Mobile Wireless Networking
The University of Kansas EECS 882
Fall 2009

James P.G. Sterbenz

Department of Electrical Engineering & Computer Science
Information Technology & Telecommunications Research Center
The University of Kansas

jpng@eecs.ku.edu

http://www.ittc.ku.edu/~jpng/courses/mwn

AE.1 Adminitrivia

AE.1.1 Schedule
AE.1.2 Prerequisites and description
AE.1.3 Instructor and GTA information
AE.1.4 Grading and student expectations

AE.2 Ethics and academic integrity
AE.3 Course outline
AE.4 Preliminaries
Mobile Wireless Networking

AE.1 Administrivia

AE.1.1 Schedule

AE.1.2 Prerequisites and description

AE.1.2 Instructor and GTA information

AE.1.3 Grading and student expectations

AE.2 Ethics and academic integrity

AE.3 Course outline

AE.4 Preliminaries

---

Course Information

High-Level Schedule

- Lecture: 151 Regnier – Edwards Campus
  - Thu. 18:10 – 21:00
- Laboratory: 368 Regnier – Edwards Campus
  - as needed
  - Wed. 19:10 – 21:00
  - no lab session before the first lecture
- 20 Aug. – 10 Dec.
  - three sectional exams plus final (17 Dec.)
  - 15. Oct. no class: fall break
  - 25 Nov. no lab: Thanksgiving break
  - 26 Nov. no class: Thanksgiving break
Course Information
Cancellation and Rescheduling

• Cancellation due to weather
  – official closings unlikely
    • follow media announcements
  – if I can’t make it from Lawrence
    • email to you by 15:00
    • phone message with Edwards reception +1 913 897 8400

• Rescheduling due to my travel
  – I try very hard to avoid rescheduling class
  – project meetings & conferences sometimes interfere
  – this is the cost of an instructor who is active in research
  – rescheduled lectures will be held during Lab period

Mobile Wireless Networking
AE.1.2 Prerequisites and Description

AE.1 Administrivia
AE.1.1 Schedule
AE.1.2 Prerequisites and description
AE.1.2 Instructor and GTA information
AE.1.3 Grading and student expectations

AE.2 Ethics and academic integrity
AE.3 Course outline
AE.4 Preliminaries
Mobile Wireless Networking
EECS 882 Prerequisites

- You must have networking background at least one of:
  - KU EECS 780 Communication Networks
    - [www.ittc.ku.edu/~jpgs/courses/nets](http://www.ittc.ku.edu/~jpgs/courses/nets)
  - KU EECS 563 | 663 Introduction to Communication Networks
  - introductory networking class elsewhere
    - Kurose, Leon-Garcia, Stallings, Tanenbaum, Peterson, etc.
  - significant experience
    - you must convince me you are comfortable with 780 material
    - talk to me after class if you intend to invoke this option

Networking Courses
MSIT Edwards Courses

- **EECS 780:** Communication Networks
  - spring at Edwards
- **EECS 881:** High-Speed Networking
  - fall in even numbered years at Edwards
- **EECS 882:** Mobile and Wireless Networking
  - fall in odd numbered years at Edwards
- **EECS 712:** Network Security
Networking Courses
Selected Lawrence Networking Courses

- EECS 563: Introduction to Communication Networks  
  *fall in Lawrence*
- EECS 766: Resource Sharing for Broadband Access Networks
- EECS 745: Implementation of Networks
- EECS 864: Multiwavelength Optical Networks
- EECS 888: Internet Routing Architectures
- EECS 983: Resilient and Survivable Networking  
  *spring in even numbered years Lawrence*

Communication Courses
Selected Lawrence Communications Courses

- EECS 861: Random Signals and Noise
- EECS 862: Digital Communication Systems
- EECS 863: Analysis of Comm. Networks
- EECS 865: Wireless Communication Systems
- EECS 869: Error Control Coding
- EECS 964: Simulation of Comm. Systems
- EECS 965: Detection and Estimation Theory
- EECS 967: Mathematical Optimization with Communications Applications
- EECS 969: Information Theory
Mobile Wireless Networking
EECS 882 Course Description

Comprehensive coverage of the disciplines of mobile and wireless networking, with emphasis on architecture and protocols. Topics include cellular telephony, MAC algorithms, wireless PANs, LANs, MANs, and WANs; wireless and mobile Internet; mobile ad hoc networking; mobility management, sensor networks; satellite networks; and ubiquitous computing.

Prerequisites: EECS 563 or EECS 780

Summary of EECS 882 Course Description

• Introductory intensive graduate-level course
  – concepts & examples of mobile wireless systems & protocols
  – mostly non-mathematical
  – simulation project oriented
• Emphasis on
  – Internet
  – mobile cellular PSTN (public switched telephone network)
  – research and emerging approaches
• Bottom-up approach
  – based primarily on journal and conference paper readings
Mobile Wireless Networking

AE.1.3 Instructor and GTA Information

AE.1 Administrivia
  AE.1.1 Schedule
  AE.1.2 Prerequisites and description
  AE.1.3 Instructor and GTA information
  AE.1.4 Grading and student expectations

AE.2 Ethics and academic integrity

AE.3 Course outline

AE.4 Preliminaries

Instructor Information

Background

• Dr. James P.G. Sterbenz
  – current positions
    • Associate Professor, KU Lawrence, US
    • Visiting Professor of Computing, Lancaster University, UK
  – past research and management positions
    • UMass, BBN Technologies, GTE Laboratories, IBM Research
  – academic background
    • D.Sc, Washington University in St. Louis, 1991
  – research interests
    • survivable and resilient networking
    • autonomic, programmable, and active networks
    • mobile wireless networking
    • high-speed networking and system architecture
Instructor Information

Contact Modes

- **Web**: check the class Web pages first
  - important announcements at top of 2009 page
  - detailed schedule
- **Email**: generally the best means of communication
  - many issues and questions can be quickly resolved
  - use to arrange other appointments
- **Interactive**
  - skype chat
  - phone
- **Office hours**
  - face-to-face contact

Office Hours

- **Thu. 16:00 – 18:00**
  - unless advised otherwise due to meetings or travel
- **125U Regents Center**
- **Or by appointment**
  - email, chat, or call to arrange in advance
  - chat or call before dropping in unless already on campus
  - MTWF: typically in Lawrence if not travelling
    - 154 Nichols research office (frequently)
    - 3036 Eaton: teaching office (occasionally)
GTA Information
Background and Office Hours

- Egemen K. Çetinkaya
  - formerly engineer at Sprint
  - PhD student, University of Kansas EECS
- Office hours: Thu. 17:00 – 18:00
  - Regnier 368 (lab room) or Regnier 125U (instructor office)
  - unless advised otherwise due to meetings or travel
- Contact information
  - email
    - ekc@ittc.ku.edu
  - phone
    - 235 Nichols office: +1 785 864 7122
    - mobile: +1 785 550 4654

Instructor and GTA Information
Contact: Email Address

- Contact information
  - email: jpgs@eecs.ku.edu or ekc@ittc.ku.edu only
    - begin subject with exact string "EECS882 - "
    - blank space between "882" and hyphen
    - email to other addresses will likely be misfiltered and unread
  - I generally check email daily
    - email is unreliable; retry if no reply within 48 hours
    - if quick reply is needed use skype chat or phone
Instructor and GTA Information
Contact: Email Subjects

- Email with *meaningful* subject lines
  - bad
    Subject: Hi!
    Subject: regarding class
  - good
    Subject: EECS882 - need help understanding CSMA/CA

Electronic Mail
Netiquette: Sender Identification Name

- Configure email client with your *name* in ISO-Latin
  - e.g. Ima K.U. Student <ima.student@eecs.ku.edu>
- CJK (Chinese, Japanese, Korean) encodings
  - appear as gibberish to older and non-GUI email clients
  - use only *after* ISO-Latin name
  - e.g. James P.G. Sterbenz 司徒傑莫 <jpgs@eecs.ku.edu>
Electronic Mail

Netiquette: Sender Identification Signature

- Define a meaningful signature (*sig*)
  - name, affiliation, telephone number, URL if you have one
  - max. of 4 lines (not including separator dashes)
  - max of 72 characters/line, e.g.

```
IMA K.U. STUDENT
ELECTRICAL ENGINEERING & COMPUTER SCIENCE, THE UNIVERSITY OF KANSAS
IMA.STUDENT@ECE.KU.EDU WWW.ITTC.KU.EDU/~IKUS
+1 785 864 4776
```

Electronic Mail

Netiquette: Formatting

- Email was originally text-only with no formatting
  - many people still like it that way!
    - some people still use text only clients
    - increasing use of PDAs
  - not all clients are MS Outlook
- Unless pre negotiated with the recipient:
  - use plain text with no formatting
    - some email clients have formatting on by default
    - some misconfigured (MS-Exchange) servers format anyway
  - do not send email as HTML
  - do not embed images
Electronic Mail
Netiquette: Content and Attachments

• Content issues
  – use meaningful subject lines
  – spellcheck (most modern clients do this)
  – think before you send
• Simple emails should not be sent as attachments
  – e.g. MS-Word document containing “where are you now?”
• Do not send very large attachments unless
  – receiver is able to handle them (broadband access)
  – small enough to pass relay & server limits (typ. <10 MB)

Electronic Mail
Netiquette: Professionalism

• Email is like conversation, writing, and attire
  – adapt style to context
  – academic and professional more formal than with friends
• Style
  – punctuate and spell check
  – judicious jargon and emoticons only to someone you know
  – plain text, no embedded images
• Proofread and think before you send!
Electronic Mail
Netiquette: Professionalism

- Avoid free email accounts
  - e.g. hotmail, yahoo
- Gives you a very unprofessional appearance
  - frequently auto-append advertisements
- Frequently spam-blocked
- Use academic or corporate email addresses
  - for professional correspondence

Electronic Mail
Netiquette: Professionalism Examples

To: James Sterbenz <jpgs@eecs.ku.edu>
From: Ima <cool_dude@stupidmail.com>
Subject: need a job!!!

i'm new at KU and really like it :-)
i'm interested in everything and
am bombing this email to all KU
professors. I've stopped by your office
in Eaton but you're never there!!! :P
do you even have office hours
dude? LOL! Just tell me when I can
dropby too learn what you do
KU THERE????
cu later,
ima

What's wrong?

Get your free email at Stupidmail.com!

Eat at Joe's: 1234 Mass, Lawrence, KS
Electronic Mail
Netiquette: Professionalism Examples

To: James Sterbenz <jpgs@eecs.ku.edu>
From: Ima <cool_dude@stupidmail.com>
Subject: need a job!!!

I’m new at KU and really like it :) I’m interested in everything and am bombing this email to all KU professors. I’ve stopped by your office in Eaton but you’re never there!!! :-( do you even have office hours dude? LOL! Just tell me when I can drop by too learn what you do at KU there????

cu later,
ima

Get your free email at Stupidmail.com!

Eat at Joe’s: 1234 Mass, Lawrence, KS

To: James Sterbenz <jpgs@eecs.ku.edu>
From: Ima Student <student@eecs.ku.edu>
Subject: Interest in ResiliNets group

Dear Professor Sterbenz,

I am a new M.S. student in the EECS department with interests in networking. I have looked at your Web pages and read the SUMOWIN paper. I am very interested in this research and will come to the next ResiliNets group meeting on Friday. I would like to discuss the possibility of you becoming my advisor and want to understand if there are any funding opportunities.

Sincerely,
Ima Student

---------------------------------------
Ima Student       EECS, Univ. of Kansas
student@eecs.ku.edu    +1 785 555 1212

Student Information
Introductions

- Brief introductions around the room
  – say who you are and why you are here
- Photos to help me learn your names
  we’ll do this next week
Student Information

Contact and Background

- Roster information to be filled in pass-around sheet
  - full name, nickname
  - employer if not full-time student
  - email for class distribution list
    - preferred and mandatory ku.edu address
  - phone numbers will only be used for urgent matters
    - day and evening
  - degree (BS, MS, PhD)
    - major (IT, CS, CoE, EE)
    - focus area if MSIT (Internet Engr., Info. Sec., Software Engr.)
    - option if MS (course, project, thesis)
    - advisor name ("none" if you don't have one yet)
  - prerequisite course (number if KU, textbook otherwise)

Course Information

Correspondence to Class

- Course information and notes
  - http://www.ittc.ku.edu/~jpgs/courses/mwnets
    - notes for each lecture will be posted in PDF
    - link typically emailed the afternoon before class
    - you may not share the notes with anyone
    - navigate to subpage for Fall 2007 specific information
      - schedule and deadlines
  - http://www.ittc.ku.edu/~jpgs/courses
    - generic information
  - check regularly for updates
    - readings and assignments in schedule table in sub-page
    - "last updated" on bottom of page
Course Information

Correspondence to Class

- Class email list
  - all students are required by EECS to use ku.edu email
    - I’m willing to use other email addresses...
    - ...but only if they are relatively reliable
      - many free email accounts are not!
      - if there are problems I’ll change your entry to a .ku.edu address
  - check email regularly
  - check email every afternoon before class
- Telephone
  - I’ll only phone you if urgent

Instructor Information

Contact: Phone and Chat

- Contact information
  - phone
    - Edwards office: +1 913 897 8538
    - Lawrence Nichols office: +1 785 864 7890
    - Lawrence Eaton office: +1 785 864 8846
    - only if urgent (consider Δtime) +1 508 944 3067
    - don’t call me at home unless emergency
  - skype: jpgsterbenz
    - ok to use chat judiciously when email not appropriate
      - send meaningful introduction message!
    - don’t use voice unless prearranged by chat
      - I frequently am not in a position to use headseat/microphone
Mobile Wireless Networking

AE.1.4 Grading and Student Expectations

AE.1 Administrivia
  AE.1.1 Schedule
  AE.1.2 Prerequisites and description
  AE.1.3 Instructor and GTA information
  AE.1.4 Grading and student expectations

AE.2 Ethics and academic integrity

AE.3 Course outline

AE.4 Preliminaries

Course Information

Reading

- Required readings are *mandatory*
  - you won't be able to use them on exams
  - survey papers are the primary reference for this course
- Reading *must* be done *before* corresponding class
  - you are doomed if you get behind on the reading
  - you are responsible for *all* required reading
    - may be on exams even if not covered in lecture!
    - contributes to your class participation grade
## Course Information

### Textbooks

- **Optional textbooks**
  - Murthy & Manoj, *Ad Hoc Wireless Networks: Arch. and Prot.*
  - Walke, Mangold, & Berleman, *IEEE 802 Wireless Systems*
  - these may help you understand the course material

- **Supplementary textbooks and monographs**
  - provide alternative, in-depth, or background coverage
  - most will be on reserve in Edwards library
  - hopefully also on reserve in Spahr library later

## Course Information

### Grades

- Grades: modified curve grouped by mode
  - based only on merit; **not** on:
    - employer reimbursement or lack thereof
    - immigration status or potential visa invalidation
    - probationary status at KU
  - qualitative meaning
    - **A**: exceptional exam results and outstanding project
    - **B**: mastery of material, labs, and solid project
      - *this is the basic expectation for a graduate student*
    - **C**: slacking but know basic material and marginal project
    - **D**: very poor performance on exams or project
    - **F**: nonperformance on exams or project
      - *academic misconduct regardless of other grades*
Course Information

Grade Contribution

- Relative grade contribution
  - 30% section exams
    - two at 10% each
    - third at 10% will be first half of final exam period
  - 10% comprehensive portion of final exam
  - 25% project report
    - significant extra credit for publishable paper
  - 15% homework and lab exercises
  - 20%: paper presentation and class participation
    - includes beginning of class pop quizzes on readings
  - mandatory academic integrity quiz in second class
    - must be made up if you miss this class

Exam Schedule and Weight

- Section exams: 30%
  - tentative schedule subject to change
    - academic integrity quiz on 27 Aug. (required to pass course)
    - exam 1 on 02 Oct. (I will be out of the country)
    - exam 2 on 19 Nov.
    - exam 3 on 17 Dec. (portion of final exam period)

- Final exam: 10%
  - comprehensive covering entire course
  - synthesis of multiple sections
  - portion of final exam period
Course Information

Exam Characteristics

- Closed book, no electronic devices
  - notify me in advance if you know you must miss
  - you will probably have to take the exam in advance
- Exams test understanding of concepts
  - not memorisation of facts that could be looked up
  - not focused on the ability to solve problems
  - this will be new to some of you!
- More exam information on
  http://www.ittc.ku.edu/~jpgs/courses/exams.html

Course Information

Exam Questions

- Exams consist of two types of questions
  - sufficient space given to properly and fully answer
- Short answer example (several per page):
  - example question:
    Compare the functionality of the link and transport layers.
- Long answer example (one per page):
  - example exam question:
    Explain the difference between proactive and reactive MANET routing protocols. Explain the relative advantages of each one to the mobility of nodes. Name an example of each protocol.
Course Information

Exam Answers

- Answers must legibly fit in space provided
  - sufficient space given to properly and fully answer
  - be brief; points will be *deducted* for irrelevant information
    - and you will have a hard time finishing the exam
  - writing on back of page & deep into margins will be ignored

- Example question:
  - example correct answer (1 minute to write):
    Both the link and transport layer transfer data; the link layer hop-by-hop and the transport layer end-to-end.
  - example poor answer (10 minutes to write):
    The link layer is layer 2 in the OSI model, shown in the figure. Examples of link layer protocols include Ethernet, 802.11, SONET, and HDLC. 802.11 was developed as a replacement for Ethernet, and thus has similar frame structure, shown in Figure 2. Note that 802.11 has more MAC address fields than Ethernet. The reason for the additional address fields has to do with the operation of the 802.11 MAC. Actually I really don't know the answer to this question, but I did memorise a bunch of stuff on some of these protocols, so I hope that if I write enough that I will get some credit for this question and that if I bomb you with information you will find some reason to give me a good grade anyway. I heard that the new phone...
Course Information

Term Project

• 25% of grade based on term project and report
• Purpose and scope:
  – research area of mobile wireless networking beyond lectures
  – technical in nature
    • may lead to publication
    • may lead to MS thesis or PhD dissertation
  – will likely use an ns-3 simulation
    • suggested list of group projects (2–3 people)
    • alternative proposals will be entertained
  – gain technical writing and presentation experience
• More information on term projects later in class

Course Information

Project Schedule

• Tentative schedule
  – presentations 09, 10 Dec.
  – report due 07 Dec.
Course Information
Sources of Literature: Library

- The Library
  - big building with books and paper journals: use it!
- Physically browsing is a wonderful way to brainstorm
  - Spahr Engineering Lib. TK numbers most relevant
  - Anschutz (science) Lib. QA and QC numbers most relevant
  - Edwards Library very small collection
- Online resources at www.ku.edu/libraries
  - ACM, IEEE, LNCS and other journals and proceedings
    - learn how to access these from home now!
  - access to archived books and journals
  - interlibrary loan

http://www.ittc.ku.edu/~jpgs/courses/source-cite.html

Course Information
Sources of Literature: Web

- The Web
  - source for journal papers
    - ACM Digital Library, IEEE (subscription through library)
    - individual and project Web pages
  - source for information on research projects
  - source for other information
    - wikipedia: increadily useful as launching point to other work
      - rarely appropriate to cite wikipedia pages
    - non-refereed reports and information
  - compare to a street corner bulletin board: use with care
  - use Web citations very judiciously
    - reports with many URL refs will not get an acceptable grade!
Course Information

Class Participation

• 20% of grade is based on class participation
  – presentation of one of the required paper readings
  – beginning-of-class written summary or pop quiz
  – insightful questions to paper presentation and lectures
  – brownie points
    • find bug in lecture note, book, good suggestion
    • email reminder with subject: "EECS882 - Brownie Point"

• Interactive class is better for all of us
  – questions, comments, arguments
  – blurt it out; don’t wait
  • don’t need to raise hand

• Reminder: reading **before** class essential

Course Information

Etiquette

• Try to be on time
  – I understand that we are all commuting, but...
  – consistent late arrivals are disruptive

• No audible mobile phone or pagers
  – if it doesn’t vibrate, turn it off!

• University does not tolerate class disruption
  – protests, etc.
AE.1 Administrivia
AE.2 Ethics and academic integrity
AE.3 Course outline
AE.4 Preliminaries

Academic Integrity and Plagiarism
Reading the Riot Act

- Apologies to those that already know this
  - ... especially who’ve heard it from me before in 780 or 881
- Opportunity to learn for those who:
  - are inexperienced in writing
  - come from an environment or culture of tolerance
- Warning of the consequences
  - ignorance will not be an excuse
  - ask me if you have any question about this
- Applies to
  - copying homework and lab exercises
  - cheating on exams
  - plagiarism on term paper and presentation
Academic Integrity and Plagiarism
Referencing and Citations

- All sources **must** be properly referenced and cited
  - authors, “paper name”, journal, date, publisher, page–range
  - also URL if from obscure source (e.g. university tech reports)
  - see course Web page or for examples

- Cite whenever
  - work is related or ideas are used
  - text is quoted or paraphrased
  - diagrams are reproduced or incorporated (even if redrawn)

Academic Integrity and Plagiarism
Proper Quoting and Paraphrasing

- Quoting text or paraphrasing
  - “quotation marks” for sentence or less
  - blockquote for multiple sentences
- Beware of read-then-write in two windows
  - **never ever** cut-and-paste into your paper
  - take intermediate notes from which you write
Academic Integrity and Plagiarism

Excessive Quoting and Paraphrasing

- Quoting is *rarely* needed
  - example: quoting or paraphrasing definition or principle
- Sequence of quotes *doesn't* show understanding
  - not a shortcut to English writing skills
    - better to be in your *own* imperfect English
  - papers with excessive quotes will not receive decent grade
    - even if properly quoted

Detection and Sanctions

- Plagiarism is remarkably easy for me to detect
  - inconsistent writing styles and language use
  - technical depth beyond the supposed author
  - inconsistent terminology
- Tools: Web makes both plagiarism & detection easier
  - google on suspicious phrases
  - turnitin automates and correlates searches; goes beyond Web
- Plagiarism will result in **F** for *course*
  - and possible further sanctions
  - it is highly unlikely that you will get away with it!
    - but students still try every semester; *you have been warned*
Academic Integrity and Plagiarism

Homework Ethics

- Homework exercises are an \textit{individual} activity
  - you may discuss the problem and solution ideas from others
  - but do walk away with anything written down
  - group homework solving is unacceptable

- Solution manuals
  - using the solution manual or solutions other have posted is:
    - unethical for which will result in a grade of \textbf{F} for the \textit{course}
    - illegal: violation of copyright laws

- Online homework help is not permitted
  - you may not ask homework questions nor seek answers
  - students are dismissed from KU for this

Academic Integrity and Plagiarism

Laboratory Ethics

- Laboratory exercises are either
  - individual with rules as for homework
  - group in which two students work together
  - each laboratory will be designated as individual or group

- For group labs
  - both students must contribute to the lab exercise
  - lab reports are individual activities
  - reports must be separately prepared
    - rules as for homework: discuss but don't copy
Academic Integrity and Plagiarism

Project Ethics

- Projects are group of 2 or 3 students
  - all students must contribute to the project
  - work should be divided between students
    - report must clearly state role of each student
- Group project report
  - each student should write text for their part of project
  - one student may do final editing of report
    - report must clearly state writing & editing role of each student

Academic Integrity Quiz

- Homework this week: read
  http://www.ittc.ku.edu/~jpgs/courses/academic-integrity.html
  http://www.ittc.ku.edu/~jpgs/courses/source-cite.html
- You *must understand* this material
  - ask me if you have *any* question
  - goal is for new students to learn
- Next week: academic integrity quiz
AE.1 Administrivia
AE.2 Ethics and academic integrity
AE.3 Course outline
   I. Fundamentals and wireless networks
   II. Mobile and ad hoc networks
   III. Domain-specific networks and special topics
AE.4 Preliminaries

EECS 882 Outline
I: Fundamentals and Wireless Networks

I: Fundamentals and wireless networks
   PL: Mobile wireless environment and physical layer
   ML: MAC algorithms and protocols
   WN: Wireless PANs, LANs, and MANs
   WI: Wireless Internet and transport protocols

II: Mobile and ad hoc networks
III: Domain-specific networks and special topics
EECS 882 Outline

PL: Mobile Wireless Environment & Phys. Layer

- This course is mostly about L2 – 4
  - introductory background to physical layer needed
  - for in-depth treatment take EECS 861, 862, 865
  - ResiliNets MSEE should take 861, 862, 865
- Mobile wireless environment
  - wireless channel: subject to eavesdropping and interference
  - mobility: dynamic topologies and QoS delivery
  - traditional static wired mechanisms and protocols insufficient
- Physical layer
  - wireless spectrum issues
  - wireless channel characteristics and impairments

EECS 882 Outline

ML: MAC Algorithms and Protocols

- Wireless is shared (not guided) medium by definition
  - contention among transmitters
  - collisions when multiple nodes simultaneously transmit
  - need arbitration mechanisms so share medium
- MAC (medium access control) algorithms
  - partitioned: TDMA, FDMA, OFDMA
  - random: Aloha, slotted, CSMA
  - spread spectrum: FHSS, DSSS
- Wireless MACs have more challenges than wired
  - collision detection not practical (why?)
  - hidden and exposed terminals
EECS 882 Outline

WN: Wireless PANs, LANs, and MANs

- Wireless link replacements for wired networks
  - permit untethered operation to mobile hosts
  - may be cheaper to deploy than fiber (e.g. backhaul)
  - avoid need for right-of-way easement (e.g. campus)
- Wireless layer 2 replacement
  - PANs (personal area networks): 802.15.1 and Bluetooth
  - LANs (local area networks): 802.11
  - MANs (metro area networks): LMDS, MMDS, 802.16, WiMAX
  - RANs (regional area networks): microwave links and 802.22
- Solves wireless link replacement
  - but challenges the overall Internet...

EECS 882 Outline

WI: Wireless Internet and Transport Protocols

- The Internet evolved to assume wired links
  - even though the ARPANET originally had wireless subnets
    - packet radio and satellite network links
  - assumes fixed hosts and intermediate systems
    - addressing and forwarding not designed for mobility
  - assumes strong bidirectional connectivity over reliable links
    - IP routing assumes stable end-to-end paths
    - TCP assumes all losses due to congestion (*implication?*)
- Strong demand for untethered hosts
  - significant challenges to Internet protocol suite
  - mobile IP a hack to allow IP address roaming
II: Mobile and Ad Hoc Networks

I: Fundamentals and wireless networks

II: Mobile and ad hoc networks

MT: Cellular mobile telephony
LM: Mobility and location management
AH: Ad hoc networking
MR: MANET routing protocols

III: Domain-specific networks and special topics

EECS 882 Outline

MT: Cellular Mobile Telephony

- Traditional PSTN designed for fixed wired telephones
  - POTS: plain ordinary telephone service
- Demand for untethered telephony
  - cordless phones in home or office
  - mobile phones in vehicles and on persons
- Mobile cellular telephony
  - evolved to provide PSTN voice services
  - evolving to provide untethered data services
    - competing with evolving wireless Internet
- Significant challenges in retrofitting cellular PSTN
  - difficult to retrofit high-rate data on low-rate infrastructure
  - 3G architecture and protocols incredibly complex
EECS 882 Outline
LM: Mobility and Location Management

- Internet and PSTN support limited mobility
  - roaming between points of connectivity: hand-off
  - depends on fixed infrastructure: base stations & cell towers
- Emerging scenarios drive more aggressive mobility
  - mobility of all nodes along a multihop path
  - mobility of entire subnetworks (individuals, groups, vehicles)
- Challenges of frequent and high mobility
  - exceeds the reactivity of current control loops
  - causes frequent path changes (routing reconvergence)
  - induces episodic connectivity and temporary store-&-forward
- Location management aids mobility

EECS 882 Outline
AH: Ad Hoc Networking

- Traditional networks can assume infrastructure
  - stable links (that may be wireless) and nodes (base stations)
  - static or slowly moving hosts (M-IP and mobile telephony)
  - therefore network can rely on fixed infrastructure
    - physical infrastructure such as base stations & cell towers
    - protocol infrastructure such as name servers and topology DBs
- Emerging scenarios challenge these assumptions
  - military tactical networks
  - ubiquitous computing and communication
- Ad hoc networks self-organise and federate
  - without needing fixed infrastructure and network resources
EECS 882 Outline

MR: MANET Routing

- MANET (mobile ad hoc network) routing
  - pronounced MANET; rhymes with “planet” 2nd syl. accent
- Routing challenges
  - conventional routing algorithms make many assumptions
    - fixed stable paths, accessibility to infrastructure
  - MANET routing must expect dynamic behaviour
    - multihop: end systems also serve as transit nodes
    - frequent path changes due to mobility & episodic connectivity
- Routing algorithm types
  - tradeoffs?
  - on-demand or reactive creates paths when needed
  - table-driven or proactive creates paths that may be used

EECS 882 Outline

III: Domain-Specific Networks & Special Topics

I: Fundamentals and wireless networks
II: Mobile and ad hoc networks
III: Domain-specific networks and special topics
  - EM: Energy and power management
  - SN: Sensor networks
  - SL: Satellite links and networks
  - UC: Ubiquitous computing and communication
  - RS: Security, survivability, and resilience
EECS 882 Outline

EM: Energy and Power Management

- Traditional wired nodes are also wired to power
  - power is energy consumed over time: \( P = \frac{E}{t} \)
- Untethered hosts still need power to operate
  - typically provided by batteries
  - some batteries difficult / impossible to replace: sensor nodes
- Optimal use of energy by a given node
  - battery management to maximise node or battery life
  - adaptive transmission power and receiver scheduling
  - management of system, CPU, and memory power
- Optimal use of energy among a set of nodes
  - energy-aware routing algorithms & functionality partitioning

EECS 882 Outline

SN: Sensor Networks

- Sensors (and actuators) increasing importance
  - sensors must be networked to return sensed information
  - frequently wireless & battery powered (some may be wired)
- Wireless sensor network characteristics
  - large scale: hundreds to millions of sensor nodes
  - limited size and power: limits processing and bandwidth
- Wireless sensor network issues
  - optimising energy consumption critical
  - sensor fusion: processing information as it flows through net
  - scheduling and routing for sensors with low duty cycle
  - resilience in the face of failed sensor nodes
Satellites have niche role in communication networks
- large footprint less susceptible to obstructions
  - urban canyons and foliage still a problem
- connectivity where terrestrial infrastructure too expensive
Satellite links and networks
- bent-pipe satellite relays provide link within larger network
- constellation of satellites that is switched network
Challenges
- long speed-of-light delay (480ms RTT for GEO)
- asymmetric up/downlink
- hostile environment (radiation) with no easy upgrade/repair
- very expensive to deploy: many failures & aborted attempts

Ubiquitous computing and communication
- also called pervasive or ambient computing
- personal computing everywhere; devolution of the PC
Synthesis, integration, extension of technologies
- Internet, PSTN, PANs, MANETs, sensor networks
- body area (BAN) wearable networks
  - personal node, heads-up display, earphone, mike, sensors
- intelligence everywhere: smart spaces
  - walk into the room and federate with others and the room itself
- dynamic coalitions
  - federation policies and security implications
RS: Security, Survivability, and Resilience

- Mobile wireless networks *challenged* by environment
  - open channel subject to eavesdropping and jamming attack
  - weak, episodic, asymmetric, and disconnected operation
  - dynamic behaviour of mobile nodes and subnetworks
  - unpredictably long delay (store-and-forward in DTNs)
- Resilient networks maintain service in face of
  - environmental challenges
  - natural failures and non-malicious challenges (flash crowds)
  - intelligent attacks and large-scale natural disasters
- Includes security, survivability, disruption tolerance

_Preview of EECS 983 next semester_

Mobile Wireless Networking

AE.4 Preliminaries

AE.1 Administrivia
AE.2 Ethics and academic integrity
AE.3 Course outline
AE.4 Preliminaries
  AE.4.1 Network topology and components
  AE.4.2 Performance metrics
  AE.4.3 End-to-end vs. hop by hop and the E2E arguments
  AE.4.4 Protocols and layering
Mobile Wireless Networking

AE.4 Preliminaries

• The vast majority of this should be *review*
  – with the exception of the end-to-end arguments
    if you haven’t previously taken EECS 780 or 881
  – if not, talk to me at break or after class
• If this material is completely new:
  – you will need to *drop* EECS 882 and first take 780 (or 563)
• If you feel that your background is weak, 2 options:
  1. you will need to spend time on the background material
  2. you can take EECS 563 concurrently
• This class is *not* an automatic B!
Network Architecture and Topology

The Network

- Collection nodes or intermediate systems (IS)
  - switches, routers, bridges, etc.
- Interconnected by links that
- Provide connectivity among end systems (ES) or hosts or terminals
  - desktops, laptops, servers, telephone handsets, etc.
  - note: in some networks nodes may be both ES and IS
- To support distributed applications
  - e.g. email, Web browsing, peer-to-peer file sharing
Heterogeneous Networks

- Disparate networks are interconnected by *gateways*
  - translate data packet formats
  - interoperate signalling and control

Application Relationships

- **Client/server**
  - e.g. Web browsing
    - data streams with embedded synchronisation

- **Peer-to-peer**
  - e.g. telepresence (video-conferencing)
Network Architecture and Topology

Group Communication Topologies

- Group communication
  - communication among participants in a group of nodes
- Topologies
  - unicast
  - anycast
  - \(k\)-cast
  - multicast
  - broadcast

---

Group Communication Topologies

Unicast

- Unicast
  - point-to-point
- Anycast
  - point-to-any in group
- \(k\)-cast
  - point-to-\(k\) receivers in group
- Multicast
  - point-to-multipoint
  - multipoint-to-multipoint
  - multipoint-to-point (reverse multicast or Concast)
- Broadcast
  - point-to-all
  - broadcast and select multicast
Group Communication Topologies

Anycast

- Unicast
  - point-to-point
- Anycast
  - point-to-any in group
- k-cast
  - point-to-\(k\) receivers in group
- Multicast
  - point-to-multipoint
  - multipoint-to-multipoint
  - multipoint-to-point (reverse multicast or Concast)
- Broadcast
  - point-to-all
  - broadcast and select multicast

\(k = 3\)
Group Communication Topologies
Multicast: Point-to-Multipoint

- Unicast
  - point-to-point
- Anycast
  - point-to-any in group
- $k$-cast
  - point-to-$k$ receivers in group
- Multicast
  - point-to-multipoint
  - multipoint-to-multipoint
  - multipoint-to-point (reverse multicast or Concast)
- Broadcast
  - point-to-all
  - broadcast and select multicast

Group Communication Topologies
Multicast: Multipoint-to-Multipoint

- Unicast
  - point-to-point
- Anycast
  - point-to-any in group
- $k$-cast
  - point-to-$k$ receivers in group
- Multicast
  - point-to-multipoint
  - multipoint-to-multipoint
  - multipoint-to-point (reverse multicast or Concast)
- Broadcast
  - point-to-all
  - broadcast and select multicast
### Group Communication Topologies

**Concast: Multipoint-to-Point**

- **Unicast**
  - point-to-point
- **Anycast**
  - point-to-any in group
- **k-cast**
  - point-to-k receivers in group
- **Multicast**
  - point-to-multipoint
  - multipoint-to-multipoint
  - multipoint-to-point (reverse multicast or Concast)
- **Broadcast**
  - point-to-all
  - broadcast and select multicast

---

**Broadcast**

- **Unicast**
  - point-to-point
- **Anycast**
  - point-to-any in group
- **k-cast**
  - point-to-k receivers in group
- **Multicast**
  - point-to-multipoint
  - multipoint-to-multipoint
  - multipoint-to-point (reverse multicast or Concast)
- **Broadcast**
  - point-to-all
  - broadcast and select multicast

---
Group Communication Topologies
Multicast: Broadcast and Select

- Unicast
  - point-to-point
- Anycast
  - point-to-any in group
- $k$-cast
  - point-to-$k$ receivers in group
- Multicast
  - point-to-multipoint
  - multipoint-to-multipoint
  - multipoint-to-point (reverse multicast or Concast)
- Broadcast
  - point-to-all
  - broadcast and select multicast

Network Architecture and Topology
Star vs. Mesh Topologies

- Star hierarchy
- Centralised control
- Examples
  - PSTN
  - early enterprise nets (SNA)
    - later became meshes
- Mesh
- Fully distributed control
- Examples
  - ARPANET, Internet
  - DECnet
- Spanning tree may be overlaid
## Mobile Wireless Networking

### AE.4.2 Performance Metrics

AE.4 Preliminaries
- AE.4.1 Network topology and components
- AE.4.2 Performance metrics
- AE.4.3 End-to-end vs. hop by hop and the E2E arguments
- AE.4.4 Protocols and layering

---

### Performance Metrics

#### Unit Multipliers

<table>
<thead>
<tr>
<th>SI decimal</th>
<th>EIC binary</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-1}$</td>
<td>deci d</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>centi c</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>milli m</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>micro μ</td>
</tr>
<tr>
<td>$10^{-9}$</td>
<td>nano n</td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>pico p</td>
</tr>
<tr>
<td>$10^{-15}$</td>
<td>femto f</td>
</tr>
<tr>
<td>$10^{-18}$</td>
<td>atto a</td>
</tr>
<tr>
<td>$10^{-21}$</td>
<td>zepto z</td>
</tr>
<tr>
<td>$10^{-24}$</td>
<td>yocto y</td>
</tr>
<tr>
<td>$10^{1}$</td>
<td>deka da</td>
</tr>
<tr>
<td>$10^{2}$</td>
<td>hecto h</td>
</tr>
<tr>
<td>$10^{3}$</td>
<td>kilo k</td>
</tr>
<tr>
<td>$10^{6}$</td>
<td>Mega M</td>
</tr>
<tr>
<td>$10^{9}$</td>
<td>Giga G</td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>Tera T</td>
</tr>
<tr>
<td>$10^{15}$</td>
<td>Peta P</td>
</tr>
<tr>
<td>$10^{18}$</td>
<td>Exa E</td>
</tr>
<tr>
<td>$10^{21}$</td>
<td>Zetta Z</td>
</tr>
<tr>
<td>$10^{24}$</td>
<td>Yotta Y</td>
</tr>
</tbody>
</table>
Performance Metrics

Delay and Bandwidth

- Delay or latency
  - \( D \) end-to-end
  - \( d \) per hop
  - jitter is delay variance
- Bandwidth or data rate
  - \( B \) aggregate
  - \( b \) per flow
  - not channel capacity (bandwidth in EE sense)
- Bandwidth-\( \times \)-delay product
  - number of bits in flight on a high-speed path
  - \( b \) [bits/sec] \( \times \) \( d \) [sec] = [bits]

Network Path Latency

- Delays sum along a path
  - benefit of optimising a link is directly proportional to contribution
## Performance Metrics

### Path Length

<table>
<thead>
<tr>
<th>Type</th>
<th>-- area network --</th>
<th>Channel</th>
<th>Distance</th>
<th>RTT</th>
<th>BW-(\times)-delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAN</td>
<td>personal</td>
<td>RF</td>
<td>10 m</td>
<td>100 ns</td>
<td>0.5 b, 50 b, 50 kb</td>
</tr>
<tr>
<td>SAN</td>
<td>system</td>
<td>Cu/Fiber</td>
<td>100 m</td>
<td>1 (\mu)s</td>
<td>0.5 b, 500 b, 500 kb</td>
</tr>
<tr>
<td>LAN</td>
<td>local</td>
<td>Cu/Fiber/RF</td>
<td>1 km</td>
<td>10 (\mu)s</td>
<td>5 b, 5 kb, 5 Mb</td>
</tr>
<tr>
<td>MAN</td>
<td>metropolitan</td>
<td>Fiber/RF</td>
<td>100 km</td>
<td>1 ms</td>
<td>500 b, 500 kb, 500 Mb</td>
</tr>
<tr>
<td>WAN</td>
<td>transcon. wide</td>
<td>Fiber</td>
<td>5000 km</td>
<td>50 ms</td>
<td>25 kb, 25 Mb, 25 Gb</td>
</tr>
<tr>
<td>WAN</td>
<td>global wide</td>
<td>Fiber</td>
<td>20,000 km</td>
<td>200 ms</td>
<td>100 kb, 100 Mb, 100 Gb</td>
</tr>
<tr>
<td>LEO*</td>
<td>low earth</td>
<td>RF</td>
<td>2-1,000 km</td>
<td>25 ms</td>
<td>12 kb, 12 Mb, 12 Gb</td>
</tr>
<tr>
<td>GEO</td>
<td>geosynchronous</td>
<td>RF/laser</td>
<td>2-36,000 km</td>
<td>480 ms</td>
<td>240 kb, 240 Mb, 240 Gb</td>
</tr>
<tr>
<td>DSN</td>
<td>earth-moon</td>
<td>RF/laser</td>
<td>400,000 km</td>
<td>2.5 s</td>
<td>1.2 Mb, 1.2 Gb, 1.2 Tb</td>
</tr>
<tr>
<td>IPN(\oplus)</td>
<td>interplanetary</td>
<td>RF/laser</td>
<td>55-400-10^6 km</td>
<td>6-45 min</td>
<td>1.3 Gb, 1.3 Tb, 1.3 Pb</td>
</tr>
<tr>
<td>IPN(\oplus)</td>
<td></td>
<td>RF/laser</td>
<td>10^6 km</td>
<td>2 hr</td>
<td>3.6 Gb, 3.6 Tb, 3.6 Pb</td>
</tr>
<tr>
<td>IPN(\oplus)</td>
<td>interplanetary</td>
<td>RF/laser</td>
<td>10^14 km</td>
<td>20 hr</td>
<td>36 Gb, 36 Tb, 36 Pb</td>
</tr>
</tbody>
</table>

* 3000 km footprint

### Network Path Bandwidth

- Maximum bandwidth limited by bottleneck link
  - there is no point in optimising a link that is not a bottleneck
Performance Metrics
Error and Loss Characteristics

- Error and loss characteristics
  - Pr[bit-error]
  - burst error (multibit)
  - channel fades (e.g. rain)
  - episodic link connectivity
  - link and node failures

Mobile Wireless Networking
AE.4.3 E2E vs. HBH and the E2E Arguments

AE.1 Administrivia
AE.2 Ethics and academic integrity
AE.3 Course outline
AE.4 Preliminaries
  AE.4.1 Network topology and components
  AE.4.2 Performance metrics
  AE.4.3 End-to-end vs. hop by hop and the E2E arguments
  AE.4.4 Protocols and layering
E2E vs. HBH

Definitions

- Hop-by-hop (HBH)
  - communication or link between directly attached nodes
  - typically IS – IS or ES – IS
  - may rarely by ES – ES (no network)

- Edge-to-edge
  - communication or link between edges of a subnetwork

- End-to-end (E2E)
  - communication or path between end systems: ES – ES
  - typically involves multiple HBH segments

- Application-to-application (A2A)
  - communication between applications (similar to E2E)

Examples

- End system
- Intermediate system
  - edge or access switch
  - core or backbone switch
End-to-End vs. Hop-by-Hop

End-to-End Arguments

- The end-to-end arguments (1st half)

- Some functions can be correctly and completely implemented only at the endpoints of a communication association
  - Providing these functions as features in the net is not possible

  paraphrased from [Saltzer, Reed, Clark 1981]

End-to-End vs. Hop-by-Hop

End-to-End Arguments

- Hop-by-Hop functions do not compose end-to-end
  - between HBH boundaries, function \( f \) is defeated \( (g) \)
    - e.g. error control: errors may occur within switches
    - e.g. encryption: cleartext within switches may be snooped
  - These functions must be done E2E
    - doing them HBH is redundant, and may lower performance
End-to-End vs. Hop-by-Hop

End-to-End Arguments

- The end-to-end arguments (2nd half)
  - performance enhancement corollary

- Functions should be duplicated hop-by-hop if there is an overall (end-to-end) performance benefit

paraphrased from [Saltzer, Reed, Clark 1981]

End-to-End vs. Hop-by-Hop

Hop-by-Hop Performance Enhancement

- E2E Argument (1st half) says what must be E2E
- HBH Performance enhancement (2nd half)
  - functions should duplicated HBH if overall E2E benefit
- Analysis is required to determine cost/benefit
  - added functionality in net may add overhead not offset
End-to-End vs. Hop-by-Hop
Performance Enhancement Example

• E2E vs. HBH error control for reliable communication
  – E2E argument says error control must be done E2E
    • e.g. E2E ARQ (error check code and retransmit if necessary
    – but should HBH error control also be done?

100 m wireless LAN
Univ. Kansas

15 000 km fiber WAN

100 m fiber LAN
Univ. Sydney

• Effect of high loss rate on wireless link
  – ~250 ms RTT retransmission for every corrupted packet
• Error control on wireless link reduces to ~1μs RTT
  – shorter control loop results in dramatically lower E2E delay
End-to-End vs. Hop-by-Hop

Security

• Security and information assurance \textit{must} be E2E
  – information in the clear inside network nodes \textit{not} secure

• Justification for HBH security mechanisms
  – link security may be good enough for \textit{some}
    • wireless link encryption for WEP (wire equivalent protection)
      note: 802.11 WEP not strong enough
  – subnetwork or edge-to-edge security for VPNs
    • assures enterprise security across open network...
    ...but not individual flow security

End-to-End vs. Hop-by-Hop

E2E Argument Misinterpretations

• E2E-only
  – do not replicate E2E services or features HBH
  – violates HBH performance enhancement corollary

• Everything E2E
  – implement as many services or feature E2E as possible
  – misstatement of Internet design philosophy:
    simple stateless network for resilience and survivability
Mobile Wireless Networking
AE.4.4 Protocols and Layering

AE.1 Administrivia
AE.2 Ethics and academic integrity
AE.3 Course outline
AE.4 Preliminaries
  AE.4.1 Network topology and components
  AE.4.2 Performance metrics
  AE.4.3 End-to-end vs. hop by hop and the E2E arguments
  AE.4.4 Protocols and layering

Protocols and Services
Definition

- Protocol: rules for communication between entities
  - message format and sequence
    - information transfer (data plane)
    - signalling of control information (control plane)
    - monitoring and management (management plane)
  - definition of actions (state machine)
- Service
  - functional primitives provided by layer
- Interface
  - service interface to layers above and below

Proper design separates protocols from services
Protocol Layering

Layering provides service abstraction
- isolate: protocols, components, technology
  - any transport layer over IP
  - IP over any link layer
  - commodity link layer chip evolution, e.g.
    - 10BASE-T → 100BASE-T → 1000BASE-X
      → 802.11b → 802.11g

Layering is useful abstraction
- thinking about networking system architecture
- organising protocols based on role
  2. link
  3. switch
  4. end system
Protocol Layering

OSI Model

- ISO 7498: open systems interconnection
- Attempt to formalise needed:
  - protocol layers and their services
  - interfaces between layers
Protocol Layering
OSI Model

- Real implementations
  - ISO model missed medium access control
  - presentation layer
    - not sensible to standardise
    - not necessarily right layer of stack
  - session layer
    - generally not needed for data
    - useful for control (e.g. SIP, H.323)
Protocol Layering

Performance Issues

• Layered implementations may perform very poorly
• Inter-layer transfers involve non-trivial overhead
  – encapsulation/decapsulation of PDUs
  – inter-layer control transfer
    • context switching and data copying
  – effects of overlapping intra-layer control mechanisms
• Protocol layers should be designed with this in mind
  – antithesis of layering to isolate protocols and technology

Protocol Layering

Planes

• Data
  – information transfer
• Control
  – signalling to control information transfer, including:
    • flow or connection establishment/modification/termination
    • error control
    • flow and congestion control
  – correspond to data layers
• Management
  – monitoring and management of network and its elements
  – cuts across all layers
Protocol Layering
Layer Names and Roles

- **L8** social (e.g. use of Facebook, Twitter)
- **L7** application (e.g. Web, mashups [L7.5?])
- **L6** presentation: format conversion
- **L5** session control: group of L4 associations
- **L4** transport: end-to-end data transfer
- **L3** network: create E2E path from HBH links
- **L2.5** virtual link: traffic/link engineering (e.g. MPLS)
- **L2** link: hop-by-hop data transfer
  - **L2** MAC: medium access control
- **L1** physical: bits in a medium

Protocol Layering
Hybrid Layer/Plane Cube
Protocol Layering
Internet Hourglass

- Internet “hourglass”
- Common network layer
  - common addressing essential for seamless interworking
  - compatible routing & signalling
- Any transport layer above
  - in practice: TCP or UDP
- Any link layer below
  - in practice: SONET, 802.n

Protocols
Communication Flow Diagrams

- Packets are parallelograms
- Messages are directed line segments
  - actually thin parallelograms
Protocols
Example: Connection Establishment

- Signalling message exchange
  - SETUP / CONNECT
  - connection established
- Data transfer
### Internet Protocols

#### Important Network Protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Name</th>
<th>Function</th>
<th>Status</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP</td>
<td>Internet protocol</td>
<td>addressing</td>
<td>standard</td>
<td>RFC 0791 STD 0005</td>
</tr>
<tr>
<td>ICMP</td>
<td>Internet control message protocol</td>
<td>signalling</td>
<td>standard</td>
<td>RFC 0792 STD 0005</td>
</tr>
<tr>
<td>IGMP</td>
<td>Internet group management protocol</td>
<td>multicast signalling</td>
<td>proposed</td>
<td>RFC 3376</td>
</tr>
<tr>
<td>BGP</td>
<td>border gateway protocol</td>
<td>interdomain routing</td>
<td>standard</td>
<td>RFC 1771</td>
</tr>
<tr>
<td>OSPF</td>
<td>open shortest path routing</td>
<td>intradomain routing</td>
<td>standard</td>
<td>RFC 2328 STD 0054</td>
</tr>
<tr>
<td>ISIS</td>
<td>intermediate system –intermediate system</td>
<td>intradomain routing</td>
<td>proposed</td>
<td>ISO10589 (RFC 908)</td>
</tr>
<tr>
<td>DNS</td>
<td>domain name system</td>
<td>domain name to IP address resolution</td>
<td>standard</td>
<td>RFC 1035 STD 0013</td>
</tr>
</tbody>
</table>

RFCs are available from www.rfc-editor.org

---

### Internet Protocols

#### Important Transport Protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Name</th>
<th>Function</th>
<th>Status</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>transmission control protocol</td>
<td>reliable data transfer with</td>
<td>standard</td>
<td>RFC 0793 STD 0007</td>
</tr>
<tr>
<td></td>
<td>protocol</td>
<td>congestion control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UDP</td>
<td>user datagram protocol</td>
<td>socket access to unreliable</td>
<td>standard</td>
<td>RFC 0768 STD 0006</td>
</tr>
<tr>
<td></td>
<td>protocol</td>
<td>IP datagrams</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTP</td>
<td>real-time protocol</td>
<td>streaming media (typically over UDP)</td>
<td>standards track</td>
<td>RFC 1889</td>
</tr>
<tr>
<td>T/TCP</td>
<td>TCP for transactions</td>
<td>remote login</td>
<td>experimental</td>
<td>RFC 1644</td>
</tr>
<tr>
<td>RDP</td>
<td>reliable data protocol</td>
<td>reliable data transfer with</td>
<td>experimental</td>
<td>RFC 0908</td>
</tr>
<tr>
<td></td>
<td>protocol</td>
<td>no congestion control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCTP</td>
<td>stream control transmission protocol</td>
<td>signalling</td>
<td>proposed</td>
<td>RFC 2960</td>
</tr>
<tr>
<td></td>
<td>protocol</td>
<td>proposed for wireless</td>
<td>standard</td>
<td></td>
</tr>
</tbody>
</table>

---

20 August 2009 – KU EECS 780 – Communication Networks – Administrivia

© James Sterbenz

ITTC
## Internet Protocols

### Important “Application Layer” Protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Name</th>
<th>Function/Use</th>
<th>Status</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTTP</td>
<td>hypertext transfer protocol</td>
<td>Web browsing</td>
<td>draft standard</td>
<td>RFC 2616</td>
</tr>
<tr>
<td>FTP</td>
<td>file transfer protocol</td>
<td>file and document transfer</td>
<td>standard</td>
<td>RFC 0959</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>STD 0009</td>
</tr>
<tr>
<td>Telnet</td>
<td>telnet</td>
<td>remote login</td>
<td>standard</td>
<td>RFC 0854</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>STD 0008</td>
</tr>
<tr>
<td>SMTP</td>
<td>simple mail transfer protocol</td>
<td>email relay and delivery</td>
<td>standard</td>
<td>RFC 0821</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>STD 0010</td>
</tr>
<tr>
<td>POP</td>
<td>post office protocol</td>
<td>server mail download</td>
<td>standard</td>
<td>RFC 1939</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>STD 0053</td>
</tr>
<tr>
<td>IMAP</td>
<td>internet message access protocol</td>
<td>server mail access</td>
<td>proposed standard</td>
<td>RFC 3501</td>
</tr>
<tr>
<td>NFS</td>
<td>network file system</td>
<td>remote access to files</td>
<td>proposed standard</td>
<td>RFC 3530</td>
</tr>
<tr>
<td>RTSP</td>
<td>real-time streaming protocol</td>
<td>control of multimedia streaming</td>
<td>proposed standard</td>
<td>RFC 2326</td>
</tr>
</tbody>
</table>