Mobile Wireless Networking
The University of Kansas EECS 882
Fall 2007

James P.G. Sterbenz

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

jpgs@eecs.ku.edu

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

AE.1  Administrivia

AE.1.1  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

AE.1.1 Prerequisites and Description

AE.1 Administrivia
   AE.1.1 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: 265 Regnier – Edwards Campus
  – Tue. 18:10 – 21:00

• Laboratory: 368 Regnier – Edwards Campus
  – as needed
  – Wed. 19:10 – 21:00
  – no lab session the first week or two

• 21 Aug. – 5 Dec.
  – three sectional exams plus final (11 Dec.)
  – 21 Nov. 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
EECS 882 Prerequisites

• You must have networking background at least one of:
  – KU EECS 780 Communication Networks
    • 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 an 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
Mobile Wireless Networking

AE.1 Administrivia
AE.1.1 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

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

Office Hours

- Tue. 16:00 – 18:00
  - unless advised otherwise due to meetings or travel
- 125U Regents Center
- Or by appointment
  - email or call to arrange in advance
  - call before dropping in unless already on campus
  - Tue: typically on Edwards campus in afternoon
  - MWTF: typically in Lawrence if not travelling
    - 209 Nichols research office (frequently)
    - 3036 Eaton: teaching office (occasionally)

GTA Information

Background and Office Hours

- Abdul Jabbar Mohammad
  - PhD student, University of Kansas EECS
- Office hours: Tue. 17:00 – 18:00
  - Regnier 368 (lab room) or Regnier 125U (instructor office)
  - unless advised otherwise due to meetings or travel
- Contact information
  - email
    - jabbar@ittc.ku.edu
  - phone
    - 217 Nichols office: +1 785 864 7122
## Instructor and GTA Information

**Contact: Email**

### Contact information
- **email:** jpgs@eecs.ku.edu or jabbar@ittc.ku.edu *only*
  - begin subject with "EECS882 - "
  - email to other addresses will likely be misfiltered and unread
  - email generally checked daily
  - email is *unreliable*; retry if no reply within 48 hours
- email with *meaningful* subject lines
  - bad
    - **Subject:** Hi!
    - **Subject:** regarding class
  - good
    - **Subject:** EECS882 - need help understanding random waypoint

## 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

- Configure email client with your name in ISO-Latin
  - Ima K.U. Student <ima.k.u.student@ku.edu>

- 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

- Avoid free email accounts
  - look unprofessional
  - frequently auto-append advertisements
  - construct meaningful signature no longer than 4 lines

- Proofread and think before you send!
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 your never there!! :-P do you even have office hours dude? LOL! Just tell me when I can drop by to learn what you do ru 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

Instructor Information

Contact: Phone

- 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
  - Web
    - http://www.ittc.ku.edu/~jpgs
Student Information
Contact and Background

- Brief Introductions around the room
- Photos to help me learn your names
- Roster information to be emailed from Web template
  - full name, nickname
  - email for class information list
    - preferred and mandatory eecs.ku.edu address
  - phone numbers will only be used for urgent matters
  - prerequisite fulfillment: school, course, year, book
  - degree (BS, MS, PhD), major (IT, CS, CoE, EE), focus area,
    option if MS (course, project, thesis), advisor
  - personal machine for simulation labs an project?

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 eecs.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

Mobile Wireless Networking

AE.1.3 Grading and Student Expectations

AE.1 Adminivia
  AE.1.1 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

Textbooks

- Required textbook
  - Murthy & Manoj, *Ad Hoc Wireless Networks: Arch. and Prot.*
- 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

Reading

- How hard is this class?
  - not a killer class in terms of homework and projects
  - but it is intellectually challenging
- Required readings are mandatory
  - the textbook is not just a reference!
  - you won’t be able to use it on exams
- 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

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 term paper
    B: mastery of material, labs, and solid term paper
      this is the basic expectation for a graduate student
    C: slacking but know basic material and marginal paper
    D: very poor performance on exams or paper
    F: nonperformance on exams or paper
      academic misconduct regardless of other grades

Course Information

Grade Contribution

• Relative grade contribution
  – 40% section exams
    • two at 15% each
    • third at 10% will be first half of final exam period
  – 10% comprehensive portion of final exam
  – 20% project report
    • significant extra credit for publishable paper
  – 10% homework and lab exercises
  – 20%: paper presentation and class participation
  – mandatory academic integrity quiz in second class
    • must be made up if you miss this class
Course Information

Exam Schedule and Weight

- Section exams: 40%
  - tentative schedule subject to change
    - academic integrity quiz on 28 Aug. (required to pass course)
    - exam 1 on 02 Oct. (I will be out of the country)
    - exam 2 in Nov.
    - exam 3 on 11 Dec. (portion of final exam period)
- Final exam: 10%
  - comprehensive covering entire course
  - synthesis of multiple sections
  - portion of final exam period

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:
  Compare the functionality of the link and transport layers
  - example correct answer (1 minutes 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 HDSL. 802.11 was developed as a replacement for Ethernet, and has similar frame structure, shown in Figure 2. Note that 802.11 has more MAC address fields than Ethernet. The reason for the addition of extra fields has to do with the operation of the 802.11 MAC. Actually I totally 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...
Course Information
Homework and Lab Assignments

- 10% of grade on homework and ns-2 lab exercises
- You *must* solve assignments individually
  - you may discuss problems and solution strategies
- Due at the beginning of class on the due date
  - usually Tue. – late assignments generally *not* accepted
- Submit either by:
  - bring hardcopy to class
  - by email
    - Subject: line *must* begin with "EECS882 - assignment"
    - homework as MIME attachment in PDF
    - lab exercise requirements will be covered in lab session

Course Information
Term Project

- 20% of grade based on term project and report
- Purpose and scope:
  - research area of mobile wireless networking beyond class
  - technical in nature
    - may lead to publication
    - may lead to MS thesis or PhD dissertation
  - will likely use an ns-2 simulation
    - build on lab exercises
    - 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: 27, 28 Nov., 4, 5 Dec.
  - report due: 5 Dec.

---

**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](http://www.ku.edu/libraries)
  - selected journals
  - access to archived books and journals
  - interlibrary loan

[http://www.ittc.ku.edu/~jpgs/courses/source-cite.html](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)
  - 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
  - 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

Mobile Wireless Networking

AE.2 Ethics and Academic Integrity

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
• 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

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
  - take intermediate notes from which you write

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
Academic Integrity and Plagiarism
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 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
Mobile Wireless Networking

AE.3 Course Outline

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
   PL: Mobile wireless environment and physical layer
   ML: MAC algorithms and protocols
   WN: Wireless PANs, LANs, MANs, and RANs
   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
- 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, MANs, and RANs

• 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
EECS 882 Outline

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

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
  - 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
EECS 882 Outline

SL: Satellite Links and Networks

- 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

EECS 882 Outline

UC: Ubiquitous Computing and Communication

- 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
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 893 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!

Mobile Wireless Networking

AE.4.1 Network Topology and Components

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
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
Network Architecture and Topology

Heterogeneous Networks

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

Network Architecture and Topology

Application Relationships

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

- Peer-to-peer
  - e.g. telepresence (video-conferencing)
Group Communication Topologies

- **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-cast

- **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: 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

Group Communication Topologies

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**
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} deci</td>
<td>d</td>
</tr>
<tr>
<td>10^{-2} centi</td>
<td>c</td>
</tr>
<tr>
<td>10^{-3} milli</td>
<td>m</td>
</tr>
<tr>
<td>10^{-6} micro</td>
<td>μ</td>
</tr>
<tr>
<td>10^{-9} nano</td>
<td>n</td>
</tr>
<tr>
<td>10^{-12} pico</td>
<td>p</td>
</tr>
<tr>
<td>10^{-15} femto</td>
<td>f</td>
</tr>
<tr>
<td>10^{-18} atto</td>
<td>a</td>
</tr>
<tr>
<td>10^{-21} zepto</td>
<td>z</td>
</tr>
<tr>
<td>10^{-24} yocto</td>
<td>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
  - \( b \text{ [bits/sec]} \times d \text{ [sec]} = \text{ [bits]} \)

\[ D = \sum d_i \]

- 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-delay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>– earth orbiting</td>
<td>RF</td>
<td>10 m</td>
<td>100 ns</td>
<td>0.05 b, 50 b, 50 kb</td>
</tr>
<tr>
<td>PAN</td>
<td>personal</td>
<td>Cu/Fiber</td>
<td>100 m</td>
<td>1 μs</td>
<td>½ 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 μs</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>transit. 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>20000 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>2–10000 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>2–36000 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>400000 km</td>
<td>2.5 s</td>
<td>1.2 Mb, 1.2 Gb, 1.2 Tb</td>
</tr>
<tr>
<td>IPN</td>
<td>interplanetary</td>
<td>RF/laser</td>
<td>55–400×10⁹ km</td>
<td>6–45 min</td>
<td>1.3 Gb, 1.3 Tb, 1.3 Pb</td>
</tr>
<tr>
<td>IPN</td>
<td>interplanetary</td>
<td>RF/laser</td>
<td>10⁸ km</td>
<td>2 hr</td>
<td>3.6 Gb, 3.6 Tb, 3.6 Pb</td>
</tr>
<tr>
<td>IPN</td>
<td>interplanetary</td>
<td>RF/laser</td>
<td>10¹⁰ 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

\[ R = \min(r_i) \]
Performance Metrics
Error and Loss Characteristics

- Error and loss characteristics
  - \( P_{\text{bit-error}} \)
  - 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)

---

E2E vs. HBH

Examples

- End system
- Intermediate system
  - edge or access switch
  - core or backbone switch

G2G, HBH, E2E, multihomed
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?

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

Security

- Security and information assurance must be E2E
  - information in the clear inside network nodes not secure
- Justification for HBH security mechanisms
  - link security may be good enough for 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

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
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*
Protocols
Communication Flow Diagrams

- Packets are parallelograms
- Messages are directed line segments
- actually thin parallelograms

Example: Connection Establishment

- Signalling message exchange
  - SETUP / CONNECT
  - connection established
- Data transfer
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

<table>
<thead>
<tr>
<th>Layer</th>
<th>Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>application</td>
</tr>
<tr>
<td>6</td>
<td>presentation</td>
</tr>
<tr>
<td>5</td>
<td>session</td>
</tr>
<tr>
<td>4</td>
<td>transport</td>
</tr>
<tr>
<td>3</td>
<td>network</td>
</tr>
<tr>
<td>2</td>
<td>link</td>
</tr>
<tr>
<td>1</td>
<td>physical</td>
</tr>
</tbody>
</table>

application–application
data formatting
dialogue management
end-to-end
forwarding/routing
hop-by-hop
medium access control
transmission

© James Sterbenz

ITTC
**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 it's elements
  - cuts across all layers
Protocol Layering

Hybrid Layer/Plane Cube

L7
application
L5
session
L4
transport
L3
network
L2
link
L2-
MAC
L1
physical

management
control plane
data plane

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

TCP  UDP  RTP  • • •
3
IP

Ethernet  SONET  • • •  802.11  • • •  λ

21 August 2007  KU EECS 882 – Mobile Wireless Nets – Administrivia  MWN-AE-112
## Internet Protocols

### Important Link and MAC Protocols

<table>
<thead>
<tr>
<th>Common name</th>
<th>Standard</th>
<th>Scope</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet</td>
<td>IEEE 802.3</td>
<td>LAN/MAN</td>
<td>wire, fiber</td>
</tr>
<tr>
<td>Token ring</td>
<td>IEEE 802.5</td>
<td>LAN</td>
<td>wire</td>
</tr>
<tr>
<td>WirelessLAN</td>
<td>IEEE 802.11</td>
<td>LAN</td>
<td>RF, (IR)</td>
</tr>
<tr>
<td>WiFi</td>
<td>IEEE 802.15</td>
<td>PAN</td>
<td>RF</td>
</tr>
<tr>
<td>WirelessMAN</td>
<td>IEEE 802.16</td>
<td>MAN</td>
<td>RF</td>
</tr>
<tr>
<td>SONET</td>
<td>ANSI T1.105 ITU G.707</td>
<td>MAN/WAN</td>
<td>fiber electronic switch</td>
</tr>
<tr>
<td>OTN</td>
<td>ITU G.709</td>
<td>MAN/WAN</td>
<td>fiber optical switch</td>
</tr>
</tbody>
</table>

## 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 standard</td>
<td>RFC 3376</td>
</tr>
<tr>
<td>BGP</td>
<td>border gateway protocol</td>
<td>interdomain routing</td>
<td>draft 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 standard</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

21 August 2007   KU EECS 882 – Mobile Wireless Nets – Administrivia   MWN-AE-113
### Internet Protocols
#### Important Transport 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>TCP</td>
<td>transmission control protocol</td>
<td>reliable data transfer with congestion control</td>
<td>standard</td>
<td>RFC 0793, STD 0007</td>
</tr>
<tr>
<td>UDP</td>
<td>user datagram protocol</td>
<td>socket access to unreliable IP datagrams</td>
<td>standard</td>
<td>RFC 0766, STD 0006</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 no congestion control</td>
<td>experimental</td>
<td>RFC 0908</td>
</tr>
<tr>
<td>SCTP</td>
<td>stream control transmission protocol</td>
<td>signalling for wireless</td>
<td>proposed standard</td>
<td>RFC 2960</td>
</tr>
</tbody>
</table>

### 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, STD 0009</td>
</tr>
<tr>
<td>Telnet</td>
<td>telnet</td>
<td>remote login</td>
<td>standard</td>
<td>RFC 0854, 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, STD 0010</td>
</tr>
<tr>
<td>POP</td>
<td>post office protocol</td>
<td>server mail download</td>
<td>standard</td>
<td>RFC 1939, 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 3339</td>
</tr>
<tr>
<td>NFS</td>
<td>network file system</td>
<td>remote access to files</td>
<td>proposed standard</td>
<td>RFC 3339</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>