Course Introduction

ECE-GY 6023: WIRELESS COMMUNICATIONS

PROF. SUNDEEP RANGAN

People and Time

- Professor: Sundeep Rangan, srangan@nyu.edu
  - Office Hours: Wed 3-4pm
- Course Assitant: None
  - But my PhD students may help
- Class time: Tuesdays 6 to 8:30, 2 Metrotech Room 810
  - I will try to also broadcast on Zoom for those unable to attend
  - Attendance is optional
  - Lectures and problems
- Online lectures from 2020 available on YouTube.
  - YouTube Wireless comm playlist
  - They are a bit out of date, but mostly OK

What is Wireless Communications?

Any communication of information via electromagnetic radio waves without a conductor

Wireless channel

Transmitter

Receiver

Wireless Communications Examples

Smartphones

Cellular base stations

WiFi Access points

Bluetooth devices

Wireless sensors

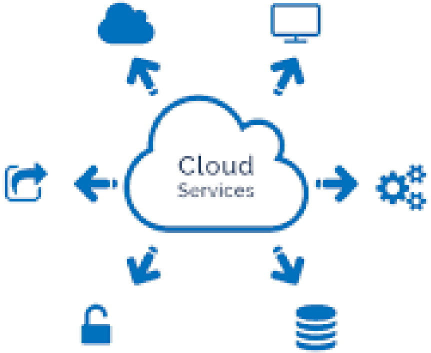
Satellite communications

Many New Applications are Coming



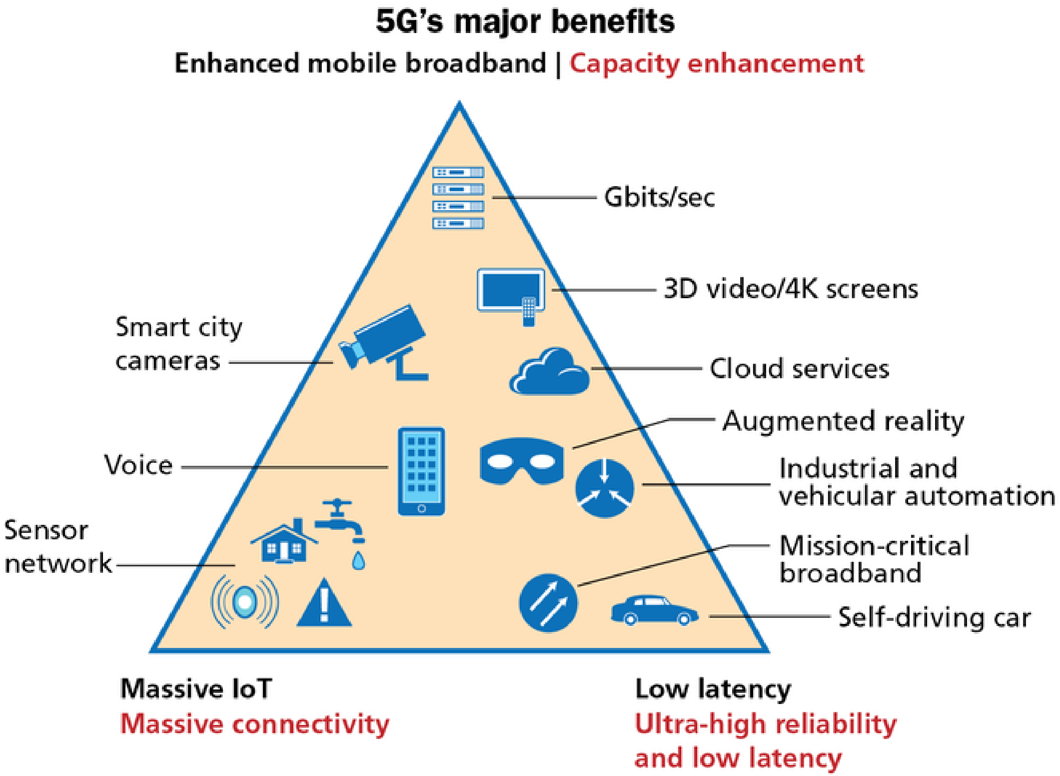


- Wireless connectivity can provide:
  - Portability and mobility
  - High data rates or low delay
  - Ubiquitous access to cloud services and data

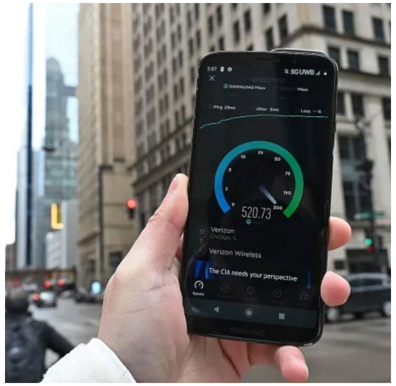


Virtually every electronic device can benefit from wireless connectivity!

5G and Wireless Evolving Today



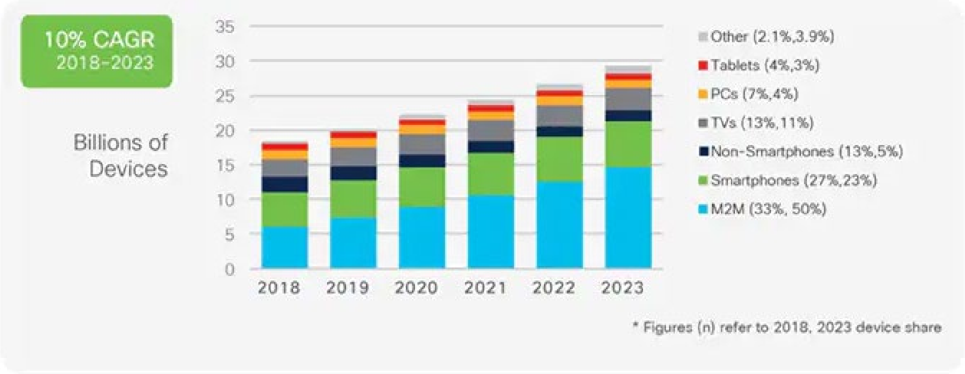
Source: ETSI/3GPP presentation, 2016



Photos from Sam Rutherford,
[Wind, Sleet, and Dead Zones: My Quest to Map Chicago's Spotty 5G]

Trial results in VZ 5G Chicago network

Wireless Continues to Grow



By 2023: >25 billion wirelessly connected devices
–Cisco Annual Internet Report (2018–2023)

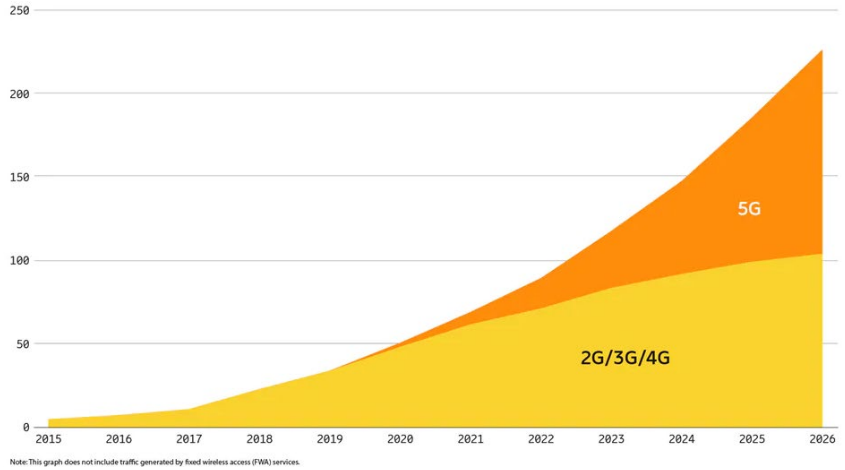


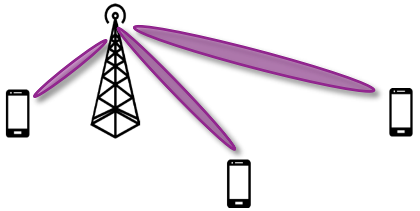
Figure 12: Global mobile data traffic (EB per month)

By 2026:

- 54% of cellular traffic will be 5G
- > 200 EtaBytes / month = 10^6 TB

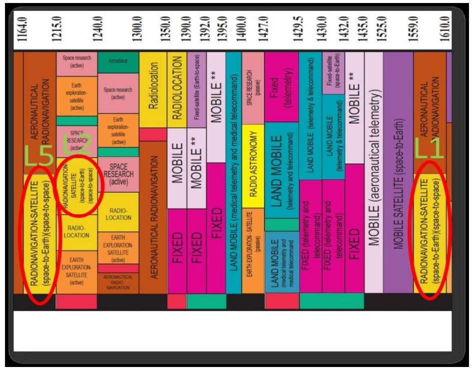
-Ericcson Mobile Data Traffic Outlook

Key Challenges for Wireless



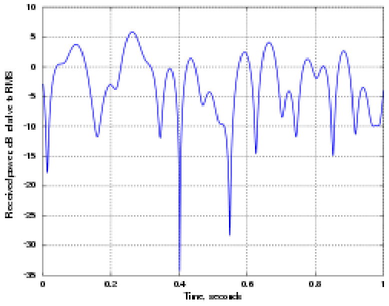
Interference and multiple users

Wireless signals radiate in all directions



Limited spectrum

Licensed and unlicensed communications



Fading and propagation

Signals have limited range

Channel quality fluctuates in time with motion

Power consumption

Limited battery and processing

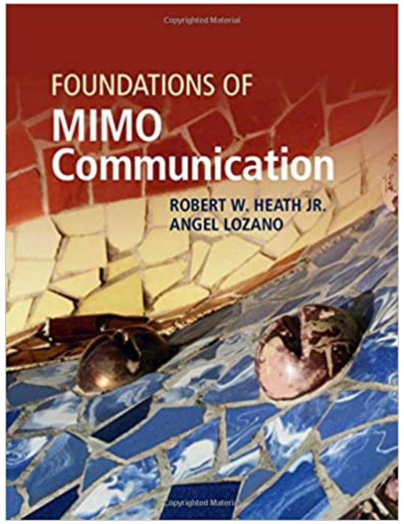
Course Learning Objectives

- Mathematically model and simulate wireless propagation
  - Antennas, EM waves
  - Multipath channels, statistical models, multi-antenna systems
- Simulate and build simple wireless transceivers
  - Filtering, synchronization, equalization, coding, …
  - MAC and network layer protocols
  - Connect it all together for a simple end-to-end system
- Analyze and optimize the system
  - Define and measure key performance metrics
  - Model impairments in the channel and devices
- Describe and analyze commercial wireless systems in use today
  - 4G, 5G cellular systems, WiFi, many others

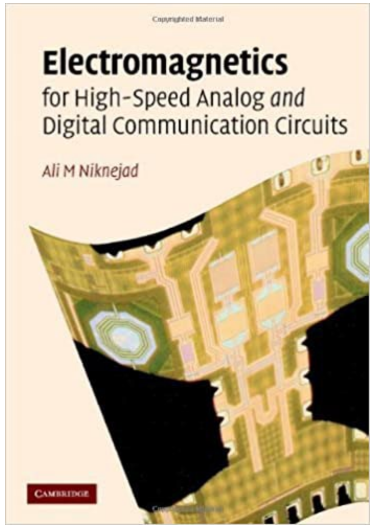
Pre-Requisites

- Graduate-level class intended for MS and PhD students in Electrical Engineering
- Course may also be of interest to:
  - Working engineers in the field
  - Related areas: Robotics or vision
- Graduate probability and digital communications
  - NYU students: ECE-GY 6013 Digital communications
  - Basics of modeling key components: mixing, synchronization, sampling, equalization, channel coding
  - Probability: Random variables and random processes
- Programming:
  - Exercises are in MATLAB and Python
  - Any programming experience is probably suitable

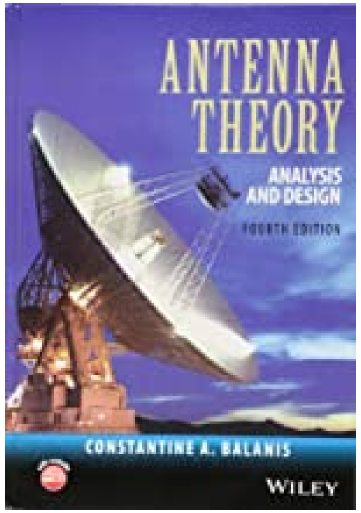
Supplementary Texts



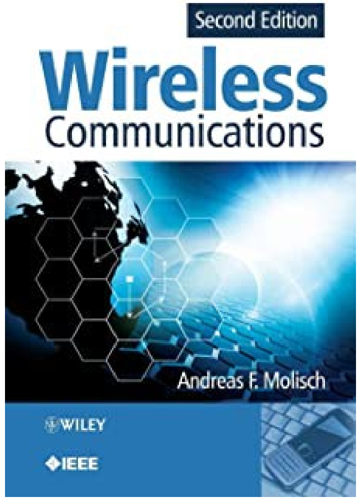
Up-to-date information theoretic perspective



EM from wireless comm perspective.
Great material on high-speed RF



Classic text on antennas



Encyclopedic reference for wireless

- No required text, but there are many good references

GitHub

- All material can be found on GitHub: https://github.com/sdrangan/wirelesscomm
  - Lecture slides
  - Links to lecture videos
  - In-class MATLAB exercises
  - Problems and labs
- Clone this repository
- Pull to get latest material
- Solutions to problems and labs:
  - Given to NYU students enrolled in class

ECE-GY 6023. Introduction to Wireless Communications

This repository is currently a collection of lecture material for ECE-GY 6023 Introduction to Wireless Communications at NYU taught by Prof. Sundeep Rangan. The class is intended to be for MS and PhD students in Electrical Engineering. Right now, only a small amount of material is available, but we are hoping to add more over the course of the semester.

Pre-requisites

The course assumes you are familiar with digital communications at the graduate level. There are many resources for digital communications, including some lecture notes I created for the NYU class.

Additionally, some lecture notes (and problems to be added later) assume you have access to MATLAB along with the communications, phased array and antenna toolboxes.

Lecture Sequence

The tentative plan for the lectures are below. Right now, only a few lectures have full material. We will be hoping to add to this material over the course of the semester. Other topics may be added at the end depending on time.

- Course Introduction
- Unit 1. Basics of Antennas and Free-space Propagation
  - Lecture: [PDF] [PPT]
  - Demo: Calculating and displaying antenna patterns [PDF] [Matlab]
  - Problems: [PDF] [Latex]
  - Lab: Simulating a 28 GHz antenna for a UAV [PDF] [Matlab]

Digital Communications

- Github site for digital communications: https://github.com/sdrangan/digitalcomm
- This class (or equivalent) is a pre-req
- Use this material for review if needed
- Github site has:
  - Lecture slides
  - In-class MATLAB exercises
  - Problems and labs
  - But no videos

Digital Communications

Prof. Sundeep Rangan, NYU:

This repository provides instructional material for digital communications. The material is used for EL-GY 6013: Digital Communications*, a graduate level class at NYU Tandon.

Anyone is free to use and copy this material (at their own risk!). But, please cite the material if you use the material in your own class.

- Introduction
  - Course Admin [pdf] [Powerpoint]
  - Matlab and SDR Lab: Getting started and transmitting and receiving complex baseband samples
- Unit 1. Passband modulation
  - Lecture notes [pdf] [Powerpoint]
  - In-Class exercises: [Matlab] [Soln]
  - Problems [pdf] [Latex]
  - Matlab and SDR Lab 1.1: Complex exponentials, frequency and carrier offset estimation
  - Matlab and SDR Lab 1.2: Up- and down-conversion
- Unit 2. Symbol mapping and transmit filtering
  - Lecture notes [pdf] [Powerpoint]
  - In-Class exercises: [Matlab] [Soln]
  - Problems [pdf] [Latex]
  - MATLAB and SDR Lab: Symbol Mapping and TX Filter design

MATLAB

- Most labs, demos and in-class exercises will be in MATLAB
  - Some parts may also use Python
- Download the latest MATLAB
- NYU students can get this for free:
  - https://www.mathworks.com/academia/tah-portal/new-york-university-618777.html
  - Make sure you get R2023B (Latest version)
- Communications, Antenna and Phased Array Toolboxes
  - Very powerful set of tools for simulating wireless systems
  - Building blocks for all common parts
  - Antennas, phased arrays
  - Channels, modulators, demod, coding, decoding, …
  - Can integrate with Simulink
  - Can even export to HDL for synthesis

OFDM with User-Specified Pilot Indices

This example shows how to construct an orthogonal frequency division modulation (OFDM) n
transmission over a 3x2 channel, pilot indices are created for each of the three transmit anter

Create an OFDM modulator object having five symbols, three transmit antennas, and length s

```
ofdmMod = comm.OFDMModulator('FFTLength',256, ...
    'NumGuardBandCarriers',[12; 11], ...
    'NumSymbols', 5, ...
    'NumTransmitAntennas', 3, ...
    'PilotInputPort',true, ...
    'Windowing', true, ...
    'WindowLength', 6);
```

Specify pilot indices for even and odd symbols for the first transmit antenna.

```
pilotIndOdd = [20; 58; 96; 145; 182; 210];
pilotIndEven = [35; 73; 111; 159; 197; 225];

pilotIndicesAnt1 = cat(2, pilotIndOdd, pilotIndEven, pilotIndOdd, ...
    pilotIndEven, pilotIndOdd);
```

Generate pilot indices for the second and third antennas based on the indices specified for th

MATLAB Live Editor

- Some course material MATLAB Live Editor
  - Will be used for in-class exercises, some labs
- Similar to Python jupyter notebook
  - All code and text cells
  - Rich content and links
  - But you need to view them in MATLAB IDE
  - Cannot view in browser

Antenna and Free-Space Propagation In-Class Exercises

These exercises follow the lectures and are to be done at the end of each section.

Problem 1: Computing Wavelength and E-Field Amplitude

Suppose that an EM-plane wave:

- Power flux density is 1 nW/m^2
- Freq = 2.3 GHz

Print the:

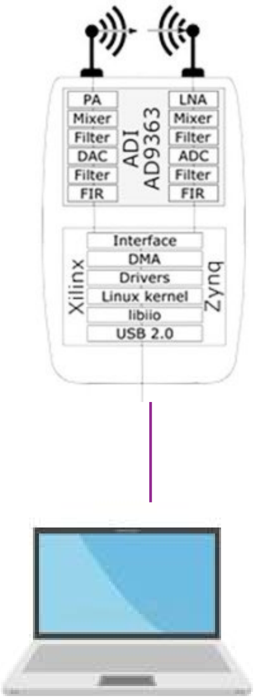
- Maximum E-field value
- Wavelength. You may use the `physconst('Lightspeed')` command to get the speed of light.

Make sure you print the units.

```
% TODO
```

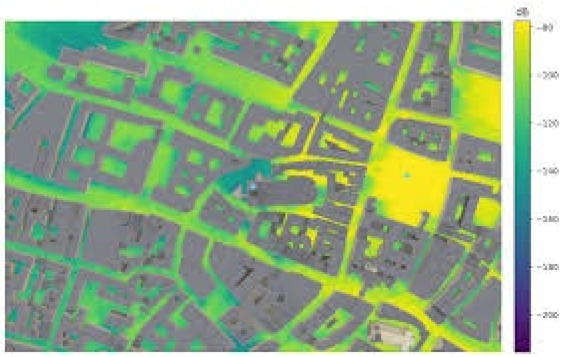
Software-Defined Radio (SDR) Labs

- Based on ADALM-Pluto devices
  - Simple, but powerful
  - Low cost
- Used in non-real-time mode
  - TX and RX signals over the air
  - Analyze offline in MATLAB
- Continue labs from digital communications
  - Measure and analyze fading channels
  - Equalization
  - Coding
- May add labs additional labs for MIMO
  - But needs other hardware



MATLAB

Nvidia Sionna



- Sionna https://nvlabs.github.io/sionna/
- Nvidia PHY layer simulation tool
- Native integration in Tensorflow
  - Excellent for projects with ML
- Full python based
  - Can be run in Google colab
- Complete integration with ray tracing
- Many comms functions
  - Basic antennas, channels, modulation, coding
  - Some 5G methods
- Not as extensive as MATLAB's Toolbox
- I will move some labs to sionna

```python
# number of bit per QAM symbol
self.num_bits_per_symbol = num_bits_per_symbol

# init components
self.source = BinarySource()

# initialize mapper and demapper for constellation object
self.constellation = Constellation("qam",
                                    num_bits_per_symbol=self.num_bits_per_symbol)
self.mapper = Mapper(constellation=self.constellation)
self.demapper = Demapper(demapping_method,
                          constellation=self.constellation)

# the channel can be replaced by more sophisticated models
self.channel = AWGN()

# FEC encoder / decoder
self.encoder = encoder
self.decoder = decoder
```

Grading

- Grading:
  - 25% Homework (including MATLAB exercises)
  - 25% Midterm 1, 25% Midterm 2
  - 25% Project

- Exams: Midterms will be given remotely
  - Take home. Approximately one day to complete.
  - May use any material in the class or Internet
  - Just cannot talk to a friend

Project

- Groups of two
- Any topic of your interest in the area of wireless
- Example:
  - 802.11ad, LTE, 5G, …
- Does not need to be original research.
  - Can be a solid implementation of something standard with a comprehensive evaluation.
- Should involve some extensive simulation
  - You need a comprehensive simulation of at least one component
  - Better yet, some experimental component
  - Code will be graded for quality
- Will give presentation in final lecture

Project Grading

- Formulation
  - How well did you formulate the problem? Was it clear? What were you trying to achieve?
- Approach and Design
  - Does your approach properly solve your problem? Is the design logical? Is the design robust?
- Evaluation and Interpretation
  - How did you evaluate the approach? Were the metrics correct? What were the test assumptions?
  - Did you test against alternative approaches?
- Implementation
  - Did the software work? Was it well-structured, commented. How modular is it?
- Presentation
  - Were the ideas clear? Were all the details conveyed. Did you highlight the main points?
  - You can select a number of formats. Whatever makes sense. A github page
- Bonus
  - Given for particularly hard / novel research

Many Resources for Your Projects

- You will simulate an end-to-end system of your choice
- Your project should comprehensively test at least one component
  - Ex: equalization, effect of phase noise, …

- Many great resources:
  - MATLAB 5G toolbox
  - MATLAB HDL generator
  - Orbit testbed in Rutgers
  - ADAM Pluto
  - Nvidia Sionna