EE-579 Wireless and Mobile Networks Design and Laboratory, Spring 2004
Instructor: Prof. Ahmed Helmy

- Catalogue course description:

Mobile Adhoc Networks:
Adhoc and geographic routing, resource discovery, medium access control, IP-mobility, mobility modeling, wired-wireless networks.
Lab: Wireless LAN measurement, Mobile-IP, adhoc routing.
Project Required.

- Goals of the course:

The purpose of the course is to expose students to emerging networking protocols and technologies in the field of wireless and mobile networks. It also involves students in group projects to identify challenging problems in wireless ad hoc networks through extensive reading and discussion, propose solutions to those problems, then conduct high quality research (usually through extensive simulations, sometimes accompanied by analysis and implementation) and produce a term project proposal that is the final product of their work.
More precisely, the objectives of this course are for the students:

- To acquire hands-on experience and get familiar with a networking laboratory setup, with emphasis on wireless and mobile networking technologies. To experiment with state-of-the-art networking technologies and tools that enable students to diagnose and perform measurements on a network.
- To get involved in research projects on advanced topics in mobile ad hoc networks (MANets), and be able to present and write high quality technical reports on protocol design, analysis and simulation in that field.
- To be part of a team and to tackle challenging research problems in a semester project. To suggest solutions to these problems and to be able to demonstrate the feasibility and performance of the solution.
- To learn how to read and review publications in the wireless networking field from selected journal articles and conference proceedings
  The skills acquired by the students in this class should emphasize and supplement deep understanding of actual protocol and network behavior. Students develop and enhance their understanding of the basic elements of wireless networking, mainly at the network and MAC layers, the behavior of the fundamental and evolving network protocols (such as unicast and multicast ad hoc routing protocols, media access control (MAC) protocol of wireless networks, among others). Aside from this basic understanding, students should realize that network behavior is a collective behavior of all such protocols (and others), their interaction among themselves, and with the 'faulty' and (sometimes highly) dynamic network environment. By integrating network dynamics, such as packet losses, link/node failures and mobility, and through diagnostic and measurement tools, students should be able to study the effects of various network conditions on the overall behavior of the network.

Such deep understanding and practicality, along with acquiring the above skills, are essential tools for future networking research and industry, that would greatly help in understanding today's networks, and designing networks of the future.

The course consists of (i) a series of lectures, supplemented by (ii) a set of laboratory experiments.

(i) The lecture series starts by a set of (approximately three week) lectures given by the instructor on fundamentals of mobile ad hoc networks, MAC, IP mobility and mobility models, followed by (approx. three week) lectures on challenges and research directions in those fields. During those initial weeks the class will be broken into groups, and every group gets to choose a topic for presentation and formulates a problem for the project. Also, each group is assigned a topic presentation slot and a project presentation slot. The weeks that follow include presentations by the students to cover specific topics and problems based on lists of readings (provided by the instructor and proposed by the students). The last lecture of class usually includes 10-15 minute slots for students to demo their projects and results.

The students learn basics of ad hoc routing protocols including

- Unicast routing using table-driven protocols (e.g., link state or DSDV), on-demand protocols with caching (e.g., DSR, AODV, TORA), hybrid protocols (e.g., ZRP, contact-based architectures), hierarchical protocols (e.g., cluster-based and landmark-based) and geographic routing (e.g., greedy routing, GPSR)
- Multicast routing using tree-based or mesh-based approaches (e.g., ODMRP, CAMP, FGMP) or extensions of unicast ad hoc routing (e.g., MAODV, MCEDAR)
- Broadcast routing using naïve flooding, heuristics (e.g., probabilistic, counter-based), minimum dominating sets (e.g., MPR multi-point relays, CEDAR)
- Resource discovery and rendezvous routing using contact-assisted protocols (e.g., MARQ, CARD, PARSE), and distributed consistent hashing (e.g., Rendezvous regions, GHT)

In addition, students get exposed to various wireless medium access control (MAC) protocols, including CSMA/CA (802.11), MACA, MACAW), and power-aware MAC (e.g., PAMAS, SMAC).

The students also gain knowledge of various movement and mobility models including random way point, group mobility, highway model, manhattan model, hybrid models, among others. Mobility metrics are defined for those models, including spatial correlation, temporal correlation, relative speed, link durations and path durations. These metrics enable us to differentiate these models, and have better understanding of their effects on protocol performance.

Furthermore the students get to know various IP mobility protocols for (a) inter-domain mobility, including Mobile IP and MIPv6, and (b) intra-domain micro-mobility, including hierarchical MIP, cellular IP, Hawaii and M&M. The students will be able to identify how wireless networks can be integrated with the wired Internet in a heterogeneous environment.

The term project has four main milestones: (1) an initial project proposal (approx. 2 pages) due around the 5th week of class, (2) a final project proposal (approx. 3 pages)

due around the 8th week of the semester, (3) an initial draft of the project report (approx. 8 pages) due around the 11th week of class, and (4) the final project report (approx. 12 pages) due on the last lecture.

(ii) The laboratory experiments start by introducing the test-bed configuration in the EE-351 wireless networking lab, followed by an experiment to setup routing configurations and measurements (for TCP and queueing disciplines) on those configurations. At the same time students perform experiments in and outside of the lab on measuring signal power strength, throughput, and delays of a wireless network using handheld PCs or laptops connected to base stations in the lab. After the students get familiar with the lab setting and the measurement tools they perform experiments for ad hoc routing in a multi-hop wireless network (sometimes using emulation) and experiments for a network of wireless sensor motes.

- Student responsibilities:
    - Attendance (lecture and lab sessions), class discussions, weekly reviews, paper readings
    - Participate in two presentations: topic presentation, project presentation
    - *High quality* final project report and demo
    - Team work, lab preparation, in-lab experiments/evaluation, assignments

This course relies heavily on students' own effort and experimentation. It is a hands-on course where most assignments are conducted in a laboratory setting by the students. The students are also involved in giving presentations and working in teams on a semester project.
The course is centered around the projects accompanied by lectures on theory and concepts (offered by the Prof. and the students), and lab experiments. The experiments (around 7 main experiments total) are carried out in groups of '3' or '4' students with combined reports. Each individual should understand and be able to perform the experiments on his/her own (there may be a random pop quiz to test this ability). Students will also be required to design parts of new lab experiments. The students will also be asked to write reviews for papers that will be presented in class (around 10 reviews total).
Students are expected to participate actively in various aspects of this course (such as, suggesting new experiments, carrying discussions on the class newsgroup, asking/answering questions on presented material, among others).
Instructions for the project proposal and report will be posted on the web in as much detail as possible. Similarly, instructions for performing lab experiments and samples of reviews will be posted.

- Pre-requisites:

  In general, very good knowledge of fundamentals of computer networks is required. In addition, very good programming skills are also a requirement, along with knowledge of operating systems (especially Unix/Linux). Knowledge of network simulation (especially using the network simulator (*ns*) or *Glomosim*), tcl/tk or a scripting language is a plus.

More specifically, the pre-requisite courses that *must* be taken (with good standing) before this course include: EE-555 or EE-550 or CS-551
The capacity of this course will be a *maximum* of '30' (thirty) students, chosen mainly based on academic merit, and background preparation.
Application form: Students willing to be considered for enrollment in this class must fill out an application form (to be placed at EEB-100 around mid October) indicating their background and preparation, interest in the wireless networking area, and their expectation of the class and the project.

- Grading:
  Class participation and 10 paper reviews (15%)
  Experiments and assignments (approximately 7 lab experiments) (28%)
  Topic Presentation (15%)
  Project(s):
    Project proposal (10%)
    Final project report (including project presentation/demo) (32%)

- Readings/books:
  Book: Ad Hoc Networking, edited by Charles Perkins, Addison Wesley, 2001, ISBN 0-201-30976-9
  Initial list of readings:

  - Unicast Adhoc routing (Week 1-2):
  - DSDV: C. E. Perkins, P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance Vector Routing for Mobile Computers", *ACM SIGCOMM CCR*, Oct. 1994.
  - DSR: D. B. Johnson, D. A. Maltz, "Dynamic Source Routing in Ad-Hoc Wireless Networks", *Mobile Computing*, 1996, pp.153-181.
  - AODV: C. E. Perkins, E. M. Royer, "Ad-hoc On-Demand Distance Vector Routing", 2nd *IEEE Workshop on Mobile Comp Systems and Applications*, Feb. 1999, p 90-100.
  - Comparison of unicast routing protocols in ad hoc networks: A. Iwata, C. Chiang, G. Pei, M. Gerla, T. Chen, "Scalable Routing Strategies for Ad Hoc Wireless Networks", IEEE *Journal on Selected Areas in Communications*, Vol. 17, No. 8, August 1999.
  - ZRP: Z. Haas, M. Pearlman, "The Performance of Query Control Schemes for the Zone Routing Protocol", *ACM SIGCOMM* '98.
  - ZRP: M. Pearlman, Z. Haas, "Determining the optimal configuration for the zone routing protocol", *IEEE JSAC*, p. 1395-1414, 8, Aug 1999.

  - Multicast Adhoc routing (Week 3):
  - ODMRP: S. Lee, M. Gerla, C. Chiang, "On-demand multicast routing protocol", *IEEE WCNC*, *p*. 1298-1302, vol. 3, 1999.
  - CAMP: J. J. Aceves, E. Madruga, "The Core-Assisted Mesh Protocol", *IEEE JSAC*, vol. 17, no. 8, pp. 1380-1394, August 1999.

- FGMP: C. Chiang, M. Gerla, L. Zhang, "Forwarding Group Multicast Protocol (FGMP) for Multihop, Mobile Wireless Networks", *ACM/Kluwer Journal of Cluster Computing*, vol. 1, no. 2, 1998.
- Comparison between multiple Multicast Ad Hoc protocols: S. Lee, W. Su, J. Hsu, M. Gerla, R. Bagrodia, "A Performance Comparison Study of Ad Hoc Wireless Multicast Protocols", *IEEE Infocom* 2000.

- Broadcast Adhoc routing (Week 4):

- OLSR: T. Clausen, P. Jacquet, A. Laouiti, P. Muhlethaler, A. Qayyum et L. Viennot, "Optimized Link State Routing Protocol", *IEEE INMIC* 2001.
- Heuristics: S. Ni, Y. Tseng, Y. Chen and J. Sheu, "The Broadcast Storm Problem in a Mobile Ad Hoc Network", *ACM Mobicom*, 1999.
- Minimum dominating set (MDS): H. Lim, C. Kim, "Flooding in wireless ad hoc networks", *Computer Communications Journal*, 24(3-4),353-363, 2001.
- Multi-point relay (MPR): A. Laouiti, A. Qayyum et L. Viennot, "Multipoint Relaying: An efficient technique for flooding in mobile wireless networks", *HICSS*, 2002.
- Comparative analysis: Yunjung Yi, Mario Gerla, Taek-Jin Kwon, "Efficient Flooding in Ad hoc Networks: a Comparative Performance Study", *IEEE ICC 2003*.

- Resource discovery and Rendezvous in MANets (Week 5-6):

- Grid: J. Li, J. Jannotti, D. Couto, D. Karger, R. Morris, "A Scalable Location Service for Geographic Ad Hoc Routing (GLS/Grid)", ACM Mobicom 2000.
- GHT: S. Ratnasamy, B. Karp, S. Shenker, D. Estrin, R. Govindan, L. Yin, F. Yu, Data-Centric Storage in Sensornets with GHT, A Geographic Hash Table, *ACM MONET*, 2003
- Jiangchuan Liu, Qian Zhang, Wenwu Zhu, Jun Zhang, and Bo Li, "A Novel Framework for QoS-Aware Resource Discovery in Mobile Ad Hoc Networks", *IEEE ICC*, 2002.
- Rendezvous Regions: A. Helmy, "Architectural Framework for Large-Scale Multicast in Mobile Ad Hoc Networks", *IEEE International Conference on Communications (ICC 2002)*, April 2002.
- MARQ: A. Helmy, "Mobility-Assisted Resolution of Queries in Large-Scale Mobile Sensor Networks (*MARQ*)", *Computer Networks Journal - Elsevier Science (Special Issue on Wireless Sensor Networks)*, August 2003.
- CARD: A. Helmy, S. Garg, P. Pamu, N. Nahata, "Contact Based Architecture for Resource Discovery (*CARD*) in Large Scale MANets", *Third IEEE/ACM International Workshop on Wireless, Mobile and Ad Hoc Networks (WMAN), part of IEEE/ACM IPDPS 2003*, April 2003, Nice, France.
- TRANSFER: A. Helmy, "*TRANSFER*: Transactions Routing for Ad-hoc NetworkS with eFficient EneRgy", *IEEE GLOBECOM*, San Francisco, December 2003.

- Geographic routing in MANets (Week 7-8):

- GPSR: B. Karp and H. T. Kung, "Greedy Perimeter Stateless Routing for Wireless Networks," *Proc. 6th Annual ACM/IEEE Int'l. Conf. Mobile comp. Net. (Mobicom)*,Boston, MA, Aug. 2000, pp.243-54.
- GOAFR: Fabian Kuhn, Roger Wattenhofer, Aaron Zollinger,"Worst-Case Optimal and Average-Case Efficient Geometric Ad-Hoc Routing", *ACM MobiHoc*, May 2003.
- A survey on position-based routing in mobile ad hoc networks Mauve, M. Widmer, A. Hartenstein, H. IEEE Network , Volume: 15 Issue: 6 , Nov/Dec 2001 Page(s): 30 -39
- LAR: Y. Ko, N. Vaidya, "Location-aided routing (LAR) in mobile ad hoc networks", Wireless Networks 6, 4, p. 307-321, July 2000.
- Geocast: Y. Ko, N. Vaidya, "Geocasting in mobile ad hoc networks: location-based multicast algorithms", IEEE WMCSA, p. 101-110, 1999.
- J. Navas, T. Imielinski, "GeoCast - Geographic Addressing and Routing", *MobiCom* 97.
- EASE: M. Grossglauser, M. Vetterli, "Locating Nodes with EASE: Last Encounter Routing for Ad Hoc Networks through Mobility Diffusion", *IEEE INFOCOM 03*, San Francisco, March 2003.
- FRESH: H. Dubois-Ferrière, M. Grossglauser, M. Vetterli, "Age Matters: Efficient Route Discovery in Mobile Ad Hoc Networks Using Encounter Ages", *ACM MOBIHOC 03* , Maryland, June 2003.
- Terminodes: L. Blazevic, L. Buttyan, S. Capkun, S. Giordano, J. Hubaux, and J. Le Boudec. Self-organization in mobile ad-hoc networks: the approach of terminodes, *IEEE Communications Magazine*, 2001.
- Terminodes: Ljubica Blazevic, Silvia Giordano, Jean-Yves Le Boudec. Anchored Path Discovery in Terminode Routing. *Networking* 2002: 141-153.

- Mobility modeling and simulation (Week 9-11):

- T. Camp, J. Boleng, and V. Davies, "A Survey of Mobility Models for Ad Hoc Network Research", *Wireless Communication & Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications*, vol. 2, no. 5, pp. 483-502, 2002. /
- X. Hong, M. Gerla, G. Pei, and C.-C. Chiang, "A Group Mobility Model for Ad Hoc Wireless Networks", *Proceedings of ACM/IEEE MSWiM'99*, Seattle, WA, Aug. 1999.
- X. Hong, T. Kwon, M. Gerla, D. Gu and G. Pei, "A Mobility Framework for Ad Hoc Wireless Networks", *Proceedings of ACM Second International Conference on Mobile Data Management (MDM '2001)*, Hong Kong, Jan. 2001.
- Christian Bettstetter, "Mobility Modeling in Wireless Networks: Categorization, Smooth Movement, and Border Effects", *ACM Mobile Computing and Communications Review*, vol. 5, no. 3, pp. 55-67, July 2001.
- M. Grossglauser and D. Tse, "Mobility Increases the Capacity of Ad Hoc Wireless Networks", *IEEE/ACM Trans. on Networking*, vol 10, no 4, August 2002. (Conf version: M. Grossglauser and D. Tse, "Mobility Increases the Capacity of Ad Hoc Wireless Networks", *IEEE INFOCOM*, Anchorage, Alaska, April 2001)

- InfoStation: D.J.Goodman,J.Borras,N.B.Mandayam,and R.D. Yates "INFOSTATIONS:A New System for Data and Messaging Services", *Proceedings of IEEE VTC '*97, 2 , 1997, pp.969-973.
- S. Diggavi, M. Grossglauser, D. Tse, "Even One-Dimensional Mobility Increases Ad Hoc Wireless Capacity", *ISIT 02*, Lausanne, Switzerland, June 2002.
- IMPORTANT: F. Bai, N. Sadagopan, A. Helmy, "The IMPORTANT Framework for Analyzing the Impact of Mobility on Performance of Routing for Ad Hoc Networks", *AdHoc Networks Journal - Elsevier Science*, August 2003. (Conf. version: F. Bai, N. Sadagopan, A. Helmy, " IMPORTANT: A framework to systematically analyze the Impact of Mobility on Performance of RouTing protocols for Adhoc NeTworks", *IEEE INFOCOM (The 22nd Annual Joint Conference of the IEEE Computer and Communications Societies)*, March/April 2003, San Francisco.)
- PATHS: N. Sadagopan, F. Bai, B. Krishnamachari, A. Helmy, " PATHS: analysis of PATH duration Statistics and their impact on reactive MANET routing protocols", *ACM MobiHoc (The Fourth ACM International Symposium on Mobile Ad Hoc Networking and Computing)*, June 2003.

- <u>MAC protocols for wireless networks (Week 12):</u>
- PAMAS: C. S. Raghavendra, Suresh Singh, "PAMAS -- Power Aware Multi-Access protocol with Signaling for Ad Hoc Networks," *Computer Communication Review*, July 1998.
- MACAW: Vaduvur Bharghavan, Alan Demers, Scott Shenker, Lixia Zhang, "MACAW: A Media Access Protocol for Wireless LAN's", *ACM SIGCOMM*, 1994.
- MACA: Chunhung Richard Lin and Mario Gerla , "MACA/PR: An Asynchronous Multimedia Multihop Wireless Network", In Proceedings of *IEEE INFOCOM*, 1997.
- MACA: F. Talucci, M. Gerla, and L. Fratta , "MACA-BI (MACA by invitation)- A Receiver Oriented Access Protocol for Wireless Multihop Networks", In Proceedings of *IEEE PIMRC*, 1997.
- SMAC: Wei Ye, John Heidemann and Deborah Estrin, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks", *In Proceedings of the 21st International Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2002)*, New York, NY, USA, June, 2002.

- <u>IP Mobility Support protocols, and micro-mobility (Week 13-14):</u>
- Mobile IP: C. Perkins, "IP Mobility Support", RFC 2002, Internet Engineering Task Force, October 1996.
- MIPv6: C. Perkins and D. Johnson, "Mobility Support in IPv6", Proceedings of MobiCom'96, November 1996.
- Hawaii: R. Ramjee, T. La Porta, L. Salgarelli, S. Thuel, K. Varadhan, L. Li, "IP-based access network infrastructure for next-generation wireless data networks", IEEE Personal Communications , Volume: 7 Issue: 4 , Page(s): 34 -41, Aug. 2000.

- Cellular IP: A. Campbell, J. Gomez, S. Kim, A. Valko, C. Wan, Z. Turanyi, "Design, implementation, and evaluation of cellular IP" IEEE Personal Communications , Volume: 7 Issue: 4 , Page(s): 42 -49, Aug. 2000.
- M&M: A. Helmy, M. Jaseemuddin, G. Bhaskara, "Multicast-based Mobility: A Novel Architecture for Efficient Micro-Mobility", *IEEE Journal of Selected areas in Communications (JSAC),* Sept 2003.
- M&M A. Helmy, "A Multicast-based Protocol for IP Mobility Support", *ACM SIGCOMM Second International Workshop on Networked Group Communication (NGC 2000), Palo Alto,* November 2000.

- Description of the networking laboratory experiments
  1. Week 1-2: (Intro to the lab) Unicast routing with dynamic routing protocols: learn how to setup a network topology (including wired and wireless components), setup the routing tables (manually or dynamically) and get to use tools to monitor the routing protocol performance and adaptivity under dynamics.
  2. Week 3-4: Measurement of TCP performance over wired and wireless networks: monitor, measure and analyze behavior of TCP over wired and wireless networks (using Mobile IP protocols)
  3. Week 5-6: Measurement of physical and MAC layer characteristics of wireless links: using signal strength, data rate, restransmission and delay measurements.
  4. Week 7-8: Differences and similarities between simulation and testbed experiments: use examples from wireless and wired networks to show similarities and differences between simulation and measured results (a) using TCP over wireless links, (b) using TCP over various queuing disciplines (FIFO, RED, WFQ).
  5. Week 9-10: Behavior of Mobile IP protocols: setup and monitor a wireless network including Mobile IP. Emulate mobility between two access points and record messages triggered by the mobility support protocol.
  6. Week 11-12: Analysis of Ad Hoc network routing: setup the ad hoc network routing protocol using link state (OLSR) or on-demand (DSR) on an emulated or real topology. Observe and record the dynamics of the routing protocol, and measure the throughput, delay, jitter and overhead.
  7. Week 13-14: Heterogeneous wireless networks: setup and experiment with a testbed consisting of a mix of handhelds, sensor nodes and base stations.

- Description of the networking laboratory (EEB 351):

Current equipment includes 35 PCs (for simulations and testbed), 20 laptops, handhelds (HP-Jornada) and pocket PCs (iPAQ), 3 wireless base stations and 14 wireless Orinoco/WaveLan cards, 10 wireless sensors (smart dust berkeley rene motes) among others. [Note: this is a joint research/instruction laboratory, so not all equipment are available for EE-579 students. Equipment will be available as necessary for the experiments.].

Statement for Students with Disabilities

‘Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m. – 5:00 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.’