CSC7290: Advanced Computer Networking

Hongwei Zhang

http://www.cs.wayne.edu/~hzhang
Q0: Why this (and not other) network topology?
Internet structure: network of networks

Q0': Why this (and not other) network hierarchy?
Q1: Why this (and not other) end-to-end path?
Q1': Given a network topology and a routing protocol, how is link weight decided?
Recurring questions in emerging contexts
Objectives of the course

- **Ultimate goal:**
  - You become an expert in network design and optimization

- Humble course objectives:
  - To help students understand the *foundation, algorithms, and systems techniques* for network design and optimization
  - To help students appreciate both classical and emerging *network design problems*
  - To build up students' capability in enhancing the state of the art in computer networking

**Suppose we are building the Internet from scratch up:**
How to solve different network design and optimization problems (e.g., topology design, routing)
Topics to cover

- **Introduction**
  - Overview of network design
  - Notation and illustrations of network design problems
  - Technology-specific network modeling

- **Foundation**
  - Modeling of network design problems
  - General optimization methods for network design:
    - linear programming
    - mixed-integer programming
    - stochastic heuristic methods
    - convex programming
    - multi-commodity flow optimization, etc
Case studies of classical network design problems
- Location and topological design
- Shortest-path routing
- Fairness, network resilience, etc

Case studies of emerging network design problems (*project-based*)
- Vehicular networks
- Sensor networks
- Wireless networks
Two major components of the course

- **Lecture**
  - Focus on basic concepts, techniques, and tools

- **Project**
  - Applying the basic concepts, techniques, and tools to real-world applications, especially in *innovative, emerging* networking technologies such as embedded wireless networks as used in connected vehicles, smart grid, and industrial automation
Textbooks

Required:

Recommended references:
Logistics

- Class timings
  - MW 3:00pm-4:20pm in 318 State Hall

- Office hours
  - MW 4:30pm-5:30pm in Suite 14101.3, Maccabees Building, or by appointment

- Teaching Assistant
  - TBA
Logistics (contd.)

- **Prerequisites**
  - Basic knowledge of computer networks, for instance, materials covered in CSC4290/CSC6290 or equivalent
  - Calculus, linear algebra
  - Or consent of instructor.

- **Course website**
  - [http://www.cs.wayne.edu/~hzhang/courses/7290b/7290b.html](http://www.cs.wayne.edu/~hzhang/courses/7290b/7290b.html)

- **Course mailing list**
  - csc7290@lists.wayne.edu
  - Web-section only: csc7290-web@lists.wayne.edu
Logistics (contd.)

- Grading
  - Class participation: 10%
  - TinyExam: 30%
  - Project: 60%
  - *Note: Students in the web section are required to come to campus to take the quizzes and to give the project presentations in class*

- Letter grades will be assigned based on performance *relative* to other students;
  A tentative grading scale:
  - A: 93-100
  - A-: 90-92
  - B+: 85-89
  - B: 80-84
  - B-: 75-79
  - C+: 70-74
  - C: 65-69
  - C-: 60-64
  - F: 0-60
Project

The project consists of three parts:

- Study *embedded wireless networking* for intra- and/or inter-vehicle sensing and control, smart grid sensing and control, or industrial plant sensing and control; characterize the corresponding *traffic demand* in wireless networked sensing and control;

- Formulate and solve the *network design problem* for wireless networked sensing and control in connected vehicles, smart grid, or industrial automation;

- *Implement and evaluate* the performance of your solution in TOSSIM, another simulator, or NetEye testbed.
Overview of an emerging networking technology ---

**Wireless Sensor Networks**

- Opportunities
- Challenges in network/system design
Retrospect on computing & networking

ENIAC: first computer (1945)

Apple II: first successful PC (1977)

Laptop, PDA ... (1979 -)

First computer network

Internet, wireless ...
What if
Ubiquitous Computing & Networking + Sensing & Control

→ Ubiquitous, fine-grained sensing & control
Sensor nodes

- A XSM sensor node (2004)
  - 8MHz CPU, 4KB RAM, 128KB ROM
  - Chipcon CC1000 radio: 19.2 kbps
  - Infrared, acoustic, and magnetic sensors
  - Sounder
  ...

- Many more (2001 - )
Wireless sensor networks: innovative ways of interacting with the world ...

Science: ecology, seismology, oceanography ...

Engineering: industrial automation, precision agriculture, structural monitoring ...

Daily life: traffic control, health care, home security, disaster recovery, virtual tour ...
Tiny computers that constantly monitor ecosystems, buildings, and even human bodies could turn science on its head.

— *Nature*, March 2006

The use of sensornets throughout society could well dwarf previous milestones in information revolution.

— *National Research Council* report, 2001
Sensor networks of today

- Redwood ecophysiology
- Wind response of Golden Gate Bridge
- Intruder detection, classification, and tracking
ExScal

- Field project to study scalability of middleware and applications in sensornets
- Deployed in an area of \(~1,300\text{m} \times 300\text{m}\)
- 2-tier architecture
  - Lower tier: \(~1,000\) XSM, \(~210\) MICA2 sensor nodes (TinyOS)
  - Higher tier: \(~210\) IEEE 802.11b Stargates (Linux)
Other sensornet projects/applications

- Precision agriculture
- Social networking
- Ecosystem conservation
- Homeland security
- Healthcare
- Industrial control

...
Precision agriculture: smart vineyard

monitor soil humidity, temperature, chemistry ...
Social dynamics and networking
BikeNet: mobile sensing system for cyclist experience mapping

- Monitor cyclist performance/fitness: speed, distance traveled, calories burned, heart rate, galvanic skin response, etc
- Collect environmental data: pollution, allergen, noise, and terrain condition monitoring/mapping, etc
TurtleNet: track wood-turtles...

the turtle came out of the water to sun itself for only brief periods and went back into the colder water...
SealNet: use nature to help scientific study

- To measure ocean’s *temperature* and *salinity* levels, as well as the seal’s location and depth.

- Sensing data are collected for every dive; Each time the seals resurfaced to breathe, that data was relayed via satellite to certain data centers in US and France

  - As the seals migrated and foraged for food during their winter journey, they circumnavigated the Antarctic continent and its continental shelf, diving down to 2,000 feet more than 60 times a day
Homeland security: BioWatch ...
Healthcare

Medical implant: artificial retina ...

Assisted living: health monitoring & coordination ...

Health-environment monitoring: air quality, noise, bio & chemical-agent ...
Industrial control: Intel Semiconductor Factory monitoring ...

Preventative equipment maintenance: monitoring vibration signals ...
Vehicular sensor networks
New applications and startups keep emerging...

- A seamless cyber-physical world of intelligent computing and networking agents...
Are sensornets mature enough to be readily used in practice?

Each large scale project may well take

- 5 professors
- 10 PhDs
- 20 Master and undergraduate students
- A few months/years of hard work
- $$$
- ...

Components of one application do not work for another!
Challenges of sensor network design?!
Challenging aspects of sensor networks

- Dynamic, unreliable, and interference-prone wireless channels
- Reliable messaging

Indoor testbed at OSU; 3 feet node separation
- 300 data points for each distance, with each data point representing the status of 100 broadcast transmissions
Challenging aspects of sensor networks

- Dynamic, unreliable, and interference-prone wireless channels
  - Reliable messaging

- Resource constraints (e.g., bandwidth, energy, memory)
  - Resource-efficient services, sensornet architecture

- 19.2 kbps
- 2 AA batteries
- 4KB RAM
...
Challenging aspects of sensor networks

- Dynamic, unreliable, and interference-prone wireless channels
  - Reliable messaging

- Resource constraints (e.g., bandwidth, energy, memory)
  - Resource-efficient services, sensornet architecture

- Application diversity (e.g., traffic patterns, QoS requirements)
  - Application-adaptivity
    - Periodic data collection
    - Can tolerate certain data loss and delay
    - Infrequent aperiodic report of hazards
    - Need reliable and real-time report
Challenging aspects of sensor networks

- Dynamic, unreliable, and interference-prone wireless channels
  - Reliable messaging

- Resource constraints (e.g., bandwidth, energy, memory)
  - Resource-efficient services, sensor network architecture

- Application diversity (e.g., traffic patterns, QoS requirements)
  - Application-adaptivity

- Complex faults and large system scale
  - Dependability despite fault complexity and system scale
    - Node/link failure, state corruption, system signal loss, malfunctioning sensor, etc
    - Increased overall probability of fault occurrence
    - Fault propagation
Challenging aspects of sensor networks

- Dynamic, unreliable, and interference-prone wireless channels
  - Reliable messaging

- Resource constraints (e.g., bandwidth, energy, memory)
  - Resource-efficient services, sensornet architecture

- Application diversity (e.g., traffic patterns, QoS requirements)
  - Application-adaptivity

- Complex faults and large system scale
  - Dependability despite fault complexity and system scale

- Heterogeneity
  - Architecture and service provisioning in integrated systems
Challenging aspects of sensor networks

- Dynamic and potentially unreliable wireless channels
  - Reliable messaging
- Resource constraints (e.g., bandwidth, energy, memory)
  - Resource-efficient services
- Application diversity (e.g., traffic patterns, QoS requirements)
  - Application-adaptivity
- Complex faults and large scale
  - Dependability irrespective of scale
- Growing heterogeneity
  - Architecture and service provisioning in integrated systems

More challenges: real-time, programming, management, connectivity
OUR FOCUS (1): mission-critical vehicular sensing and control
Our focus (2): mission-critical sensing and control in smart grids and industrial automation
Project (contd.)

- Rules
  - Students are allowed to form groups in doing projects, but the number of students per group should be no more than 2

- Deliverables
  - In-class presentation
  - Written project report (in the form of a technical paper)

- Timeline
  - Form your project team and select reading materials by 01/31/2015
  - Submit your detailed project plan (including precise problem formulation) and timeline by 02/28/2015
  - Submit slides for your presentation at least one day before your presentation (date to be decided)
  - Submit your project report electronically by midnight 05/01/2015
Project (contd.)

- Evaluation criteria
  - Breadth and depth of your understanding of the problem, as evidenced by your project report and presentation
  - Presentation quality (e.g., clarity, readability, and conciseness) of your talk and written report
  - Whether or not you are able to stick to the project timeline
Project (contd.): related resources

- **MatLab**

- **AMPL/CPLEX optimization software package**
  - [http://www.ampl.com/](http://www.ampl.com/)

- **Tools for performance evaluation**
  - Network simulators: TOSSIM, ns-2, qualnet/glomosim, opnet
  - NetEye sensor network testbed

- **TinyOS**
  - TinyOS Community Forum, [http://www.tinyos.net/](http://www.tinyos.net/)
  - TinyOS documentation: [http://www.tinyos.net/tinyos-2.x/doc/](http://www.tinyos.net/tinyos-2.x/doc/)
  - Resources on using TinyOS and motes: [http://www.tinyos.net/scoop/special/support](http://www.tinyos.net/scoop/special/support)
What is this course NOT for?

- Technology tutorial
  - Instead, we focus on foundational issues
- Network programming
- Assemble networks with switches, routers, firewalls, etc.
- Design websites

- I do not really want to learn anything new, just want to get the credits and a good grade 😊
Policies

- Lecture attendance required
  - *Students in web section*: watch webcasting after each lecture and ask questions via the course mailing list

- TinyExam

- Exercises
  - Strongly encouraged; help understanding and quiz

- Frequently check out the course website for updated information

- Other university regulations apply
How to succeed in this course?

- Attend lectures
  - Look at the “big” screen, NOT the “small” computer monitor
- Read books
- Work on exercises and project
- Ask questions!!!
Student questionnaire

- Name (optional):
- E-mail (optional):
- Major:
- Degree/Expected Year:
- Previous coursework in computer networking:
- Previous coursework in calculus, linear algebra, probability theory, and statistics:
- What do you expect to learn from this course? How do you think this course should be taught?
- How might this course contribute to your career objectives?