Preview of today’s lecture

- Introduction to wireless communication
- Wireless communication lab at UT
  - How the course works
  - A DSP approach to wireless
  - Connection to the lab
  - Contents of the course
  - Materials
- Preparation for next week
Introduction to wireless communication

Key points

- Understand the different applications of wireless communications
- A view of current and under development wireless technologies
Wireless is everywhere

- Cellular networks
- Local area networks
- Personal area networks
- Emerging applications
The cellular concept

- Base stations serve multiple subscribers
- Frequencies are geographically reused in cells
- Handoff provides seamless connection
Evolution of cellular systems

- First generation systems - known after the fact as 1G
  - Conceived in the 1960’s
  - Deployed in the late 1970’s / early 1980’s
  - Built around analog technology, FM modulation
  - Limited data, little security
  - Expensive due to analog technology
  - Little roaming
  - Examples AMPS, NTT, NMT-450, etc.


Most of you in have never used 1G 😞
Evolution of cellular systems

- Second generation systems - known as 2G
  - Conceived in the 1980’s
  - Deployed in the 1990’s
  - **Digital Voice**
  - More subscribers per bandwidth, some data
  - Enabled roaming in Europe (GSM)
    - not in US (IS-95, IS-136)
  - Examples GSM, IS-95, IS-136, PDC, EDGE (2.5G)

- Image from [http://www.tutorialspoint.com/gsm/gsm_mobile_station.htm](http://www.tutorialspoint.com/gsm/gsm_mobile_station.htm)

You may not have used 2G, but many phones are 2G compatible
Evolution of cellular systems

- Third generation systems - known as 3G
  - Conceived in the 1990’s
  - Deployed in the 2000’s
  - Digital voice plus data
  - Video telephony
  - Higher capacity
  - CDMA (code division multiple access)
  - Examples: 3GPP WCDMA, HSDPA, etc.

  3GPP2 cdma2000, 1xEV, 1xEV-DO, 1xEV-DV, etc.

Most phones are 3G compatible, and revert to 3G occasionally
Evolution of cellular systems

- After 3G, cellular systems began fine-grained development
  - 3GPP updates were made in stages e.g. R7, R8, R9, R10, R11, etc
  - Transition to 4G at Release 10 known as 3GPP LTE Advanced

- Fourth generation systems - known as 4G
  - IP based backbone, supports VoIP
  - OFDMA allows efficient resource allocation
  - MIMO (multiple antennas)
    - 8 @ base station, 4 at handset
  - Higher data rates
  - 3GPP Long Term Evolution Advanced

Most of you use 4G on a daily basis
Evolution of cellular systems

- Fifth generation systems - known as 5G
  - 3GPP after Rel-14 is considered as 5G new radio (NR)
  - Rel-15, the first 5G NR release, was frozen in Jun. 2018
  - Rel-16, the next 5G NR release, was kicked off in Jun. 2018
  - Target completion date for Rel-16 is Dec. 2019

- Key features of 3GPP 5G NR Rel-15
  - Numerology, frame structure and initial access support for above-6 GHz
  - New channel coding (LDPC for data, Polar codes for control)
  - MIMO enhancements: beam management for above-6 GHz
  - MIMO enhancements: new codebook for more antenna configurations

With 5G everything will be connected: you, your pet, your car, …
Evolution of cellular systems

- Other features
  - Vehicle to X (V2X)
  - Non-orthogonal multiple access (NOMA)
  - Industrial IoT
  - Location and positioning enhancements
  - URLLC enhancements

With 5G everything will be connected: you, your pet, your car, …
Wireless is everywhere

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IEEE 802.11 Wireless LAN

- IEEE is the Institute of Electrical and Electronics Engineers
  - Main professional society for electrical engineers
  - Everyone should become a student member of the IEEE
  - You might also want to join COMSOC (communications society), SPSOC (signal processing society), and ITSOC (information theory society)

- IEEE 802 is a group that develop local area network and metropolitan area network standards, focusing on the PHY, MAC, and LINK layers

- IEEE 802.11 is WLAN working group (members develop standards + vote)
IEEE 802.11 Subgroups

- **802.11**: 1/2Mbps in 2.4GHz band, FHSS or DSSS
- **802.11a**: extend to 5GHz band, 54Mbps, OFDM
- **802.11b** (WiFi): DSSS with 11Mbps in 2.4GHz band
- **802.11g**: similar to 802.11a but for 2.4GHz
- **802.11n**: MIMO enhancement, 100-200Mbps
- **802.11ac**: Very high throughput < 6GHz carrier
  - More bandwidth aggregation, more MIMO, multiuser MIMO
- **802.11ad**: Very high throughput > 6GHz carrier

Many more subgroups, some successful and some not
New generation of WLAN operates at 60 GHz

<table>
<thead>
<tr>
<th>Standard</th>
<th>Bandwidth</th>
<th>Rates</th>
<th>Approval Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.11ad</td>
<td>2.16 GHz</td>
<td>6.76 Gbps</td>
<td>Dec. 2012</td>
</tr>
</tbody>
</table>

- Wireless local area networking (WLAN)
  - Gbps peak throughputs
  - In-room local area networking
  - Cable replacement
- Chipsets are available and some products are shipping
- Next gen is currently in development (802.11ay)****
  - Will support MIMO spatial multiplexing
  - Channel bonding for even larger bandwidths
  - Targets 100 Gbps data rates
Wireless is everywhere

- Cellular networks
- Local area networks
- Personal area networks
- Emerging applications
Personal Area Networks (PAN)

- Lower range connectivity compared to WLAN
  - Cable replacement is one of the primary applications
  - Has an ad hoc network architecture (usually called a piconet)
- IEEE 802.15 is the main standard
  - Examples are Bluetooth used for keyboards and handsfree headsets

PAN/LAN boundaries are blurring
New generation WPAN at 60 GHz

<table>
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<th>Standard</th>
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</tr>
</thead>
<tbody>
<tr>
<td>WirelessHD 1.1</td>
<td>2.16 GHz</td>
<td>4 x 7.138 Gbps</td>
<td>Jan. 2010</td>
</tr>
</tbody>
</table>

- Wireless personal area networking (WPAN)
  - Multimedia streaming especially HDMI
  - Peripheral connections
  - Wearable networks
- Compliant products are available
  - Dell Alienware laptops, Epson projectors, etc.

* http://www.wirelesshd.org/consumers/product-listing/
Other applications of wireless

- wearables
- car area networks
- mobile ad hoc networks
- powerline communication
- vehicular area networks
- underwater communication
Wireless communications lab at UT EE 471C / EE 381K-17

Key points
- Main contents of the course
- Connection between the lectures and labs
- Materials required
Preview of today’s lecture

◆ Introduction to wireless communication

◆ Wireless communication lab at UT
  ✩ How the course works
  ✩ A DSP approach to wireless
  ✩ Connection to the lab
  ✩ Contents of the course
  ✩ Materials

◆ Preparation for next week
Wireless communications lab @ UT

- Instructor: Robert W. Heath Jr.
- TA: Yi Zhang
- EE 471C Prerequisites: EE 345S or EE 351M or EE 360K
- Premises of the course
  - Wireless communication can be taught to undergraduates
  - Wireless communication can be taught w/out communication background
  - Students can implement what they learn while they learn it
- Key ideas
  - Teach digital communication from a digital signal processing perspective
  - Incorporate modulation, channel estimation, equalization, synchronization
  - Use algorithmic design examples, not comprehensive theory
  - Leverage flexible software defined radio prototyping

Developed and tested over 12 years
How it works

- The course is **cross-listed** for undergrads and grads
  - Pre-requisites: a course in DSP and a course on probability
  - Undergraduates take in 3rd or 4th year as a **4 credit course**
  - Graduate students take their 1st or 3rd semester as a **3 credit course**

- **Structure of the course**
  - 3 hours of lecture per week, covers the theory of the course
  - 3 hours in the lab per week, demonstrate what has been learned
  - Homework assignments include theory and lab preparation
  - Two midterm exams, one final exam
Grad versus undergrad

- Lectures, assignments, and homework is the same

- Graduate course requires a final project
  - Implementation of key features of IEEE 802.11ad (preferred), or
  - Research paper

- Final grading of undergrad and grad sections is independent
  - Please note the grading is not dependent
  - Seriously, the grades are computed differently
  - This doesn’t mean, however, that you should slack off in either case
Differences with other courses at UT

- EE 445S (real-time DSP) – one of the possible pre-reqs, covers DSP theory, uses communications as a design example

- EE 360K (digital communications) – another possible pre-req, focuses more on digital communication

- EE 381K II (wireless communications) – communication theory fundamentals, more of a system perspective, less emphasis on algorithms

This course emphasizes signal processing for communications
- Includes channel estimation and frame / frequency offset synchronization
- Single carrier frequency domain equalization
- OFDM with channel estimation and synchronization
- Has a lab component
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The network stack

OSI Network Model

Focus of this class

Signal Processing Algorithms
Antennas & Circuits
DSP approach to wireless

Use systems approach for communication
Typical digital communication system
How this fits with the lab

transmitter

Source → Channel Coding → Modulation → D/A → RF Upconversion

receiver

Sink → Channel Decoding → Demodulation → A/D → RF Downconversion

channel

Laptop with MATLAB
(all digital signal processing)

NI USRP 2921

Real world
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Content of the course

- Digital comm overview
- Signals, stochastic processes
- Transforms, sampling theorem
- Frequency response, power spectrum, bandwidth
- Upconversion, downconversion, complex baseband
- Quadrature pulse amplitude modulation
- Optimal pulse shapes
- Maximum likelihood detection in AWGN
- Sample timing offset, sample timing algorithms
- Frequency selective channels, least squares channel estimation
- Frequency offset estimation and correction, frequency domain equalization
- Single carrier frequency domain equalization, OFDM, the cyclic prefix
- Introduction to propagation, large-scale fading, link budgets, path-loss
- Small-scale fading, coherence time, coherence bandwidth
- Introduction to MIMO communication, spatial multiplexing
- Introduction to MIMO-OFDM
- Multiuser and massive MIMO
- Millimeter wave MIMO
Content of the course

- Digital comm overview
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New features for Fall 2018

◆ All labs are being rewritten to use the USRP + MATLAB
  ✦ Leverages available universal drivers for MATLAB
  ✦ Less time spent learning LabVIEW, more on other experiments

◆ Better coordination of the lecture and lab materials
  ✦ Labs and homeworks are tightly coupled
  ✦ Reduced redundancy between the lecture and lab
  ✦ Material in lab comes after the lecture
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Course textbook

- Written over 12 years
  - Around 470 pages
  - Many examples
  - Problems from homeworks / exams

- Innovations from previous years
  - More examples
  - Additional problems
  - New content especially in impairments
Laboratory equipment

- Tunable RF Transceiver
- Signal Processing and Synthesis
- Time Reference
- Frequency Reference
- MIMO cable to connect 2 USRPs
- Gigabit Ethernet to PC
  - Plug-and-play capability
  - Up to 25 MS/s baseband IQ
- Power Supply

You will plug the USRP into your laptop (bring gigabit ethernet adapter)
Laboratory experiments

Software defined radio and the USRP hardware
Working with the USRP
Estimating signal parameters
Sampling and interpolation
Communication in AWGN channels
Narrowband channel impairments
SCFDE and channel estimation
Joint carrier frequency offset estimation and synchronization
OFDM and channel estimation
Synchronization in OFDM systems
Preview of today’s lecture

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◆ Preparation for next week
Preparation for next week

◆ Reading
  ✦ Chapter 1 and 2 of the textbook

◆ Lab
  ✦ Introduction to the USRP
  ✦ No preparation required
  ✦ For future labs: Review MATLAB and install on your laptop

◆ Homework
  ✦ Complete homework #1