Chapter 1
INTRODUCTION

Course Objectives:

- This course will cover the fundamental aspects of wireless networks, with emphasis on current and next-generation wireless networks. Various aspects of wireless networking will be covered including: fundamentals of cellular communication, mobile radio propagation, multiple access techniques, mobility support, channel allocation, Wireless PAN/LAN/MAN standards, mobile ad-hoc networks, wireless sensor networks, and routing in wireless and mobile networks.
- The goal of this course is to introduce the students to state-of-the-art wireless network protocols and architectures.
- We will introduce the students to wireless networking research and guide them to investigate novel ideas in the area via semester-long research projects.
- We will also look at industry trends and discuss some innovative ideas that have recently been developed. Some of the course material will be drawn from research papers, industry white papers and Internet RFCs.
Wireless History

- Ancient Systems: Smoke Signals, Carrier Pigeons, …
- Radio invented in the 1880s by Marconi
- Many sophisticated military radio systems were developed during and after WW2
- Cellular has enjoyed exponential growth since 1988, with almost 1 billion users worldwide today
  - Ignited the recent wireless revolution
  - 3G roll-out disappointing in Europe, nascent in US
  - Asia way ahead of the rest of the world
- Much hype in 1990s, great failures around 2000
  - 1G Wireless LANs/Iridium/Metricom

Exciting Developments

- Internet and laptop use exploding
- 2G/3G wireless LANs growing rapidly
- Huge cell phone popularity worldwide
- Emerging systems such as Bluetooth, UWB, Zigbee, and WiMAX opening new doors
- Military and security wireless needs
- Important interdisciplinary applications
Future Wireless Networks

Ubiquitous Communication Among People and Devices

- Wireless Internet access
- Nth generation Cellular
- Wireless Ad Hoc Networks
- Sensor Networks
- Wireless Entertainment
- Smart Homes/Spaces
- Automated Highways
- All this and more…
  - Hard Delay Constraints
  - Hard Energy Constraints

Design Challenges

- Wireless channels are a difficult and capacity-limited broadcast communications medium

- Traffic patterns, user locations, and network conditions are constantly changing

- Applications are heterogeneous with hard constraints that must be met by the network

- Energy and delay constraints change design principles across all layers of the protocol stack
Evolution of Current Systems

- Wireless systems today
  - 2G Cellular: ~30-70 Kbps.
  - WLANs: ~10 Mbps.

- Next Generation
  - 3G Cellular: ~300 Kbps.
  - WLANs: ~70 Mbps.

- Technology Enhancements
  - Link: Antennas, modulation, coding, adaptivity, DSP, BW.
  - Network: Dynamic resource allocation. Mobility support.
  - Application: Soft and adaptive QoS.

"Current Systems on Steroids"

Future Generations

<table>
<thead>
<tr>
<th>Rate</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b WLAN</td>
<td>2G Cellular</td>
</tr>
<tr>
<td>3G</td>
<td>4G</td>
</tr>
</tbody>
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Other Tradeoffs:
- Rate vs. Coverage
- Rate vs. Delay
- Rate vs. Cost
- Rate vs. Energy

Fundamental Design Breakthroughs Needed
Multimedia Requirements

<table>
<thead>
<tr>
<th></th>
<th>Voice</th>
<th>Data</th>
<th>Video</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>&lt;100ms</td>
<td>-</td>
<td>&lt;100ms</td>
</tr>
<tr>
<td>Packet Loss</td>
<td>&lt;1%</td>
<td>0</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>BER</td>
<td>$10^{-3}$</td>
<td>$10^{-6}$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Data Rate</td>
<td>8-32 Kbps</td>
<td>1-100 Mbps</td>
<td>1-20 Mbps</td>
</tr>
<tr>
<td>Traffic</td>
<td>Continuous</td>
<td>Bursty</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

One-size-fits-all protocols and design do not work well
Wired networks use this approach, with poor results.

Wireless Performance Gap

![Wireless Performance Gap Graph]
Quality-of-Service (QoS)

- QoS refers to the requirements associated with a given application, typically rate and delay requirements.
- It is hard to make a one-size-fits-all network that supports requirements of different applications.
- Wired networks often use this approach with poor results, and they have much higher data rates and better reliability than wireless.
- QoS for all applications requires a cross-layer design approach.

Crosslayer Design

- Application
- Network
- Access
- Link
- Hardware

Adapt across design layers
Reduce uncertainty through scheduling
Provide robustness via diversity
Current Wireless Systems

- Cellular Systems
- Wireless LANs
- Satellite Systems
- Bluetooth
- Ultrawideband radios
- Zigbee radios

Fundamentals of Cellular Systems

Illustration of a cell with a mobile station and a base station
FDMA (Frequency Division Multiple Access)

FDMA Bandwidth Structure

Total bandwidth

Frequency
FDMA Channel Allocation

User 1 → Frequency 1
User 2 → Frequency 2
... → ...
User n → Frequency n

Mobile Stations → Base Station

TDMA (Time Division Multiple Access)

Frequency

User 1 | User 2 | ... | User n

→ Time
TDMA Frame Structure

```
1 2 3 4 ... n
```

Time

Frame

TDMA Frame Illustration for Multiple Users

User 1

User 2

...  

User n

Mobile Stations

Base Station
CDMA (Code Division Multiple Access)

Transmitted and Received Signals in a CDMA System

- Information bits
- Code at transmitting end
- Transmitted signal
- Received signal
- Code at receiving end
- Decoded signal at the receiver
Frequency Hopping

Cellular System Infrastructure

Early wireless system: Large zone
Cellular Systems:
Reuse channels to maximize capacity

- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations/MSCs coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden
MS, BS, BSC, MSC, and PSTN

Control and Traffic Channels
Steps for a Call Setup from MS to BS

1. Need to establish path
2. Frequency/time slot/code assigned
   (FDMA/TDMA/CDMA)
3. Control Information Acknowledgement
4. Start communication

Steps for a Call Setup from BS to MS

1. Call for MS # pending
2. Ready to establish a path
3. Use frequency/time slot/code
   (FDMA/TDMA/CDMA)
4. Ready for communication
5. Start communication
A Simplified Wireless Communication System Representation

Information to be transmitted (Voice/Data)
- Coding
- Modulator
- Transmitter

Information received (Voice/Data)
- Decoding
- Demodulator
- Receiver

Antenna

Signaling

*signaling: exchange of messages among network entities to enable (provide service) to connection/call*

- before, during, after connection/call
  - call setup and teardown (state)
  - call maintenance (state)
  - measurement, billing (state)
- between:
  - end-user <-> network
  - end-user <-> end-user
  - network element <-> network element
Telephone network: circuit-switched voice trunks (data plane)

Telephone network: data and control planes
SS7: telephone signaling network

Note: redundancy in SS7 elements

Signaling System 7: telephone network signaling

- **out-of-band signaling**: telephony signaling carried over separate network from telephone calls (data)
  - allows for signaling between any switches (not just directly-connected)
  - allows for signaling during call (not just before/after)
  - allows for higher-than-voice-data-rate signaling
  - security: in-band tone signaling helps phone phreaks; out of band signaling more secure

- SS7 network: *packet-switched*
  - calls circuit-switched

- lots of redundancy (for reliability) in signaling network links, elements
Signaling System 7: telephone network

- signaling between telephone network elements:
  - signaling transfer point (STP):
    - packet-switches of SS7 network
    - send/receive/route signaling messages
  - signaling control point (SCP):
    - “services” go here
    - e.g., database functions
  - signaling switching point (SSP):
    - attach directly to end user
    - endpoints of SS7 network

Example: signaling a POTS call

1. caller goes offhook, dials callee. SSP A decides to route call via SSP B. Assigns idle trunk A-B
2. SSP A formulates Initial Address Message (IAM), forwards to STP W
3. STP W forwards IAM to STP X
4. STP X forwards IAM SSP B

Example: signaling a POTS call

5. B determines it serves callee, creates address completion message (ACM[A,B,trunk]), rings callee phone, sends ringing sound on trunk to A.

6. ACM routed to Z to Y to A.

7. SSP A receives ACM, connects subscriber line to allocated A-B trunk (caller hears ringing).

8. Callee goes off hook, B creates, sends answer message to A (ANM[A,B,trunk]).

9. ANM routed to A.

10. SSP A receives ANM, checks caller is connected in both directions to trunk. *Call is connected!*
Example: signaling a 800 call

800 number: logical phone number

- translation to physical phone number needed

1. A begins signaling to set up call to number associated with 800 number

Example: signaling a 800 ca11

800 number: logical phone number

- translation to physical phone number needed, e.g., 1-800-CALL_ATT translates to 162-962-1943

1. Caller dials 800 number, A recognizes 800 number, formulates translation query, send to STP W

2. STP W forwards request to M

3. M performs lookup, sends reply to A
3G Cellular Design: Voice and Data

- Data is bursty, whereas voice is continuous
  - Typically require different access and routing strategies
- 3G “widens the data pipe”:
  - 384 Kbps.
  - Standard based on wideband CDMA
  - Packet-based switching for both voice and data
- 3G cellular struggling in Europe and Asia
- Evolution of existing systems (2.5G, 2.6798G):
  - GSM+EDGE
  - IS-95(CDMA)+HDR
  - 100 Kbps may be enough
- What is beyond 3G? The trillion dollar question

Third Generation Cellular Systems and Services

  - Fulfill one's dream of anywhere, anytime communications a reality.
- Key Features of IMT-2000 include:
  - High degree of commonality of design worldwide;
  - Compatibility of services within IMT-2000 and with the fixed networks;
    - High quality;
    - Small terminal for worldwide use;
    - Worldwide roaming capability;
    - Capability for multimedia applications, and a wide range of services and terminals.
Third Generation Cellular Systems and Services

- **Important Component of IMT-2000 is ability to provide high bearer rate capabilities:**
  - 2 Mbps for fixed environment;
  - 384 Kbps for indoor/outdoor and pedestrian environments;
  - 144 kbps for vehicular environment.

- **Standardization Work:**
  - Release 1999 specifications
  - In processing

- **Scheduled Service:**
  - Started in October 2001 in Japan (W-CDMA)

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### Subscriber Growth

- **3G Subscribers**
- **2G Digital only Subscribers**
- **1G Analogue only Subscribers**
Wireless Local Area Networks (WLANs)

- WLANs connect “local” computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
  - Poor performance in some apps (e.g. video)

Wireless LAN Standards

- **802.11b (Current Generation)**
  - Standard for 2.4GHz ISM band (80 MHz)
  - Frequency hopped spread spectrum
  - 1.6-10 Mbps, 500 ft range

- **802.11a (Emerging Generation)**
  - Standard for 5GHz NII band (300 MHz)
  - OFDM with time division
  - 20-70 Mbps, variable range
  - Similar to HiperLAN in Europe

- **802.11g (New Standard)**
  - Standard in 2.4 GHz and 5 GHz bands
  - OFDM
  - Speeds up to 54 Mbps

In 200?, all WLAN cards will have all 3 standards.
Satellite Systems

- Cover very large areas
- Different orbit heights
  - GEOs (39000 Km) versus LEOs (2000 Km)
- Optimized for one-way transmission
  - Radio (XM, DAB) and movie (SatTV) broadcasting
- Most two-way systems struggling or bankrupt
  - Expensive alternative to terrestrial system

Bluetooth

- Cable replacement RF technology (low cost)
- Short range (10m, extendable to 100m)
- 2.4 GHz band (crowded)
- 1 Data (700 Kbps) and 3 voice channels
- Widely supported by telecommunications, PC, and consumer electronics companies
- Few applications beyond cable replacement
Ultrawideband Radio (UWB)

- UWB is an impulse radio: sends pulses of tens of picoseconds ($10^{-12}$) to nanoseconds ($10^{-9}$)
- Duty cycle of only a fraction of a percent
- A carrier is not necessarily needed
- Uses a lot of bandwidth (GHz)
- Low probability of detection
- Excellent ranging capability
- Multipath highly resolvable: good and bad
  - Can use OFDM to get around multipath problem.

IEEE 802.15.4 / ZigBee Radios

- Low-Rate Low-Cost WPAN
- Data rates of 20, 40, 250 kbps
- Star clusters or peer-to-peer operation
- Support for low latency devices
- CSMA-CA channel access
- Very low power consumption
- Frequency of operation in ISM bands

*Focus is primarily on radio and access techniques*
Emerging Systems

- Ad hoc wireless networks
- Sensor networks
- Distributed control networks
Ad-Hoc Networks

- Peer-to-peer communications.
- No backbone infrastructure.
- Routing can be multihop.
- Topology is dynamic.
- Fully connected with different link SIRs

Design Issues

- Ad-hoc networks provide a flexible network infrastructure for many emerging applications.
- The capacity of such networks is generally unknown.
- Transmission, access, and routing strategies for ad-hoc networks are generally ad-hoc.
- Crosslayer design critical and very challenging.
- Energy constraints impose interesting design tradeoffs for communication and networking.
Sensor Networks

Energy is the driving constraint

- Nodes powered by nonrechargeable batteries
- Data flows to centralized location.
- Low per-node rates but up to 100,000 nodes.
- Data highly correlated in time and space.
- Nodes can cooperate in transmission, reception, compression, and signal processing.

Spectrum Regulation

- Spectral Allocation in US controlled by FCC (commercial) or OSM (defense)
- FCC auctions spectral blocks for set applications.
- Some spectrum set aside for universal use
- Worldwide spectrum controlled by ITU-R

Regulation can stunt innovation, cause economic disasters, and delay system rollout
Interacting systems require standardization

Companies want their systems adopted as standard
- Alternatively try for de-facto standards

Standards determined by TIA/CTIA in US
- IEEE standards often adopted
- Process fraught with inefficiencies and conflicts

Worldwide standards determined by ITU-T
- In Europe, ETSI is equivalent of IEEE

Protocols are standardized by IETF as RFCs