UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

GOOGLE LLC
Petitioner

v.

ADVANCED CODING TECHNOLOGIES, LLC,
Patent Owner.

Case No. IPR2025-XXXXX
U.S. Patent No. 7,804,891

DECLARATION OF JUNE ANN MUNFORD IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW OF U.S. PATENT NO. 7,804,891

I. Introduction

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.

2. I have been retained by Petitioner Google LLC ("Petitioner"), as an independent expert in this proceeding before the Patent Trial and Appeal Board ("PTAB" or "Board"). I understand that Petitioner is requesting that the Board institute an *inter partes* review ("IPR") proceeding of U.S. Patent No. 7,804,891 ("'891 patent") (Ex.1001), currently assigned to Advanced Coding Technologies, LLC ("Patentee").

3. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am not and have never been an employee of Petitioner. I am being compensated for my services in this matter at the rate of $200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

A. Qualifications

4. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services

Librarian and Library Director. I have attached my Curriculum Vitae as Appendix CV.

5. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog search performance and creating lending agreements between libraries during my time as a Library Director.

B. Background of Library Records

6. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in Machine Readable Catalog (herein referred to as "MARC") code and contain information such as a physical description of the material, metadata from the material's publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public

access, it is my experience that an item's MARC record indicates the date of an item's public availability.

7. Typically, in creating a MARC record, a librarian would gather various bits of metadata such as book title, publisher and subject headings among others and assign each value to a relevant numerical field. For example, a book's physical description is tracked in field 300 while title/attribution is tracked in field 245. The 008 field of the MARC record is reserved for denoting the creation of the library record itself. As this is the only date reflecting the inclusion of said materials within the library's collection, it is my experience that an item's 008 field accurately indicates the date of an item's public availability.

8. With respect to periodicals, the MARC record typically indicates the date of public availability of the first issue of the periodical (e.g., a journal). It is my experience that the 008 field of the MARC record for a periodical may not be modified upon the library receiving new issues of a periodical. However, MARC records are still pertinent to whether a periodical is publicly available at a particular library. Additionally, it is my experience that, for periodical in a library's catalog, new issues are regularly received by the library and made available to interested readers very soon after the library receives those issues, as that is one of the primary purposes of libraries — to make available information to interested patrons on a timely basis.

C. Yeh

9. I have reviewed Ex. 1006, "Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard" by Ernest Nanjung Yeh.

10. Attached hereto as Appendix YEH01 is a true and correct copy of the MARC record for Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard as held by the Massachusetts Institute of Technology Library. Based on my experience, the Massachusetts Institute of Technology Library public catalog would have had a similar search functionality in 2004; by that time, most universities had digitized their catalogs and made them available to electronically search over the Internet, or at the very least, electronically search within the library itself. I secured this record myself from the library's public catalog. The MARC record contained within Appendix YEH01 accurately describes the title, author, publisher, and ISBN number of Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard.

11. Attached hereto as Appendix YEH02 is a true and correct copy of Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard as held by the Massachusetts Institute of Technology Library. This copy was secured from the library's online thesis repository at https://dspace.mit.edu/handle/1721.1/47580. In comparing Exhibit 1006 to Appendix YEH02, it is my determination that Exhibit 1006 is a true and correct copy of Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard by Ernest Nanjung Yeh.

12. The 008 field of the MARC record in Appendix YEH01 indicates the date of record creation. The 008 field of Appendix YEH01 indicates the Massachusetts Institute of Technology Library first acquired Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard as of June 2, 1999. Considering this information, it is my determination that Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard was made available to the public shortly after its initial acquisition as of June 2, 1999.

II. CONCLUSION

13. In signing this Declaration, I recognize that the Declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination. If cross-examination is required of me, I will appear for cross-examination during the time allotted for cross-examination.

14. I reserve the right to respond to any declarations that are submitted by Patentee's expert witnesses or to any testimony by Patentee's fact or expert witnesses, whether at deposition or at trial.

15. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made the knowledge that willful false statements and the

like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 5/23/2025

June Ann Munford

APPENDIX CV

June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.

- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.

- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over $400,000 and total assets of approximately $1,300,000.

● Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.

● Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.

● Led the organization and digitization of the library's archival records.

● Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.

● Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013
Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

● Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.

● Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.

● Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013
Library Assistant, Hart Area Public Library
Hart, MI

● Responsible for verifying imported MARC records and original MARC cataloging for the local-level collection as well as the Michigan Electronic Library.

● Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter

● Treasurer, 2012

Library Of Michigan
● Level VII Certification, 2008
● Level II Certification, 2013

Michigan Library Association Annual Conference 2014
● New Directors Conference Panel Member

Southwest Michigan Library Cooperative
● Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008
Petoskey, MI
● Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011
Nashville, TN
● Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012
Fairbanks, AK
● Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Case No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Case No. IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (Case No. IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (Case No. IPR2021-01182)

2023 ● Fish & Richardson

Neuroderm Ltd. v. Abbvie, Inc (Case No. PGR2022-00040)

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (Case No. IPR2022-00735)

2023 ● Fish & Richardson

Samsung Electronics v. MemoryWeb LLC (Case No. 39843-0136PS1)

2023 ● Pillsbury Winthrop Shaw Whitman LLP

Gravel Rating Systems v. Costco Wholesale Corp. (Case No. 4:21-cv-149-ALM)

2024 ● Willkie-Farr

Netflix, Inc. v. VideoLabs. Inc. (Case No. IPR2023-00628)

2024 ● Quinn Emanuel Urquhart & Sullivan

Purdue University v. Wolfspeed (Case No. 1:21-CV-840)

2024 ● Fish & Richardson

Dish Network v. Entropic Communications (Case No. IPR2024-00393)

2025 ● Perkins Coie

Amazon.com, Inc. v. Nokia Technologies Oy (Case No. IPR2024-00572)

2025 ● Fish & Richardson

Dish Network v. Entropic Communications (Case No. IPR2024-00373)

Limited Case and Clientele History

Alston & Bird

- Ericsson

  v. Collision Communications (Case No. IPR2022-01233)

- Nokia

  v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)

- Universal Electronics Inc

  v. Roku Inc (Case No. IPR2022-00818)

Alavi & Anaipakos PLLC

- Stingray Group Inc. and Stingray Music USA, Inc.

  v. Edwin A. Hernandez-Mondragon and Egla Corp. (Case No. 1:24-cv-21226-RAR)

Arnold & Porter

- Ivantis

  v. Glaukos (Case No. 8:18-cv-00620)

- Samsung

  v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis

  v. Cathx (Case No. 5:21-cv-00077-RWS)

Buchanan, Ingersoll & Rooney PC

- Google LLC, AT&T Service Inc., T Mobile USA Inc., Cellco Partnership, Ericsson Inc. & Nokia of America Corp.

  v. KT Corp & Pegasus Wireless Innovation LLC (Case No. IPR2025-00293)

Deschert LLP

- Smaxtec Animal Care

  v. ST Reproductive Technologies, LLC (Case No. IPR2024-00885)

Duane Morris

- Kangxi Communication Technologies

  v. Skyworks Solutions Inc. (Case No. IPR2025-00373)

- Microsoft

  v. Edge Networking Systems LLC (Case No. 1:24-cv-00215)

Erise I.P.

- Apple

  v. Ericsson Inc. (Case No. IPR2022-00715)

  v. Future Link Systems (Case No. IPRs 6317804, 6622108, 6807505, and 7917680)

  v. INVT (Case No. 20-1881)

  v. Navblazer LLC (Case No. IPR2020-01253)

  v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)

v. Telefonaktiebolaget LM Ericsson (Case No. IPR2022-00275)

v. Theta IP, LLC (Case No. IPR2024-00818)

v. THL Holding Company LLC (Case No. 1:23-cv-00548)

- Fanduel

v. CGT (Case No. 19-1393)

- Garmin

v. Phillips North America LLC (Case No. 2:19-cv-6301-AB-KS)

- Netscout

v. Longhorn HD LLC (Case No. 2:20-cv-00349)

v. Implicit, LLC (Case No. 2:18-cv-53-JRG)

- Sony Interactive Entertainment LLC

v. Bot M8 LLC (Case No. IPR2020-01288)

v. Infernal Technology LLC (Case No. 2:19-CV-00248-JRG)

- Tesla

v. Charge Fusion Technologies LLC (Case No. IPR2025-00032)

- Unified Patents

v. GE Video Compression (Case No. 2:19-cv-248)

Fish & Richardson

- Apple

v. AliveCor (Case No. 3:21-cv-03958)

v. LBS Innovations (Case No. 2:19-cv-00119-JRG-RSP)

v. Koss Corporation (Case No. IPR2021-00305)

v. Masimo (Case No. IPR 50095-0012IP1, 50095-0012IP2, 50095-0013IP1, 50095-0013IP2, 50095-0006IP1, 50095-0135IP1)

v. Neonode (Case No. 21-cv-08872-EMC)

v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

v. Resonant Sys. (Case No. 7:23-cv-00077-ADA)

- AsusTek Computer Inc.
  - v. Videolabs, Inc. (Case No. 22-CV-00720-ADA)

- Dell
  - v. Neo Wireless (Case No. IPR2022-00616)

- Dish Network
  - v. Entropic Communications, LLC (Case No. 2:2023-CV-01043)
  - v. Entropic Communications LLC (Case No. IPR2024-00393)
  - v. Realtime Adaptive Streaming (Case No. 1:17-CV-02097-RBJ)
  - v. TQ Delta LLC (Case No. 18-1798)

- Evapco Dry Cooling
  - v. SPG Dry Cooling (Case No. IPR2021-00688)

- Genetec
  - v. Sensormatic Electronics (Case No. 1:20-CV-00760)

- Huawei
  - v. Bell Northern Research LLC (Case No. IPR2019-01174)

- Kianxis
  - v. Blue Yonder (Case No. 3:20-cv-03636)

● LG Electronics

v. Bell Northern Research LLC (Case No. 3:18-cv-2864-CAB-BLM)

● MediaTek

v. MOSAID (Case No. IPR2024-00718)

● Metaswitch

v. Sonus Networks (Case No. IPR2018-01719)

● Microsoft

v. Throughputer Inc (Case No. IPR2022-00757)

● Mom Enterprises

v. Ddrops Company (Case No. 1:22-cv-00332)

● MLC Intellectual Property

v. MicronTech (Case No. 3:14-cv-03657-SI)

● Nearmap Inc

v. EagleView Technologies (Case No. IPR2022-01009)

● Neuroderm Ltd.

v. Abbvie, Inc (Case No. PGR2022-00040)

● Posco Co Ltd.

v. Pascal Drillet et al. (Case No. IPR2025-00370)

● Realtek Semiconductor

v. Future Link (Case No. IPR2021-01182)

- Quectel

  v. Koninklijke Philips (Case No. 1:20-cv-01710)

- Samsung

  v. Aire Technology (Case No. IPR2022-00877)

  v. Bell Northern Research (Case No. 2:19-cv-00286-JRG)

  v. Communication Technologies Inc (Case No. IPR2022-01221)

  v. Jawbone Innovations (Case No. IPR2022-00865)

  v. MemoryWeb LLC (Case No. IPR2022-00885)

  v. Dodots Licensing Solutions (Case No. IPR2023-00701)

  v. Telefonaktiebolaget LM Ericsson (Case No. IPR2021-00615)

- Texas Instruments

  v. Vantage Micro LLC (Case No. IPR2020-01261)

- Xilinx

  v. Sentient Sensors LCC (Case No. 1:22-cv-00173)

Goodwin Proctor

- Intel

  v. Proxense, LLC (Case No. 6:24-cv-00283)

- Samsung Electronics

  v. Mobile Data Technologies (Case No. 2:24-cv-00435)

- Taiwan Semiconductor Manufacturing Company Ltd.

  v. Advanced Integrated Circuit Process LLC (Case No. 2:24-cv-00623)

Groombridge Wu

- Nearmap

  v. Eagle View Technologies Inc. and Pictometry International Corp. (Case No. 2:21-cv-00283-TS-DAO)

Irell & Manella

- Curium

Latham & Watkins LLP

- Apple

  v. Advanced Coding Research LLC

Leydig, Voit & Mayer, Ltd.

- Public Availability Consultancy

O'Melveny & Myers

- Apple

  v. Maxell (Case No. 5:19-cv-00036-RWS)

- Disney Media & Entertainment Distribution LLC

  v. Digital Media Technology Holdings, LLC (Case No. 2:22-cv-01642)

- Micron Technology Inc.

  v. Besang Inc (Case No. IPR2023-00900)

- Samsung

  v. Daedalus Prime LLC (1335 Investigation)

Perkins-Coie

- Amazon
  - v. Nokia (Case No. IPR2024-00847 and IPR2024-00848)
  - v. Nokia Technologies Oy (Case No. IPR2024-00572)
- Heru Industries
  - v. The UAB Research Foundation (Case No. IPR2022-01148)
- Intel Corporation
  - v. BeSang Inc. (Case No. IPR2023-00991)
  - v. BitMICRO (Case No. 5:23-cv-00625)
  - v. Telefonaktiebolaget L M Ericsson (Case No. IPR2024-00610)
- Realtek Semiconductor
  - v. Future Link (Case No. IPR2021-01182)
- r-pac
  - v. Adasa, Inc. (Case No. 1:2024cv06102)
- Twitter Inc
  - v. VOIP-Pal.com (Case No. 3:20-cv-02397-JD)
- TCL Industries
  - v. Koninklijke Philips NV (Case No. IPR2021-00495, IPR2021-00496 and IPR2021-00497)
- VusionGroup
  - v. Hanshow (Case No. IPR2024-00857)

Pillsbury Winthrop Shaw Pittman

- Intel

    v. FG SRC LLC (Case No. 6:20-cv-00315)

- Gravel Rating Systems

    v. Costco (Case No. 4:21-cv-149)
    v. Lowe's Home Centers (Case No. 4:21-cv-150)
    v. T-Mobile USA (Case No. 4:21-cv-152)
    v. Kohl's Inc. (Case No. 4:21-cv-258)
    v. Under Armor (Case No. 4:21-cv-356)

Quinn Emanuel

- Exact Sciences Corporation

    v. Geneoscopy, Inc. (Case No. IPR2024-00459 and IPR2024-1330)

- ServiceNow, Inc.

    v. InQuisient, Inc. (Case No. 22-900-CJB)

- Wolfspeed

    v. The Trustees of Purdue University (Case No. 1:2021-cv-00840)

Sheppard, Mullin, Richter & Hampton LLP

- Advanced Micro Devices, Inc and Pensando Systems, Inc.

    v. Concurrent Ventures LLC and Xtreamedge, Inc. (Case No. IPR2025-00478)

- Cadence Design Systems Inc.

    v. Semiconductor Design Technologies (Case No. 3:23-cv-01001)

Shook, Hardy & Bacon LLP

- HP Inc.

  v. Universal Connectivity Technologies (Case No. 1:23-cv-01177)

Stern, Kessler, Goldstein & Fox

- Preliminary Research

Wilmer, Cutler, Pickering, Hale and Dorr

- Apple

  v. Shunock (Case No. 1:23-cv-08598)

- Quest Diagnostics Inc., Haystack Oncology Inc. and Haystack Oncology GmbH

  v. Natera, Inc. (Case No. 1:23-cv-08598)

- Roche Diabetes, Inc.

  v. Trividia Health, Inc. (Case No. 1:24-cv-00668)

Willkie, Farr & Gallagher LLP

- Lenovo, Dell, HP

  v. Universal Connectivity Technologies Inc. (Case No. 2:2023cv00449)

- Neurent

  v. The Foundry, LLC (Case No. IPR2024-00669)

- Netflix, Inc.

  v. VideoLabs, Inc. (Case No. IPR2023-00628)

APPENDIX YEH01

```
leader  01116ntm  2200325Ka 4500
001     990008819770106761
005     20241114035430.0
008     990602s1998    xx a     b    000 0 eng d
035     ##$a(MCM)000881977
035     ##$a(MCM)000881977MIT01
035     ##$a(OCoLC)41473690
040     ##$aMYG $cMYG
049     ##$aMYGG
099     ##$aThesis $aE.E. $a1998 $aM.Eng.
100     1#$aYeh, Ernest Nanjung, $d1975-
245     10$aAdvanced Vocoder Idle Slot Exploitation for TIA IS-136 standard / $cby Ernest Nanjung Yeh.
246     3#$aADVISE for TIA IS-136 standard
260     ##$cc1998.
300     ##$a55 p. : $bill. ; $c29 cm.
336     ##$atext $btxt $2rdacontent
337     ##$aunmediated $bn $2rdamedia
338     ##$avolume $bnc $2rdacarrier
502     ##$bM. Eng. $cMassachusetts Institute of Technology, Department of Electrical Engineering and Computer Science $d1998
504     ##$aIncludes bibliographical references (p. 55).
856     40$uhttp://hdl.handle.net/1721.1/47580 $3DSpace@MIT
910     ##$arch990602.
910     ##$aMARCIVEAUT
961     ##$a 1998  $a xx
969     ##$a41473690
992     00$aSupervised by G. David Forney, Jr.
```

THESIS/DISSERTATION

Advanced Vocoder Idle Slot Exploitation for TIA IS-136 standard

Yeh, Ernest Nanjung, 1975-
c1998

Available at Barker Library Microforms (THESIS Thesis E.E. 1998 M.Eng.) and other locations
Available Online

Ask Us Chat

Actions

PRINT | CITATION | EXPORT RIS | EXPORT BIBTEX | EXPORT TO EXCEL/CSV | LINK
EMAIL

Get it online

Online availability

MIT Theses in DSpace

Find/request items

MIT faculty, students, and staff: Please sign in to check if there are any request options. Sign in

LOCATIONS

Barker Library
Available , Microforms ; THESIS Thesis E.E. 1998 M.Eng.

Institute Archives
Available , Microforms ; THESIS Thesis E.E. 1998 M.Eng.

Institute Archives
Available , Noncirculating Collection 3 ; THESIS Thesis E.E. 1998 M.Eng.

More options

DSpace@MIT
View record metadata - MARC format

Details

Title	Advanced Vocoder Idle Slot Exploitation for TIA IS-136 standard
Creator	Yeh, Ernest Nanjung, 1975-
Dissertation	M. Eng. Massachusetts Institute of Technology, Department of Electrical Engineering and Computer Science 1998
Thesis Supervisor	Supervised by G. David Forney, Jr.
Other title	ADVISE for TIA IS-136 standard
Creation Date	c1998
Format	55 p. : ill. ; 29 cm.
Notes	Includes bibliographical references (p. 55).

Identifier OCLC : (OCoLC)41473690
Source Library Catalog

Browse virtual shelf

I ... s ...	Integration of handheld computers into distributed ... c1998	Determining the position of underwater tethers in real time ... c1998	Audio interconnect Performance : claims versus laboratory ... c1998	Real-time embedded sensor processing for an ... c1998	Advar Vococ Slot Explo for TI/ c1998

DSpace@MIT Home » MIT Libraries » MIT Theses » Undergraduate Theses » View Item

Advanced Vocoder Idle Slot Exploitation for TIA IS-136 standard

Author(s)
Yeh, Ernest Nanjung, 1975-

Download
Full printable version (2.120Mb)

Alternative title
ADVISE for TIA IS-136 standard

Advisor
G. David Forney, Jr.

Metadata
Show full item record

Show Statistical Information

Description
Thesis (S.B. and M.Eng.)--Massachusetts Institute of Technology, Dept. of Electrical Engineering and Computer Science, 1998.

Includes bibliographical references (p. 55).

Date issued
1998

URI
http://hdl.handle.net/1721.1/47580

Department
Massachusetts Institute of Technology. Department of Electrical Engineering and Computer Science

Publisher
Massachusetts Institute of Technology

Keywords
Electrical Engineering and Computer Science

Collections
Undergraduate Theses

APPENDIX YEH02

Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard

by
Ernest Nanjung Yeh

Submitted to the Department of Electrical Engineering and Computer Science in partial fulfillment of the requirements for the degrees of

Bachelor of Science in Electrical Engineering and Computer Science
Master of Engineering in Electrical Engineering and Computer Science

at the
Massachusetts Institute of Technology

May 1998

Author...
Department of Electrical Engineering and Computer Science
May 26, 1998

Certified by...
G. David Forney, Jr.
Adjunct Professor of Electrical Engineering
Thesis Supervisor

Accepted by...
Arthur C. Smith
Chair, Department Committee on Graduate Students

Advanced Vocoder Idle Slot Exploitation for TIA IS-136 Standard

by
Ernest Nanjung Yeh

Submitted to the Department of Electrical Engineering and Computer Science
on June 26, 1998
in partial fulfillment of the requirements for the degrees of

Bachelor of Science in Electrical Engineering and Computer Science
Master of Engineering in Electrical Engineering and Computer Science

Abstract

BellSouth has proposed a modification to the IS-136 digital cellular standard, which they refer to as Advanced Vocoder Idle Slot Exploitation (ADVISE), in which base stations can transmit auxiliary coded (redundant) bits on otherwise unused time slots to assist certain subscriber units (SUs). In this master's thesis, we investigate two aspects of ADVISE: 1) adaptive redundancy schemes by which the auxiliary bits are generated, and 2) autonomous detection mechanisms by which the SUs detect the presence of such auxiliary bits without external signaling. The adaptive redundancy schemes are designed as an overlay to the existing IS-136 forward error correction (FEC) design. We propose and test a scheme which starts with a base code of a given rate and derives lower rate codes by adding FEC overlay. When the channel is favorable, for example, only the coded bits from the base code are sent; as the channel condition deteriorates, the FEC overlay bits are sent along with the existing coded bits to increase coding gain. On the other hand, we propose an autonomous detection method which exploits the fact that some of these FEC overlay bits are mere repetition of the standard slot bits. The detection method makes use of a distance-based metric which, after simplification, performs hypothesis testing based on the Hamming distance between the two sets of received bits. If the Hamming distance is smaller than a threshold, the detection method declares ADVISE to be present and allows the channel decoder to use the auxiliary data. Otherwise, the method declares ADVISE to be absent, and the channel decoder uses only the data received in the standard slot.

Thesis Supervisor:	Dr. G. David Forney, Jr.
Title:	Adjunct Professor of Electrical Engineering, MIT Laboratory for Information and Decision Systems
Industry Supervisor:	Dr. A. Roger Hammons
Title:	Principal Engineer, Hughes Network Systems

Acknowledgments

It has been an incredibly meaningful and fulfilling five years at MIT. I would like to extend my sincere gratitude to those who have made tremendous contributions to my intellectual development and my personal growth.

To Professor William Peake, for his guidance and sense of humor have been the highlights of my MIT experiences. To Dr. Roger Hammons, for his supervision over this thesis project. He has inspired me with his breadth of knowledge and his mind of inventiveness. To Professor David Forney, for his critique and encouragement throughout the revision of this thesis. He has given the thesis a magic touch.

To all my brothers and sisters in the Hong Kong Student Bible Study Group, especially to Kelvin, Sbwong, Oyip, Agnes and Belvin, for their friendship and prayer support.

To Sunnia, for her companionship throughout the days of joy and sorrow.

To Selina, my big sister, for being a good role model. To Teemwing, my little sister, for bringing laughter.

To my family, especially to my parents, Uncle Sam and Uncle Tony, for their sacrifice and firm support for my education. Mom and Dad, I *will* get my MD/PhD before you retire!

To my Lord Jesus Christ, for you are just awesome!

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

The goal of the Advanced Vocoder Idle Slot Exploitation (ADVISE) project is to investigate first the optimal utilization of unused resources (idle channels) for voice quality improvement to specific subscriber units (SUs) on the downlink (base station to SU), and second, the best autonomous detection method by which the SUs can detect the presence or absence of ADVISE bits without explicit external signaling.

In IS-136, each radio frequency (RF) channel supports 3 full-rate users by time-division multiple access (TDMA). That is, each SU is assigned slots in a round-robin scheme (6 time slots per frame; 2 time slots per SU). Traditionally, as long as one user is active on any given RF channel, all other time slots are turned on with filler information at the same transmit power; therefore, the utilization of the idle slots does not add any additional interference to the system.

In general, the voice quality of the call is proportional to the bit rate sent to the SU. If it is possible to identify that a particular channel is idle, then extra speech information could be sent on this channel to the SU. Consider the following example illustrating how ADVISE might work in IS-136. Suppose in a given RF channel (with a capacity of 3 full-rate subscribers), there are only two subscribers, leaving the third time slots idle. One of the two subscribers, denoted here as Mobile1, experiences a poor quality radio link. The base station, after realizing that Mobile1 has a poor quality link, sends Mobile1 extra speech information on the idle time slots. Mobile1 combines all the speech information as inputs into its decoding process. The downlink error rate of this SU will thus be decreased, and the voice quality improved.

If some of this extra speech information is a simple repetition of that in the standard slot, then Mobile1 can autonomously detect the presence or absence of this extra information by comparing the two sets of data received. When Mobile1 decides such extra data are indeed available, it can proceed to use them in channel decoding. No handshaking occurs between the base station and Mobile1, and there is no latency due to message passing. Thus, the implementation of ADVISE can operate using the current IS-136 message protocol.

Chapter 2

Background

The concept of ADVISE is intended to be a modification to the existing IS-136 architecture. Our objective is to make as little perturbation as possible to the current system while designing ADVISE to best exploit the unused resources. In this chapter, we discuss the parts of the IS-136 standard that are relevant to the design and implementation of ADVISE.

2.1 IS-136 Standard: An Overview

IS-136 is a TDMA mobile digital cellular standard which specifies the use of a 7.4 kb/s algebraic-codebook code-excited linear predictive (ACELP) vocoder for speech source coding, a convolutional code (rate ½, K = 6) for channel coding, and quadrature phase-shift keying (QPSK) for modulation.

2.2 Ordering of the speech encoder bitstream

The existing IS-136 FEC scheme is diagrammed in Figure 2.1. It is an unequal error protection scheme in which the vocoder output bits are classified into three distinct categories. There are 48 Class 1A bits, which are protected by both a 7-bit cyclic redundancy check (CRC) and a K = 6, rate ½ convolutional code; 48 Class 1B bits, which are protected by the convolutional code alone; and 52 Class 2 bits, which are unprotected.

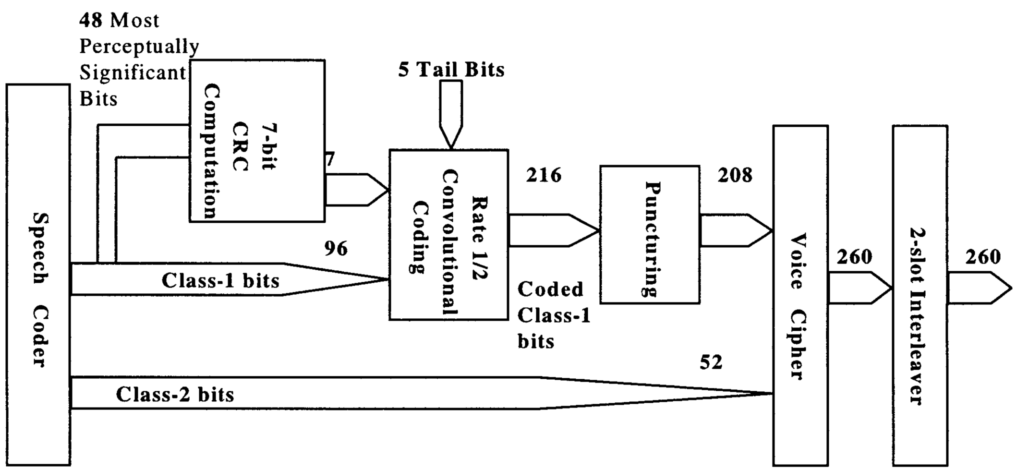

Figure 2.1 Flow Chart for IS-136 FEC

2.3 CRC for Error Detection

The 48 Class 1A bits are protected by seven parity bits used for error detection. The parity bits are calculated according to the CRC polynomial

$$g(x) = 1 + x + x^2 + x^4 + x^5 + x^7 .$$

At the transmitter, the 7-bit CRC is first computed. The Class 1A, CRC, Class 1B, and tail bits (48 + 7 + 48 + 5 = 108) are all encoded by a rate-½ convolutional encoder. The exact ordering of the input bit stream is shown in Figure 2.2.

At the receiver, channel decoding is performed. Based on the decoded Class 1A bits, another 7-bit CRC is calculated using the same CRC generating polynomial. This calculated CRC is compared to the decoded CRC. If the CRCs match, the receiver assumes no errors have occurred. Otherwise, a bad frame indicator is signaled to the speech decoder, and the speech decoder performs appropriate error concealment, such as attenuating the parameters or muting the output. This error detection method is illustrated in Figure 2.3.

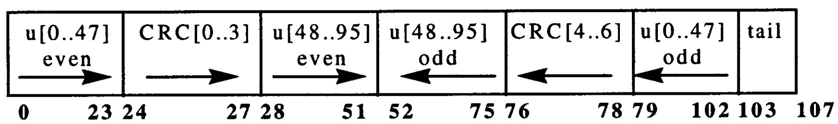

Figure 2.2 Input Bit Stream to the Convolutional Encoder

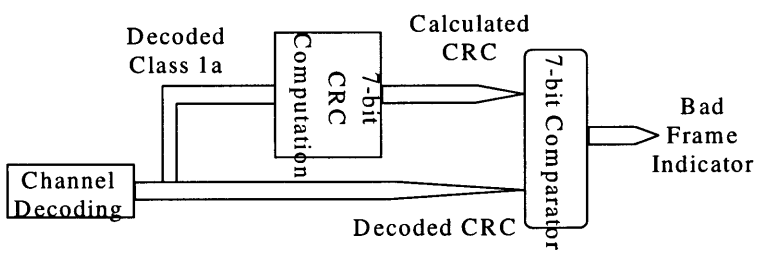

Figure 2.3 Error Detection and Bad Frame Indicator

2.4 Generators for the Rate-½ Convolutional Code

The rate-½ convolutional code used by IS-136 is the optimal nonsystematic K = 6 (32-state) code cited in standard texts (e.g., see Lin & Costello, Table 11.1, pp. 330-331), with generators

$$g_1(x) = x^5 + x^4 + x^2 + 1 \; ; \qquad\qquad g_2(x) = x^5 + x^3 + x^2 + x + 1 \; .$$

An encoder for this code is illustrated in Figure 2.4. The d_{free} of this optimal rate-½ encoder is 8.

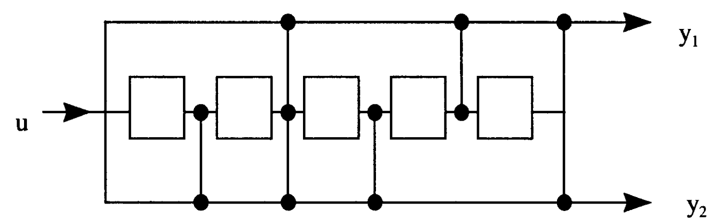

Figure 2.4 Encoder for Optimal Rate-½ Convolutional Code

2.5 Puncturing and Interleaving

The outputs of the convolutional encoder consist of 2 x 108 = 216 coded bits, of which 8 are punctured (deleted). The vocoder output is therefore represented by a total of 260 bits, corresponding to the 208 punctured coded bits and the 52 uncoded Class 2 bits.

$$Bits_{ch} = 2 \times (Class\ 1A + Class\ 1B + CRC + Tail) - PUNCT + Class\ 2 = 260,$$

where

$$Class\ 1A = 48,\ Class\ 1B = 48,\ Class\ 2 = 52,\ CRC = 7,\ Tail = 5,\ \text{and}\ PUNCT = 8.$$

The pattern of puncturing, as illustrated in Figure 2.5, is arranged so that there is maximum separation between the punctured bits, to minimize the adverse effect due to puncturing.

The 260 bits are then passed to a two-slot interleaver in which the bits are rearranged in a 26-by-10 array. Of the 26 rows, the odd rows are sent during the current time frame, whereas the even rows are saved in a buffer to be transmitted during the next frame. This 2-slot interleaving scheme provides some time diversity so that in a slow fading channel, channel error events are delocalized. In most cases, the error correction ability of the convolutional code is enhanced, and the decoded word error rate is reduced. The 2-slot interleaver is illustrated in Figure 2.6.

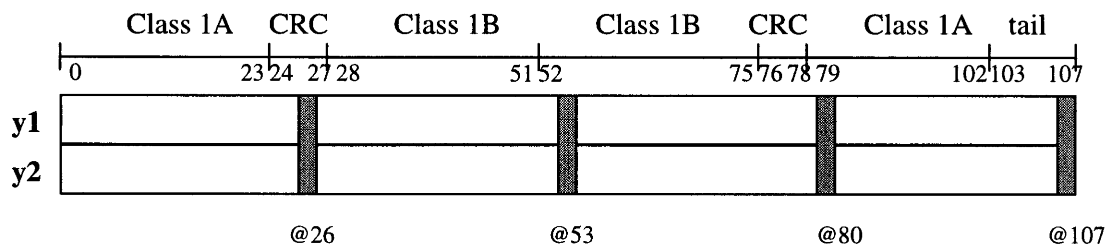

Figure 2.5 Encoder Output and Puncturing Pattern

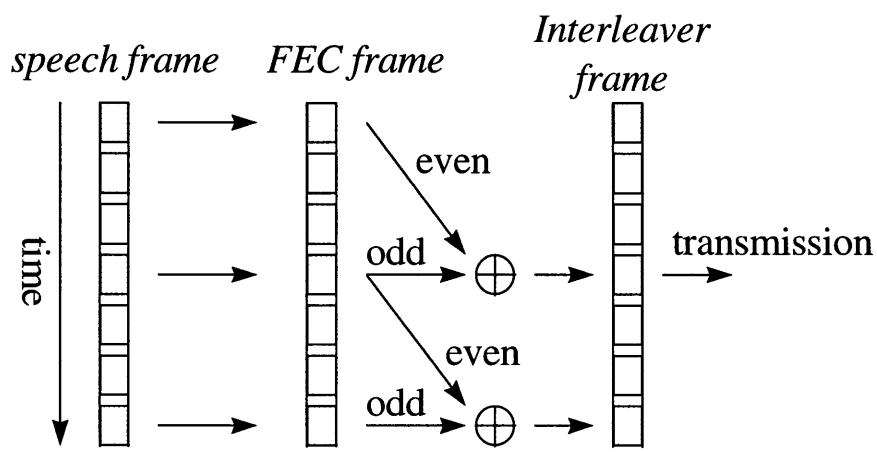

Figure 2.6 Two-Slot Interleaver

Chapter 3

Exploitation of Idle Slots

As discussed in previous chapters, the concept of ADVISE can be implemented when there is an idling time slot in the TDMA system. However, there are additional timing constraints which limit the window of time during which ADVISE can transmit. The width of this window is also handset-dependent, but we will leave that aspect to future detailed investigation.

3.1 Downlink and Uplink Timing

The IS-136 standard specifies a time-division structure of 40 ms/frame, or 6.7 ms/slot (six slots in one frame).

The uplink frame leads the downlink frame by 1¼ slot so that subscriber units will not have to employ duplexors. Suppose a full-rate subscriber unit uses slots 1 and 4. At the beginning of the uplink frame (slot 1), the subscriber unit tunes to the transmission frequency and subsequently transmits one slot worth of data. At the completion of transmission, it has ¼ of a slot to perform maintenance and to retune to the receiving frequency before receiving a slot of data from the downlink. After that, there will be approximately ¾ of a slot before the transmission during slot 4. During this period, the subscriber unit may be busy performing other maintenance functions. The exact length of time during which the subscriber unit is idle depends on the specifications of the handset provider. This overlapping of the uplink and downlink time slots is illustrated in Figure 3.1.

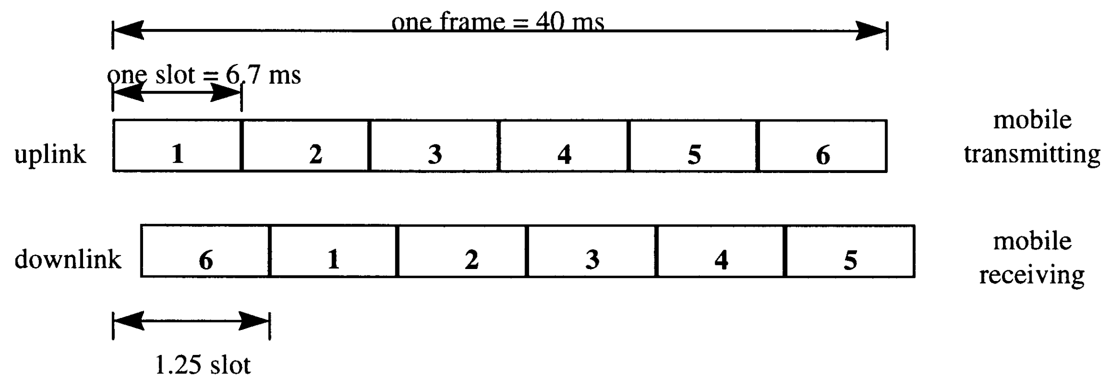

Figure 3.1 Uplink and Downlink Frame/Slot Structure

3.2 Number of Extra Bits Available

In the ADVISE concept, the base station is capable of making additional bits available to a particular subscriber unit in a neighboring idle time slot. Due to timing and other system requirements, the subscriber unit is believed to have access to up to 100 extra bits in the neighboring slot in the existing IS-136 mode of operation and up to a full slot (260 extra bits) in the Discontinuous Transmission (DTX) mode of operation under consideration for IS-136+.

3.2.1 A One-Hundred-Bit Solution

In IS-136, a frame can be divided into two subframes of three slots each, which simplifies the bookkeeping because the rules used in the second subframe are merely a repeat of those for the first subframe. In each subframe, there are two windows of time during which the mobile is neither transmitting or receiving. The first window starts at the end of uplink slot 1 and lasts until the beginning of downlink slot 1. The second window starts at the end of downlink slot 1 and lasts until the beginning of uplink slot 4. The first window lasts only ¼ of a slot, and is too short for ADVISE. However, the second window, about ¾ of a slot, can be used to send extra information to the subscriber unit (SU). According to the data provided by the SU manufacturer Nokia, approximately 100 channel bits can be sent during the second window.

3.2.2 A Full-Slot Solution

If the subscriber unit employs DTX on the uplink, then the subscriber unit will turn off transmission if there is a silence in the mobile user's speech. Once the mobile user speaks again, the uplink transmission will be turned on. When DTX is used, there is a potential of extending the second window because now the mobile station does not need to transmit during the uplink slot 4. Thus a full slot (260 channel bits) worth of extra information can be sent.

Chapter 4

FEC Overlay

The availability of the ADVISE slot allows us to adopt a lower-rate code. In this chapter, we propose and test different lower-rate convolutional codes. The objective is to achieve maximum coding gain while minimizing decoder complexity. Compatibility with existing systems is highly desirable.

4.1 Adaptive Rate-Compatible Convolutional Code

We investigate a variable-rate convolutional coding scheme in which the encoder is capable of generating a code of rate ½, 1/3 or ¼. In such an encoder, the first two connection polynomials are chosen to be the same as the two specified by IS-136. The third and fourth connection polynomials are chosen so that the rate 1/3 and rate ¼ codes have the best d_{free}, respectively. When the channel is good and ADVISE is not used, both the third and fourth coded bits will be punctured, so the resultant bit stream is identical (hence backward compatible) to the current IS-136. When the channel deteriorates and the 100 ADVISE bits are used for extra protection, the base station will transmit the third coded bits in the idle slot, lowering the overall coding rate to 1/3. If all 260 extra bits are available, all four coded bits will be transmitted, making the rate ¼ . The concept is illustrated in Figure 4.1.

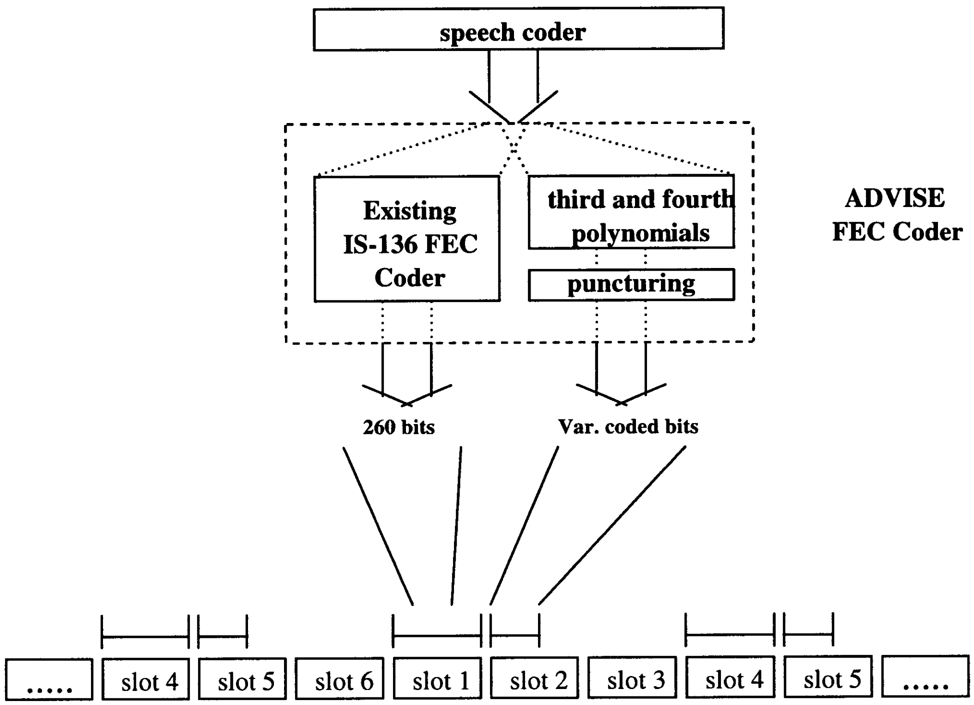

Figure 4.1 Rate-Compatible FEC Overlay

4.1.1 Rate-1/3 Convolutional Code

In the 100-bit ADVISE scenario, we propose to add a third connection polynomial to create a rate-1/3 code. Although not obvious, it is possible to augment the IS-136 rate-½ code to an *optimal* rate-1/3 code. Lin and Costello give the following optimal K = 6, rate-1/3 convolutional code generators:

$$g_1(x) = x^5 + x^3 + x + 1\ ;\ g_2(x) = x^5 + x^4 + x^3 + x^2 + 1;\ g_3(x) = x^5 + x^2 + x + 1.$$

We note that the first two of these generators are the reverse of the polynomials generating the rate-½ code. Since reverse polynomials generate a code with the same weight distribution, an optimal augmentation of the IS-136 code is achieved by using the reverse of the third polynomial. Therefore, for IS-136, we propose the use of the rate-1/3 code with generators:

$$g_1(x) = x^5 + x^4 + x^2 + 1 \ ; \ g_2(x) = x^5 + x^3 + x^2 + x + 1; \ g_3(x) = x^5 + x^4 + x^3 + 1 \ .$$

The d_{free} for this optimal rate-1/3 code is 13.

4.1.2 Rate-¼ Convolutional Code

For the rate-¼ version, we add the following additional connection polynomial:

$$g_4(x) = x^5 + x^4 + x^3 + x + 1 \ .$$

This rate-¼ code has $d_{free} = 18$, whereas the optimal rate-1/4 code has $d_{free} = 19$. We are unable to have an optimal encoder for rate-¼ because the first three generators restrict our choice. The trade-off is made in order to preserve backward compatibility.

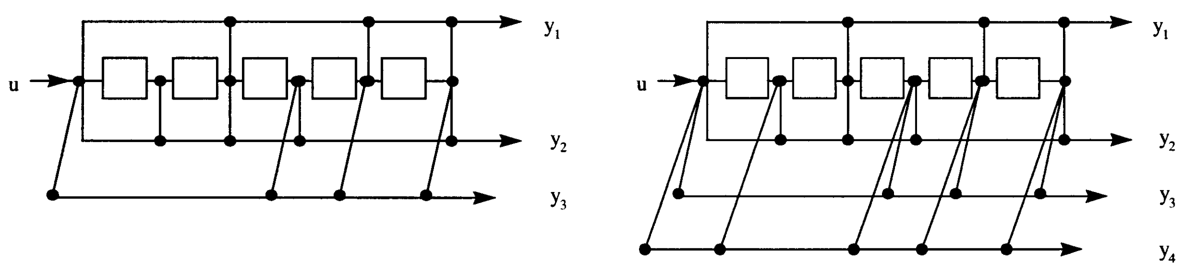

Figure 4.2a *Optimal* Rate-1/3 Encoder

Figure 4.2b Rate-¼ Encoder

4.1.3 A Mix-and-Match Approach

The rate-compatible coding proposal above provides extra protection to the already protected bits, namely the Class 1 bits. The Class 2 bits are unprotected in the existing IS-136 FEC scheme. These bits are perceptually less important and do not play a significant role in the overall voice quality under normal channel conditions. However, when the channel deteriorates to the point that ADVISE is needed, badly corrupted Class 2 bits will adversely affect quality. An optimal allocation of the extra coded bits, therefore, is not to use them for Class 1 protection only. Rather, we investigate schemes which mix and match the extra check bits for both Class 2 and Class 1 protection.

4.1.4 Simple Full-Slot Repeat

When an extra full slot is available, one can merely repeat the original coded bits in the ADVISE slot. Despite its simplicity, the full-slot repeat provides significant performance improvement because of the 3 dB increase in signal energy obtained by sending twice as many channel bits. Implementation of slot repeat decoding is also straightforward. We can make use of the second set of data by using an antenna-diversity combining algorithm. Alternatively, we can optimally combine the extra set of data in the branch metric computation as though the code was a rate-¼ convolutional code, where the third and fourth generators are a repeat of the first and second. Both decoding methods are optimal; the former is slightly less computationally burdensome.

When we decode a simple slot-repeat using a rate-1/4 Viterbi algorithm, the effective d_{free} is 16, twice of the d_{free} of the original optimal rate-1/2 code. If we used the rate-1/4 code recommended in Section 4.1.2, then we would have $d_{free} = 18$ instead. In return, we would have to support a more complex decoding scheme. The trade-off between more complex encoding versus better performance, as in this case, is not entirely clear even after our simulations. We conclude that a simple full-slot repeat remains as an attractive candidate in comparison to other schemes. Table 4.1 summarizes the d_{free} of the proposed encoders.

Encoder Rate	**d_{free}**
rate-½	8
rate-1/3	13
rate-¼	18
full-slot repeat	16

Table 4.1 d_{free} Summary

4.1.5 A Split-and-Merge Trellis

If a full ADVISE slot repeat is available, we can achieve better voice quality by protecting the currently unprotected Class 2 bits. In addition, for the third and fourth generators, we can use the generators as proposed in Section 4.1.2. The basic scheme is illustrated in Figure 4.3. In this case we substitute the Class 2 bits for the Class 1B bits and re-encode the Class 1A + Class 2 bits for transmission in the ADVISE slot. The Class 1B bits are sent uncoded in the ADVISE slot.

In the Viterbi decoder, we optimally combine the received data from both transmissions to decode the various bits. This requires separate Viterbi decoding steps for the Class 1B and Class 2 bits. For the Class 1A bits, we effectively have rate-¼ coding. For the Class 1B and Class 2 bits, we effectively have systematic rate-1/3 coding. In order to optimally combine received data for the Class 1A bits at the end of the frame, we use the five Class 1B bits in both endings to ensure that the final encoder state is the same for both transmissions.

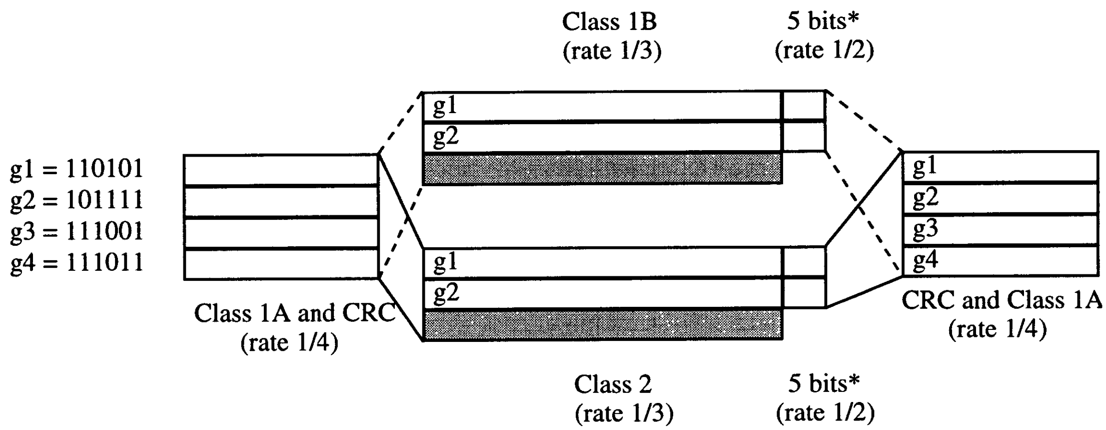

Figure 4.3 Split-and-Merge Trellis (systematic bits are shown shaded)

In Figure 4.4, we further improve upon this idea by using nonsystematic rate- 1/3 encoding for the Class 1B bits. That is, in the ADVISE slot, we do not send the Class 1B bits uncoded but perform additional coding using the optimal generators for the rate-1/3 code described earlier.

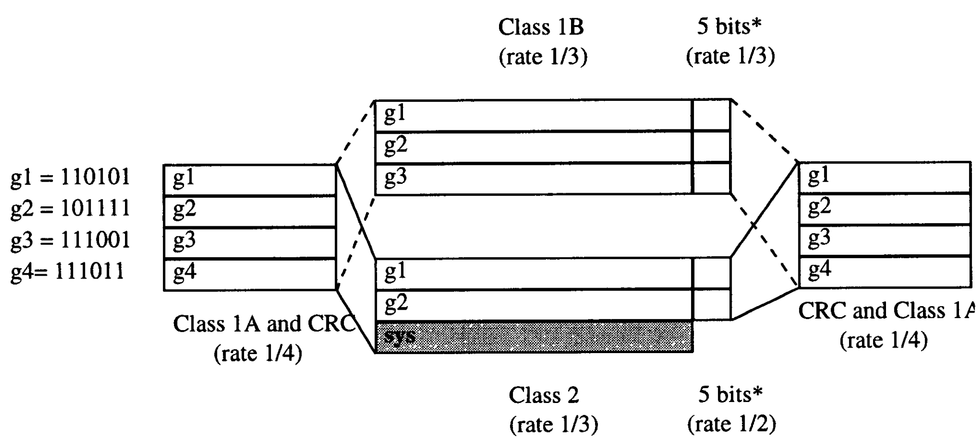

Figure 4.4 Optimal Rate-1/3 Code for Class 1B and Systematic Rate 1/3 Code for Class 2

4.2 Viterbi Decoders

4.2.1 Existing Viterbi Decoding Algorithm for Rate-½ Code

Given soft decisions from the receiver front end, the Viterbi decoder optimally uses the data to decode the various bits. The Viterbi decoder for the rate-½ code ideally computes branch metrics of the following squared-Euclidean distance form:

$$\mu(\lambda; b) = \sum_{i=1}^{2} \left| r_i(t_{\lambda,i}) - \alpha_i(t_{\lambda,i}) s_i(b) \right|^2$$

where:

- $\mu(\lambda; b)$ denotes the branch metric computed for branch b at trellis stage λ;
- $(r_1(t), r_2(t))$ denotes the received signals at time t corresponding to the transmitted code bits;
- $(s_1(b), s_2(b))$ denotes the ideal modulated signals corresponding to the coded bits for branch *b*;
- $\alpha_i(t)$ denotes the channel fade coefficient at time *t*;
- $t_{\lambda,i}$ denotes the transmission time associated with the i-th coded bit at the λ-th trellis stage.

Note that the times $t_{\lambda,i}$ are not necessarily uniformly spaced from one trellis stage λ to the next, or from one coded bit *i* to the next, due to interleaving. We note that there are well-known simplifications of the Viterbi branch metric that can be performed to reduce implementation complexity, so this form of metric is used primarily to illustrate the concept. In the event of puncturing, the decoder sets $r_i(t)$ to a neutral value favoring neither a 0-bit nor a 1-bit; e.g., for BPSK or QPSK, we set $r_i(t)$ = 0. The channel fade coefficient $\alpha_i(t)$ is usually not known at the receiver. In this case, the receiver may form an estimate of the fade coefficient and use the estimate in the branch metric calculations (decoding with channel state information) or may ignore fading altogether and set $\alpha_i(t) = 1$ in the branch metric calculations (decoding without channel state information).

4.2.2 Viterbi Decoder for Rate-1/3 and Rate-1/4 Codes

With minor modifications, the Viterbi decoding subroutine can be used "as is" from the existing system. In case of the augmented rate-1/3 code, the ideal branch metrics take the following form:

$$\mu(\lambda; b) = \sum_{i=1}^{3} \left| r_i\left(t_{\lambda,i}\right) - \alpha_i\left(t_{\lambda,i}\right) s_i(b) \right|^2 .$$

Therefore, after an additional term $\left| r_3\left(t_{\lambda,3}\right) - \alpha_3\left(t_{\lambda,3}\right) s_3(b) \right|^2$ is added to the branch metrics of the rate-½ code, the rest of the Viterbi decoder is the same. (If selected Class 2 bits are to be encoded, the number of trellis stages will also be increased somewhat.) This results in a negligible increase in decoder complexity.

Similarly, a rate-¼ Viterbi decoder adds a fourth term $\left| r_4\left(t_{\lambda,4}\right) - \alpha_4\left(t_{\lambda,4}\right) s_4(b) \right|^2$ to the branch metric computation, but otherwise is the same.

4.3 Simulation Results

As we lower the rate of the encoder, the corresponding d_{free} increases and therefore the CRC failure decreases. We perform simulations in two fading environments (slow-fading and fast-fading) to investigate the incremental improvement between each successive coding rate.

4.3.1 Slow Rayleigh Fading Channel

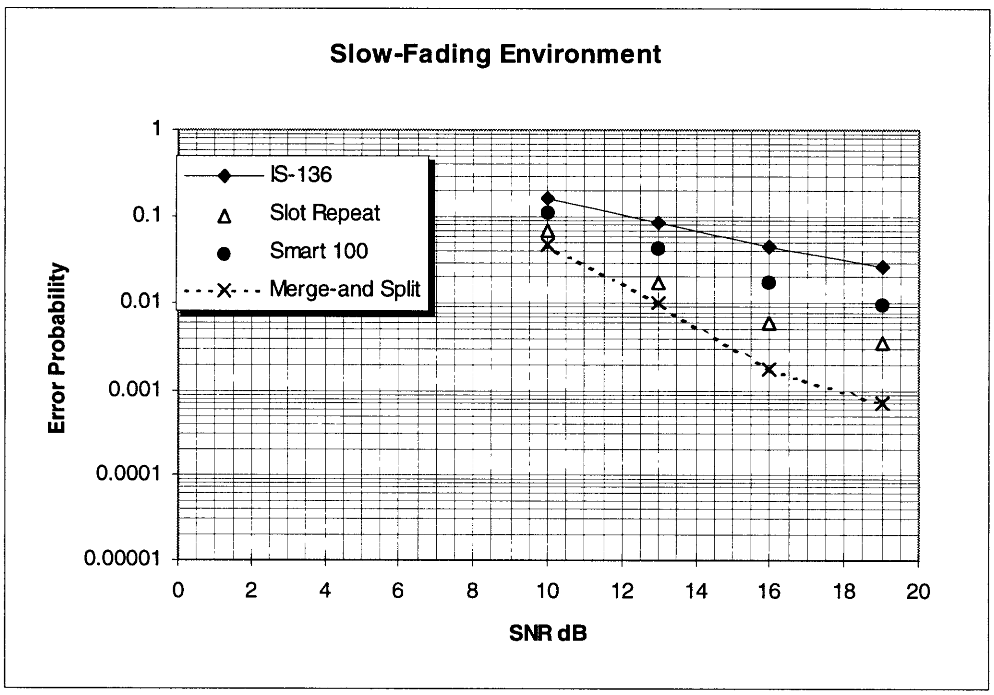

Figure 4.5 Comparison of Different Schemes in a Slow-Fading Environment.

As shown in Figure 4.5, we observe the performance curves improve as we lower the coding rate. The simulation results are consistent with our expectation. In this slow-fading environment, the performance curves are relatively flat. Improvement due to lowering the coding rate is insignificant. We conclude that ADVISE is not effective in such a slow-fading environment.

4.3.2 Fast Rayleigh Fading Channel

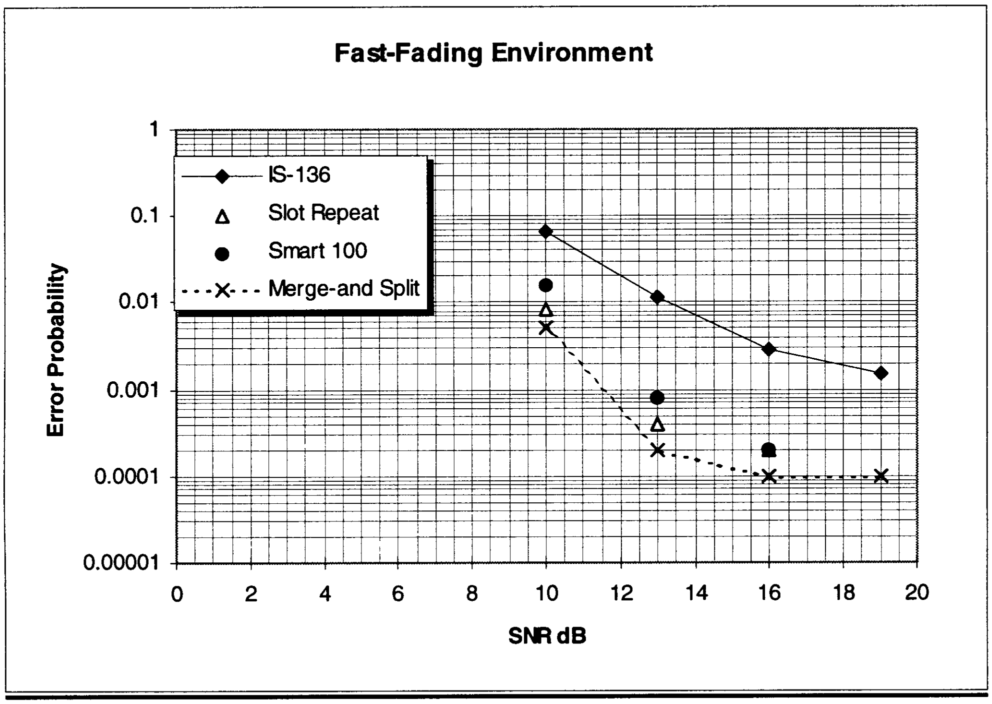

Figure 4.6 Comparison of Different Schemes in a Fast-Fading Environment.

In a fast-fading environment, as shown in Figure 4.6, ADVISE proves to be much more effective. The most significant improvement occurs between the original IS-136 (rate-½) and the Smart 100 (rate-1/3). The subsequent incremental improvements (i.e., between rate-1/3 to full-slot repeat and between full-slot repeat to merge-and-split) are not as significant.

4.3.2 Performance of Rate-1/4 versus Full-Slot Repeat

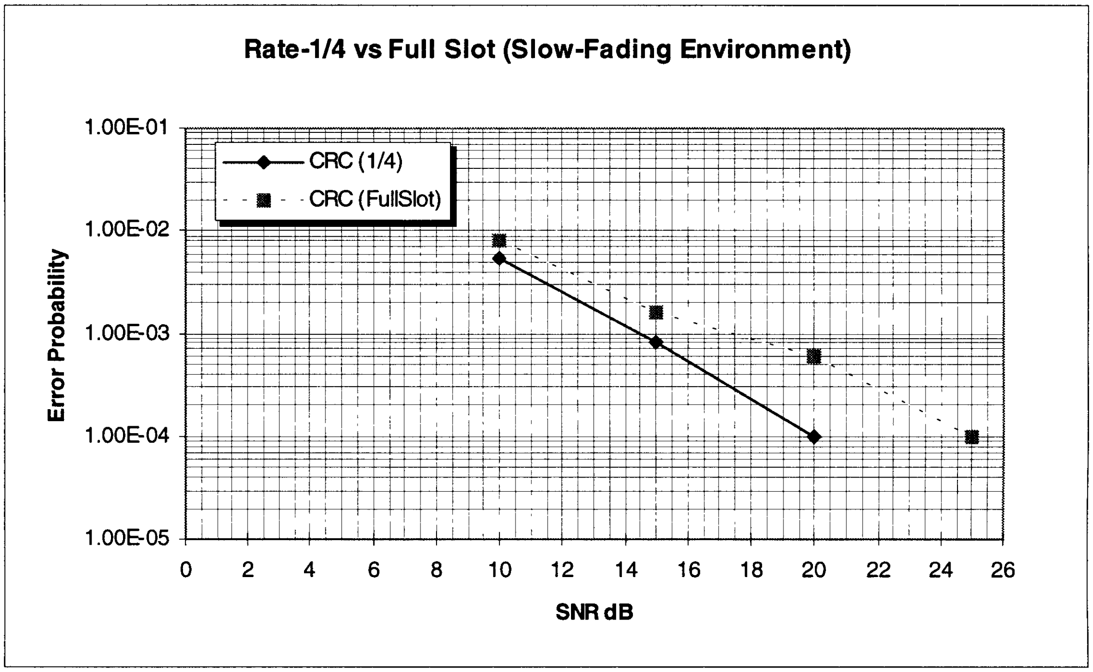

Figure 4.7 Rate-¼ Coding vs Full-Slot Repeat in a Slow-Fading Environment

(Note: Rate-¼ Coding and Full-Slot Repeat have virtually indistinguishable results in a Fast-Fading Environment.)

Further, we are interested to investigate the performance difference between full-slot repeat and the proposed rate-¼ code. As stated in previous sections, full-slot repeat has a smaller d_{free} but is less complex in decoding compared to the rate-¼ code. In a slow-fading environment, the full-slot repeat and the rate-1/4 code have virtually indistinguishable performance curves. In a fast-fading environment, as shown in Figure 4.7, the performance difference is marginal, which strongly suggests that the full-slot repeat solution is very attractive despite the minor trade-off of a smaller d_{free}.

Chapter 5

Autonomous ADVISE Detection Algorithm

The BellSouth proposal does not specify the signaling mechanism by which the base stations inform the SUs that auxiliary ADVISE bits are available. In this chapter, we describe a method by which the SUs can autonomously detect the presence or absence of auxiliary bits without explicit signaling.

5.1 Autonomous Detection Algorithm: An Overview

In our blind detection method, we assume that the auxiliary slot contains a certain number (approximately 50) of bits that are identical with those transmitted on the standard slot. At the mobile end, the receiver makes preliminary hard decisions regarding the channel bits that are repeated on both the standard and auxiliary (ADVISE) slots and counts the number of decisions that are the same for both slots, i.e., the Hamming distance. The set of repeated channel bits may be arbitrarily chosen from the coded bits (Class 1) and/or the uncoded bits (Class 2). If the Hamming distance is less than a threshold, the method declares ADVISE to be present and allows the channel decoder to use the auxiliary data. Otherwise, the method declares ADVISE to be absent, and the channel decoder uses only the data received in the standard slot. The threshold may be a predetermined constant or selected adaptively to maximize performance.

The proposed algorithm serves as a blind detection mechanism for any ADVISE FEC overlay in which some number of coded or uncoded bits are transmitted in an identical fashion on both the normal and the auxiliary slots (i.e., the same channel symbols are transmitted but in perhaps a different order). With only a modest increase in decoder and handset complexity, the method allows the utilization of the auxiliary bits (if available) without any external signaling or handshaking between the SU and base station.

Since the method can be applied on a slot-by-slot basis, it provides the base station greater flexibility in switching ADVISE on and off without the latency associated with traditional message passing. By employing the autonomous blind detection method, no modification is needed in the existing message standard, and backward compatibility is achieved.

5.2 Two-Stage Viterbi Decoding

An alternative non-distance-based method of autonomous blind detection is to perform two stages of decoding as depicted in Figure 5.1. In the first stage, the decoder assumes that the ADVISE bits are present and uses the data received on the auxiliary slot (by combining the auxiliary data with the normal slot data via maximal-ratio combining if the coded bits are identical on the two slots, or by incorporating both sets of data into the branch metric computations if the coded bits are different). At the completion of the first

Viterbi decoding, a cyclic redundancy check (CRC) is performed on the decoded word. If the CRC check fails, the decoder discards the ADVISE bits and performs a second stage of Viterbi decoding in which only the data from the normal slot are used in the branch metric computations. As is clear from Figure 5.1, the two-stage non-distance-based method disadvantageously requires a significant increase in decoder processing requirements and latency as compared with the proposed distance-based method. On the other hand, the distance-based method, imposes a constraint that a set of channel bits must be identical in the two slots, which reduces the flexibility of the encoder.

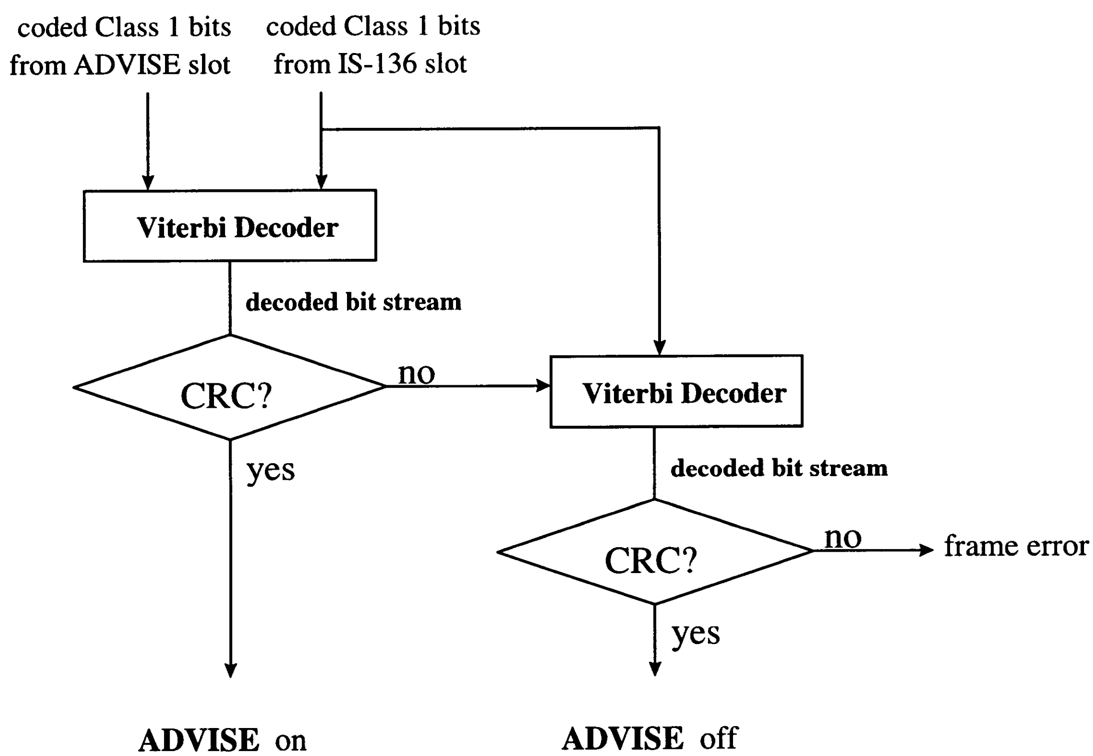

Figure 5.1 Two-stage Viterbi Decoding

5.3 Distance-based Metrics Algorithm

In the absence of explicit signaling to inform the SU that ADVISE is on or off, the SU needs to make such a determination autonomously. The ADVISE bits need not be transmitted in the same sequence as the original bit stream as long as the SU has prior knowledge of their reordering.

The distance metric can be adapted to suit implementation requirements. Useful metrics include squared Euclidean distance and Hamming distance. As is well known, distance metrics may be manipulated into many equivalent forms with corresponding modifications of the comparison rule. For example, before comparison, the metric value may be processed by applying an arbitrary monotonic increasing or montonic decreasing function. Common examples include taking the logarithm (often applied to reduce dynamic range requirements) and linear or affine transformations (to place metric values in a desired range of values).

5.3.1 Euclidean-Distance Metric

The proposed Euclidean-distance algorithm is shown in general form in Figure 5.2. The SU extracts the soft-decision values of the common bits on the auxiliary slot as one data vector and the soft-decision values of the same bits as received on the standard slot as a second data vector. The distance between the two data vectors is computed and compared to a detection threshold which is SNR-dependent. For fading channels, SNR estimation must also include estimation of the channel fading parameters $\alpha_i(t)$. If the distance between the vectors is less than the detection threshold, the receiver declares that useful ADVISE data are available and proceeds to use the ADVISE data in its decoding process. If the distance between the data vectors is large, indicating that the supposedly common bits are not the same, the receiver declares that ADVISE data are not available and proceeds to use its standard IS-136 decoder without processing the auxiliary data.

Maximum-likelihood statistical decision theory can be used to derive optimal rules for deciding between two hypotheses. For the autonomous detection algorithm, let

$$r_i(t) = \alpha_i(t)s_i(t) + n_i(t)$$

denote the complex baseband received signals for the common portion of the two slots, i = 1,2 (standard slot and auxiliary ADVISE slot, respectively). Here $s_i(t)$ denotes the transmitted QPSK symbol, $\alpha_i(t)$ denotes the fading coefficient, and $n_i(t)$ denotes the complex AWGN whose real and imaginary components each have variance σ^2. The receiver is assumed to estimate the $\alpha_i(t)$ and correct for the phase shift introduced by the fading channel. Ideally,

$$r_i'(t) = \frac{\alpha_i^*(t)r_i(t)}{|\alpha_i(t)|}$$

$$r_i'(t) = \alpha_i'(t)s_i(t) + n_i'(t)$$

where $\alpha_i'(t) = |\alpha_i(t)|$ and $n_i'(t)$ is again AWGN with real and imaginary components having variance σ^2.

To simplify notation, we drop the primes and use the following signal model:

$$r_i(t) = \alpha_i(t)s_i(t) \; + \; n_i(t)$$

where $r_i(t)$, $s_i(t)$ and $n_i(t)$ are complex, but $\alpha_i(t)$ is real. Taking L complex samples of $r_i(t)$ at multiples of the sampling interval T, we form a real-valued vector of dimension $2L$:

$$\bar{r}_i = \left[r_i^I(0), r_i^Q(0), r_i^I(T), r_i^Q(T), \ldots, r_i^I((L-1)T), r_i^Q((L-1)T)\right]$$

where $r_i^I(kT)$ and $r_i^Q(kT)$ are the real and imaginary (in-phase and quadrature) components of r_i at time $t = kT$. Similarly,

$$\bar{s}_i = \left[s_i^I(0), s_i^Q(0), s_i^I(T), s_i^Q(T), \ldots, s_i^I((L-1)T), s_i^Q((L-1)T)\right]$$

$$\bar{\alpha}_i = \left[\alpha_i(0), \alpha_i(T), \ldots, \alpha_i((L-1)T)\right].$$

Let H_0 denote the hypothesis that ADVISE is present; i.e., $\bar{s}_1 = \bar{s}_2$. The alternative hypothesis H_1 is that ADVISE is absent; i.e., $\bar{s}_1 \neq \bar{s}_2$.

A generalized likelihood ratio is given by the ratio of conditional probabilities averaged over the unknown signal pairs $(\bar{s}_1, \bar{s}_2)$:

$$\Lambda(\bar{r}_1, \bar{r}_2 \mid \bar{\alpha}_1, \bar{\alpha}_2) = \frac{\left\langle P(\bar{r}_1, \bar{r}_2 \mid \bar{s}_1, \bar{s}_2, \bar{\alpha}_1, \bar{\alpha}_2)\right\rangle_{\bar{s}_1 \neq \bar{s}_2}}{\left\langle P(\bar{r}_1, \bar{r}_2 \mid \bar{s}_1, \bar{s}_2, \bar{\alpha}_1, \bar{\alpha}_2)\right\rangle_{\bar{s}_1 = \bar{s}_2}}$$

where the angle brackets $\langle \cdot \rangle$ denote averaging with respect to the sequence $(\bar{s}_1, \bar{s}_2)$ satisfying the constraint.

In decision theory, assuming equal costs, hypothesis H_0 is accepted when $\Lambda \leq 1$. Since the conditional probability density functions are Gaussian, we have

$$P\left(\overline{r_1},\overline{r_2} \mid \overline{s_1},\overline{s_2},\overline{\alpha_1},\overline{\alpha_2}\right)$$
$$= C\cdot\exp\left\{-\frac{1}{2\sigma^2}\sum_k\left[r_1(kT)-\alpha_1(kT)s_1(kT)\right]^2\right\}\cdot\exp\left\{-\frac{1}{2\sigma^2}\sum_k\left[r_2(kT)-\alpha_2(kT)s_2(kT)\right]^2\right\}$$

where C is a constant.

After canceling common terms, Λ is proportional to the ratio

$$\frac{\left\langle \exp\left\{\frac{1}{\sigma^2}\sum_k\sum_{i=1}^{2}\left[r_i^I(kT)\alpha_i(kT)s_i^I(kT)+r_i^Q(kT)\alpha_i(kT)s_i^Q(kT)\right]\right\}\right\rangle_{\overline{s_1}\neq\overline{s_2}}}{\left\langle \exp\left\{\frac{1}{\sigma^2}\sum_k\left[s_1^I(kT)\sum_{i=1}^{2}r_i^I(kT)\alpha_i(kT)+s_1^Q(kT)\sum_{i=1}^{2}r_i^Q(kT)\alpha_i(kT)\right]\right\}\right\rangle_{\overline{s_1}=\overline{s_2}}}.$$

For QPSK, s_i^I and s_i^Q are proportional to ± 1. Hence, the dominant term in the numerator occurs when

$$s_i^I(kT)=\operatorname{sgn}\left\{r_i^I(kT)\alpha_i(kT)\right\}$$

and

$$s_i^Q(kT)=\operatorname{sgn}\left\{r_i^Q(kT)\alpha_i(kT)\right\}.$$

The dominant term in the denominator occurs when

$$s_1^I(kT)=s_2^I(kT)=\operatorname{sgn}\left\{\sum_{i=1}^{2}r_i^I(kT)\alpha_i(kT)\right\}$$

and

$$s_1^Q(kT)=s_2^Q(kT)=\operatorname{sgn}\left\{\sum_{i=1}^{2}r_i^Q(kT)\alpha_i(kT)\right\}.$$

Therefore, the dominant term in the numerator is

$$\exp\left\{\frac{1}{\sigma^2}\sum_k\sum_{i=1}^{2}\left[\left|r_i^I(kT)\alpha_i(kT)\right|+\left|r_i^Q(kT)\alpha_i(kT)\right|\right]\right\}$$

and in the denominator, it is

$$\exp\left\{\frac{1}{\sigma^2}\sum_k\left[\left|\sum_{i=1}^{2} r_i^I(kT)\alpha_i(kT)\right| + \left|\sum_{i=1}^{2} r_i^Q(kT)\alpha_i(kT)\right|\right]\right\}.$$

After taking logarithms, we have the approximate maximum likelihood test in which the distance-like measure

$$D = \sum_{k=0}^{L-1}\left\{\sum_{i=1}^{2}\left|r_i^I(kT)\alpha_i(kT)\right| - \left|\sum_{i=1}^{2} r_i^I(kT)\alpha_i(kT)\right| + \sum_{i=1}^{2}\left|r_i^Q(kT)\alpha(kT)\right| - \left|\sum_{i=1}^{2} r_i^Q(kT)\alpha_i(kT)\right|\right\}$$

is compared to a threshold λ. If $D < \lambda$, then H_0 is accepted. In an actual implementation, the receiver would use estimates $\tilde{\alpha}_i$ of the α_i. Also, more complex tests could be derived by including additional terms other than the dominant ones identified above.

In this formulation, the threshold should ideally be a function of the effective SNR after fading since one would usually prefer to have approximately constant false-alarm rate (CFAR) operation. We note that, in the absence of noise, the term

$$\sum_{i=1}^{2}\left|r_i^I(kT)\alpha_i(kT)\right| - \left|\sum_{i=1}^{2} r_i^I(kT)\alpha_i(kT)\right|$$

has minimum value 0 and maximum value $2\sqrt{E_b}\,\min\left\{\alpha_1^2(kT), \alpha_2^2(kT)\right\}$. With noise, at high SNR, the standard deviation of the above term is approximately 2σ. Hence, to achieve approximately CFAR operation, we propose the following threshold

$$\lambda = \mu\sqrt{\tilde{SNR}}\sum_{k=0}^{L-1}\min\left\{\tilde{\alpha}_1^2(kT), \tilde{\alpha}_2^2(kT)\right\},$$

where μ is a constant multiplier chosen to meet desired operating points with respect to missed detection and false-alarm rates, and the $\tilde{\alpha}_i$ and $\tilde{SNR}$ are the receiver's best estimates of the channel fading and signal-to-noise ratio, respectively. Depending on implementation constraints and specific operating conditions, other functions of the $\tilde{\alpha}_i$ and $S\tilde{N}R$ would also be possible.

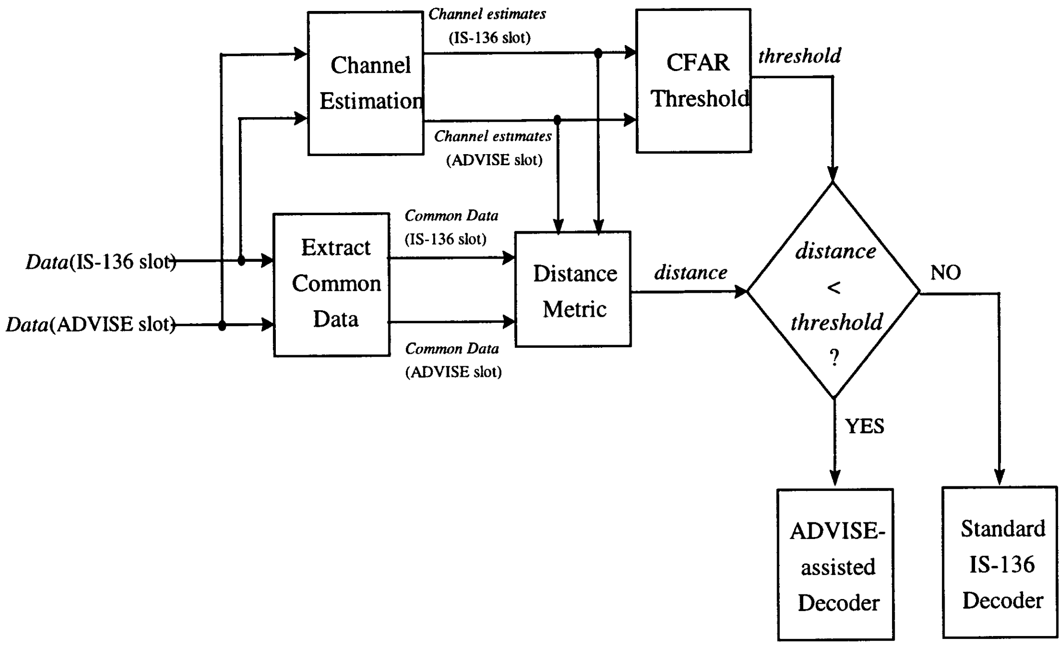

Figure 5.2 Distance-based Detection Algorithm

5.3.2 Hamming-Distance Metric

ADVISE pre-processors derived from squared Euclidean-distance metrics can be expected to provide optimal performance under AWGN conditions but, because of the real-valued multiplications involved in the metric computations and the necessity of adapting the threshold using constant false-alarm rate (CFAR) techniques, may be too computationally burdensome to be attractive for all applications.

The Hamming-distance metric involves making hard decisions as to the bit values and then counting disagreements between the two hard-decision data vectors. In fact, the measure D from the previous section is closely related to the Hamming-distance metric.

$$D=\sum_{k=0}^{L-1}\left\{\sum_{i=1}^{2}\left|r_i^I(kT)\alpha_i(kT)\right|-\left|\sum_{i=1}^{2}r_i^I(kT)\alpha_i(kT)\right|+\sum_{i=1}^{2}\left|r_i^Q(kT)\alpha(kT)\right|-\left|\sum_{i=1}^{2}r_i^Q(kT)\alpha_i(kT)\right|\right\}$$

By making hard decisions on the $r_i^I(kT)\alpha_i(kT)$ and $r_i^Q(kT)\alpha_i(kT)$ before computing D, the result is twice the Hamming distance. Hamming distance has the advantage that it is independent of SNR and the fading amplitude $\left|\alpha_i(t)\right|$, so setting the detection threshold is a simpler matter. The receiver makes a favorable decision with regard to similarity of the two data vectors only when the number of disagreements is small. Equivalently, the receiver can count the number of *agreements* and declare the two data vectors to be similar when the number of agreements is *large*. A constant threshold λ is appropriate to be effective with this decision statistic.

Pre-processors derived from Hamming-distance metrics would be less powerful than the Euclidean-distance counterparts, but the simplicity of their implementation (involving only binary logic operations) and their robustness to varying channel conditions may make them particularly attractive when processor loading is a major concern and/or channel estimates of adequate quality are not readily available. Operation of ADVISE within a handset is likely to be such an application.

A proposed design of the Hamming-distance type is shown in Figure 6.4. Because the Hamming-distance metric is simple to compute, we assume the handset has sufficient computational power to make decisions on a frame-by-frame basis. However, in practice, ADVISE will persist for many slots. We can easily add some memory to a frame-by-frame detection method.

For illustrative purposes, we consider the case in which the 52 Class 2 bits are repeated on the ADVISE slot. For detection, we require N of the 52 bits to produce agreements for ADVISE to be detected. In general, the threshold N can be made adaptive to the channel condition. We first consider a non-adaptive implementation in which a constant threshold is used. Then we consider a simple adaptive implementation that is well suited to the IS-136 application.

5.3.3 Non-adaptive Hamming-Distance Threshold

For a non-adaptive implementation, we propose a nominal threshold value of $N = 35$. We note that, by lowering the value of N, we increase the ADVISE detection rate but also increase the false-alarm rate. Conversely, by increasing the value of N, we decrease both the detection rate and the false-alarm rate. A low detection rate is undesirable from the system point of view since the ADVISE bandwidth is wasted when the targeted SU is unable to make use of the auxiliary bits. A high false-alarm rate is undesirable in that it degrades the performance of the already disadvantaged SU: false ADVISE detections will usually result in loss of the burst since the Viterbi decoder is unlikely to produce a valid codeword that passes the CRC test. The relative costs of these two different error events depend upon the application, so the setting of an optimal threshold will depend on detailed system trade-offs. The values of N reported here are offered as nominal values, expected to be roughly correct for the IS-136 application.

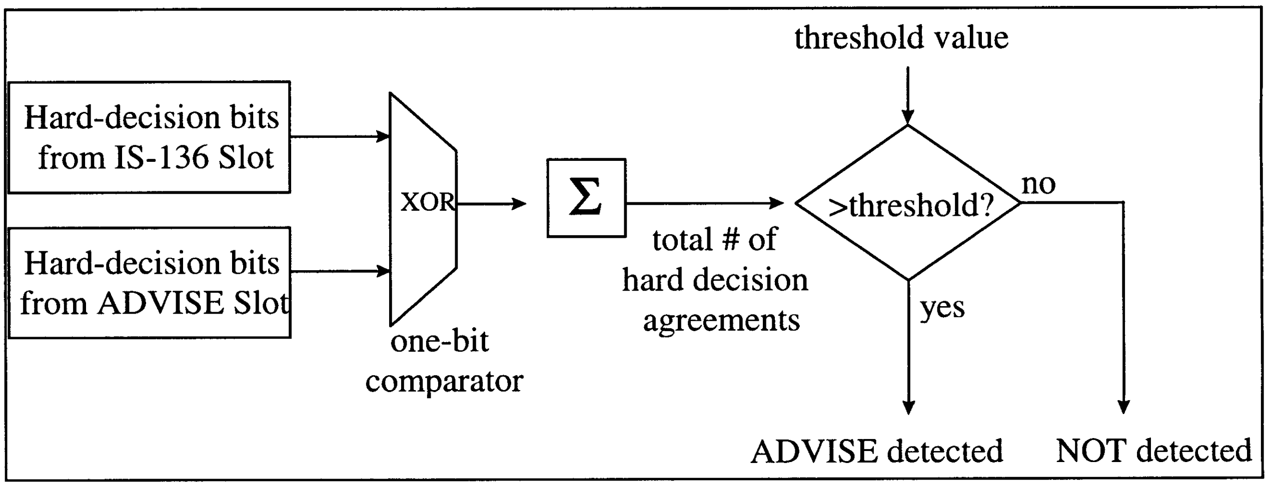

Figure 5.3 Hamming-Distance Threshold Detection

In Figures 5.5a-b and 5.6a-b, we compare the false-alarm and missed-detection rates versus SNR under two fading rates (slow and fast) for two non-adaptive thresholds, $N = 35$ and $N = 39$. We show that when we lower the threshold N, the detection rate improves whereas the false-alarm rate degrades. For a fixed N, we achieve approximately constant false-alarm rate (CFAR) in both slow-fading and fast-fading environments.

Representative performance results for ADVISE using the proposed non-adaptive autonomous blind detection method are presented in Figures 5.6c and 5.7c. In addition, we compare the CRC failure rates for the non-adaptive implementation versus the ideal case in which the SU has perfect knowledge about whether or not the ADVISE bits are available. From these results, we see that, when ADVISE is present, the lower threshold $N = 35$ results in virtually no performance degradation since the auxiliary data are almost always detected. When ADVISE is absent, however, the lower threshold causes some degradation due to the occasional acceptance of a bad frame as valid auxiliary data. For the higher threshold $N = 39$, the opposite is true: There is no degradation due to false acceptance of invalid data, but there is less ADVISE performance gain due to the higher rate at which valid ADVISE data are rejected.

5.3.4 Adaptive Hamming-Distance Threshold

It is possible to enhance the robustness of the basic detection method by making the threshold adaptive. For the IS-136 application, the SU can reasonably determine when it is a candidate for the auxiliary ADVISE bits and, once it begins receiving ADVISE bits, can reasonably expect the help to continue over an extended period of time (even though the actual duration is a random variable depending on traffic load). Thus, a simple finite-state machine representation of system operation would enable the ADVISE detection threshold to be set higher for initial acquisition and then reduced once sustained ADVISE service begins.

Let us designate three system states as follows:

State	**Description**	**Threshold**

NORMAL	Standard IS-136 mode of operation – SU does not look for ADVISE	–
EXPECTANT	SU with disadvantaged RF channel searches for ADVISE	$N_{expectant}$
ENHANCED	SU enjoys sustained ADVISE service	$N_{enhanced}$

Table 5.1 Table of Dual-Threshold Mode State Transition

The SU begins in the NORMAL state. As part of its normal IS-136 processing, it provides the base station with information as to the perceived quality of the radio downlink. While the channel is favorable, the SU has no expectation that the base station will begin offering it the ADVISE service and therefore will not look for it. When the channel deteriorates, however, the SU can expect the base station to begin providing ADVISE service, subject to the availability of resources. The SU then enters the EXPECTANT state and begins autonomously looking for the ADVISE bits using the threshold value $N_{expectant}$. Since the SU does not know when, if ever, the ADVISE service will begin, the threshold $N_{expectant}$ must be set relatively high to keep the false detection rate low. Once ADVISE is successfully detected, the SU uses the auxiliary bits to enhance the performance of its channel decoder. It continues in the EXPECTANT state, using the ADVISE bits as they are detected, until sustained ADVISE service has been achieved. When this condition is reached, the SU enters the ENHANCED state and, in order to maximize detection success, continues to look for the ADVISE bits using the lower threshold $N_{enhanced}$. Under these circumstances, the overall false-alarm rate is not adversely affected by the lower threshold, since the ADVISE service is usually present. Once the base station stops providing ADVISE, the SU quickly detects its absence and returns either to the EXPECTANT state with the higher detection threshold (if the unaided RF channel is still disadvantaged) or to the NORMAL state (if the unaided RF channel is no longer disadvantaged).

As a specific example design, we set $N_{\text{expectant}} = 39$ and $N_{\text{enhanced}} = 35$, based on the simulation results for the non-adaptive method. In the EXPECTANT mode, the SU uses the detection method to check for the presence of ADVISE bits. If the detection threshold is exceeded and the resultant decoded word passes the CRC test, the SU records a hit. If Q of the last P frames score a hit, then the SU declares that sustained ADVISE service has been established. It then switches to the ENHANCED state and uses the higher detection threshold. Similarly, the SU falls out of the ENHANCED state if the history of the last P frames suggests that ADVISE is no longer on. The state diagram for this these transition rules is illustrated in Figure 5.4.

In Figures 5.5d and 5.6d, we show how the three-state adaptive implementation using two thresholds provides enhanced detection/false-alarm rate operation. These results have been confirmed by tests in which the autonomous blind detection method has been simulated and applied to actual speech samples in controlled laboratory tests.

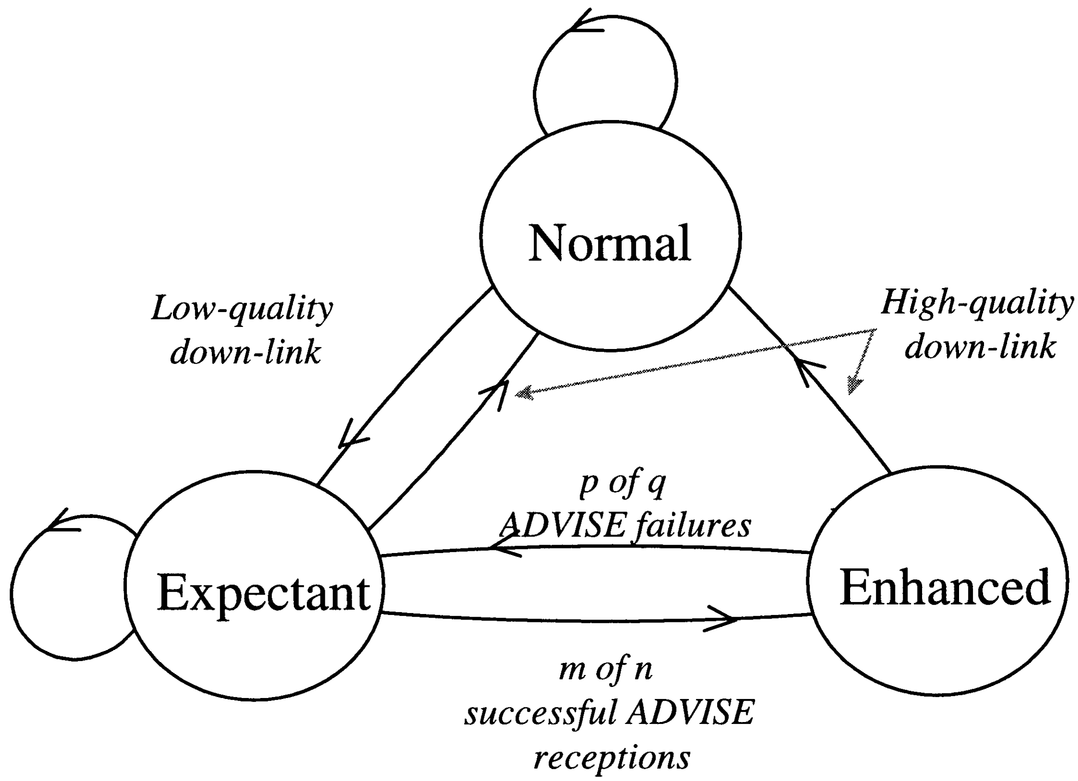

Figure 5.4 Dual-Threshold-Mode State-Transition Diagram

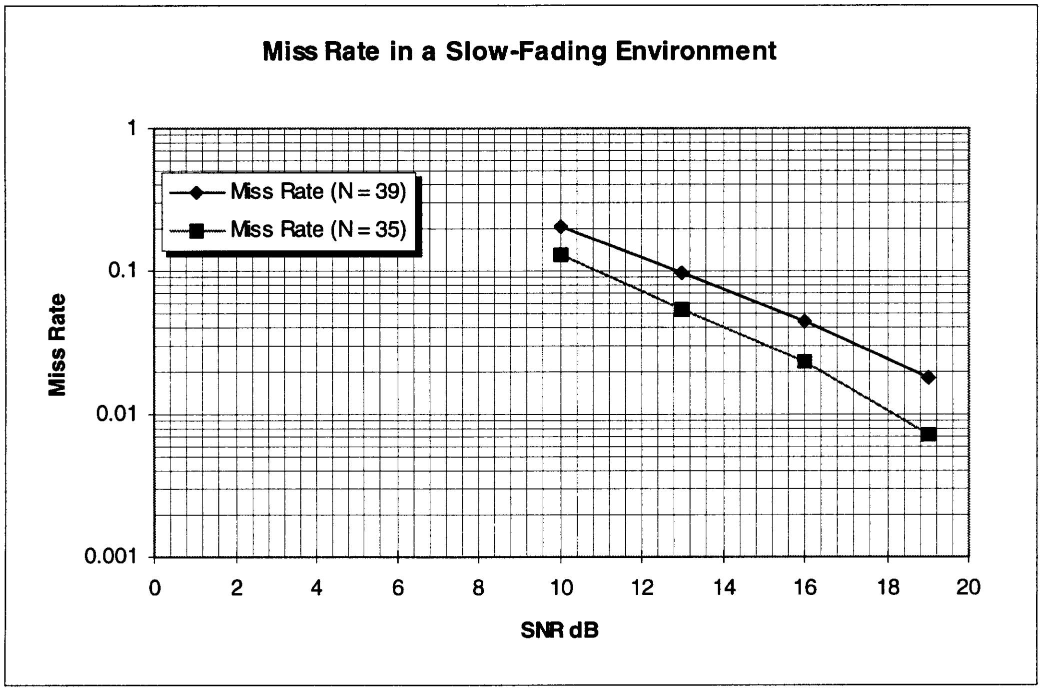

Figure 5.5a Missed-Detection Rate in a Slow-Fading Environment

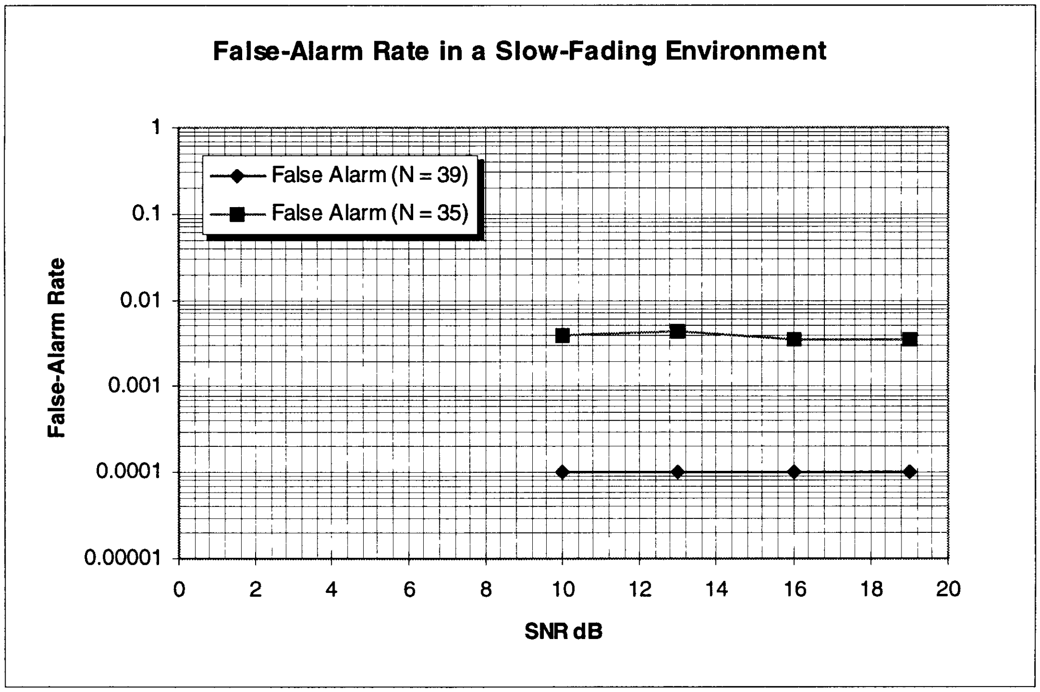

Figure 5.5b False-Alarm Rate in a Slow-Fading Environment

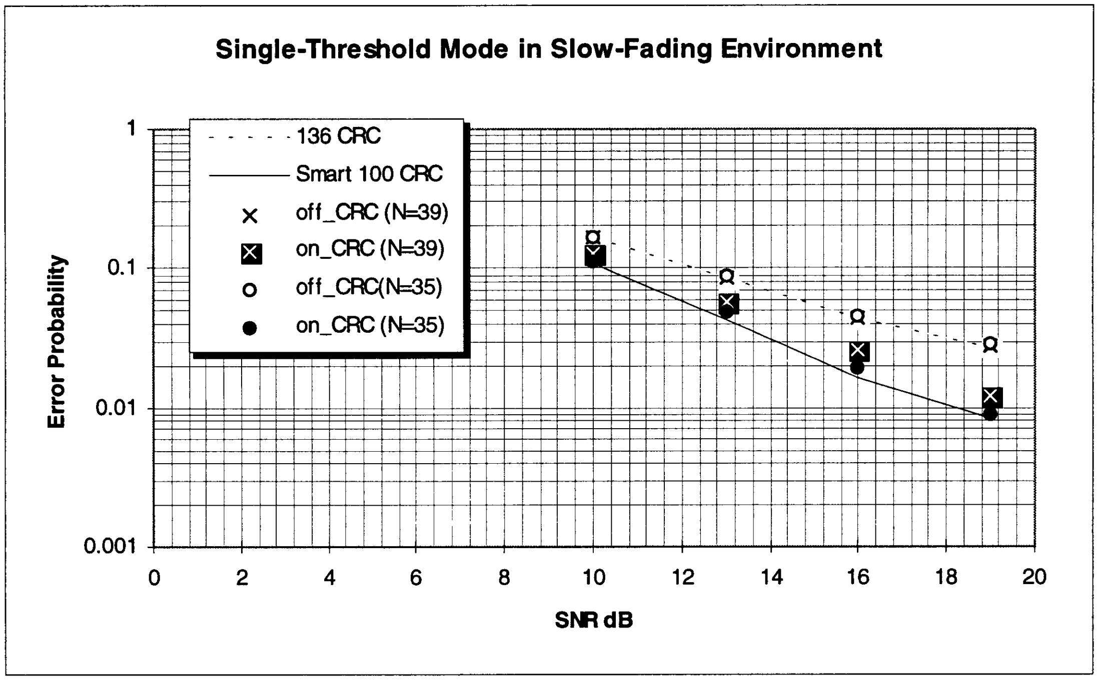

Figure 5.5c Single-Threshold Mode in Slow-Fading Environment

- 136 CRC: Standard IS-136 Coding/Decoding (zero false-alarm);
- Smart 100: 100 ADVISE Bits are available (perfect detection);
- Off_CRC (N = 39): CRC Error Rate when ADVISE is off; threshold = 39;
- On_CRC (N = 39): CRC Error Rate when ADVISE is on; threshold = 39;
- Off_CRC (N = 35): CRC Error Rate when ADVISE is off; threshold = 35;
- Off_CRC (N = 35): CRC Error Rate when ADVISE is on; threshold = 35.

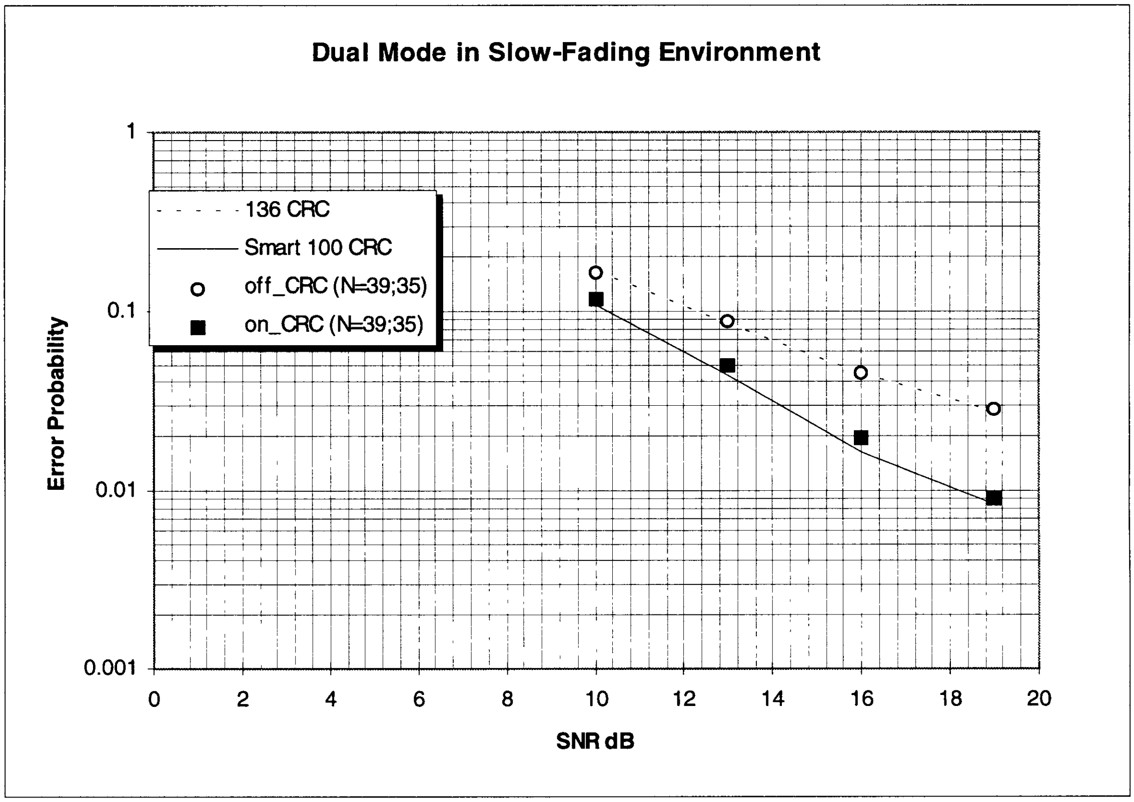

Figure 5.5d Dual-Threshold Mode in Slow-Fading Environment

- 136 CRC: Standard IS-136 Coding/Decoding (zero false-alarm);
- Smart 100: 100 ADVISE Bits are available (perfect detection);
- Off_CRC (N = 39; 35): CRC Error Rate when ADVISE is off;
  Threshold of Expectant State = 39; Threshold of Enhanced State = 35;
- On_CRC (N = 39; 35): CRC Error Rate when ADVISE is on;
  Threshold of Expectant State = 39; Threshold of Enhanced State = 39.

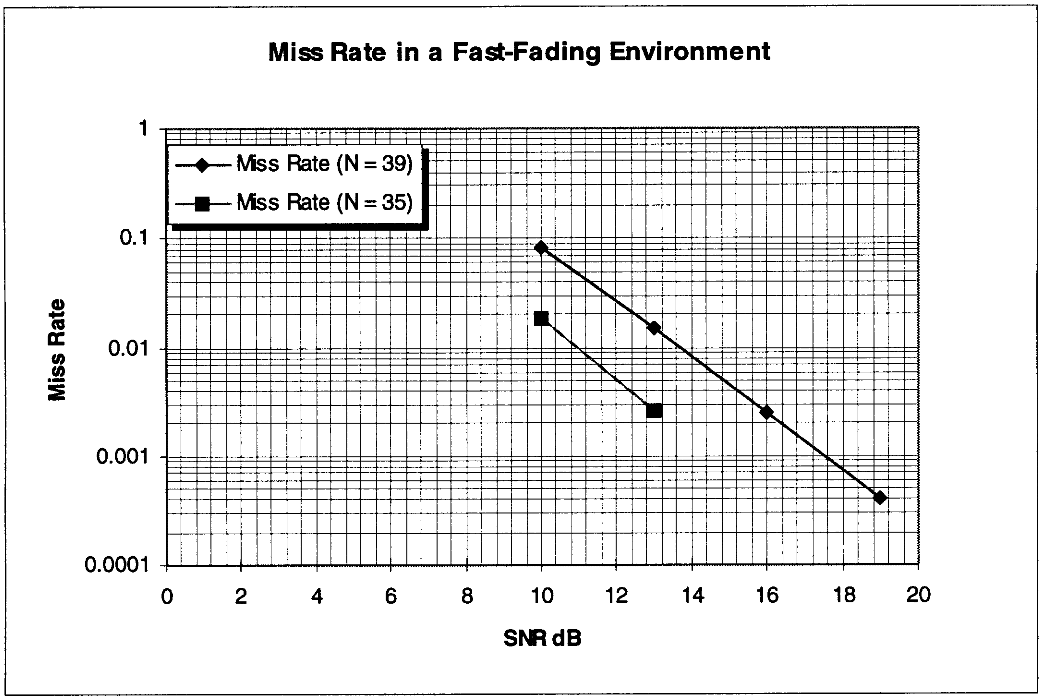

Figure 5.6a Missed-Detection Rate in a Fast-Fading Environment

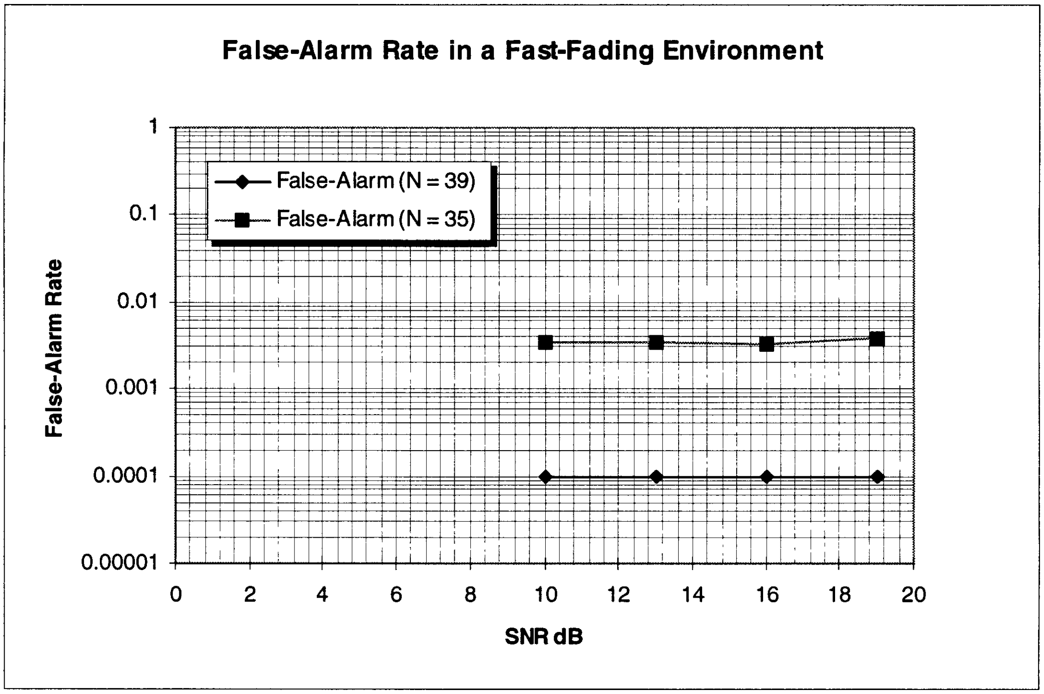

Figure 5.6b False-Alarm Rate in a Fast-Fading Environment

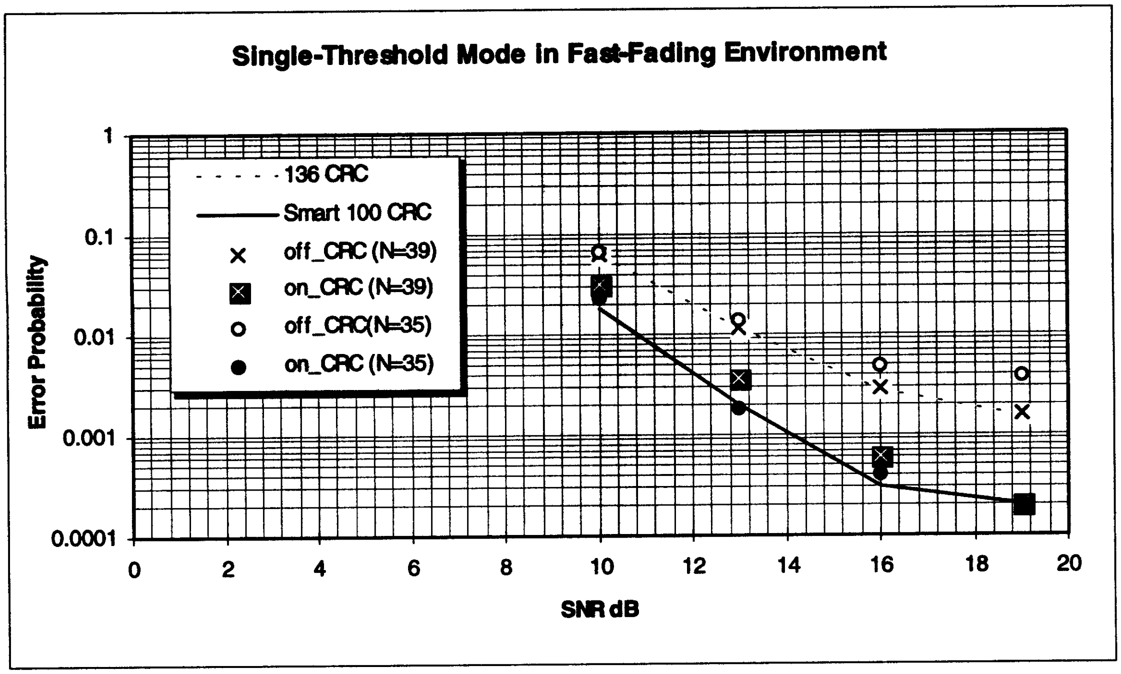

Figure 5.6c Single-Threshold Mode in Fast-Fading Environment

- 136 CRC: Standard IS-136 Coding/Decoding (zero false-alarm);
- Smart 100: 100 ADVISE Bits are available (perfect detection);
- Off_CRC (N = 39): CRC Error Rate when ADVISE is off; threshold = 39;
- On_CRC (N = 39): CRC Error Rate when ADVISE is on; threshold = 39;
- Off_CRC (N = 35): CRC Error Rate when ADVISE is off; threshold = 35;
- Off_CRC (N = 35): CRC Error Rate when ADVISE is on; threshold = 35.

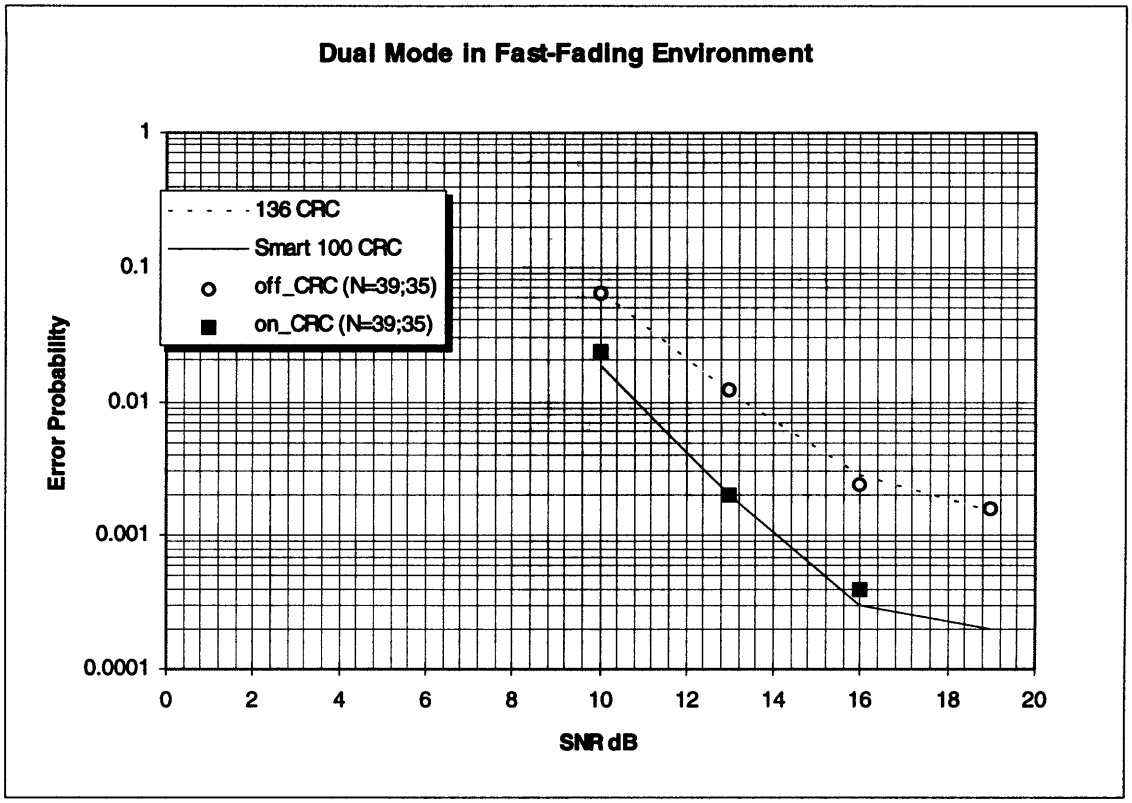

Figure 5.6d Dual-Threshold Mode in Fast-Fading Environment

- 136 CRC: Standard IS-136 Coding/Decoding (zero false-alarm);

- Smart 100: 100 ADVISE Bits are available (perfect detection);

- Off_CRC (N = 39; 35): CRC Error Rate when ADVISE is off;
  Threshold of Expectant State = 39; Threshold of Enhanced State = 35;

- On_CRC (N = 39; 35): CRC Error Rate when ADVISE is on;
  Threshold of Expectant State = 39; Threshold of Enhanced State = 39.

Chapter 6. Conclusion and Suggested Work

The various FEC overlay schemes proposed in Chapter 4 have been tested by simulations. We conclude that the ADVISE concept of utilizing the idle slot by transmitting variable lower-rate codes is both attractive and practical. With few added computations, the existing decoding firmware can be modified to work with rate-1/3, rate-¼ codes, etc. All of the proposed ADVISE implementations are backward-compatible, so that old handsets without ADVISE support can continue to operate.

The most attractive ADVISE coding scheme, according to our results, is the mix-and-match scheme. In addition to extra Class 1A and 1B protection, the mix-and-match scheme provides protection to previously unprotected Class 2 bits.

The autonomous detection algorithm discussed in Chapter 5 is also an important consideration for selecting an optimal ADVISE scheme. Augmented codes such as rate-1/3 and rate-¼ codes transmit different coded bits in the ADVISE slots, therefore cannot exploit the benefit of the autonomous detection algorithm. On the other hand, the autonomous detection algorithm is applicable with the mix-and-match scheme or for simple full-slot repeat because a set of identical bits is sent twice to the mobile. As shown in our simulations, the proposed detection algorithm using dual-threshold-mode with the Hamming distance metric provides a higher detection rate and a lower false-alarm rate. This detection algorithm is computationally simple, and requires only minor modifications of the existing firmware.

We recommend further analysis of the mix-and-match scheme by more refined simulations and by subjective human listening tests. Forward error correction (FEC) for voice is full of surprises. Incremental improvements in word error rate are often too subtle for human ears to distinguish. Consequently, we believe that simple schemes such as full-slot repeat, though inferior in simulation performance, may offer voice quality that is competitive with more sophisticated FEC schemes. Future investigations should address trade-off issues in voice quality, decoder complexity and signaling complexity, as well as backward compatibility.

References

[1] Hagenauer, Joachim. "Rate-Compatible Punctured Convolutional Codes (RCPC Codes) and their Applications." IEEE Transactions on Communications. Vol. 36, pp. 389-400, April 1988.

[2] Harvey, Bruce A. and Wicker, Stephen. "Packet Combining Systems Based on the Viterbi Decoder." IEEE Transactions on Communications. Vol. 42, pp. 1544-1557, Feb/March/April 1994.

[3] Kallel, Samir and Haccoun, David. "Sequential Decoding with ARQ and Code Combining: A Robust Hybrid FEC/ARQ System." IEEE Transactions on Communications. Vol. 36, pp. 773-779, July 1988.

[4] Kallel, Samir and Haccoun, David. "Sequential Decoding with an Efficient Partial Retransmission ARQ Strategy." IEEE Transactions on Communications. Vol. 39, pp. 208-213, Feb 1991.

[5] Lin, Shu and Costello, Daniel J. Jr. *Error Control Coding: Fundamentals and Applications.* Prentice Hall, 1983.

[6] IS-641 Manual. TDMA Cellular/PCS - Radio Interface - Enhanced Full-Rate Speech Codec. TIA/EIA, March 1996.