Digital Wireless Communications (361-2- 5901) Fall 2017

מקצוע קדם: מבוא לתורת התקשורת (361-1-3221)

<u>Abstract</u>

Wireless communications is a one of the most rapidly evolving fields in electrical engineering. Recent years have witnessed the expansion of wireless communication into every aspect of modern life including, among others, business, leisure, healthcare and transportation. In recent years the development of *5G cellular* has been making rapid progress. It is clear today that 5G will be based on *massive MIMO* communications and on node cooperation. Another notion that is in the present focus is the *internet of things* (IoT). IoT will heavily rely on communications which will be realized by low-cost devices and will operate in unfavorable conditions. Understanding how to optimally implement communications, e.g., for 5G and IoT.

In order to support the future direction of wireless communications, communication systems have become more complex than ever and in accordance so have the tools required to design and analyze them. This class aims at introducing the students to some of the most advanced methods for analysis of modern communications systems and the basic principles guiding their design. The knowledge given in the class is fundamental and will remain valid as new standards evolve.

<u>Syllabus</u>

Channel models: fading channels, the Rayleigh fading model, channel characteristics (Doppler spread, delay spread, coherence), multipath. Error exponent, lower bound on the capacity of the channel, sphere packing bound on the error exponent. SISO Gaussian channel: capacity with and without fading, ergodic capacity, outage and outage capacity, diversity in communication over fading channels. MIMO communications: diversity gain, multiplexing gain (degrees of freedom), diversity-multiplexing tradeoff. Multicarrier modulation and OFDM: water-filling over parallel Gaussian channels. Secure communications: principles of physical-layer security. Cooperation in multi-user wireless networks: types of relays, achievable rates with decode-and-forward, diversity-multiplexing tradeoff for single antenna relays with decode-and-forward (full duplex vs. half duplex), clustering, virtual MIMO.

Reference Texts:

- Andrea Goldsmith. Wireless Communication. Cambridge University Press, 2006.
- Robert Gallager. Information Theory and Reliable Communication. Wiley, 1968.
- David Tse and Pramod Viswanath. *Fundamentals of Wireless Communication*. Cambridge University Press, 2005.

Instructor:

Ron Dabora (<u>http://www.bgu.ac.il/~daborona</u>). Office hours: By appointment.

Lectures:

Wednesdays 1pm-4pm, Bldg. 90, Room 240.

Administrative & Grading:

- Grade composition: 100% homework.
 - There will be 4 homework sets.

- Homework assignments are to be submitted two weeks after publication (strict deadline).
 Homework submission is mandatory.
- Homework assignments are individual.
- In HWs 1-3 each homework question is 10 points. In HW 4 the points are indicated for each item.
- The final grade will be : (Total HW points received) / 145 * 100.

"Digital Wireless Communication" Tentative Class Outline

- 1. Introduction, course overview and channel models
 - Placing the class in context: overview of subjects to be covered and motivation.
 - Channel models: multiples reflectors (Jakes/Clarke's model), Rayleigh fading, Rician fading, flat fading, selective fading, multipath.
 - Shadowing (relationship to the concept of outage).
 - Channel characteristics: Doppler spread, delay spread, coherence time, coherence bandwidth.
- 2. The error exponent for the discrete point-to-point channel
 - Error exponent and random coding.
 - Derivation of a lower bound on capacity using the ML decoder (upper bound on the probability of error). Mutual information.
 - Sphere packing bound (lower bound on the probability of error), the reliability function and cutoff rate. Practical implications: optimal modulator design, complexity.
- 3. Single-input-single-output (SISO) Gaussian channel
 - Capacity for additive white Gaussian noise (AWGN) channels.
 - Limits for asymptotically high bandwidth and the minimum Eb/N0.
 - Capacity for fading channels
 - Fast Rayleigh fading: ergodic capacity.
 - Slow fading: outage capacity.
- 4. Concept of diversity for communication over fading channels: time, frequency and space.
 - Maximal diversity for SIMO and MISO communications: Schemes and performance analysis.
- 5. Basic concepts of multiple-input-multiple-output (MIMO) communication
 - Capacity expression for MIMO AWGN channels.
 - Diversity gain.
 - Example: maximum-ratio combining.
 - Degrees of freedom \ multiplexing gain.
 - Example: 2X2 system.
- 6. Multicarrier modulation and OFDMA
 - $\circ~$ Power allocation: water-filling over parallel Gaussian channels.
 - $\circ~$ Implementation of multicarrier modulation via OFDM.
- 7. Secure physical-layer communications
 - Definition of secure communications.
 - Modelling secure physical layer scenarios.
 - $\circ~$ The principles of secure physical-layer transmission.
- 8. Diversity-multiplexing tradeoff (DMT)
 - •Detailed derivation of the basic result.
- •Examples: evaluating DMT for V-Blast and Alamouti's scheme against the optimal tradeoff.
- 9. Cooperation in multi-user wireless networks
 - Types of relays: regenerative, decode-and-forward.
 - Achievable rate of decode-and-forward (w/o derivation).
 - Diversity-multiplexing tradeoff for single antenna relays: multi-hop relays with decode-and-forward (full duplex vs. half duplex), clustering, virtual MIMO.

10. Summary and pointers to additional topics

- Uplink: multiple access: ALOHA, multi-packet reception
- Downlink: broadcast, superposition coding.
- The (near) future: 5G, IoT.