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CARLETON UNIVERSITY
Department of Systems and Computer Engineering

SYSC 5606 (formerly 94.566) Introduction to Mobile Communications
Fall 2002/2003

This course covers mainly the propagation and transmission (i.e. physical layer) aspects of wireless cellular communications systems. The course relies heavily on fundamentals of communication theory and stochastic processes. The Principles of Digital Communication (SYSC5504 or 94.554 or ELG 5375) graduate course, or its equivalent, is an important prerequisite.

Lecturer:

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Office hours in Fall Term: Tuesdays 11:00-12:00, and Wednesdays 11:00-12:00 (other times by appointment)

Prerequisites / Corequisites

SYSC 5504 (formerly 94.554) or ELG 5375 (Principles of Digital Communication), or their equivalents (note that Stochastic Processes (94.553 or ELG5375) is also a prerequisite/corequisite for Principles of Digital Communication). Students taking the graduate level Principles of Digital Communications course concurrently with this course should also have passed at least an undergraduate course on digital communications. To test your level of understanding of prerequisite undergraduate background material see the example undergraduate Digital Communications exam attached to this handout.

Recommended Texts:

T.S. Rappaport, *Wireless Communications: Principles and Practice,* Second Edition, Prentice-Hall, New Jersey, 2002, ISBN 0-13-042232-0.
Note: There is no single text that covers everything in this course. Another useful text is:
S. Sampei, *Applications of Digital wireless Technologies to Global Wireless Communications*, Prentice-Hall, New Jersey, 1997 (TK5103.483.S26)

Other recommended reference texts include, for example:
W.C. Jakes (ed.), *Microwave Mobile Communications*, Wiley, New York, 1974. (TK6570.M6J34)
K. Pahlavan and A.H. Levesque, *Wireless Information Networks*, Wiley, New York, 1995, (TK5103.2.P34)
G.L. Stüber, *Principles of Mobile Communications*, 2nd ed. Kluwer Academic Publishers, 2001. (TK6570.M6S78 2001)

The second edition of Rappaport should be in the Carleton Bookstore. The other four texts listed are on reserve in the Carleton University Library

Other References:

A reading list of books and papers is attached to this handout.

Course Web Site:

There is a course web site for Fall, 2002, accessible from the department's web site [www.sce.carleton.ca]. More details will be given later.

Marking Scheme:

Assignments	25%
Term Paper	25%
Final Examination	50%

Note: The final examination is for evaluation purposes only. It will not be returned to the student.

Term Paper

There are two options for the term paper:

(1) A critical literature review of a chosen topic of a current interest in the propagation or transmission area of mobile communications systems. It should consist of definition of the problem, its understanding, and plausible solutions. Marking is based on: understanding and correctness; depth of coverage; clarity and coherence; use of references; and originality beyond material covered in lectures. Simulations or other original analyses are encouraged, and may generate bonus marks. A list of references to papers in the literature should be included at the end of the paper, and the references should be referred to in the text.

(2) A computer simulation, and report on its results, for transmission or propagation in a mobile communications system or technique. The report should give background on the system or subsystem simulated, with references, and should report performance results obtained from the simulation. A listing of the simulation program should be given and (optionally) the simulation software on floppy disk.

A typical simulation could include:

- a baseband equivalent propagation channel model, including:
  - path loss model, including assumptions about antennas.
  - shadowing
  - fading
  - doppler
  - multipath, according to a given power-delay profile.
- TDMA, CDMA or FDMA system.
- interference model
- noise
- baseband equivalent modulation and demodulation; e.g. QPSK, GMSK, ….
- multipath mitigation - one or more of antenna diversity; adaptive equalization; adaptive RAKE.
- (optional): adaptive antenna array; coding/decoding or speech coding.

A list of references to papers in the literature should be included at the end of the paper, and the references should be referred to in the text. Any direct quotations must be referred to as such, with specific reference to the source. Apart from any such direct quotations, all parts of the paper must be in your own words. Plagiarism (copying or closely paraphrasing another’s work without acknowledgement) will not be condoned. [see the section on plagarism in the section on “instructional Offences” in the Carleton graduate calendar].

The term paper is due on the last class date. A typical term paper length would be about 20 typewritten pages, double spaced plus figures. Please give your choice of term paper topic, with a short (one paragraph summary of its proposed scope) to Prof. Falconer by Sept. 30.

Plagiarism

Any direct quotations must be referred to as such, with specific reference to the source. Apart from any such direct quotations, all parts of the paper must be in your own words. Plagiarism (copying or closely paraphrasing another's work without acknowledgement) will not be condoned. See the section on plagarism in the section on "instructional Offences" in the Carleton graduate calendar. See also "Guidelines for writing academic manuscripts and avoiding plagiarism" at www.plagiarism.org/articles.html. That website also gives you access to the textbook *Elements of Style* by William Strunk. Strunk's short textbook is a well-known and highly recommended classic, which can help you write better for the rest of your life.

Students with disabilities: Students with disabilities who require academic accomodations in this course please feel free to discuss with me. Students must also contact the Paul Menton Centre)PMC) to complete the necessary *letters of accommodation*. After registering with the PMC, make an appointment to meet and discuss your needs with PMC at least two weeks prior to the first exam. This is necessary in order to ensure sufficient time to make the necessary arrangements. Please note that the Paul Menton Centre deadline for submitting completed forms to the PMC for formally scheduled exam accommodations is Nov. 1, 2002 for Fall Term courses.

Topics Covered

Actual coverage as we progress, will be listed on the course web site.

Radio propagation

- Pathloss in different wireless environments
- Shadowing, reflection, diffraction, scattering, coverage
- Multipath and small scale signal variations
- Channel measurements and simulation

Cellular radio systems

- Brief overview of cellular radio principles and multiple access methods
- Interference characterization

Digital modulation and interference

- Digital modulation methods
- Error performance in interference and fading

Diversity, adaptive equalization and coding

- Principles, types and performance of diversity combining
- Adaptive equalization techniques for combating multipath
- Block and convolutional coding techniques and interleaving

System examples and current topics

- TDMA and CDMA systems, OFDM, Multiuser detection, space-time processing and coding, etc.

Some Possible Term Paper Topics

(Emphasize systems aspects to which principles covered in the course have been applied in the design.)

Case studies of propagation channel measurements and modelling
Effects of rain and vegetation in EHF (>20 GHz) fixed wireless communications systems
Propagation modelling and prediction using ray tracing approaches
Interference cancelling techniques for CDMA or TDMA systems
Applications of Turbo codes to digital mobile radio systems
Power control techniques
Base station signal processing architectures
Handset (mobile) signal processing architectures
Infrared propagation indoors, with application to wireless LANs
Influence of interference cancellation and/or directional antenna techniques on cellular system capacity

Digital speech coding techniques in digital cellular systems.
Signal processing for vehicle location
Problems of broadband (>2 Mb/s) wireless communications systems
Adaptive antenna array implementations
Interference mitigation methods
…

Some Possible Simulation Topics

Adaptive antenna array
Adaptive equalization
Bit interleaved coded modulation (BICM)
Single carrier frequency domain equalization
OFDM
CDMA receiver with RAKE and/or multiuser detection
Synchronization techniques
…

Introduction to Mobile Communications Reading List

Note: all the IEEE journals and conference proceedings should be available by accessing IEEE explore [http://ieeexplore.ieee.org/Xplore/DynWel.jsp] from a Carleton University internet address.

Texts and General References:

D.C. Cox, "Universal Digital Portable Radio Communications", *Proc. IEEE*, Vol. 75, April 1987, pp. 436-477.
J.K. Cavers, *Mobile Channel Characteristics*, (with interactive CD), Kluwer Academic Publishers, 2000 (TK6570.M6C38 2000)
J.D. Gibson (ed.), *The Mobile Communications* Handbook, CRC Press and IEEE press, 1996, (TK6570.M6M5934)
Hess, Gary C., *Land-mobile Radio System Engineering*. Boston, Mass., Artech House. 1993 371 p. (TK6570.M6H45)
W.C. Jakes (ed.), *Microwave Mobile Communications*, Wiley, New York, 1974. (TK6570.M6J34)
W.C.Y. Lee, *Mobile Communications Design Fundamentals*, (2nd ed.), Wiley, New York, 1993. (TK 6570.M6L36).
K. Pahlavan and A.H. Levesque, *Wireless Information Networks*, Wiley, New York, 1995, (TK5103.2.P34)
J.D. Parsons and J.G. Gardiner, *Mobile Communication Systems*, Blackie, London and Halstead Press, New York, 1989. (TK6570.M6P37)
S. Sampei, "*Applications of Digital Wireless Technologies to Global wireless Communications*", Prentice-Hall, New Jersey, 1997 (TK5103.483.S26)
R. Steele (ed.), *Mobile Radio Communications*, Pentech Press, London, 1992, (TK6570.M6M59)
T.S. Rappaport, *Wireless Communications: Principles and Practice,* Second Edition, Prentice-Hall, New Jersey, 2002, ISBN 0-13-042232-0.
T.S. Rappaport (ed.), *Cellular Radio and Personal Communications: Selected Readings*, IEEE Press, New York, 1994, (TK6570.M6R37)
S.H. Redl, M.K. Weber and M.W. Oliphant, *An Introduction to GSM,* Artech House, 1995, TK6570.M6R43
G.L. Stüber, *Principles of Mobile Communications*, Kluwer Academic Publishers, 1996.
M.D. Yaccoub, *Foundations of Mobile Radio Engineering*, CRC Press, 1993, (TK6570.M6Y33)

Relevant Journals:

IEEE Transactions on Wireless Communications
IEEE Communications Letters (TK5101.A1I23)
IEEE Communications Magazine (TK5101.A1I526)
IEEE Journal of Selected Areas in Communications (TK5101.I195)
IEEE Personal Communications (TK5101.A1I33)
IEEE Transactions on Communications (TK5101.I204)
IEEE Transactions on Vehicular Technology (TK6570.M6I242)
IEEE Transactions on Antennas and Propagation (TK7800.I202)
International Journal of Wireless Information Networks (Plenum Pub.) (TK5103.2.I54)
Proceedings of the IEEE (TK5700.I61)
Wireless Networks (Baltzer Science Pub.) (TK5103.2.W65)
Wireless Personal Communications (Kluwer) (TK6570.M6W575)

Relevant Annual Conference Proceedings

IEEE International Conference on Communications (ICC) (TK5101.A1I53)
IEEE Globecom (TK5101.A1I13)
IEEE Vehicular Technology Conference (VTC) (TK6570.M6I13)
International Conference on Universal Personal Communications (ICUPC)
IEEE Wireless Communications and Networking Conference

International Symposium on Personal, Indoor and Mobile Communications (PIMRC) (TK5103.2.I33)

Systems

F. Adachi, M. Sawahashi and H. Suda, "Wideband DS-CDMA for Next-Generation Mobile Communications Systems", *IEEE Comm. Magazine*, Sept. 1998, pp. 56-69.
S. Chennakeshu, A. Hassan, J. Anderson and B. Gudmundson, “Capacity Analysis of a TDMA-Based Slow-Frequency-Hopped Cellular System”, *IEEE Transactions on Vehicular Technology*, Vol. 45, No. 3 Aug. 1996 pp. 531-542.
D.C. Cox, "Cochannel Interference Considerations in Frequency Reuse Small-Coverage-Area Systems", *IEEE Trans. Communications*, Vol. COM-30, Jan. 1982, pp. 135-142.
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D. Cox, "Wireless Network Access for Personal Communications",*IEEE Communications Magazine*, VOL. 30 No. 12, December 1992, pp. 96-115.
D,C. Cox, “Wireless Personal Communications: What is it?”, *IEEE Personal Communications*, Vol. 2, No. 2, April 1995, pp. 20-35.
D.D. Falconer, F. Adachi and B. Gudmundson, “Time Division Multiple Access Methods for Wireless Personal Communications”, *IEEE Communications Magazine*, Vol. 33, No. 1, Jan. 1995.
K.S. Gilhousen, I.M. Jacobs, R. Padovani, A.J. Viterbi, L.A. Weaver and C.E. Wheatley, "On the Capacity of a Cellular CDMA System" , *IEEE Trans. Vehic. Technol.*, Vol. 40, May 1991, pp. 303-312.
B. Gudmundson, J. Sköld and J. Ugland, "A Comparison of CDMA and TDMA Systems", *Proc. Vehicular Technol. Conf.*, May 1992, pp. 732-735.
V.H. MacDonald, "The Cellular Concept", *Bell System Tech. J.*, Vol. 58, Jan. 1979, pp. 15-41.
J.E. Padgett, C.G. Gunther and T. Hattori, “Overview of Wireless Personal Communications”, *IEEE Communications Magazine*, Vol. 33, No. 1, Jan. 1995, pp. 28-41.
R.L. Pickholtz, L.B. Milstein and D.L. Schilling, "Spread Spectrum for Mobile Communications", *IEEE Trans. Vehic. Technol*., Vol. 40, May 1991, pp. 313-322
K. Raith and J. Uddenfeldt, “Capacity of Digital Cellular TDMA Systems”, *IEEE Trans. Vehic. Technol*., Vol. 40, No. 2, May 1991, Pp. 323-332
A. Salmasi and K.S. Gilhousen, "On the System Design Aspects of CDMA Applied to Digital Cellular and Personal Communications Networks", *Proc. Vehicular Technol. Conf.* 1991, pp. 57-62.

Channel Characteristics - Propagation and Interference

D. S. Baum, R. Nabar, S. Panchanathan, K. V. S. Hari, V. Erceg, A. Paulraj, `Measurements and Characterization of Broadband MIMO Fixed Wireless Channels at 2.5 GHz,' Proc of IEEE Intl. Conf. on Personal Wireless Commn (ICPWC 2000), Hyderabad, India, Dec 2000.
R.J.C. Bultitude, S.A. Mahmoud and W.A. Sullivan, "A Comparison of Indoor Radio Propagation Characteristics at 910 MHZ and 1.75 GHz", *IEEE J. Sel. Areas in Communication*, Vol. 7, Jan.. 1989, pp. 20-30.
R.J.C. Bultitude and G.K. Bedal, "Propagation Characteristics on Microcellular Urban Mobile Radio Channels at 910 MHz", *IEEE J. Sel. Areas in Communication*, Vol. 7, Jan.. 1989, pp. 31-39.
D.C. Cox, "Universal Digital Portable Radio Communications", *Proc. IEEE*, Vol. 75, April 1987, pp. 436-477.
J.K. Cavers, *Mobile Channel Characteristics*, (with interactive CD), Kluwer Academic Publishers, 2000 (TK6570.M6C38 2000)
D.C. Cox, "Co-Channel Interference Considerations in Frequency Reuse Small Coverage Area Radio Systems, *IEEE Trans. Commun*., Vol. COM-30, Jan. 1982, pp. 135-142.
J.P. Decruyenaere and D.D. Falconer, “A Shadowing Model for Prediction of Coverage in Fixed Terrestrial Wireless Systems”, Proc. IEEE Vehic. Technol. Conf., Amsterdam, Sept. 1999.
D.M.J. Devasirvatham, "A Comparison of Time Delay Spread and Signal Level Measurements Within Two Dissimilar Office Buildings", *IEEE Trans. Antennas and Propagation*, Vol. AP-35, Mar. 1987, pp. 319-324.

V. Erceg, D.G. Michelson, S.S. Ghassemzadeh, L.J. Greenstein, A.J. Rustako, P.B. Guerlain, M.K. Dennison , R.S. Roman, D.J. Barnickel, S.C. Wang and R.R. Miller, “A Model for the Multipath Delay Profile of Fixed Wireless Channels”, IEEE J. Sel. Areas in Communications, Vol. 17, No. 3, March, 1999, pp. 399-410.
R.B. Ertel, P. Cardieri, K.W. Sowerby, T.S. Rappaport and J.H. Reed, “Overview of Spatial Channel Models for Antenna Array Communication Systems”, IEEE Personal Communications, Vol. 5, No. 1, Feb. 1998, pp. 10-22.
B.H. Fleury and P.E. Leuthold, "Radiowave Propagation in Mobile Communications: An Overview of European Research", IEEE Communications Magazine, Vol. 34, No. 2, Feb., 1996, pp. 70-81.
H. Hashemi, “The Indoor Radio Propagation Channel”, *Proc. IEEE*, Vol. 81, No. 7, July 1993, pp. 943-968.
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N. Naz and D. Falconer, “Temporal Variations Characterization for Fixed Wireless at 29.5 GHz”, Proc. VTC 2000, Tokyo, May, 2000.
K.I. Pedersen, P.E. Mogensen and B.H. Fleury, “A Stochastic Model of the Temporal and Azimuthal Dispersion Seen at the Base Station in Otdoor Propagation Environments”, IEEE Trans. Vehic. Technol., Vol. 49, No. 2, March 2000, p. 437.
A.A.M. Saleh and R.A. Valenzuela, "A Statistical Model for Indoor Multipath Propagation", *IEEE J. Sel. Areas in Communication*, Vol. SAC-5, Feb. 1987, pp. 128-137.
S.R. Todd, M. El-Tanany and S.A. Mahmoud, "Space and Frequency Diversity Measurements of the 1.7 GHz Indoor Radio Channel Using a Four-Branch Receiver", *IEEE Trans. Vehicular Technol.,* Vol. 41, Aug. 1992, pp. 312-320.
B.D. Woerner, J.H. Reed and T.S. Rappaport, “Simulation Issues for Future Wireless Modems”, *IEEE Communications Magazine,* Vol. 32, No. 7, July 1994, pp. 42-53.

Modulated System Performance in Interference, Fading and Multipath

A. Abu-Dayya and N. C. Beaulieu,"Outage Probabilities in the presence of Correlated Lognormal Interfers", *IEEE Transactions on Vehicular Technology*, Vol. 43, No. 1 Feb. 1994 pp. 164-173.
N.C. Beaulieu, A.A. Abu-Dayya, and P.J. McLane, "Estimating the Distribution of a Sum of Independent Lognormal random variables", IEEE Trans. Commun., Vol. 43, No. 12, Dec. 1995, pp. 2869-2873.
J.C-I Chuang, "The Effects of Time Delay Spread on Portable Radio Communications Channels with Digital Modulation", *IEEE J. Sel. Areas in Communication*, Vol. SAC-5, June 1987, pp. 879-889.
E.H. Dinan and B. Jabbari, "Spreading Codes for Direct Sequence CDMA and Wideband Cellular Networks", *IEEE Comm. Mag*., Vol. 36, No. 9, Sept. 1998, pp. 48-54.
K. Feher (ed.), *Advanced Digital Communications - Systems and Signal Processing Techniques*, Prentice-Hall, New York, 1987 (TK5103.7.F428), (Ch. 10 on "Mobile Radio Communications").
J-P M.G. Linnartz, “Exact Analysis of the Outage Probability in Multiple User Mobile Radio”, *IEEE Trans. Communications,* Vol. 40, Jan. 1992, pp. 20-23.
R. Prasad and A. Kegel, " Effects of Rician Faded and Log-Normal Shadowed Signals on Spectrum Efficiency in Microcellular Radio", *IEEE Transactions on Vehicular Technology*, Vol. 42, No. 3 Aug. 1993 pp. 274-281.
J.G. Proakis, *Digital Communications*, McGraw-Hill, New York, 1983. (TK5103.7.P76) (Ch. 7).
A. Safak, "Statistical Analysis of the Power Sum of Multiple Correlated Log-Normal Components", *IEEE Transactions on Vehicular Technology*, Vol. 42, No. 1 Feb. 1993 pp. 62-67.
S.C. Schwartz and Y-S Yeh, "On the Distribution Function and Moments of Power Sums with Log-Normal Components", *Bell System Tech. J.*, Vol. 61, Sept. 1982, pp. 1441-1462..
Y-S Yeh and S.C. Schwartz, "Outage Probability in Mobile Telephony Due to Multiple Log-Normal Interferers", *IEEE Trans. Communications*, Vol. COM-32, Apr. 1984, pp. 380-388.

Diversity, Coding and Equalization

M. Abdulrahman, A. Sheikh and D. Falconer, "Decision Feedback Equalization for CDMA in Indoor Wireless Communications", *IEEE J. Sel. Areas in Commun.*, Vol. 12, No. 4, May 1994, pp. 698-706.

S.M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communication", IEEE J. Sel. Areas in Commun., Oct. 1998, pp. 1451-1458.

N. Al-Dhahir and A. H. Sayed, "The Finite-Length Multi-Input Multi-output MMSE-DFE", To appear in IEEE Trans. Sig. Proc., 2000

S. Ariyavisitakul and L.J. Greenstein, "Reduced-Complexity Equalization Techniques for Broadband Wireless Channels", IEEE JSAC, Vol. 15, No. 1, Jan. 1997, pp. 5-15.

S. Ariyavisitakul, J.H. Winters and I. Lee, "Optimum Space-Time Processors with Dispersive Interference: UnifiedAnalysis and Required Filter Span", IEEE Trans. Commun., Vol. 7, No. 7, July 1999, pp. 1073-1083.

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J.B. Cain and D.N. McGregor, "A Recommended Error Control Architecture for ATM Networks with Wireless Links", *IEEE J. Sel. Areas in* Communications, Vol. 15, No. 1, Jan. 1997, pp. 16-27.

G. Caire, G. Taricco and E. Biglieri, "Bit-Interleaved Coded Modulation", *IEEE Trans. Information Theory*, May 1998.

S. Catreux, P.F. Driessen, and L.J. Greenstein, "Simulation Results for an Interference-Limited Multiple-Input Multiple-Output Cellular System", IEEE Comm. Letters, Vol. 4, No. 11, Nov. 2000, pp. 334-336.

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R.D'Avella, L. Moreno,and M. Sant'Agostino, "An Adaptive MLSE Receiver for TDMA Digital Mobile Radio", *IEEE J. Sel. Areas in Communication*, Vol. 7, Jan. 1989, pp. 122-129.

M.V. Clark, "Adaptive Frequency-Domain Equalization and Diversity Combining for Broadband Wireless Communications", IEEE JSAC, Vol. 16, No. 8, Oct. 1998, pp. 1385-1395.

C.L.B. Despins, D.D. Falconer and S.A. Mahmoud, "Compound Strategies of Coding, Equalization and Space Diversity for Wide-Band TDMA Indoor Wireless Channels", *IEEE Trans. Vehicular Technol.*, Vol. 41, Nov. 1992, pp. 369-379.

E. Eleftheriou and D.D. Falconer, "Tracking Properties and Steady State Performance of RLS Adaptive Filter Algorithms", *IEEE Transactions on Acoustics, Speech and Signal Processing*, October 1986, pp.1097-1110.

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D.Falconer, S. Ariyavisitakul, A, Benyamin-Seeyar and B. Eidson, "Frequency Domain Equalization for Single-Carrier Broadband Wireless Systems", IEEE Communications Magazine, Vol. 40, No. 4, April, 2002, pp. 58-66.

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B. Glance and L.J. Greenstein, "Frequency-Selective Fading Effects in Digital Mobile Radio with Diversity Combining", *IEEE Trans. Commun.,* Vol. Com-31, Sept. 1983, pp. 1085-1094.
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H. Sari, G. Karam and I. Jeanclaude, “Transmission Techniques for Digital Terrestrial TV Broadcasting”, IEEE Comm. Mag., Vol. 33, No. 2, Feb. 1995, pp. 100-109.
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SAMPLE UNDERGRADUATE DIGITAL COMMUNICATIONS EXAM QUESTIONS (to test your level of understanding of prerequisite digital communications theory)

Question 1
Give brief answers to the following:

(a) Define and give an example of a matched filter. Why is it used?

(b) A company claims to have developed a modem that will reliably transmit 100 Kb/s over a channel with a bandwidth of 10 KHz. What assumption must be made about one or more channel parameters for this claim to be true?

(c) Give an example of a simple rate 1/2 convolutional code with 4 trellis states, by drawing a block diagram of the encoder, and by drawing a section of the trellis diagram.

Question 2
(a) Prove that the following set of $2N$ signals $\{c_1(t), s_1(t), \ldots c_N(t), s_N(t)\}$, each lasting T seconds, is an orthonormal set; i.e. they are all orthogonal to one another, and their energies are all unity:

$$\text{For } i = 1,2,....N:$$

$$c_i(t) = \sqrt{\frac{2}{T}}\cos 2\pi f_i t \qquad 0 \le t \le T$$
$$= 0 \qquad \text{otherwise}$$
$$s_i(t) = \sqrt{\frac{2}{T}}\sin 2\pi f_i t \qquad 0 \le t \le T$$
$$= 0 \qquad \text{otherwise}$$
$$\text{where } f_i = \frac{i+10}{T}.$$

(b) A digital modulated data signal is formed using this set as a basis, as follows:

$$x(t) = \sum_{i=1}^{N}\left[a_i c_i(t) + b_i s_i(t)\right] \qquad 0 \le t \le T$$

where a_i and b_i are independent 4-level data symbols; each is equally likely to be any one of the 4 equally-spaced amplitude levels: $3\sqrt{\frac{E}{10}}, \sqrt{\frac{E}{10}}, -\sqrt{\frac{E}{10}}, or -3\sqrt{\frac{E}{10}}$.

Determine the average energy per bit, E_b in terms of the parameter E.

(c) Determine the bit error probability, assuming $E=10^{-3}$, and that the signal is corrupted by additive white gaussian noise with single sided power spectral density $N_0=10^{-15}$.

(d) If this signal is used to transmit data symbols every T seconds, determine the bit rate, if $1/T = 100$ Hz and $N=32$.

(e) What is the approximate bandwidth of this signal?

Question 3

In a PCM system, an audio signal is to be sampled with a sampling rate of 8 KHz; the samples are quantized with a uniform quantizer, and transmitted as *b* - bit code words, so that the total transmitted bit rate is 8*b* Kb/s. This bit stream is transmitted over a channel using two-level bipolar (i.e. ±1) NRZ pulses. The received bit stream is then detected and converted back to an analog signal.

(a) What is the maximum bandwidth of the original audio signal for no aliasing to occur?

(b) Specify *b* if the peak signal to quantization noise ratio is to be at least 30 dB.

(c) Draw a block diagram of the PCM system, including sampling, quantizing, coding, transmission and reception.

(d) Write a mathematical expression for the power spectrum of the modulated transmitted bit stream, and sketch it.

Question 4

(a) Find the minimum value of E_b/N_0, in dB, to achieve a bit error probability of 10^{-5} for each of the following modulation schemes:

(i) coherent BPSK.
(ii) differentially coherent binary DPSK
(iii) noncoherent binary FSK
(iv) coherent 8-phase PSK.

(b) A digital communications system is to have the following specifications:

bit rate=100 Kb/s
bandwidth=50 KHz
transmitted power =1 watt (i.e. 0 dBw)
received signal power= -85 dBw (i.e. 85 dB below transmitted power)
noise power spectral density $N_0=10^{-15}$ watts/Hz.

Will one of the modulation schemes in part (a) satisfy these requirements? Which one if any? Show the analysis that supports your answer.

Question 5

(a) Calculate the bit error probability for a (24,12) block code that corrects three errors per block, assuming that coherent BPSK modulation is used, and that the received E_b/N_0 is 10 dB.

(b) Calculate the coding gain (the increase in required E_b/N_0 for an equivalent uncoded system which has the same bit error probability as that calculated in (a)).

Question 6

Consider a (7,4) code whose generator matrix is

$$G = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

(a) Find *H*, the parity check matrix of the code.

(b) Compute the syndrome for the received vector (1 1 0 1 1 0 1). Is this a valid code word?