; FAX (416) 920-6689

MILCOM '93, Stouffers Bedford Glen Hotel, Bedford, MA
October 11-14
Info: Anthony Rutti
GTE Government Systems, Building 23,
77 "A" Street
Needham Heights, MA 02194-2892
Tel: (617) 455-4805; FAX (617) 455-5734

GLOBECOM '93, Westin Galleria Hotel, Houston, Texas
November 29-December 2
Info: Robert Finley
Southwestern Bell
6500 West Loop South, Zone 3.3,
Bellaire, TX 77401
Tel:(713) 567-8127; FAX(713) 567-6133

1994

NOMS '94 Orlando, FL
February 14-16
Info: Michelle Nessler
Action Motivation
188 King Street
San Francisco, CA 94107
Tel:(415) 512-0800; FAX(415) 512-1325
e-mail: 4367585@mcimail.com

TUTORIALS

TUTORIAL 4: *(Room: Sapphire)* ISO 9000 Quality Management Standards and Their Impact on Global Businesses

Monday, Dec. 7, 2 pm - 5 pm

INSTRUCTOR: B. S. Liebesman,
AT&T Bell Laboratories, USA

The European Community, as part of EC '92, has initiated a new approach to ensuring the quality of goods and services. This approach is centered around third party registration of quality systems based on the ISO 9000 Series Standards. It is expected that many European customers will require conformance by their suppliers to one of the ISO 9000 Contractual Standards. This tutorial will cover the basics of the standards and the registration process. Specific issues that will be discussed will include business implications of the registration process, a discussion of selected requirements in ISO 9001, information on registration bodies operating in the United States; the typical effort required to register, and sources of information and reference material.

TUTORIAL 5: *(Room: Sapphire)* Network Intrusion Detection

Tuesday, Dec. 8, 9 am - 12 pm

INSTRUCTOR: Biswanath Mukherjee
L. Todd Heberlein
University of California, Davis, USA

Network Intrusion Detection is a mechanism for providing security against not only outside attackers to a computer system or network, but also against insider threats. Traditional (network) security methods, such as authentication techniques or cryptography guard against outsiders from entering the system they are designed to protect. Hence they can not deal with insiders misusing their privileges or against lost or stolen keys. Intrusion detection systems, an essential component of network security, can be designed and deployed on the existing (and vast) infrastructure of heterogeneous computer networks for identifying unauthorized use, misuse, and abuse of computer systems. As a result, intrusion detection is gaining increasing attention from numerous security-conscious organizations. This tutorial will examine the characteristics of intrusion detection systems which have been designed and some of which have been deployed. Methods based on statistical analysis and rule-based expert systems will be covered.

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Volume I

SESSION 16
Emerging Software Technologies for Services Support

ORGANIZERS: M. E. Nilson, Bellcore, USA
R. Sundaraman, AT&T Bell Laboratories, USA
CHAIRPERSON: *M. E. Nilson*
SPONSOR: *Multimedia Services & Terminals Communications Software*

Oral Presentation

SESSION 17
Network Planning, Management and Interconnection

ORGANIZERS: *Bhumip Khasnabish, University of Windsor, Canada*
Jonathan Wang, Bellcore, USA
Guy Omidyar, Computer Sciences Corporation, USA
CHAIRPERSON: *Wen-Pai Lu, BellSouth, USA*
SPONSOR: *Computer Communications*

Oral Presentation

SESSION 18
Advances in the Theory and Practice of Fault Tolerance with Applications to Information Networks

ORGANIZERS: *Anindo Bagchi, Bellcore, USA*
T. V. Lakshman, Bellcore, USA
CHAIRPERSON: *Anindo Bagchi*
T. V. Lakshman
SPONSOR: *Network Operations & Management*

Oral Presentation

REFERENCES

1. R. Richard et al., "Advanced Communications Technology Satellite (ACTS)", ICC'89, 52.1-12, 1989.

2. N. Hamamoto et al., "Results on CRL's Mobile Satellite Communication Experiments Using ETS-V", Space Communications, No.7, pp.483-493, 1990.

3. M. Shimada et al., "Experimental Millimeter-Wave Satellite Communications System", 17th Int. Symposium on Space Technology and Science, O-4-3, Tokyo, May 1990.

APPENDIX

JAPAN'S COMETS PROGRAM

The COMETS is being developed by CRL and the National Space Development Agency of Japan (NASDA). Figure A-1 shows a conceptual sketch of the COMETS. It is a geostationary three-axis stabilized satellite and has three deployable antennas and a 32 m long solar paddle.
Table A-1 shows Japan's COMETS Program. The COMETS will be launched by Japan's H-II rocket in the beginning of 1997. Its mission life is three years and the in-orbit weight is about two tons. The COMETS has three mission payloads. The first is an advanced mobile satellite communications system using millimeter-wave and Ka-band, which is being developed by CRL. The second is a 22 GHz band advanced broadcasting system developed by CRL and NASDA. The third is an intersatellite communication system developed by NASDA using the S-band and Ka-band.

Table A-1: COMETS program in Japan

Launch date	:	1997
Launch vehicle	:	H-II
Spacecraft bus	:	Based on ETS-VI
Mission life	:	3 years
Weight(in orbit)	:	about 2,000 kg

Principal COMETS mission
- Advanced mobile communications system in MM-wave and Ka-band
- Advanced broadcasting system in Ka-band
- Intersatellite communication system in Ka-band and S-band

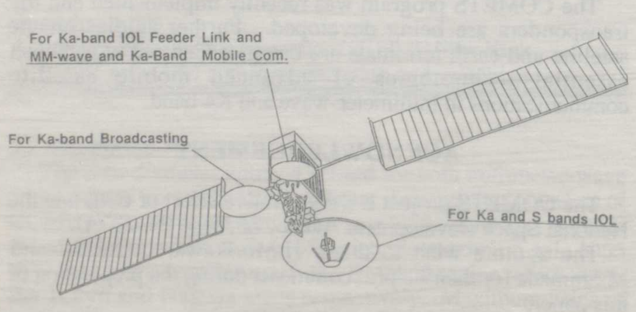

Fig.A-1 Conceptual sketch of COMETS

REAL-TIME IMPLEMENTATION OF A 9.6 KBIT/S ACELP WIDEBAND SPEECH CODER

R.SALAMI, C.LAFLAMME, and J-P.ADOUL

Department of Electrical Engineering, University of Sherbrooke,
Sherbrooke, Québec, CANADA J1K 2R1

ABSTRACT In this paper, the real-time implementation of a wideband ACELP speech coder at 9.6 kbit/s is presented. The coder is implemented on a TMS320C30 floating point DSP chip. The attempt to implement an ACELP coder for wideband speech in real-time results in a complexity which is 3–4 times more that that of narrowband speech. Very efficient algorithms for searching the pitch and codebook parameters have been introduced to enable this real-time implementation. The pitch search was brought down to 20% of real-time by the combination of an efficient open-loop approach and a decimation procedure. The excitation search complexity was significantly reduced by using two codebooks. The first models the main features in the excitation and it is very efficiently searched using a focussed search technique. The second has a simple structure and doesn't need exhaustive search. The quality of the encoded wideband speech at 9.6 kbit/s was judged vastly superior to that of original narrowband speech.

I. INTRODUCTION

In the recent years, there has been a great advance in the development of speech coding algorithms at very low bit rates. High-quality speech coders are now available at bit rates below 8 kbit/s. Researchers' efforts, however, have focussed on narrow-band speech signals where the transmission bandwidth is limited to 300–3400 Hz, as in analog telephone systems. This bandwidth limitation degrades the speech quality, specially when the speech is to be heard through loudspeakers. For many future applications, a wider bandwidth is needed in order to achieve face-to-face communication quality. A bandwidth of 50–7000 Hz was found appropriate, resulting in significantly improved quality as compared to narrow-band speech. The quality improvements are in terms of increased intelligibilty, naturalness and speaker recognition. High frequency enhancement (3400–7000 Hz) provides greater intelligibility and fricative differentiation, and low frequency enhancement (50–200 Hz) contributes to increased naturalness [1]. Several future applications are foreseen for wideband (50–7000 Hz) speech coders, such as teleconferencing, commentary channels, and high-quality wideband telephony.

We have recently developed a high quality wideband speech coder based on algebraic code-excited linear prediction (ACELP) techniques [3] which operates in the bit rate range from 9.6 to 16 kbit/s. In this paper, we address the real-time implementation of such a coder at the bit rate of 9.6 kbit/s. This special bit rate will allow the transmission of AM quality speech through the present telephone lines using 9.6 kbit/s modems. The drawback of the CELP-type algorithms is their excessive computational complexity. In our contribution to CELP coding, we have developed an improved CELP version, called Algebraic CELP (ACELP), which allows the real-time implementation of a 4.8 kbit/s high-quality codec on a fixed point TMS320C25 DSP chip. The ACELP outperforms the traditional CELP in computational/storage efficiency due the use of an excitation codebook with an algebraic structure which allows a very efficient search algorithm [2,3,4]. However, as we move from narrowband to wideband, the sampling frequency is doubled, and the analysis frames will contain twice the number of samples. This will give rise to a complexity which is 3 to 4 times that of narrowband. For example, a convolution will take 4 times the number of operations, and the pitch search will take also 4 times (twice the samples and twice the delays). Further, very large excitation codebooks will be needed in order to maintain high speech quality. This illustrates the difficulties encoutered when a full-band approach is used to implement a wideband CELP algorithm in real-time.

In this paper, we report on the strategies used to reduce the algorithmic complexity in order to allow the real time implementation of the coder on a TMS320C30 floating point processor. We also report on some procedures used to improve the speech quality at low bit rates. Section II briefly describes the ACELP coder structure. In Section III we discuss the pitch analysis and present a fast algorithm to perform pitch search. The structure of the excitation codebooks is given in Section IV, and a breakdown of the real-time implementtion is presented in Section V.

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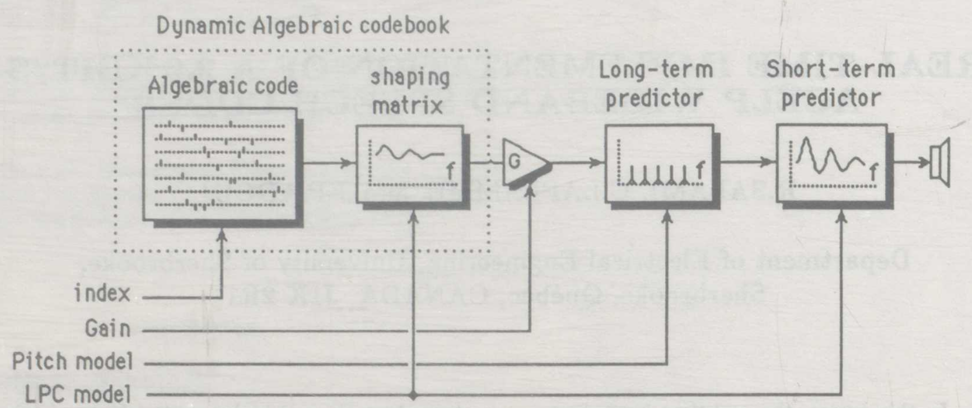

Figure 1: Synthesis model of an ACELP speech coder.

II. ACELP STRUCTURE

Figure 1 shows the synthesis model in ACELP coders. In this model, a block of N speech samples is synthesized by filtering an appropriate innovation sequence from a codebook, scaled by a gain factor, through two time varying filters. The first is known as the long-term predictor (LTP) filter, which aims at modeling the pseudo-periodicity in the speech signal (pitch periodicity). The LTP synthesis filter is given by

$$\frac{1}{B(z)} = \frac{1}{1-\beta z^{-\alpha}}, \quad (1)$$

where β is the pitch gain and α is the pitch delay. The second filter is a short-term predictor (STP) filter modeling the speech spectral envelope. It is known as the linear prediction (LP) filter and given by

$$\frac{1}{A(z)} = \frac{1}{\sum_{i=0}^{p} a_i z^{-i}}, \quad (2)$$

where p is the predictor order and a_i are the predictor coefficients. The LP coefficients are determined using the method of linear prediction analysis by minimizing the mean-squared prediction error. The pitch parameters (delay and gain) and the codeboook parameters (address and gain) are determined at the encoder using an analysis-by-synthesis technique. In this technique, the synthetic speech is computed for all candidate innovation sequences in the codebook retaining the particular codeword that produces the output closer to the original signal according to a perceptually weighted distortion measure. The error weighting filter is given by

$$W(z) = \frac{A(z)}{A(z/\gamma)}, \quad (3)$$

where $0 < \gamma < 1$.

The originality of the ACELP coder is a special innovation codebook. As opposed to most CELP coders, which utilize stochastic codewords, we use an algebraic structure that permits a fast search and requires no memory storage. Moreover, the codebook spectrum is dynamically shaped before the search procedure. This shaping utilizes a filter that emphasizes frequencies corresponding to the formants of speech resulting in an improved speech quality.

Separate sections will be devoted to discussing the pitch search and codebook search. Concerning LP analysis, a 16th predictor order was found the best trade-off. At 9.6 kbit/s encoding rate, the filter parameters are updated every 30 ms. The LP analysis is performed using the autocorrelation method. This method ensures the stability of the synthesis filter, however, the increased sampling of 16000 sample/s and the higher filter order needed for wideband speech result in filters with very high prediction gains (or very small prediction errors). To improve the LP analysis, two procedures were followed. The first is to preemphasize the input speech signal. This is accomplished by filtering the input speech by the single zero filter $1-\mu z^{-1}$. The preemphasis has two advantages. It reduces the dynamic range of the input signal resulting in lower required precision, and it emphasizes the higher frequencies in the speech signal, so that higher frequencies can be accounted for by the fixed order model of the ACELP algorithm. The second procedure used to improve the LP analysis is to perform lag windowing on the autocorrelations of speech prior to solving the Toeplitz system of equations [5]. Lag windowing has the effect of widening the bandwidths of the speech formants, thus avoiding bandwidth underestimation which is manifested by extremely sharp peaks in the spectral envelope. A binomial window is used where the autocorrelations are modified by

$$r'(i) = r(i)\exp\left[-\frac{1}{2}\left(\frac{2\pi f_0 i}{f_s}\right)^2\right], \quad i = 1, \ldots, m, \quad (4)$$

where f_0 is the bandwidth expansion and f_s is the sampling frequency. The described LP analysis was found fairly robust and could be implemented in single precision on the C30 DSP. The 16 coefficients are quantized using the line specral frequency representation (LSF). The 16 LSFs are quantized with 54 bits. The 30 ms speech frame is divided into 5 subframes of 6 ms. The pitch and codebook parameters are updated every subframe. The LSFs are interpolated to produce a different LP filter at each subframe.

III. PITCH ANALYSIS

Pitch analysis is performed every 6 ms, and consists of determining the pitch delay and gain. The pitch parameters are usually computed in a closed loop approach, which requires filtering the previous excitation in the given delay range. The delay range 40–295 is used (8 bit adaptive codebook). The pitch delay is determined by maximizing the term

$$T_\alpha = \frac{\left(\sum_{n=0}^{N-1} x(n) y_\alpha(n)\right)^2}{\sum_{n=0}^{N-1} y_\alpha^2(n)} \quad (5)$$

where $x(n)$ is the target signal given by the weighted input speech after subtracting the zero-input response of the weighted synthesis filter $1/A(z/\gamma)$, and $y_\alpha(n) = u(n-\alpha) * h(n)$ is the filtered excitation at delay α ($u(n)$ is the excitation signal and $h(n)$ is the impulse response of the filter $1/A(z/\gamma)$). The complexity of the pitch search arises from the need to compute the filtered excitation $y_\alpha(n)$ for $\alpha = 40, \ldots, 295$. The convolution $u(n-\alpha) * h(n)$ can be updated exploiting the overlaping nature of the delayed excitation vectors. Using this closed loop approach, and with an optimized C30 code, the pitch search complexity was found to consume 120% of the real-time on the C30 chip. Therefore, a careful attention had to be paid in order to reduce the complexity of pitch computation without affecting the speech quality. The complexity reduction was accomplished using two strategies. The first is to by-pass the need to compute the filtered excitation. The second is to use decimation to reduce the number of searched delays and the number of terms in the summmations.

Eliminating the need to compute the filtered excitation can be simply done at the numerator of Equation (5) by the use of backward filtering, whereby the numerator is given by $\sum_{n=0}^{N-1} d(n)u(n-\alpha)$ where $d(n) = x(n) * h(-n)$ is the backward filtered target signal. The denominator in Equation (1) represents the energy of the filtered excitation. The filtered excitation need not be computed if we can find a signal which has a similar energy behaviour in the given delay range. By examining the excitation signal itself, $u(n)$, it was found to have the same energy behaviour before and after filtering. This was more evident when a stronger weighting factor of 0.6 was used for pitch search. Thus the delay is now found by maximizing the term

$$T_\alpha = \frac{\left(\sum_{n=0}^{N-1} d(n) u(n-\alpha)\right)^2}{\sum_{n=0}^{N-1} u^2(n-\alpha)}, \quad (6)$$

Search method	*SNR (dB)*	% of real-time
Closed loop	17.48	120
fast approach	17.23	45
fast with decimation	17.12	20

Table 1: SNRs for different pitch search strategies.

which has the complexity of an open loop approach. The correlation in Equation (6) requires N operations and the energy can be updated using 2 operations. By taking into account the possibility of pitch multiples, the performance of this simple procedure was indistinguishable from that of the closed loop approach. The pitch search complexity in this case is dropped to 45% of the real-time.

The second approach followed to cut the complexity was by decimating the signals $d(n)$ and $u(n)$. The signals are first low-pass filtered using the single zero filter $1+0.7z^{-1}$ to produce the signals $u'(n)$ and $d'(n)$ given by

$$d'(n) = d(2n+1) + 0.7d(2n), \qquad n = 0, \ldots, \frac{N}{2} - 1. \quad (7)$$

Therefore, only the even values in the delay range are searched, and the number of terms in the summations in Equation (6) is reduced to $N/2$. Once an initial even delay is determined, the two odd values around that delay are also examined and the one which minimizes the weighted error criterion is chosen. The excitation at the chosen delay is then filtered in order to determine the proper value of the gain. With this approach, we were able to cut the pitch search complexity down to 20%. This was the key factor in enabling the real-time implementation of the coder. Table 1 shows SNR values using the closed loop approach, the fast approach as in Equation (6), and the ultra fast aprroach using decimation. The SNR values are averaged over 6 sentences uttered by three males and three females.

IV. THE ALGEBRAIC CODEBOOKS

The innovation codebooks in ACELP are generated from an algebraic codebook $\mathbf{a}_k$ and a shaping matrix $\mathbf{F}$. Thus an excitation vector is given by

$$\mathbf{c}_k = \mathbf{F}\mathbf{a}_k. \quad (8)$$

The advantage of this structure is that the codebook search is decoupled from the codebook properties. The algebraic codebook is properly chosen so that it is very efficiently searched and need not be stored. The shaping matrix renders the flexibility in obtaining any desired codebook properties. The search procedure can be easily brought to the algebraic domain by combining the matrix $\mathbf{F}$ with $\mathbf{H}$, the matrix containing the impulse response of the weighted synthesis filter $1/A(z/\gamma)$.

Concerning the choice of shaping matrix which is used to frequency shape the algebraic codebook, the impulse response of a filter which emphasizes the formant regions in the speech spectrum is used. The filter could be given by [3]

$$F(z) = (1 - \mu z^{-1}) \frac{A(z/\gamma_1)}{A(z/\gamma_2)}. \quad (9)$$

A better choice is to use an impulse response given by the sum of cosines at the formant frequencies weighted by an exponential window. The peak frequencies of the LPC spectrum are found, and the impulse response is given by

$$f(n) = \rho^n \sum_{k=1}^{K} \cos(\theta_k n) \quad (10)$$

where $\theta_k \in [0, \pi]$ are the peak frequencies in the spectrum. The fraction ρ controls the amount of enhancement in the formant regions.

Concerning the algebraic codebooks, a two stage search using two different books is performed. In the first codebook, the excitation vector contains 4 nonzero pulses in an excitation frames of 96 samples (6 ms). The pulse amplitudes are fixed to 1, −1, 1, and −1, respectively, and their positions are given by

$$m_i^{(j)} = 3i + 12j, \qquad \begin{array}{l} i = 0, \ldots, 3, \\ j = 0, \ldots, 7. \end{array} \quad (11)$$

Each pulse can have 8 possible positions distinct from the other pulses. As each pulse position is encoded with 3 bits, a 12 bit codebook is obtained. It can be shown that the optimum codeword is that one which maximizes

$$\frac{\left(\sum_{i=0}^{q-1} d(m_i) b_i\right)^2}{\sum_{i=0}^{q-1} \sum_{j=0}^{q-1} b_i b_j \phi(m_i, m_j)} \quad (12)$$

where q is the number of pulses, $d(n)$ is the backward filtered target vector, b_i are the pulse magnitudes, and $\phi(i,j)$ is the autocorrelation of the impulse response of $F(z)/A(z/\gamma)$. The codebook is very efficiently searched using the focussed search strategy described in [3]. The innermost loop in the search is entered 64 times at most, so that, in the worst case , only 512 codewords are examined.

As the pulse positions in the first codebook are properly chosen, the codebook is able to catch the main features in the excitation signal. The second codebook is left with almost an uncorrelated signal to model, after the pitch codebook and the first codebook has been searched. Thus a simpler model is used for the second stage codebook. A regular binary pulse excitation codebook is used [6]. A codeword contains 11 pulses with amplitudes 1 or −1

parameter	*update interval (ms)*	*bit no*
LP filter	30	54
pitch delay	6	8
pitch gain	6	4
1st codebook index	6	12
1st codebook gain	6	6
2nd codebook index	6	13
2nd codebook gain	6	3
unused bits	30	4

Table 2: Bit allocation for 9.6 kbit/s wideband ACELP coding.

spaced by a distance of 9. The first pulse can have 4 possible positions (2 bits). This results in a 13 bit codebook. Opposed to the first codebook, in the second one the pulse position are known and we look for their optimum signs. Using the approximation that the energy of the filtered codewords (the denominator in Equation (12)) is nearly constant, the pulse amplitudes are easily found as the signs of the backward target vector at the given positions. that is

$$b_i = \text{sign}\{d(m_i)\}, \qquad i = 0, \ldots, 10. \quad (13)$$

As it can be seen, the search of the second codebook is extremely simple. The approximation did not have impact on the quality as this codebook is modelling a less correlated signal.

V. BREAKDOWN OF THE REAL-TIME IMPLEMENTATION

The bit allocation of the 9.6 kbit/s coder is shown in Table 2. The pitch and innovation parameters are updated every 6 ms. The second codebook gain is quantized with 3 bits relative to the first gain. The coder is implemented on a Texas Instrument TMS320C30 floating point DSP at 33.33 MHz. The processor can perform 16.7 MIPS (million instructions per second). The break-down of the percentage of real-time is shown in Table 3. It can be seen that 29% of real-time is left for codebook search. The advantage of our codebook structure is that the search complexity can be controled using the focussed search procedure. For example, for a C30 DSP running at 40 MHz (now available), we have 20% extra processing power, so we can afford to search a larger portion of the codebook. Also, with the C30 at 40 MHz, we can afford to implement a higher bit rate coder with higher quality than that at 9.6 kbit/s. From the results of a recent subjective test carried out by Norwegian Telecom Research, a 14 kbit/s version of the wideband ACELP was equivalent to the G.722 CCITT standard at 56 kbit/s. From informal listening tests at

function	*% of real-time*
Every speech frame:	
preemphasis, deemphasis, LPC analysis and quantization	8.3
Every subframe	
LSF interp., LSF to a_i, weighting $(a_i\gamma^i)$, residual	4.5
pitch search	20
compute $f(n)$, $h(n)$, $\phi(i,j)$	13
initialize 1st book search: target vector, backward filtering	10.5
initialize 2nd book search: target vector, backward filtering	10.5
1st and 2nd book searches (controlable)	< 29
excitation, update filter memory	4.2

Table 3: Real-time break-down for the 9.6 kbit/s ACELP coder.

9.6 kbits, the degradation can easily be heard, as compared to the 14 kbit/s case, however, it is vastly preferable to the original narrowband signal.

Although the second stage search in the described implementation is very simple, its initialization (taget vector and backward filtering computation) consumes 10.5% of real-time (as shown in Table 3). When a single stage approach is used, 40% of real-time will be available for the quantization of the innovation signal. A novel approach was developed which permits the quantization of the innovation signal with a very large number of bits in a transform domain. Using this new approach, a higher bit rate version of the coder with higher speech quality is currently being implemented. The new innovation quantization approach, coupled with even more efficient methods for pitch search, allows the implementation of the codec in duplex on a single C30 chip.

VI. CONCLUSION

To conclude, the ACELP coding technique has been successfully implemented in real-time for encoding wideband speech at a bit rate of 9.6 kbit/s. A TMS320C30 floating point DSP at 33 MHz was used. Careful measures had been taken in order to enable this implementation. The main obstacle was the pitch algorithm, and this problem was circumvented by introducing an ultra fast pitch algorithm which didn't have a significant effect on the speech quality. The real-time implementation was also made possible by the use of two algebraic codebooks. The first models the main features in the excitation and it is very efficiently searched using a focussed search technique. The second has a simple structure and doesn't need exhaustive search. Using a 40 MHz chip, better performance can be obtained as we can search larger portions of the codebooks. It also allows the implementation of a higher quality coder at 14 kbit/s.

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probable network states are involved, having a total probability of 0.90.

Four items of network service performance measures, loss probabilities of the two largest PABXs which have the largest number of users, loss probabilities of priority users and common users, are involved in the analysis. The corresponding threshold vector is specified as :

T = {0.03, 0.03, 0.005, 0.05}.

With computer simulation, the performance Q(s) for each network state s is evaluated, and the available probability vector is calculated to be :

A = {0.8044, 0.7931, 0.7723, 0.7978}.

The actual performance (loss probability) vector is shown to be :

R = {0.0233, 0.0239, 0.0198, 0.0312}.

Assuming that the importance weight factors for the two largest PABXs, the priority users and the common users are 2, 2, 3, 1 respectively, the grade of service G for the whole network is found to be 0.7887.

IV. CONCLUSION

The approach proposed above for evaluating the reliability of telecommunication networks with multi-threshold model has shown to be more precise than the previous approaches with single-threshold [4, 5], appearing to be feasible and adoptable for any type and any size of networks. However, there are still some problems remained to be investigated further. One of these problems is the determination of service performance thresholds, within them some would not be independent from each other. Another problem is the selection of operation modes for network components, within them the statistical dependencies also exist. By solving of such problems, it would make the proposed approach more attractive and more consistent with the actual network configurations.

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