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DOCKET FILE COPY ORIGINAL

February 2, 1994

Mr. William F. Caton
Acting Secretary
Federal Communications Commission
Room 222 -- Mail Stop 1170
1919 M Street, N.W.
Washington, D.C. 20554

Re: Ex Parte Communication in
PR Docket No. 93-61

Dear Mr. Caton:

Pursuant to Section 1.1206(a)(2) of the Commission's Rules, I am filing the original and one copy of this letter to report an ex parte communication in the above-referenced proceeding.

On February 1, 1994, representatives of Southwestern Bell Mobile Systems, Inc. ("SBMS") met with Mr. Bruce A. Franca, Mr. Steve Sharkey and Mr. John A. Reed of the Office of Engineering and Technology ("OET") to discuss an interim report prepared by the Mobile and Portable Radio Research Group ("MPRG") of Virginia Tech. MPRG has been studying the capacity and interference resistance of spread spectrum automatic vehicle monitoring systems in the 902-928 MHz band.

Enclosed is a copy of MPRG's interim report and related attachments that was provided to the OET staff members by Wayne Watts, Vice President-General Attorney of SBMS, Jonathan Riso, Director-Specialized Applications of SBMS, Keith Rainer of Southwestern Bell Technology Resources and Louis Gurman, Esq. and the undersigned of this office. The representatives also presented modifications to the AVM/LMS spectrum allocation model that SBMS originally proposed in its comments in this proceeding. An outline of SBMS' current allocation proposal and a revised spectrum allocation chart are also enclosed.

Due to the number and length of meetings between SBMS representatives and Commission staff members during the afternoon of February 1, 1994, it was not possible to prepare and file this notice on the day of the meeting. Therefore this notice is submitted the day following.

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Please call me if you have any questions regarding this matter.

Very truly yours,

Robert L. Hoggarth

Enclosure

cc (w/o enclosure):
Bruce A. Franca
Steve Sharkey
John A. Reed

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

SOUTHWESTERN BELL MOBILE SYSTEMS, INC.
PROPOSED LMS LICENSING SCHEME

1. The Commission should allocate the spectrum available for wide band Location and Monitoring Services to encourage competition and technical innovation.

2. SBMS proposes a licensing scheme that allocates spectrum into four exclusive licenses of 4 MHz each.

   - Maximizes the number of licensees in each market given the constraints of existing operators;
   - Provides exclusive (subject to government and scientific usage) spectrum for each licensee;
   - Provides sufficient spectrum to accommodate systems currently operated by PacTel Teletrac and MobileVision's test systems which are only using 4 MHz.

3. The Commission should establish specific licensed geographic boundaries for the provision of LMS services.

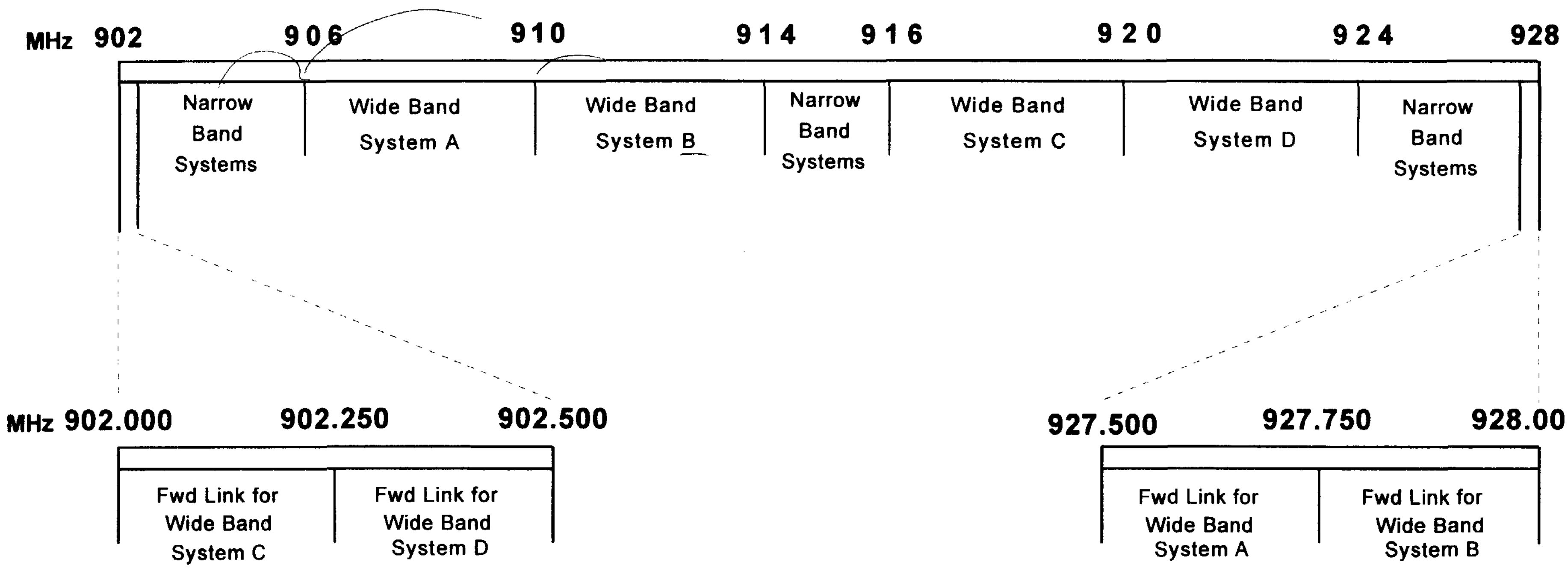
   - SBMS proposed the use of MSA and RSA boundaries.
   - PacTel Teletrac's proposal that BTA boundaries be used is an acceptable alternative.

4. The Commission should establish build-out requirements for LMS licensees allowing 12 months to construct LMS systems.

PR Docket No. 93-61
Automatic Vehicle Monitoring Systems

Recommended Spectrum Allocation

Forward Links for Wide Band LMS Outside All Other LMS Use



Southwestern Bell Mobile Systems

January 31, 1994

VIRGINIA TECH INTERIM REPORT SUMMARY:

1. Sharing

   - Systems can be located on adjacent channels with negligible interference. (see page 7 of report). This is described as partial overlay in the report.

   - Direct overlay of TDMA systems would not be workable. (see page 6 of report).

   - Direct overlay of CDMA systems is more promising, if the systems are relatively similar in signal power, processing gain, and bandwidths. However, differences in system operating parameters may result in significant interference to at least one system. (see page 6 of report).

2. Bandwidth

   - Bandwidths should be no more than twice the chipping rate. (see page 7 of report). Note that for every operational wideband AVM licensee less than 4 MHz of bandwidth is required for the wideband portion of their system.

3. Capacity's Relation to Bandwidth

   - Information carrying efficiency increases linearly with bandwidth (this applies to messaging, data, and voice). (see page 8 of report).

   - The relationship between increasing bandwidth and a system's location attempt capacity is less than exponential but may be slightly greater than linear, though this is a function of many parameters. (see page 8 of report).

4. Part 15 Devices

   - LMS and Part 15 systems should be able to coexist in spectrum. (see page 9 of report).

Capacity and Interference Resistance of Spread-Spectrum Automatic Vehicle Monitoring Systems in the 902-928 MHz ISM Band

Interim Progress Report

submitted to

Jonathan Riso
Southwestern Bell Mobile Systems
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Dallas, TX 75252

by

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Brian D. Woerner

Mobile and Portable Radio Research Group
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January 14, 1994

Executive Summary

Automatic Vehicle Monitoring (AVM) systems constitute an important new class of wireless service which is capable of providing position location, fleet management, vehicle security and message services to vehicles throughout a metropolitan area. Several companies are making plans to offer wideband AVM service in the 902-928 MHz frequency bands. Although substantial similarities exist between each system, each has made substantially different competing claims regarding the spectrum requirements, overlay capability, and interference resistance of their system. The Federal Communication Commission (FCC) is attempting to address these issues and formulated guidelines for the future operation of wideband AVM systems through Notice of Proposed Rulemaking 93-61.

In this study, we attempt to evaluate the relevant interference issues for real-world AVM systems. During the first two months of effort, we have conducted a review of the relevant literature and drawn several qualitative conclusions regarding the performance of AVM systems. This interim report reflects the results of these efforts. In a future final report, we intend to quantify the general results drawn here.

We find that although direct overlay of systems is not technically feasible, it should be possible to locate systems on adjacent channels with minimal interference. We find that the stated bandwidth requirements for all systems under study are excessively pessimistic. Reasonably good pulse shaping techniques should produce bandwidths no more than twice the chipping rate, allowing another CDMA system to operate on a channel directly adjacent to this bandwidth. Furthermore, sidelobes of adjacently located CDMA systems will produce minimal interference.

Another issue of overriding importance in formulating the guidelines for future AVM systems is the effect of bandwidth on system capacity. The overall information carrying efficiency of an AVM system will not significantly increase with bandwidth. Although the efficiency of determining a pulse time of arrival may improve with bandwidth, this operation constitutes only a portion of overall AVM system operation. Clearly, larger bandwidth systems will have at least proportionally higher capacity, but some results indicate that capacity and efficiency increase more than linearly with bandwidth. We conclude that although increased bandwidth may increase the efficiency of the position location operation, the bandwidth will not increase the overall information carrying capacity of the system. Furthermore, increasing bandwidth will have a modest effect on the capability of the systems to resolve and reject multipath propagation.

Techniques which allow purely orthogonal CDMA/FDMA will have a similar effect, increasing the position location capacity of the system but not the overall messaging

capacity. For lightly-loaded systems, CDMA/FDMA will modestly reduce interference levels by maintaining full orthogonality between channels. For heavily loaded systems, all CDMA systems will exhibit similar capacity.

In general, Part 15 devices will share the same frequency bands, but will operate in low power, short distance applications. AVM systems will operate at comparatively high power and long range. Under these conditions, interference between the two systems should not prove excessive; however, it is possible to formulate siting conditions under which interference will occur.

During the remainder of this study, we intend to quantify the qualitative conclusions described above. Major efforts will include: further investigation of the capacity/bandwidth tradeoff in an attempt reconcile the disparate conclusions of Cramer-Rao theory and Shannon information theory, simulation of AVM performance in multipath propagation and impulsive noise, and development of analytical techniques to quantify the performance effects of adjacent or partially overlapping spread-spectrum systems.

1. Problem Statement

Innovations in wireless technology have enabled the rapid growth of a large range of mobile communications services. Although cellular telephone service and the forthcoming personal communications service have attracted the widest attention, a broad range of more specialized services are also becoming commercially viable. Automatic Vehicle Monitoring (AVM) is one such service. AVM systems might typically offer the following services:

- Fleet Management. Dispatch, routing, and position location of large fleets of vehicles within a metropolitan area. This could include taxis, delivery vehicles and service trucks.
- Vehicle Security. Tracking and location of stolen vehicles. Enabling and disabling of vehicle security alarms.
- Emergency Services. Notification and position location of roadside emergencies. Routing of service vehicles to the emergency location.
- Messaging. Transmission of alphanumeric and voice messages to vehicles within a metropolitan area.

Several companies are in the process of developing and deploying AVM systems. These companies include:

- MobileVision of Indianapolis, IN
- North American Teletrac of Walnut Creek, CA
- Pinpoint Communications of Richardson, TX
- Southwestern Bell Mobile Systems of Dallas, TX [1]

Each of these AVM systems is designed to operate in the 902-928 MHz ISM band. Although implementation details vary between systems, they share several common technical features. Each employs a set of narrowband (25 to 50 kHz) channels for the forward link from the base station to the mobile. This forward link carries control, status and group and individual messaging information. The reverse link from the mobile to the base station employs a wideband direct-sequence spread-spectrum (DS/SS) signal. The characteristics of this DS/SS signal vary widely between systems. Southwestern Bell claims their system requires a 2 MHz bandwidth, while MobileVision and Teletrac claim their systems require 8 MHz bandwidth and Pinpoint has proposed a 26 MHz bandwidth system. The majority of these systems allow multiple access along the reverse link using Code Division Multiple Access (CDMA) techniques, although the Southwestern Bell system uses a combination of CDMA and Frequency Division Multiple Access (FDMA). All systems employ triangulation on the DS/SS signal for position location.

The Federal Communications Commission (FCC) has indicated its intention to create rules which foster creative use of Specialized Mobile Radio (SMR) Service such as AVM. In one recently proposed rule (NPRM 93-144), the FCC proposed the consolidation of channel allocations for private land mobile radio stations in the 800

MHz band to metropolitan service areas (MSA) or even larger areas. In another proposed rule (NPRM 93-61), the FCC proposed guidelines for AVM service within the 902-928 MHz ISM bands.

While agreement among commenters can be found on many issues, spectrum sharing remains a significant point of contention. System developers that currently have licenses to commercially operate an AVM system have proclaimed that spectrum sharing is not possible between AVM system providers. System developers who do not currently have licenses have taken a more positive view towards spectrum sharing. In addition to interference between AVM systems, there exist concerns over potential interference with Part 15 devices, also operating in the 902-928 MHz ISM band.

Several studies have addressed portions of the interference problem. However, each of the studies to date has been primarily theoretical in nature. As a result, the studies do not reflect many of the important characteristics of the mobile communications channel at these frequency bands, such as multipath propagation and impulsive noise. Neither do these studies take into account the characteristics of real-world communication systems, including nonlinearities and intermodulation products. As a result, questions remain about the effects of interference between systems. The purpose of this study will be to determine the feasibility of spectrum sharing in AVM bands and to determine possible techniques to mitigate potential interference problems. We believe that this study will be useful to the FCC in formulating rules for the operation of AVM systems.

The remainder of this report is organized as follows. Section 2 discusses interference issues between systems on a qualitative basis. Section 3 outlines future work for undertaking a rigorous analysis of capacity and interference issues for an AVM system.

2. Interference Issues

In this section we summarize the qualitative conclusions of our investigation to date. We focus on the interference issues affecting AVM system performance. We discuss the interference of directly overlaid AVM systems, as well as AVM systems located on adjacent channels. We describe the tradeoff between bandwidth and capacity in AVM systems, as well as the effect of orthogonal channelization on system capacity. We also discuss the effects of multipath propagation on the choice of system bandwidth, as well as possible interference issues between AVM systems and Part 15 devices.

Co-Channel Interference for Direct Overlay

Some commenters, notably Pinpoint, have proposed overlay of all AVM systems within the same spectrum. Two options exist for overlaying systems: time division multiple access (TDMA) which is proposed by Pinpoint and code division multiple access (CDMA). We conclude that TDMA operation shared by many separate systems would be unworkable. The infrastructure required for coordinating individual systems would be unworkable, and inordinate amount of system capacity would be wasted in the large guard times which would be necessary. Furthermore, the system design flexibility which is the primary advantage of spectrum sharing would be completely eliminated by the rigid rules which are required for time sharing.

CDMA is more promising as a technology for direct overlay of AVM systems. However, experience in PCS field trials indicates that spread-spectrum technology is more useful for the CDMA application than for the overlay application [2]. That is, if the received signal powers, bandwidths, and processing gains are relatively similar, spread-spectrum systems are able to operate with relatively little interference. However, if system parameters are substantially different, significant interference may result for at least one system. For separate systems with mobile users, it is highly likely that near/far problems will arise, resulting in performance degradation. The traditional solution to the near/far problem is power control; however, power control levels optimized for one set of base stations may still result in a near/far problem at a separate set of base stations associated with another system. The temptation would be strong to increase power levels to overcome the near/far problem, escalating into what has been characterized as a "tragedy of the commons." [3]

For these reasons, we conclude that direct overlay of AVM systems within the same frequency spectrum is not a viable option.

Adjacent Channel Interference Effects

Although direct overlay of CDMA systems may not be feasible, it may well be possible to reduce the spacing required between adjacent AVM channels. The Mobilevision, Teletrac and SBMS systems all operate with chip rates of 2 Megachips/second (Mcps) or less. However, both Mobilevision and Teletrac systems claim a required bandwidth of 8 MHz bandwidth, while the bandwidth of the 1Mcps SBMS system has been estimated at 2-4 MHz, depending on the measure of bandwidth used. These bandwidth estimates would appear to be extremely pessimistic in light of today's technology.

As an example, in the cellular telephone band, the Qualcomm CDMA system operates with a chip rate of 1.24 Mcps and a bandwidth of 1.25 MHz [4,5]. This system satisfies the cellular telephone requirements for out of band sidelobes and is able to operate in frequency bands directly adjacent to analog AMPS cellular signals as well as other CDMA signals. The key difference is the improved pulse shaping techniques used by the Qualcomm CDMA systems. Even with less sophisticated pulse shaping, the system bandwidth occupancy should be no more than two times the chip rate.

Although Mobilevision argues that linear amplifiers or high-power filters are excessively costly [6], IC technology has advanced considerably and relatively low-cost linear amplifiers are now commercially available which operate at 900 MHz and powers up to 5 W.

Furthermore, spread-spectrum systems possess inherent interference resistance. Although direct overlay of distinct spread-spectrum systems would prove risky for the reasons outlined in the preceding section, two CDMA systems operating in the other's sideband in which 20-30 dB of margin is available will result negligible interference between systems.

Bandwidth vs. Capacity

A key issue for determination of the optimum bandwidth for CDMA systems is how the capacity varies as a function of bandwidth. Pickholtz argues for Teletrac that the capacity of an AVM system is proportional to the *square* of the system bandwidth. Pickholtz bases this argument on the Cramer-Rao bound [7,8]:

$$\sigma_t^2 \geq \frac{T_c}{4\beta_r^2\left(\frac{S}{N}\right)T}$$

where σ_t^2 is the variance of the error in the estimate of the arrival time of a pulse, T_c is the chip duration, β_r is one measure of system bandwidth, $\left(\frac{S}{N}\right)$ is the ratio of signal power to noise power, and T is the time duration of the pulse. This result was derived by extending an earlier result for detection of the rising edge of a pulse to the case of a spread-spectrum signal. The conclusion which Pickholtz derives from this result is that a constant precision $\left(\sigma_t^2\right)$ can be maintained by doubling the bandwidth (β_r) while reducing the time duration of the signal for position location (T) by a factor of four. Because each position location operation requires one fourth of the time, the number of such operations in a given time period may presumably be increased.

Although this argument is essentially correct for the operation of edge detection, some confusion may result from the multiple operations performed by the AVM system. One can imagine two distinct capacities: the position location capacity of the system and the information carrying capacity of the system. The former measures the number of position fixes which may be generated in a fixed time and bandwidth while the latter measures the amount of data which can be transmitted in a given time and bandwidth.

The shorter time required for a single position fix may result in a higher position location capacity for wider bandwidth systems (although the improvement will be less the indicated above because the time required for other operations and guard times remains unchanged). However, the information carrying capacity of any system only increases linearly with bandwidth. The result follows directly from the field of information theory [9]. As a result, there is no disadvantage from subdividing this bandwidth for different systems. While the position location operation may be slightly more efficient at higher bandwidth, there is no such relationship for the messaging capabilities of the system.

Effect of Channelization on Capacity

The SBMS AVM system features a unique FDMA/CDMA system for transmission of the channel. The line spectra of the CDMA code is constrained so that 5 orthogonal FDMA channels are formed. Although this does not significantly increase the information-carrying capacity of the AVM messaging system, it does allow for up to 5 simultaneously orthogonal position location signals. As a result, for low loading levels, the position location capacity of the SBMS system is increased by a factor of five.

Effects of Bandwidth on Multipath

The choice of bandwidth is also influenced by multipath propagation experienced in the mobile environment. Multipath transmission results from signal reflection off of large objects such as hillsides and buildings. Multipath can result in two significant sources of error for AVM systems. Detection of the wrong arriving multipath component can result in large timing errors and catastrophic failure of the position location attempt. Coherent combination of closely spaced multipath components can resulting in fading which reduces signal to noise ratio. Both effects can be minimized by resolving the multipath components as completely as possible which requires larger bandwidth.

In order resolve all multipath components, system bandwidth must exceed the coherence bandwidth of the channel [10,11]. Because of the proximity of the AVM frequency bands to cellular bands, the effects of multipath propagation have been extensively characterized in this region of the frequency spectrum. Results indicate that significant multipath resolution can be achieved with a 1 MHz signal bandwidth. However, resolution of all significant multipath components requires a system bandwidth of 10 MHz. Beyond 10 MHz, there is no significant improvement. In the range of 1 MHz to 10 MHz, wider bandwidth will result in some modest improvements in multipath rejection [12].

Interference with Part 15 Devices

In addition to other AVM systems, the AVM systems considered here share the 902-928 MHz frequency band with low power devices which operate under Part 15 of the FCC regulations. In order to comply with FCC regulations, these devices must use low power (< 1W) and spread-spectrum signaling with a processing gain of at least 10. Under current FCC rules the Part 15 users must operate on a secondary basis to other licensed users such as AVM systems.

Although there is a substantial literature on performance of spread-spectrum systems in the presence of multiple access interference and narrowband interference, there is a relative paucity of work on the performance of spread-spectrum systems which partially overlay other spread-spectrum systems with significantly different parameters. As a result, the interference issues involving AVM systems and Part 15 devices will require significant further study to resolve.

However, we can make the following qualitative conclusions. Since AVM systems will operate at significantly higher power levels (5-10W) and have the advantage of siting base stations at favorable locations, it is likely that the interference from Part 15 devices will be small. Nonetheless, when a Part 15 device is operating much closer to a base station than an AVM mobile unit, the transmitted power is large enough to produce a significant near/far problem. In the other direction, Part 15 devices operating indoors and over short distances are unlikely to experience significant interference from AVM systems. However, Part 15 devices designed for outdoor operation my experience significant interference. Some interference rejection techniques may be available to address narrowband interference from Part 15 devices.

Summary

We have carried out a qualitative investigation of the interference and capacity issues regarding AVM systems. Based on the results of this investigation, we believe that direct overlay of AVM systems is not practical at the present time. However, adjacent location of AVM systems should result in minimal interference. Increasing the bandwidth of AVM systems may result in increased position location efficiency, but it will not affect the information carrying capacity of the messaging portion of the AVM system. Similarly, orthogonal channelization will increase the position location capacity of an AVM system without significantly increasing the messaging capacity. Increased bandwidth will also result in marginal but not enormous improvements in multipath resolution. Interference between AVM and Part 15 devices should remain within tolerable limits provided that these systems do not operate in close proximity; however, interference is certainly possible for closely located systems.

3. Future Work

At this stage, we have completed a review of relative literature on AVM systems and drawn qualitative conclusions on the performance of these systems under a variety of conditions. There remain a number of important unanswered questions which we will address with quantitative study.

Tradeoffs between Bandwidth and Capacity for Position Location

As discussed above, the information carrying capacity of a CDMA system increases only linearly with bandwidth [9]. Although the Cramer-Rao bounding technique seems to indicate that the position location capability of an AVM system increases with the square of the bandwidth, there remain some unresolved issues [7]. If we view each position location transmission as the transmission of a message, it seems unlikely that the number of messages could increase indefinitely with the square of bandwidth. We believe that the Cramer-Rao bound may hold only for certain detection methods or within a certain range of system operation. We hope to reconcile these conflicting results with further study.

Simulation of Position Location in Multipath Interference and Impulsive Noise

Over the next several months, we intend to obtain quantitative results on system performance for realistic channel models. The MPRG has an extensive database of channel impulse measurements and impulse noise measurements for the 900 MHz band which we employ in simulations [13,14].

Evaluation of CDMA Interference between Adjacent Systems

We believe that the bandwidth expectations used by the AVM systems under study are excessively pessimistic. As a result, it should be possible to operate two AVM systems on nearly adjacent channels with little or no interference. We intend to demonstrate this through two avenues of research. First, we will suggest pulse shaping techniques to reduce the sidelobe levels of AVM systems. Second, we will assume pessimistic results for sidelobe shape, and evaluate the interference induced in the main lobe of one AVM system by the sidelobe of a second AVM system.

Evaluation of CDMA Interference between Disparate Systems

As indicated above, although there has been substantial work completed evaluating the performance of CDMA systems in the presence of multiple access interference and narrowband interference, there has been relatively little effort invested in studying how the performance of CDMA systems are affected by partially overlapping systems or by CDMA systems with different powers or bandwidths. These results would be directly relevant the performance of adjacently located AVM systems or the performance of

Part 15 systems. We believe that one recently published analysis technique may be directly relevant to this problem [15].

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Brian D. Woerner

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Education

Master of Public Policy, Institute of Public Policy Studies, University of Michigan, Ann Arbor 1992

Ph.D., Electrical Engineering Systems, University of Michigan, Ann Arbor. 1991
Dissertation Title: "Coded Modulation for a Direct-Sequence Spread-Spectrum Communication System"
Committee Chair: Professor Wayne E. Stark

MS., Electrical Engineering Systems, University of Michigan, Ann Arbor. 1987

BS. (highest honors), Computer and Electrical Engineering, Purdue University, West Lafayette. 1986

Employment

Assistant Professor, Virginia Polytechnic Institute and State University. 1991-present
Taught classes in the area of communications systems while developing a research program in the field of mobile communications, error-correction coding, and spread-spectrum communications systems.

Unisys Fellow, EECS Department, University of Michigan, Ann Arbor. 1988-91
Conducted research in the areas of trellis coding and direct-sequence spread-spectrum communications systems, while working towards doctorate degree. Significant results include the design of trellis codes suitable for direct-sequence spread spectrum communications, the development of algorithms to efficiently compute the bit error probability of these codes, and the development of improved bonds on packet error probability for spread-spectrum systems with convolutional coding. Possible applications of these results include code division multiple access for cellular telephone, personal communications systems and wireless information networks.

Grader, EECS Department, University of Michigan, Ann Arbor. 1987-90
Graded graduate level courses on digital communication, information theory, and communications networks for Professors David L. Neuhoff and Wayne E. Stark.

Graduate Student Research Assistant, EECS Department, University of Michigan, Ann Arbor. 1987-88
Conducted research into spread-spectrum communications under the supervision of Professor Wayne E. Stark, and assisted Professor Stark in reviewing journal publications and preparing proposals for funded research.

Benton Fellow, EECS Department, University of Michigan, Ann Arbor. 1986-87

Associate Engineer, Harris Corporation Semiconductor Sector, Palm Bay, FL. 1983-85
Worked a total of 17 months while successfully completing cooperative education program. Collected and analyzed statistical data on semiconductor device characteristics, automated data collection procedures, and conducted computer simulations of semiconductor devices.

Professional Affiliations

Member, Institute of Electrical and Electronics Engineers (IEEE): Communications Society, Information Theory Society, Computer Society, Vehicular Technology Society.

Member, Tau Beta Pi

Honors and Awards

Unisys Fellow 1988-91
Three year fellowship awarded competitively to one University of Michigan graduate student in EECS on the basis of faculty evaluations and personal interviews.

Benton Fellow 1987-88
One year fellowship awarded competitively to incoming EECS graduate students at the University of Michigan.

Purdue Presidential Engineering Scholarship 1982-83

Publications

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Yingjie Li, Brian D. Woerner, William Tanis II and Mike Hughes, *IEEE Vehicular Technology Conference (VTC)*, Seacaucus, NJ, May 1993.

Joseph Lichtenstein, Rob Morgenstern, Brian D. Woerner, William Tanis II and Mike Hughes, *IEEE Vehicular Technology Conference (VTC)*, Seacaucus, NJ, May 1993.

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Brian D. Woerner and Wayne E. Stark, "Interleaved Trellis Coded Spread-Spectrum for Rician Fading Channels," 1991 Phoenix Conference on Computers and Communications, Phoenix, AZ, May 1991.

Brian D. Woerner and Wayne E. Stark, "Trellis Coded Spread-Spectrum for Fading Channels," 1990 Conference on Military Communications (MILCOM), Monterey, CA, October 1990.

Brian D. Woerner and Wayne E. Stark, "The Performance of Trellis Coded Spread-Spectrum Communications," 1990 Conference on Tactical Communications (TACCOM), Fort Wayne, IN, April 1990.

Brian D. Woerner and Wayne E. Stark, "Performance Bound for Trellis Coded Direct-Sequence Spread-Spectrum Communications Systems," 1990 IEEE International Symposium on Information Theory, San Diego, CA, January 1990.

Brian D. Woerner and Wayne E. Stark, "The Application of Trellis Coding to Direct-Sequence Spread-Spectrum Multiple-Access Communications," Twenty-Sixth Annual Allerton Conference on Communication, Control and Computing, Urbana, IL, October 1998.

Invited Presentations

"Mobile and Portable Communications Research at Virginia Tech," BNR University Forum, Ottawa, Canada, August 1991.

"Spread Spectrum Communications and Propagation Effects," Invited tutorial, Federal Communications Commission, June 1992.

"Communications Research Capabilities for IVHS Research at Virginia Tech," invited presentation to Federal Highway Administration, January 1993.

"Recent Developments in Wireless Communication," seminar presented to Northern Viginia Campus of Virginia Tech, April 1993.

Funded Research (Principal Investigator or Co-P.I.)

"Combined Coding and Modulation for Spread-Spectrum Communications", National Science Foundation Research Initiation Grant, August 1992-August 1995. $100,000

"Simulation of Large Cell PCS Systems," Bell Atlantic Mobile Systems, July 1992 - May 1993. $99,400.

"Fellowships for IVHS Research," General Motors Corporpation, August 1992 - August 1997, $50,000

"Spread-Spectrum for LEOSAT Communications in the VHF Band," Interferometrics, Inc., Vienna, VA, January 1992-March 1992. $5,000.

"LEOSAT Communications in the 6/4 GHz Band," Virginia's Center for Innovative Technology, November 1991-August 1992. $5,000.

"Analysis of Direct-Sequence Spread-Spectrum for Fading Channels," MPRG Industrial Affiliates Foundation, November 1991-May 1992. $10,000.

"Analysis of PASTA Aucoustic Signal Processing," AT&T, April 1993 - September 1993. $25,000.

"Evaluation of NTP-based Protocols," BellSouth/Mobilecom, July 1993 - October 1993. $38,000.

MPRG Industrial Affiliates Foundation (Apple Computer, AT&T, Bellcore, BellSouth, Ericsson-GE Mobile Communications, Federal Bureau of Investigation, Grayson Electronics, GTE Mobile Communications, MCI, Motorola, Rockwell, Telesys Technologies Laboratories, USWest), August 1991-present. $150,000.

Consulting Experience

COMDIAL Corporation — January-March 1993
Study of Impulse Communications Technology for Indoor Wireless Communications.

Ericcson/GE Mobile Communications, Lynchburg, VA. — March-May 1992
Developed and taught short course on digital communications attended by over 100 engineers.

LCG Communications Group LTD., Gaithersburg, MD. — August 1992
Evaluated novel technologies for cellular telephone service.

Richard A. Cameron

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Permanent Address
558 Tanner Ave.
Lawrenceburg, IN 47025
(812) 537-3028

OBJECTIVE

Position in mobile communications

EDUCATION

Virginia Polytechnic Institute and State University
Ph.D., Electrical Engineering, May 1995
QCA: Overall 3.818 Major 3.889

Virginia Polytechnic Institute and State University
M.S., Electrical Engineering, May 1993
QCA: Overall 3.818 Major 3.889

Virginia Polytechnic Institute and State University
B.S., Electrical Engineering, May 1990
QCA: Overall 3.491 Major 3.399

EMPLOYMENT

Graduate Research Assistant
Mobile and Portable Radio Research Group (MPRG)
Blacksburg, VA 24060
Nov. 1991 - present
- performed performance analysis on Code Division Multiple Access (CDMA) systems in multipath channels (Rayleigh or Rician)
- modeled imperfect power control
- modeled RAKE receiver

Summer Intern (Electrical Engineer)
Grayson Electronics
Forest, VA 24551
May 1993 - August 1993
- performed simulations for various system levels of the IS-54 digital repeater

Summer Intern (Electrical Engineer)
Grayson Electronics
Forest, VA 24551
May 1992 - August 1992
- developed program to simulate bit error rates in mobile communication channels using convolutional coding and block or convolutional interleaving

Summer Intern (Electrical Engineer)
Department of Defense
Fort Meade, MD 20755
May 1991 - August 1991
- worked on projects in the telecommunications area

PUBLISHED PAPERS

R. A. Cameron and B. D. Woerner, "Measurement-Based Performance Analysis of CDMA Systems in Multipath Fading ", *IEEE Veh. Tech. Conf.*, May 1993.

R. A. Cameron and B. D. Woerner, "An Analysis of CDMA with Imperfect Power Control," *IEEE Veh. Tech. Conf.*, May 1992, pp. 977-980.

B. D. Woerner and R. A. Cameron, "A Comparison of Performance Analysis Techniques for Code Division Multiple Access," *Proceedings of the International Symposium on Wireless Communications*, July 1993.

ACTIVITIES AND HONORS

Eta Kappa Nu - Electrical Engineering Honor Society
Institute of Electrical and Electronics Engineers (IEEE)
IEEE Communications Society
IEEE Vehicular Technology Society

References furnished upon request.