CIS6930 Wireless Mobile Networks Design and Analysis, Spring 2007

Instructor: Prof. Ahmed Helmy

Lecture meeting time: Monday 10:40am-1:40pm, place: NRN (Norman Hall) 0184

- Course description:

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

Major term 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 mobile networks. It also involves students in group projects to identify challenging problems in wireless ad hoc networks through extensive reading and discussion, to propose solutions to those problems, then conduct high quality research (through extensive simulations, analysis and implementation) to produce a term project report (of conference and journal quality) that is the final product of their work.

More precisely, the objectives of this course are for the students:

- To acquire hands-on experience of 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.
- To be part of a team and to tackle challenging research problems in a semester-long 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.

  Skills acquired in this class should emphasize and supplement deep understanding of actual protocol and network behavior. Students develop and enhance their understanding of the basics of wireless networking, mainly at the network and MAC layers, the behavior of the fundamental and evolving network protocols (e.g., unicast/multicast ad hoc routing protocols, media access control (MAC) protocol of wireless networks, among others). Students also study that the network behavior is a collective behavior of all such protocols (and others), their interaction among themselves, and with the ‘faulty’ and dynamic network environment. By integrating network dynamics, such as packet losses, link/node failures and mobility, and through diagnostic and measurement tools, students study and analyze the effects of various network conditions on the overall behavior of the network.

Such deep practical understanding, along with strong analytical skills, are essential 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, (ii) a set of assignments and experiments.

(i) The lecture series starts by a set of ~3 weeks of lectures given by the instructor on fundamentals of mobile ad hoc networks, MAC, IP mobility and mobility models, followed by 2~3 three weeks of 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) and based on the projects progress. 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 the following list:
[* This list is updated during the semester based on discussion and students' interest]

- 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, landmark-based) and geographic routing (e.g., greedy routing, GPSR)
- 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 consistent distributed hashing (e.g., Rendezvous regions, GHT)
- Multicast routing using tree or mesh-based protocols (e.g., ODMRP, CAMP, FGMP) or extensions of unicast adhoc routing (e.g., MAODV, MCEDAR)

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 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.

Project: The term project has four main milestones: (1) an initial project proposal (~2 pages) due around the 5^{th} week of class, (2) a final project proposal (3~4 pages) due around the 8^{th} week of the semester, (3) an initial draft of the project report (~8 pages) due around the 11^{th} week of class, and (4) the final project report (~12 pages) due on the last lecture.

(ii) Assignments and experiments:
Students perform experiments around campus on measuring signal power strength, throughput, and delays of a wireless network using handheld PCs or laptops connected to base stations around the University of Florida campus.
The students also perform experiments for ad hoc routing in a multi-hop wireless network and experiments for a network of wireless sensor nodes and motes.

Examples of experiments/assignments include:
- Drawing a wireless coverage map and measurements (cross validation through various measurement techniques, GPS, encounters, etc.)
- Encounter based networks (discovering devices, building ad hoc net, increasing the coverage of the wireless net, using static or mobile nodes, etc.)
- The 'socializer' experiments: establishing friendship and interest group links in mobile societies (through analysis of traces, mobile device experiments, surveys, etc.)
- Simulation of disaster scenarios and establishment of networks for the relief and search/rescue missions.

The over-arching themes for the Spring '07 class for the project and experiments will be:
- disaster relief networks, and mobile social networking.

The experiments 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 random pop quizes to test this ability). Students will also be required to design parts of new experiments. The students will also be asked to write reviews for papers that will be presented in class.

- Student responsibilities:
    - Attendance, class discussions, weekly reviews, paper readings
    - Participate in two presentations: topic presentation, project presentation
    - *High quality* final project report and demo
    - Team work, assignment and experiments evaluation

This course relies heavily on students' own effort and experimentation. It is a hands-on course where many presentations and experiments are conducted by the students. The students are also involved in working in teams on a semester project.

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 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 a network simulator such as *NS, Glomosim, OpNet* or other), 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: graduate level networking course.
The capacity of this course will be a *maximum* of 25 students, chosen mainly based on academic merit, and background preparation.

- Grading:
  Class participation and paper reviews (15%)
  Experiments and assignments (~4 experiments) (20%)
  Topic Presentation (15%)
  Project(s):
    Project proposal (10%)
    Final project report (including project presentation/demo) (40%)

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

  Some related websites:
  - The IMPORTANT mobility framework and mobility simulation tool: http://nile.cise.ufl.edu/important/ (or nile.usc.edu/important)
  - MobiLib (Community-wide Library of Mobility and Wireless Networks Measurements): http://nile.cise.ufl.edu/MobiLib/ (or nile.usc.edu/MobiLib)
  - The VINT project; NS (Network Simulator) and NAM (Network Animator): http://www.isi.edu/nsnam/vint

  Initial list of readings (to be updated every semester and during class as per the discussions and the student interest/input):

  - 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.

- IP Mobility Support protocols, and micro-mobility (Week 13-14):

- 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.