QUALCOMM, Inc.

SPREAD SPECTRUM

MYTH OR REALITY?

Andrew J. Viterbi
QUALCOMM, Inc.

Montebello, Quebec
May 1991

QUALCOMM, Inc.

SPREAD SPECTRUM COMMUNICATION:

MYTHS AND REALITIES

(IEEE Communication Magazine May, 1979)

Modern Digital Communication

- Origins in Landmark Year of 1948 with Two Dramatic Events:

- Discovery of Transistor by Shockley et al, opening the Solid-State Electronic era.

- Shannon's formulation of Information Theory providing guidance for all future communication system designs.

Shannon's Three Lessons

- Never discard information prematurely that may be useful in making a decision until after all decisions related to that information have been completed.

- Completely separate techniques for digital source compression from those for channel transmission even though the first removes redundancy and the second inserts it.

→ • Minimax Solution to "Contest" between Communication Signals and Interference: Make both Signal and Interference appear like additive wideband Gaussian noise.

QUALCOMM, Inc.

Third Lesson

In the "Words of the Teacher"

Excerpt from "A Conversation with Claude Shannon
Edited by Robert Price, IEEE Communication Magazine (Centennial Issue)
May, 1984

Editor: There is one particular area that I asked your colleagues about. You proposed using a noise carrier for what is now called CDMA (Code Division Multiple Access). You seemed to start into this by observing that multiplexing is generally achieved by the use of orthogonal functions, and then you went on and said, "Why don't we use quasi-orthogonal functions?" Then it suggested itself to you to use noise waveforms.

Shannon: Brilliant idea!

Editor: Well, your colleagues thought so

Shannon: I appreciated it, too. I thought it was clever.

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Third Lesson

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Shannon: I think that's right. It would fit logically into my thinking at that time. That's the kind of idea I had at about that time.

Editor: You want to be quasi-orthogonal to your other friends in the channel. You're sharing the frequency spectrum.

Shannon: Yes, Even more, it seemed like a very democratic way to use up the coordinates that you have, and to distribute the "cost of living," the noise, evenly among everyone. The whole thing seemed to have a great deal of elegance in my mind, mathematically speaking, and even from the point of view of democratic living in the world of communications.

Editor: And, furthermore, it could be actually *applied*, not like channel capacity; it actually could be instrumented. Therefore, a real world system could have been configured around it if you had gotten the right encouragement, more than just everyone saying, "Yes, that's a good idea." But nothing further happened to it. Now what's happening is that the FCC has set up a special docket for this very idea.

Third Lesson Applications

Spread Spectrum For Military

- Since 1940's, Anti-Jam, Secure, Low Probability-of-Intercept
- SHF, UHF, EHF-band Strategic Satellite Communication (since '60's)
- UHF-band Tactical Ground Communication (since '70's)
- L-Band Tactical Airborne Communication (since '80's)

Spread Spectrum for Commercial CDMA

- Fixed Satellite: C-Band Equatorial (Contel ASC) (early '80's)
- Mobile Satellite: Ku-Band QUALCOMM OmniTRACS (North America)
  and EutelTRACS (Europe) (late '80's)
- Cellular and PCN: CDMA (NOW)

The Four Multiple Interferers

a) Multiple-User Access

b) Multiple Cell-Sites

c) Multipath

d) Multiple Media

Mitigation

- Soft Handoff (multiple cell)
- RAKE Receiver (multipath)
- Spread Spectrum with FEC and Soft Decisions (all)

"Near-Far Problem"

- Solution: Power Control (both open and closed-loop)

Power Control

1. Compensates for "Near-Far" Unbalance Among Users (- 80 dB)

2. Adjusts Partially for All But Very Fast Fading - Especially Effective Where Interleaving Fails.

3. Maintains Each Subscriber's Power at Lowest Acceptable Level.

Other Improvement Techniques

	Capacity Multiplying Factor
• Voice-Activity Gating	- 2 to 2.5
• Cell-Site Sectorization	- 2.5 to 5

• Frequency Reuse (Universal and Ubiquitous) see below

Frequency Reuse Factor

- **CDMA:** Between 3/5 and 1

  Contrasted to

- **GSM-TDMA:** 1/4
- **North American - TDMA (IS-54):** 1/7
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Capacity

QUALCOMM, Inc.

Capacity: Bits/Sec/Hz/Cell and Bandwidth Occupancy per User

	Bits/Sec/Hz/User/Cell	Bandwidth/User
AMPS:	1/21	210 KHZ
N.A. - TDMA:	1/7	70 KHZ
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a) Transmitter power requirements of subscriber units;

b) Costs, which are dominated by RF and analog circuitry;

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d) Security and privacy.

All favor CDMA

Complexity Comparisons

- **Algorithmic Complexity is in Microchips (Microprocessor and ASIC's)**
  (Difficulty of Concept ° Implementation Complexity; e.g. CD-Player)

  "Smart" and "Difficult" Algorithms reside in solid state circuitry where levels of integration and speed double every 2 years.

- **Multiple Users/Analog Channel Front End;**
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Capacity

MILITARY SPREAD SPECTRUM

$$J/S = \frac{W/R}{E_b/N_0}$$

where

- J is Jamming (Interference) Power Received.
- S is Signal Power Received.
- W is Spread Bandwidth Occupied.
- R is Bit Rate of Digitally Coded Voice.

E_b/N_0 is Performance Measure of Receiver:

Varies from about 2 to about 5 (3 dB to 7 dB) depending on channel and receiver quality.

COMMERCIAL SPREAD SPECTRUM: CDMA

$$N \approx \frac{W/R}{E_b/N_0} \frac{G_A \; G_V}{H_O}$$

where

- N is Number of Simultaneous Calls per Cell.
- G_A is 3-Sectored Antenna Interference Reduction (Gain): about 2.5 (or 4 dB).
- G_V is Voice Activity Interference Reduction (Gain): about 2.5 (or 4 dB).
- H_O is Interference Increase Factor due to Users in Other Cells (Loss): about 1.6 (or 2 dB).

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Figure 1: Steady-state Energy Probabilities with Power Control (Full Simulation)

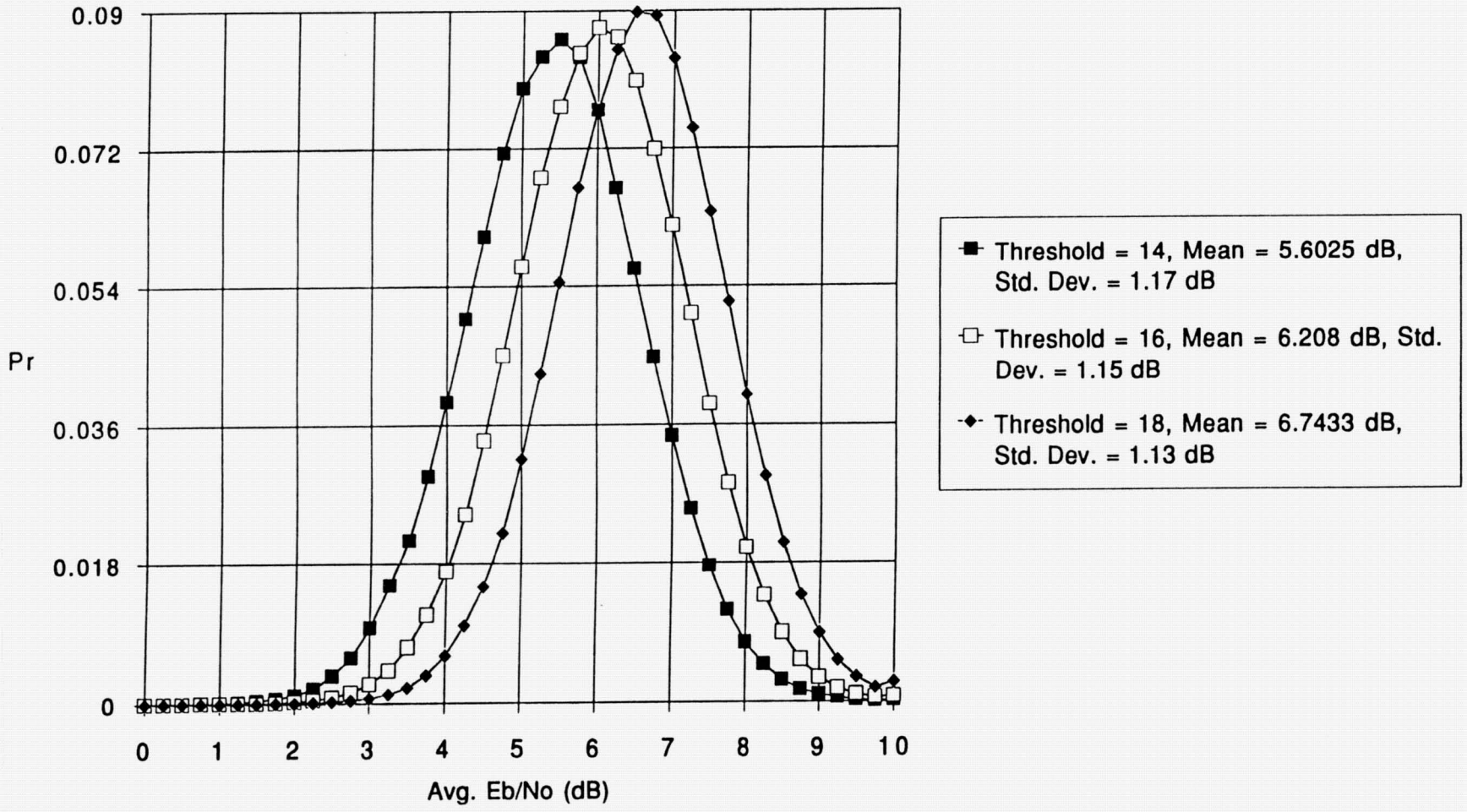
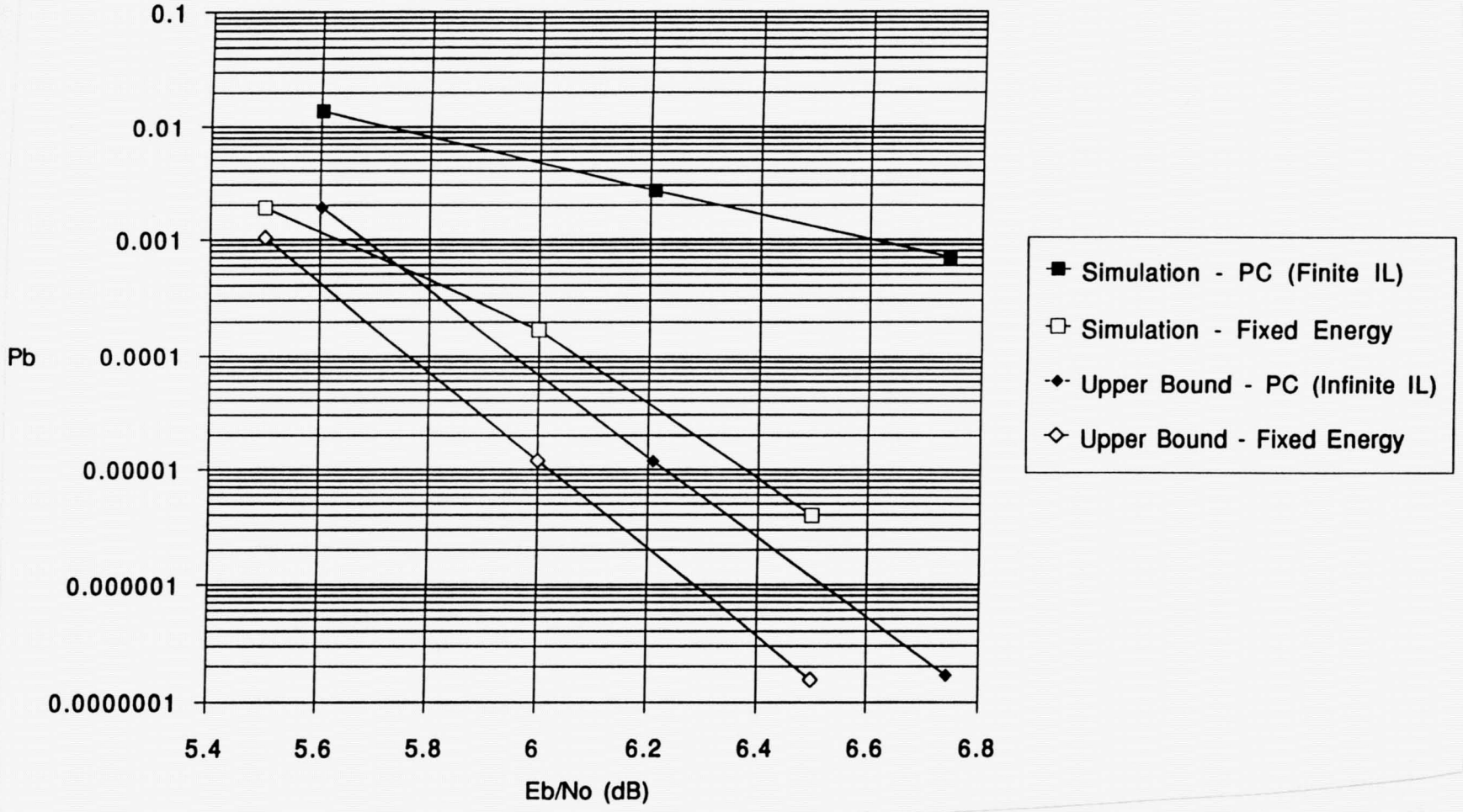


Figure 3: Reverse Link Bit Error Rate: Single Path, Full Rate, 5 Levels



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  and
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SPREAD SPECTRUM

Potential Commercial Applications Myth or Reality?

Montebello, Quebec, Canada
May 21 - 23, 1991

in cooperation with:

Telecommunications Research Institute of Ontario (TRIO)
Alberta Telecommunications Research Centre (ATRC)
Institute of Electrical & Electronics Engineers (IEEE), Ottawa Section
Ottawa Carleton Research Institute (OCRI)

It is intended in this workshop to focus on the relevance and viability of spread spectrum communications. Special attention will be given to the classical problems of spread spectrum, and new research results which overcome those problems are sought. Applications of spread spectrum communications systems will be presented, with a clear representation of the application niche, the benefits as well as the limitations of spread spectrum over alternative methods. Since spread spectrum techniques are not limited to the radio domain, optical research and applications are part of the workshop agenda as well. Technologies, pertinent to spread spectrum research and application are also part of the workshop. Workshop participants should come away from the session with a better understanding of the current status of research in the technology, its potential applications and viability, and an appreciation of the current activity in product applications and trials.

Workshop Environment

The workshop will be held at the Montebello Resort situated between Ottawa and Montreal. It will be a single stream meeting with significant time allotted for discussion. Invited and plenary presentations, poster sessions and parallel panel interactions are planned. To facilitate open discussion and interaction, attendance is limited to 200 with preference given to authors.

Invited Speakers include:

D. Coll	Carleton Univ., Canada
B. Felstead,	CRC, Canada
M. Kavehrad,	Univ. of Ottawa, Canada
R. Kohno,	Yokohama Univ., Japan
S. Lipoff,	Arthur D. Little, USA
M. Marcus,	FCC, USA
J. Omura	Cylink, USA
A. Polydoros,	Univ. of Souther Cal., USA
J. Salehi,	Bellcore, USA
D.L. Schilling	City College NY, USA
R. Scholtz,	Univ. of Southern Cal, USA
E. Sousa,	Univ. of Toronto, Canada
A. Viterbi,	QUALCOMM, USA
W. Zenko,	Telesystems, Canada

Technical Program Co-chairmen:

Mohsen Kavehrad
University of Ottawa
Department of Electrical Engineering
Ottawa, Ontario, Canada K1N 6N5
Tel: (613)564-7079
Fax: (613)564-6882

George Squires
ATRC
Suite 280, 3553 31st St. North West
Calgary, Alberta Canada T2L 2K7
Tel: (403)289-3140
Fax: (403)282-5870

Registration Chairman:

Bill Collins, OCRI, Canada
Tel: (613)592-8160
Fax: (613)592-8163

Organizing Committee:

Dr. B. Felstead, CRC, Canada
Dr. S. Kato, NTT Labs, Japan
Dr. A. Sesay, Univ. of Calgary, Canada
Dr. A. Yongacoglu, Univ. of Ottawa, Canada

Registration Information

REGISTRATION FEE (does not include 7% GST):	Member	Non-member
Advanced registration (prior to 20 April 91)	$225	$300
Late registration (after 20 April 91)	$275	$350

(member rates applicable to members of OCRI, TRIO and ATRC)

ACCOMMODATIONS:

All participants will be accommodated at the Chateau Montebello and will be expected to arrive by 20 May 1991. A block of rooms has been set aside at a reduced conference rate until 20 April 1991. Please reference Spread Spectrum when making reservations.

Room rates per person (all meals inclusive, 12.5% gratuities and 7% GST extra):

Prior to 20 April 91	Single	$172.75 per night
	Double occupancy	$128.25 per night
After 20 April 91	Single	$202.75 per night
	Double Occupancy	$143.25 per night

To make reservations contact: Le Chateau Montebello, 392 rue Notre-Dame, Montebello, Quebec CANADA J0V 1L0. Telephone: (819)423-6341 or FAX:(819)423-5283.

Conference registration fees may be paid by cheque/money order, in Canadian Funds, made payable to Ottawa Carleton Research Institute. American Express, Master Card or VISA accepted. A shuttle bus may be arranged from Ottawa International Airport and downtown Ottawa (from Chateau Laurier Hotel) to Le Chateau Montebello if needed. Please indicate flight number and time of arrival when registering.

For more information or to register photocopy and return this form to: Kathy Mahoney, Conference Registrar, SPREAD SPECTRUM, 340 march Road, Suite 400, Kanata, Ontario K2K 2E4 (telephone: (613)592-8160 or FAX:(613)592-8163.

Name _____

Title _____

Organization _____

Address _____

_____

Postal Code _____

Telephone _____ FAX _____

I would prefer shuttle transportation from: (20 May 91)
❑ Ottawa International Airport ❑Return 23 May 91
❑ Downtown Ottawa ❑Return 23 May 91

Time of Arrival _____ Flight #_____

Method of Payment

❑ cheque/money order

❑ VISA

❑ Master Card

❑ American Express

expiry date _____

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Signature _____

QUALCOMM INCORPORATED

10555 Sorrento Valley Road, San Diego, CA 92121-1617 ☐ (619) 587-1121 ☐ Fax: (619) 452-9096

January 10, 1991

Dr. M. Kavehrad
University of Ottawa
Dept. of Electrical Engineering
Ottawa, Ontario K1N 6N5

Dear Dr. Kavehrad:

Enclosed is the corrected summary of my proposed talk (originally sent on 26 November) for the "Spread Spectrum-Potential Workshop. The original title was incomplete and the word QUATERNARY on line 2 was misspelled.

Sincerely,

Andrew J. Viterbi
Chief Technical Officer

AJV/dc
Encl.

Modulation and Coding Performance of the Power-Controlled Direct-Sequence CDMA Cellular Channel

Andrew J. Viterbi

Summary

A generic direct sequence code-division multiple access (DS/CDMA) transmission system can be viewed as a binary code followed by quaternary phase-shift direct-sequence spreading and upconversion. At the receiver, despreading with a given user's spreading sequence causes all other user signals to appear like wideband noise to the given user.

On the reverse link (or uplink) from mobile user to base station, coherent demodulation is not practical, especially for fast moving vehicles. For a noncoherent receiver employing M-ary orthogonal modulation and powerful low-rate convolutional codes, it is shown that adequate performance is attained on the unfaded Gaussian channel at E_b/N_0 slightly above 5dB. Lognormal fading, both short term and long term, is assumed and justified. A power control technique operating on the noncoherently demodulated waveform is described which, for independent-increment lognormal fading, controls transmitted power from each mobile so that the corresponding received power at the base station is maintained within a standard deviation of ± 1.5dB. The resulting coded, interleaved (power-controlled) system performance is within 0.5dB of the unfaded case. With imperfect interleaving, performance is within 1dB of the unfaded case, leading in this case to acceptable performance at $E_b/N_0 = 6$ dB.

IEEE

FEB 14 1991

IEEE COMMUNICATIONS SOCIETY

PLEASE REPLY TO:
Dr. Mohsen Kavehrad
University of Ottawa
Dept. of Electrical Engineering
Ottawa, Ontario K1N 6N5

February 8, 1991

Dr. Andrew J. Viterbi
QUALCOMM Incorporated
10555 Sorrento Valley Road
San Diego, CA
92121-1617
U.S.A.

Dear Dr. Andrew J. Viterbi:

Please find enclosed additional information concerning the Montebello workshop "Spread Spectrum Potential Commercial Application".

If further information is needed please do not hesitate to contact me.

Thank you, once again, for accepting our invitation as a speaker and am looking forward to welcoming you at the Workshop.

Sincerely,

Dr. M. Kavehrad
Professor

MK/ma

Enclosure

DEC 19 1990

IEEE

IEEE COMMUNICATIONS SOCIETY

PLEASE REPLY TO:
Dr. Mohsen Kavehrad
University of Ottawa
Dept. of Electrical Engineering
Ottawa, Ontario K1N 6N5

December 14, 1990

Dr. Andrew J. Viterbi
QUALCOMM Incorporated
10555 Sorrento Valley Road
San Diego, CA
92121-1617
U.S.A.

Dear Dr. Andrew J. Viterbi:

Thank you very much for accepting our invitation to participate in our Montebello Workshop in Montebello, Quebec, on May 21 to May 23, 1991. I am certain that your presentation will greatly contribute to the enhancement of the program.

Attached, please find some additional information on the Workshop.

If you have not sent me a (less than 3 page) summary of your presentation, please do so as soon as possible.

I am looking forward to welcoming you at the Workshop.

Sincerely,

M. Kavehrad

Dr. M. Kavehrad
Professor

MK/ma

Enclosure

SPREAD SPECTRUM – – POTENTIAL COMMERCIAL APPLICATIONS, MYTH OR REALITY?

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J. Omura	Cylink, U.S.A.
A. Polydoros	Univ. of Southern Cal., U.S.A.
J. Salehi,	Bellcore, U.S.A.
D. L. Schilling	City College NY, U.S.A.
R. Scholtz	Univ. of Southern Cal., U.S.A.
E. Sousa	Univ. of Toronto, Canada
A. Viterbi	QUALCOMM, U.S.A.
W. Zenko	Telesystems, Canada.

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November 26, 1990

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IEEE

IEEE COMMUNICATIONS SOCIETY

OK

PLEASE REPLY TO:
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Ottawa, Ontario K1N 6N5

Aug. 31, 90

Dr. A. Viterbi

We (University of Ottawa, TeleComm. Research Institute of Ontario and Alberta TeleComm Research Centre) are in process of defining a preliminary program for a 2-day Workshop on "Commercial Applications of Spread Spectrum," This is to be held in Ottawa – Montreal area in May or June of 1991 (options open). The purpose is public awareness about what is happening in Spread-Spectrum area. Would you Consider participating in program formulation and present a Seminar?

Sincerely
M. Kavehrad
Professor

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
Tel: 613-564-7079
Fax: 613-564-6882

Cadie: OK - Tell him we'll participate & interested?

IEEE

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Tel: 613-564-7079(o) M. Kavehrad
Fax: 613-564-6882 Professor

Registration Form

Name _____

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Shuttle Transportation

I would prefer shuttle transportation (21 May 1991):

- ☐ Ottawa International Airport
- ☐ Downtown Ottawa
- ☐ Return (23 May 1991 only)

Time of Arrival _____

Flight # _____

Registration Information

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Advanced registration (prior to 20 April 91)		
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(member rates applicable to members of OCRI, TRIO and ATRC) GST # 122847510

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392 rue Notre-Dame, Montebello, Quebec
CANADA J0V 1L0.
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Potential Commercial Applications

Myth or Reality?

21 -23 May 1991

Le Chateau Montebello
Montebello, Quebec, Canada

in cooperation with:

Institute of Electrical & Electronics Engineers (IEEE), Ottawa Section
Ottawa Carleton Research Institute (OCRI)
Telecommunications Research Institute of Ontario (TRIO)
Alberta Telecommunications Research Centre (ATRC)

May 21, 1991

5:00 pm Registration and Reception
6:30 pm Dinner

May 22, 1991

8:30 Welcome
Mohsen Kavehrad / George Squires

8:45 - 10:15
Chairman: **Mohsen Kavehrad**,
University of Ottawa, Canada

Modulation and Coding Performance of the Power Controlled Direct-Sequence CDMA Cellular Channel
Andrew J. Viterbi, Qualcomm, U.S.A.

Regulatory Policy for Civil Uses of Spread Spectrum in the U.S.A.
M.J. Marcus, FCC, U.S.A.

Practical Aspects of Systems Design and Circuit Realization of Spread Spectrum Data Communications Links for use in License Free Applications
S.J. Lipoff, Arthur D. Little, Inc., U.S.A.

10:15 Coffee

10:45 - 12:15

The Vulnerability of Spread Spectrum to Self-Jamming
Dave Coll/A.V. Sheikh, Carleton University, Canada

Processing Techniques & Technology for Fast FH Anti-Jam EHF Uplinks
Barry Felstead, CRC, Ottawa, Canada

Cross-Correlation Cancellation with SS-DS Block Demodulator
A. Kajiwara, M. Nakagawa, Keio University, Yokohama, Japan

Block Coded Frequency-Hopped Multiple-Access Communications
Q. Wang/V.K. Bhargava, University of Victoria, Canada

12:15 Lunch

1:30 - 3:00
Chairman: **Abbas Yongacoglu,**
University of Ottawa, Canada

Common-Code Multiple-Access Spread-Spectrum Systems
R.A. Scholtz, University of Southern California, U.S.A.

Physical, Link-Access and Topological-Level Aspects on Slotted Aloha, Packet Switched, Code-Division Random Access Networks
A. Polydoros, University of Southern California, U.S.A.

Spread Spectrum Multiple Access
E.S. Sousa University of Toronto, Canada

3:00 Coffee

3:30 - 5:00

Ultrashort Light Pulse Code-Division Multiple-Access Techniques & Prospects
A.M. Weiner, Bellcore, U.S.A.

Demonstration of a Novel Optical Code Division Multiplex System at 800 M chips/sec
Ian MacDonald/N. Vethanayagam,
Alberta Telecommunications Research Centre, Canada

Optical CDMA Systems
J.A. Salehi, Bellcore, U.S.A.

Spread Spectrum for Non-Intrusive Optical Time-Domain Reflectometry,
J.F. Dawson, T.C. Tozer, University of York, U.K.

May 23, 1991

8:45 - 10:15
Chairman: **George Squires**,
Alberta Telecommunications Research Centre,
Canada

Spread Spectrum Radios for Personal Communications Services
J. Omura, Cylink Inc., U.S.A.

Future Personal Communications and Spread Spectrum Management
Donald L. Schilling, et al, City College of New York, U.S.A.

Remote Control Radio System Based on Hybrid DS/FH Spread Spectrum Technique
R. Kohno, et al, Yokohama National University, Japan

10:15 Coffee

10:45 - 12:15

CDMA Wireless PBX
M. Kavehrad, University of Ottawa, Canada

Wireless Network Applications Using Spread Spectrum Transmission
Wence Zenko, Telesystems SLW Inc., Canada

Benefits of CDMA for VSAT Networks
D.J. Sparkes/T.C. Tozer, University of York, U.K.

Applications of Spread Spectrum Communications in Manufacturing Environments
M. Barakat/R. Kjaldgaard, NRC, Canada

12:15 - 12:30 Referees Report

12:30 Lunch

1:30 - 3:00
Chairman: **B. Felstead,**
CRC, Ottawa, Canada

Spreading Code CCL Occurrence Frequencies and Their Influence on BER Performance of CDMA Networks
H. Chen/J.Oksman, University of Oulu, Finland

Modeling for Digital Signatures
R.J. Perry/S.M. Kasturi, Villanova University, U.S.A.

Structure of Composite Codes for Rapid Acquisition of DS/SS Signals
S.A. Faulkner/J.S. Wight, Carleton University, Canada

Spread-ALOHA Techniques for Universal Satellite Network Control System
K.M.S. Murthy, Telesat Canada

3:00 Coffee

3:30 - 5:00

A Direct-Sequence Spread-Spectrum Communication System with Self-Synchronizing Capability
N. Boutin/J. Mouine, Université de Sherbrooke, Canada

More on the Design and Implementation of a Frequency Hopping Modem
D. Romalo, et al, MPR Teltech Ltd., Canada

Frequency Independent Suppression of Interference Signals on Spread Spectrum Communication
A. Gagnon, Telemus Electronic Systems Inc., Canada

A New Secure High Capacity Mobile Communication System (both distributed and centralized) Employing the "SUGARW" Principle
A.K. Elhakeem/A. Rahman, Concordia University, Canada

Technical Program Co-Chairmen: Mohsen Kavehrad, U. of Ottawa/ **George Squires,** Alberta Telecommunications Research Centre

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