ECEN310 Communications Engineering (Lec 0 Introduction)

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Communications is everywhere…

Communication Engineering Course Overview

- This is a 1 semester undergraduate course, covering the basics of Communication Engineering :

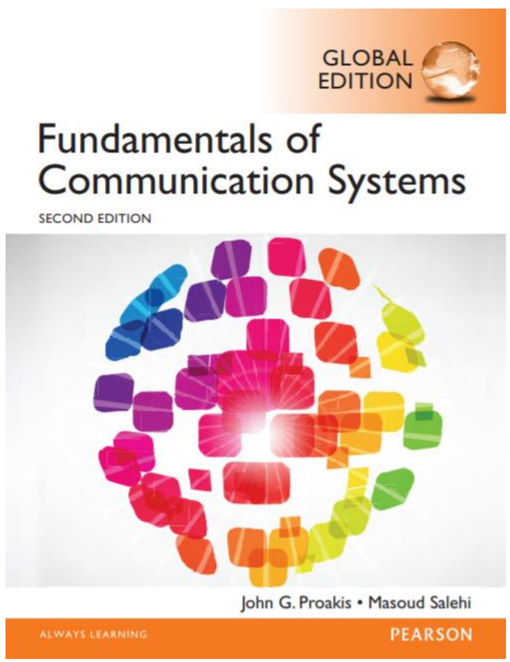
  - ☐ Revision on Signals and Systems
  - ☐ Amplitude Modulation
  - ☐ Frequency/Phase Modulation
  - ☐ Line Coding
  - ☐ (Random process and noise)
  - ☐ Digital Shift Keying techniques
  - ☐ Performance of digital techniques

All LABS will be conducted by Fu Maozhong

Textbook

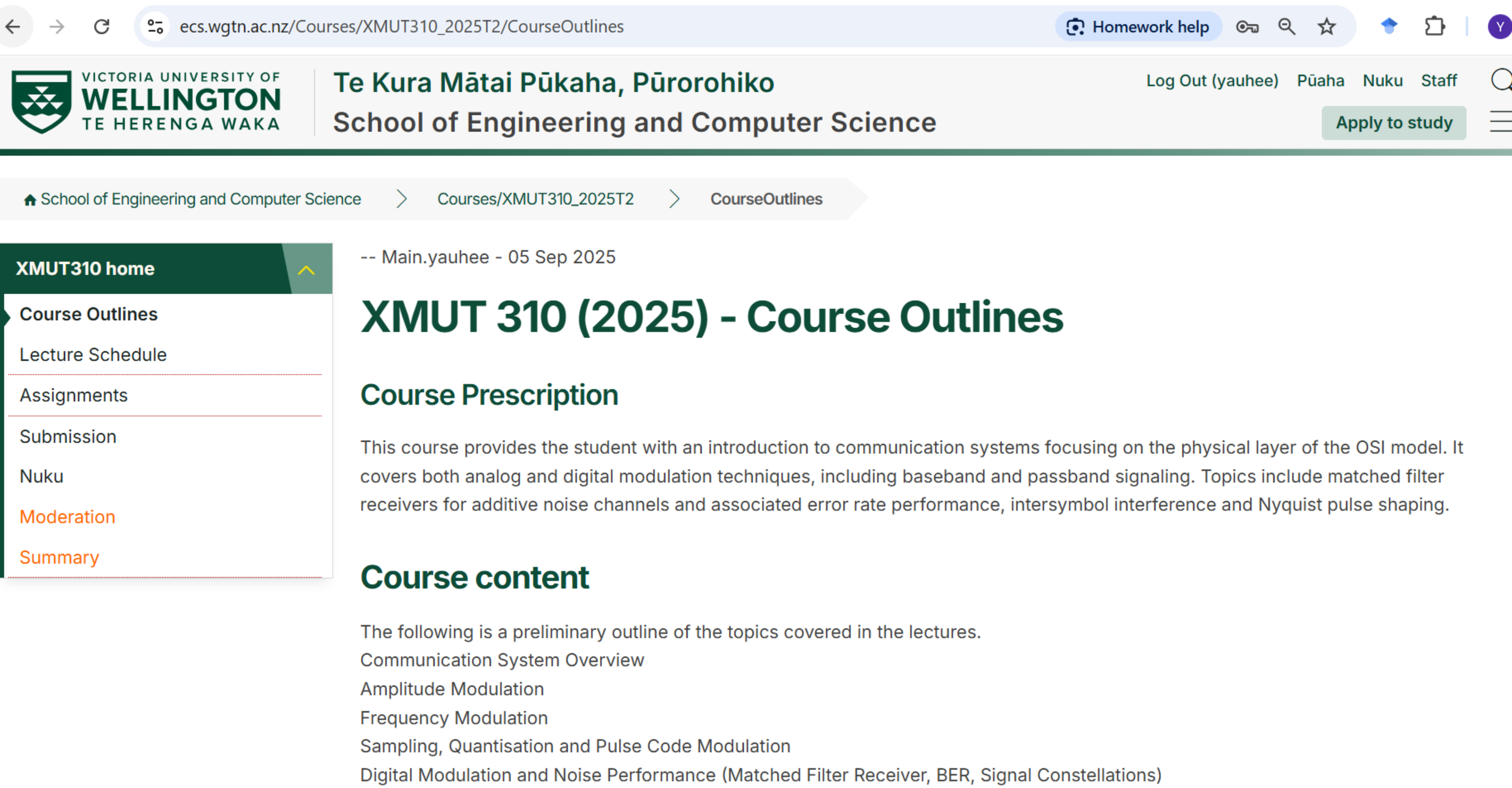
- ☐ Any book on Communication Engineering is equally good.
- ☐ But we will refer to this book:

"Fundamentals of Communication Systems" by John G Proakis and M Salehi, published by Pearson, 2nd edition.



Course website

- https://ecs.wgtn.ac.nz/Courses/XMUT310_2025T2/CourseOutlines



Assessment Criteria (subject to confirmation)

- One end-of-semester final exam 25%.
- 1 mid-semester Test at 25%.
- 2 Labs reports (8% each, giving a total of 16%).
- 2 Labs demo (2% each, giving a total of 4%).
- 3 Homework Assignments (5%,7.5%,7.5% with a total of 20%).
- Participation in Classes and Labs (10%)

On top of the above, you need to manage on your own:

- Tutorials
- Reading

Teaching Schedule: compressed 8 weeks

Teaching schedule

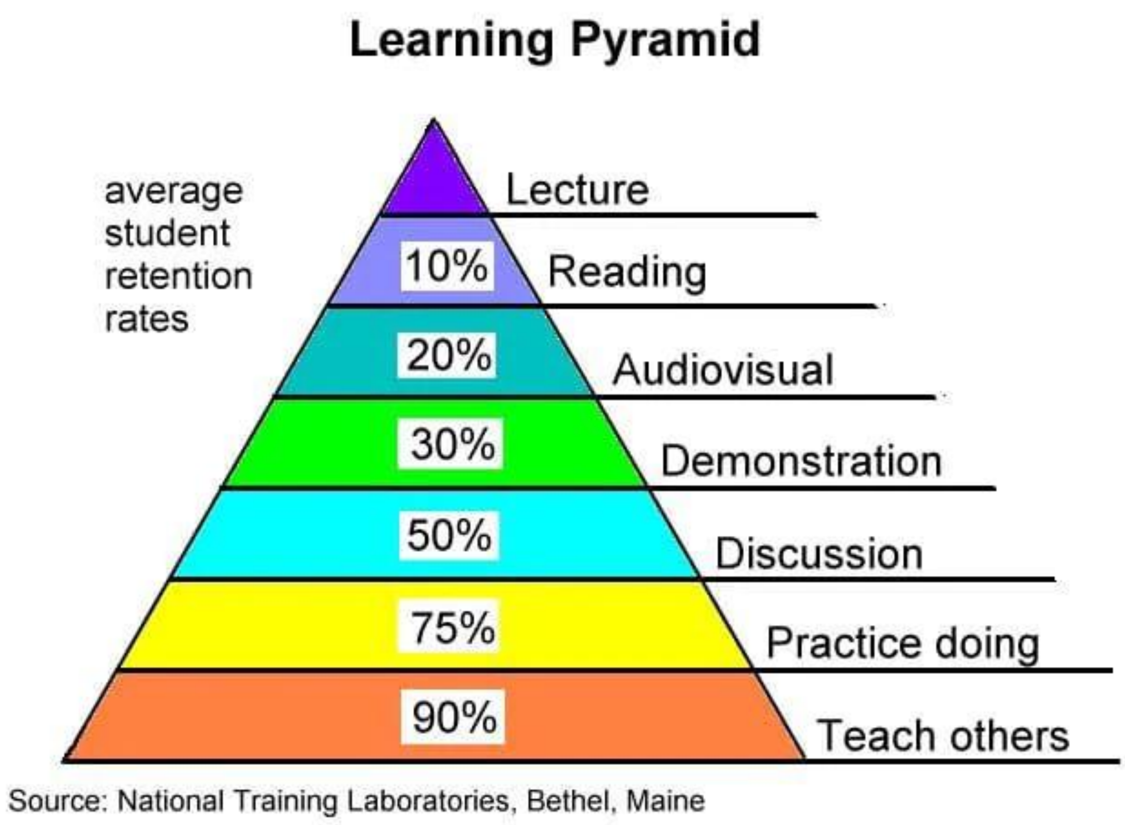
Week	Lectures	Labs	HWs	**Due**
1	Introduction to Communications Engineering	Lab 1 Revisions on Matlab	HW1	
2	Review on Signals and Systems	Lab 1 Revisions on Matlab		
3	Amplitude Modulation	Lab 2: Analog Modulation Techniques (to submit)	HW2	HW1
4	Angle/Phase Modulation	Lab 2: Analog Modulation Techniques		
5	Angle/Phase Modulation	Lab 3 Example of BER Simulations	**Test**:	Lab2,HW2
6	Analog to Digital Conversion	Lab 3 Example of BER Simulations	HW3	
7	Digital Modulation with Bandlimited Channel	Lab 4: Digital Modulation Techniques (to submit)		HW3
8	Digital Modulation with AWGN	Lab 4: Digital Modulation Techniques		Lab4
9	**Final Exams**			

How to study Communication Engineering?

Tell me and I forget,

Show me and I remember,

Involve me and I learn.



Expected hours of study

- 6 hours of lectures per week,
- 6 hours of Labs per week,
- You also need self-directed study; how many hours per week will be required?
- At VUW this is a 15-point course; 1 point ~ 10 hours, so this means a total of 150 total hours for whole course.
- We have 8 weeks, so ~ **20 hours per week**!
- These include class/lab times, doing homeworks, assignments, write lab reports, reading etc

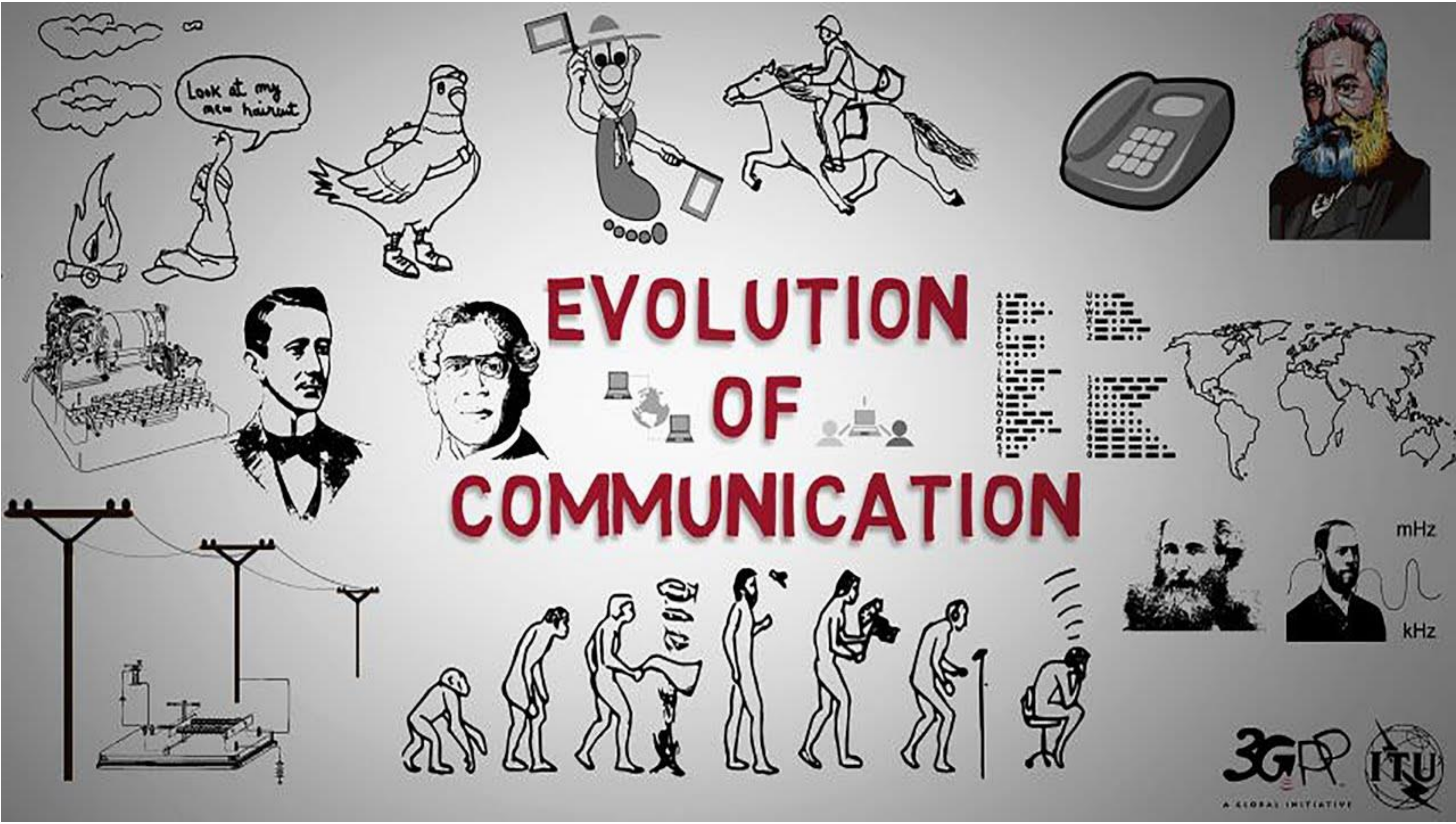
General Information

- Difference between the style of teaching and learning at VUW and XMUT
- Plagiarism – do not copy from your classmates
- Attendance – make sure you have enough attendance to sit final exam.
- Mark scaling between VUW and XMUT
- Resit exam – course marks will be calculated.
- Recommendation letters – show me how good you are for me to write good about you

ECEN310 What is Communication Engineering?

- A study on how to transmit information reliably from point A to B, as much as possible, without errors, by using minimum resources (power, bandwidth and time).
- Concepts are highly mathematical and abstract.
- Eg, information is in the airwaves, but you cannot see it, feel it, nor taste it.
- But we use devices to transmit and receive these information; this is “radio frequency” hardware.
- Nowadays, many functions are implemented in “software-defined radios”.
- Our course focuses on the theories behind these techniques

Evolution of Communication Systems



Smoke 烽火台 狼烟传讯

Horses 快马加急八百里?

Pigeons 飞鸽传书？

Men 马拉松?

What else can be used?

Evolution of of Communication Systems

- 1G – 1980s AMPS – voice only
- 2G – 1990s GSM – voice plus simple texts
- 3G – 2000s CDMA – voice plus pictures
- 4G – 2010s - multimedia
- 5G – 2020s - right now
- 6G and beyond

Technology evolution (every 10 years)

1G	2G	3G	4G	5G	6G

1980 1985 1990

Car phone	Shoulder phone	MOVA
Portable telephone	Handy telephone	Mobile phone for everyone

The First Wave
Dissemination of Mobile Phones

2000 2010

i-mode	Smartphone
Information in hand	A variety of apps/videos

The Second Wave
Mobile Multimedia

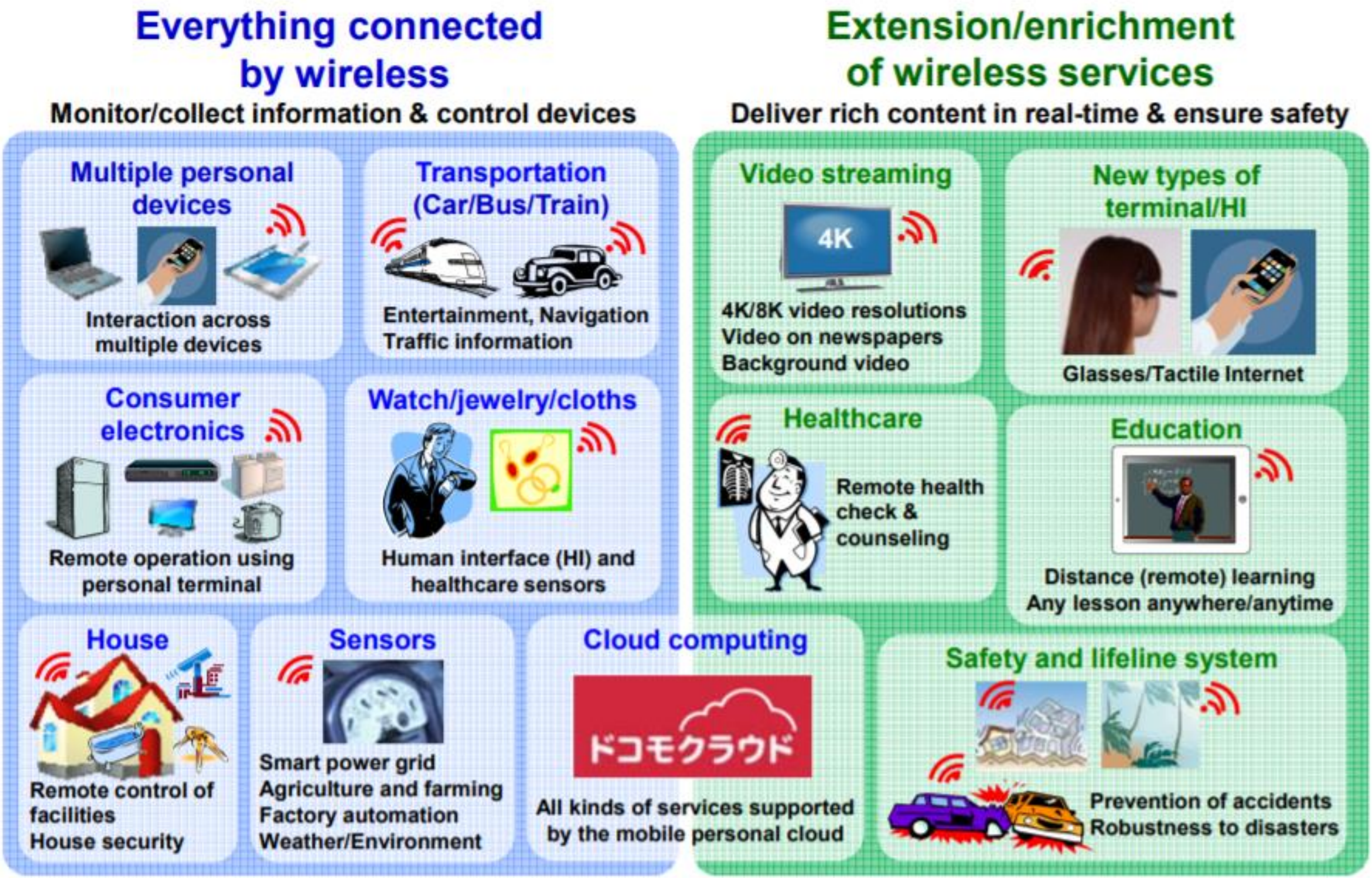
2020 2030

Resolution of social issues
Human-centered value creation

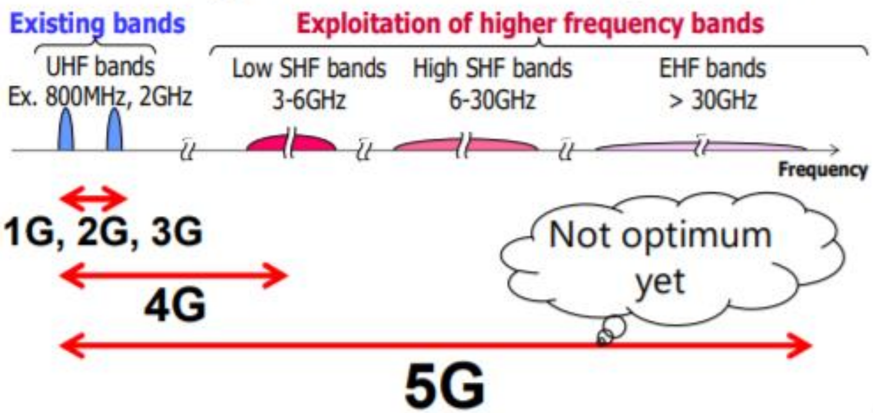
The Third Wave
New Business Value

Creating new value for markets (every 20 years)

Evolution of Handphones


Everything connected by wireless
Monitor/collect information & control devices
Multiple personal devices
Interaction across multiple devices
Transportation (Car/Bus/Train)
Entertainment, Navigation
Traffic information
Consumer electronics
Remote operation using personal terminal
Watch/jewelry/cloths
Human interface (HI) and healthcare sensors
House
Remote control of facilities
House security
Sensors
Smart power grid
Agriculture and farming
Factory automation
Weather/Environment
Cloud computing
ドコモクラウド
All kinds of services supported by the mobile personal cloud
Extension/enrichment of wireless services
Deliver rich content in real-time & ensure safety
Video streaming
4K
4K/8K video resolutions
Video on newspapers
Background video
New types of terminal/HI
Glasses/Tactile Internet
Healthcare
Remote health check & counseling
Education
Distance (remote) learning
Any lesson anywhere/anytime
Safety and lifeline system
Prevention of accidents
Robustness to disasters

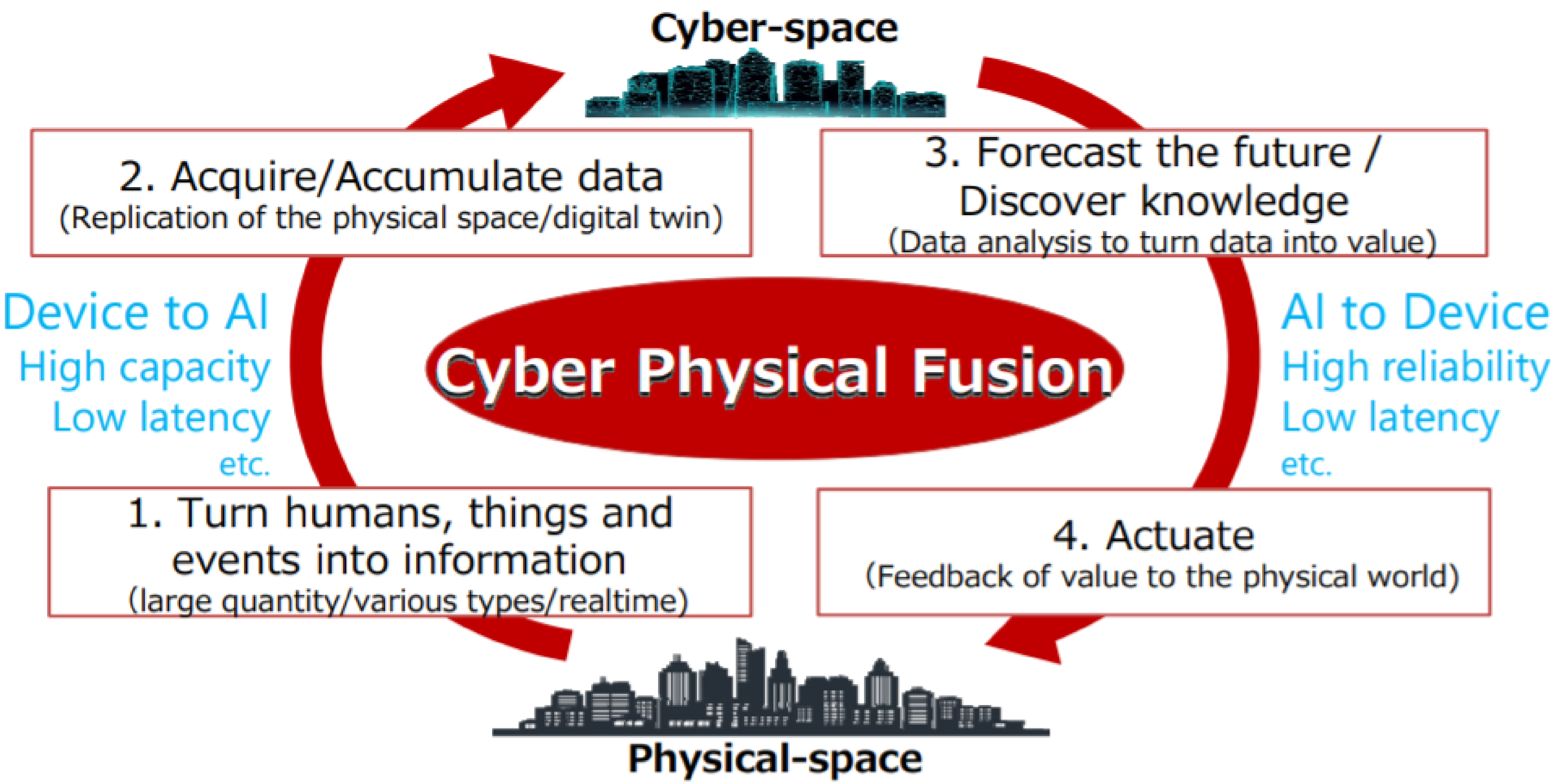
First generation using mmW



High interests from industries

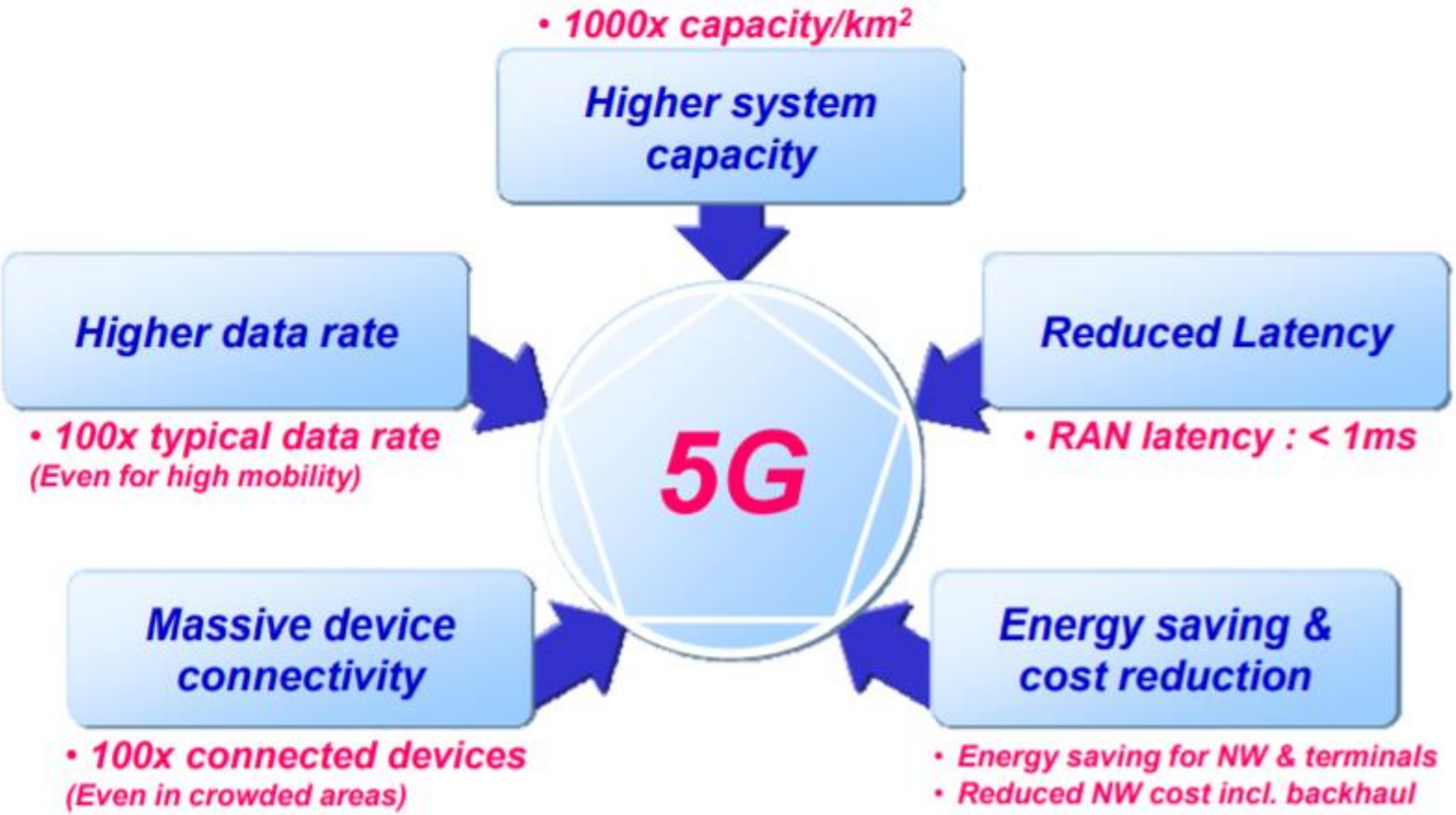
Key technical issues

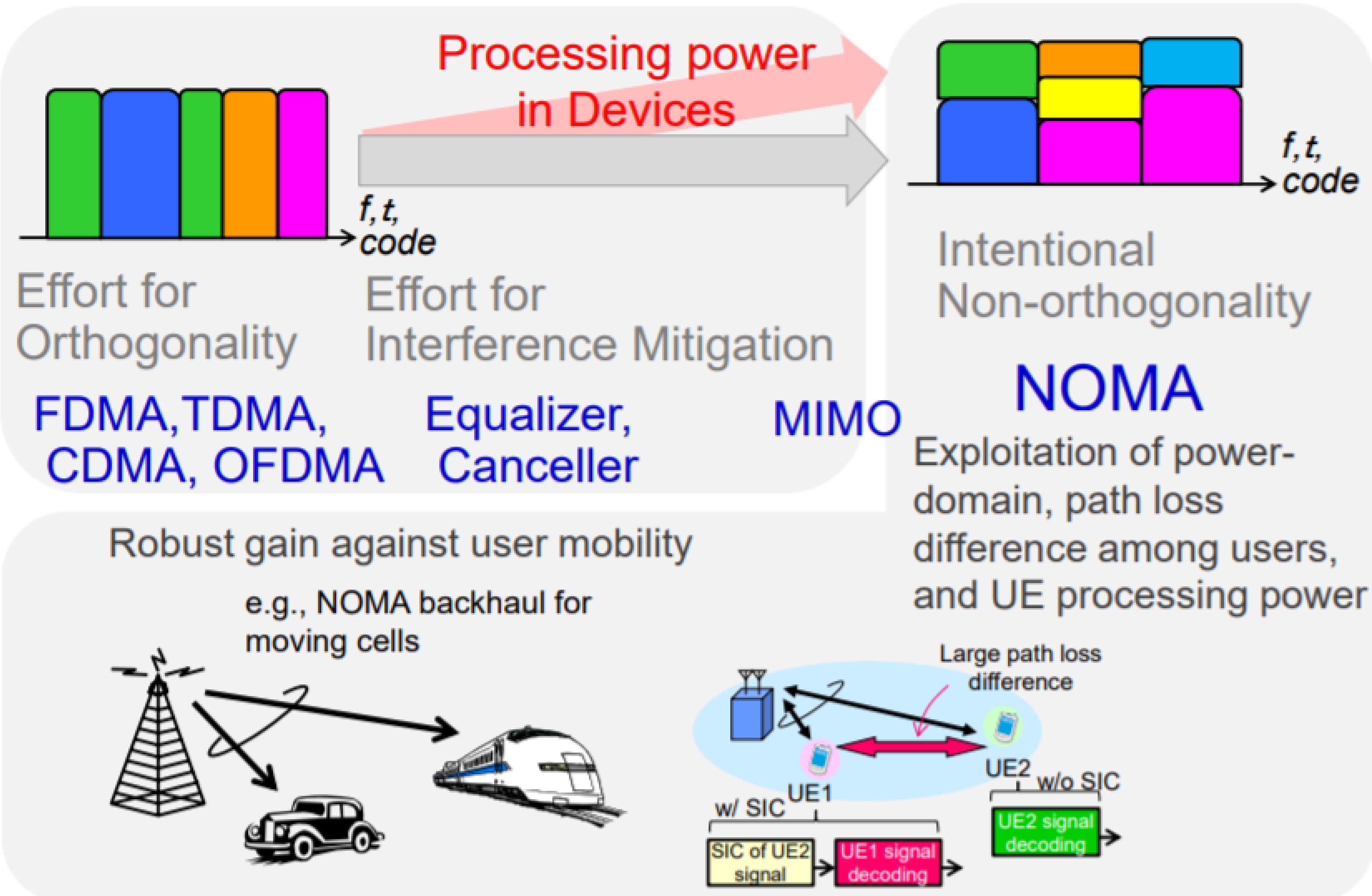
- mmW coverage/mobility improvement
- Uplink performance enhancement
- High requirements for industry use cases


Cyber-space
2. Acquire/Accumulate data
(Replication of the physical space/digital twin)
3. Forecast the future / Discover knowledge
(Data analysis to turn data into value)
Device to AI
High capacity
Low latency
etc.
Cyber Physical Fusion
AI to Device
High reliability
Low latency
etc.
1. Turn humans, things and events into information
(large quantity/various types/realtime)
4. Actuate
(Feedback of value to the physical world)
Physical-space

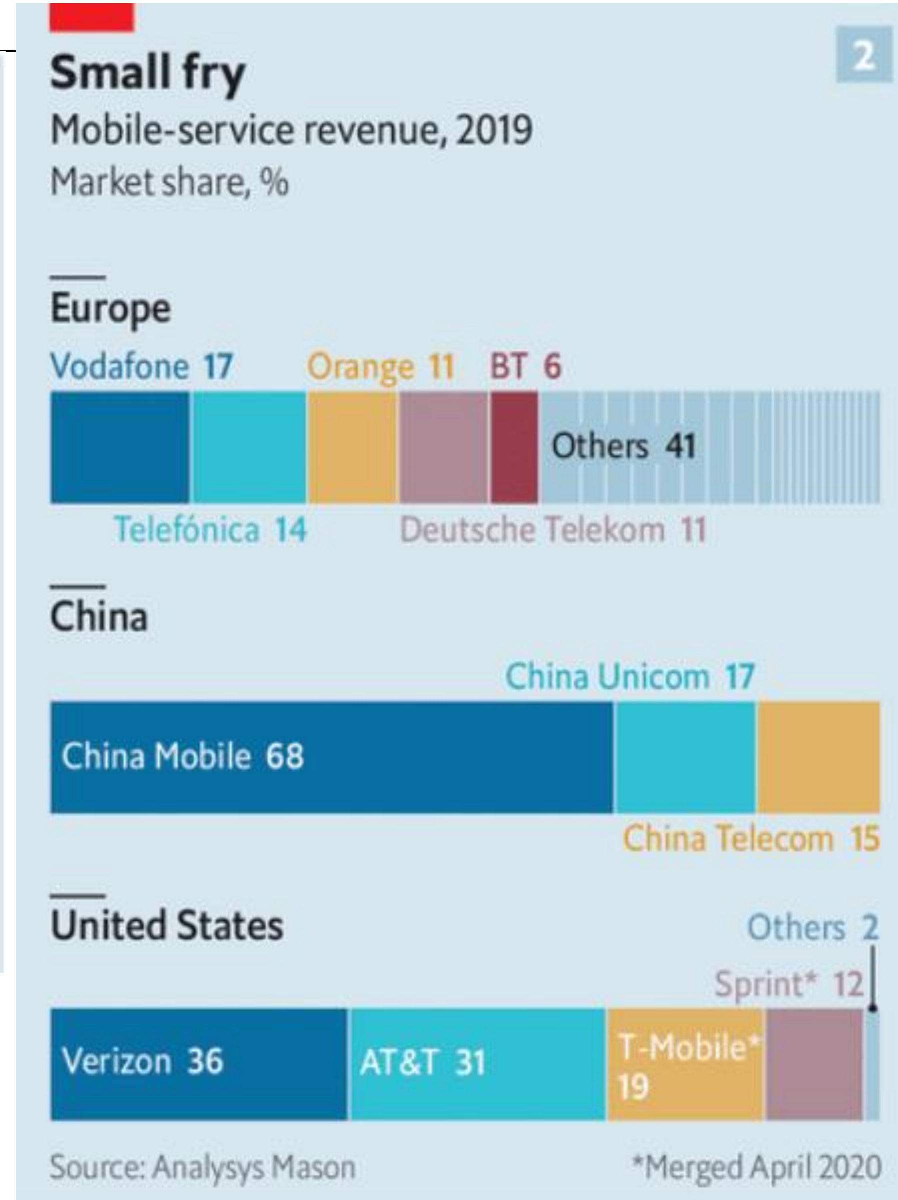

Solving social problems
Communication between humans and things
Expansion of communication environment
Sophistication of cyber-physical fusion

We are now going towards 6G and beyond…




Processing power
in Devices
f, t,
code
Effort for
Orthogonality
Effort for
Interference Mitigation
FDMA,TDMA,
CDMA, OFDMA
Equalizer,
Canceller
MIMO
f, t,
code
Intentional
Non-orthogonality
NOMA
Exploitation of power-
domain, path loss
difference among users,
and UE processing power
Robust gain against user mobility
e.g., NOMA backhaul for
moving cells
Large path loss
difference
UE1
UE2
w/ SIC
w/o SIC
SIC of UE2
signal
UE1 signal
decoding
UE2 signal
decoding


1
Big fish
Global telecom equipment sales
Market share, %
30
25
20
15
10
5
0
Huawei
Nokia
Ericsson
ZTE
Cisco
2015
16
17
18
19
Source: Dell'Oro Group


2
Small fry
Mobile-service revenue, 2019
Market share, %
Europe
Vodafone 17
Orange 11
BT 6
Others 41
Telefónica 14
Deutsche Telekom 11
China
China Unicom 17
China Mobile 68
China Telecom 15
United States
Others 2
Sprint* 12
Verizon 36
AT&T 31
T-Mobile* 19
Source: Analysys Mason
*Merged April 2020

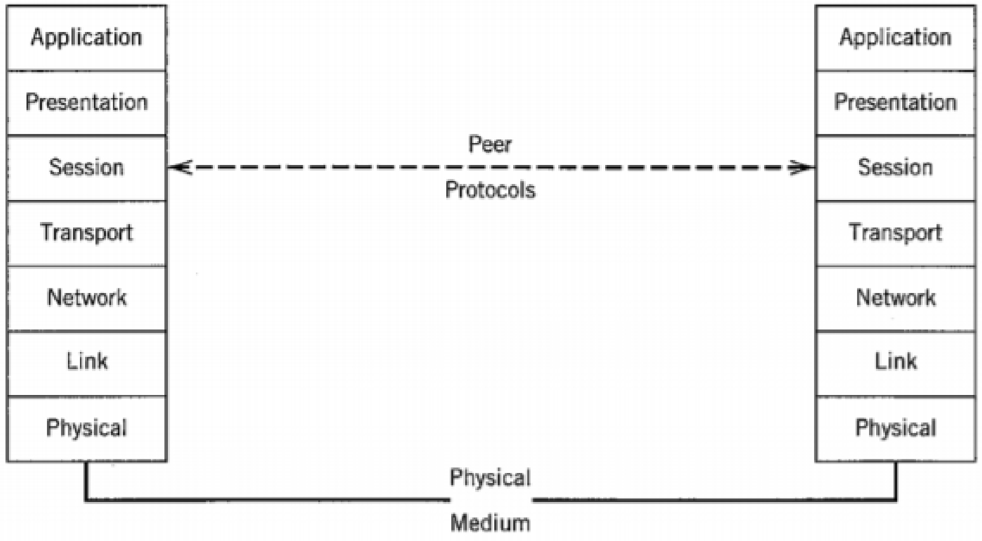
Back to the Basics

- The latest developments in 5G, 6G and beyond, all built upon basic theories,
- A good grasp of the basic knowledge will provide a strong foundation to future advances,
- In this course, we will study such basic analogue communication theories such as amplitude modulation (AM), frequency modulation (FM) used in simple radio and TV broadcasts,
- Then we will study digital communication theories.
- Making use of knowledge gained from Circuit Analysis, Signals and Systems, Engineering Statistics etc.
- We will use Matlab to simulate analogue and digital communication techniques.

Standing on the shoulders of giants

OSI Layers

Communications system divided into layers of abstraction, to manage the complexity



- Open Systems Interconnect (OSI), originally developed for computer communications
- often referred to as the *protocol stack*
- virtual connections between layers
- actual connection between physical layers only

OSI Layers

Layers which are less affected by the transmission medium

- Application Layer
  - end user interface, gui
- Presentation Layer
  - date encryption, data conversion
- Session Layer
  - virtual end-to-end message service
  - access rights, billing functions
- Transport Layer
  - end-to-end transport of messages across network
  - separates message into packets, assembles at destination

OSI Layers - communication process

Layers affected by the transmission medium

- Network Layer
  - determines the routing packets
  - flow control to guarantee *Quality of Service* (QoS)
  - includes *Internet sublayer*
- Data Link Layer
  - error detection/correction of packets
  - ordering of packets
  - when multiple nodes present, *medium access control* (MAC) sublayer ensures minimum interference between nodes
- Physical Layer (PHY)
  - physical mechanism for transmission of bits across a link
  - module for performing this function is the *modem* (**mo**dulator / **dem**odulator

OSI Layers

- in analogue communications the layers are somewhat blurred
- presentation and application layers are often combined into a single application
- error correction is often performed in the physical layer (modem)
- session, transport and network layers are treated as single

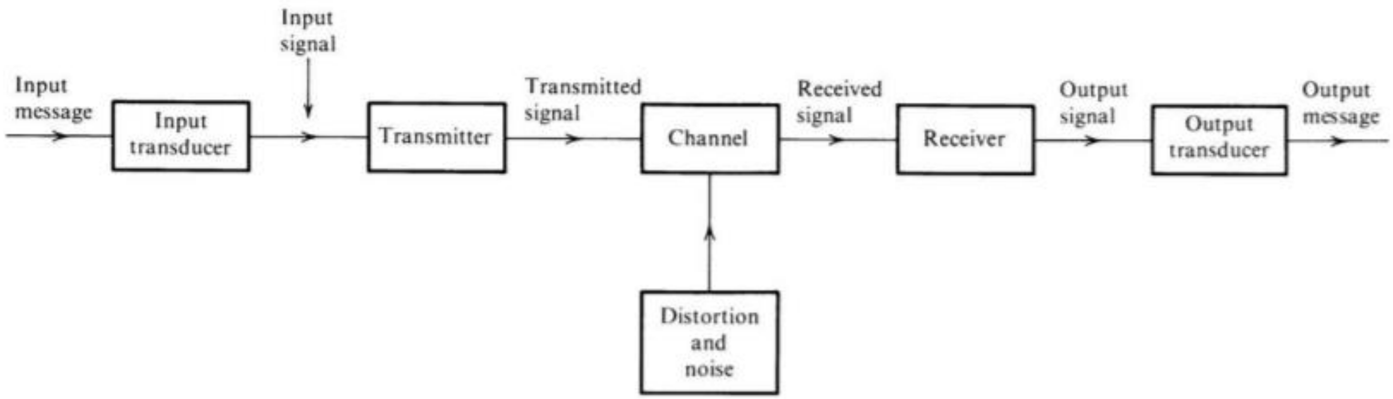
ECEN 310 focuses on the Physical Layer (PHY)

Layered view of Communication Systems

example: e-mail

- *application*: email client - provides interface for entering message, address of recipient
- *presentation*: email client - encrypts and compresses message
- *session*: email client - authenticates session with the email server
- *transport*: TCP protocol - divides message into packets, adds headers for packet numbering
- *network*: add network header including source and destination addresses
- *data link*: adds error checking bits; MAC sublayer determines if the link is available
- *physical*: add synchronisation preambles, error correction bits, modulates data onto carrier for transmission

Elements of Communication System



- **Input Transducer**: converts the message (speech, image, video...) to electrical form (message)
- **Transmitter**: generic term for the processing of information into the form suitable for transmission over a channel (eg. AM transmitter/modulator)
- **Channel**: transmission medium over which the message is to be sent (eg. cable, optical fiber, free space...)
- **Receiver**: generic term for the processing of the signal transmitted over the channel into the form that may be understood at the destination
- **Output Transducer**: converts the electrical signal to the original form (the received message)

Fundamental theories

- Fourier Analysis (ECEN 220, ECEN 320)
- Modulation Theory (ECEN 310)
- Probability and Stochastic Processes (ECEN 321, ECEN 410)
- Detection and Estimation Theory (ECEN 421)
- Information Theory (ECEN 421)

  Coding Theory (Special Topic)

Modulation Theory

- Reginald Fessenden (1868-1932)
- radio pioneer (AM modulation)

- Modulation Theory
  - Modulation - signal processing operation of modifying some property of a *carrier wave* according to the information message such that the resulting signal is suitable for reliable transmission over a channel
  - analogue and digital modulation schemes
  - key considerations: time- and frequency- domain representation of the modulated signal, detection capabilities and robustness to noise

Fourier Analysis

- Joseph Fourier (1768-1830)
- Mathematician and physicist (Fourier transform)

- Fourier Analysis
  - Fourier Transform - linear mathematical operation that transforms a time-domain signal into its frequency-domain description
  - Allows to analyse the *bandwidth* of the signal/channel, correlation (similarity) between signals (important!)
  - Very widely used due to the Fast Fourier Transform (FFT) - a very efficient algorithm for calculating a (discrete version of) Fourier Transform

Probability Theory and Stochastic Processes

- Carl Gauss (1777-1855)
- Mathematician: Number Theory, statistics (Gaussian distribution)

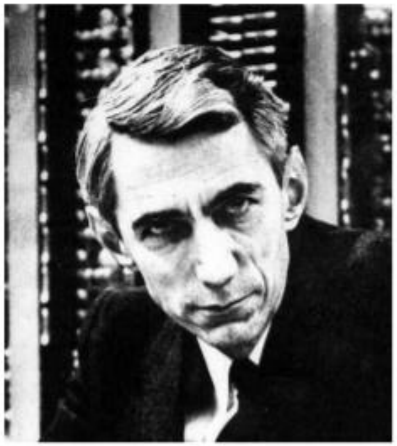
- Probability and Stochastic Processes
  - Theory of mathematically describing the behaviour of randomly occuring events
  - Statistical characterisation of random signal, noise, wireless channels

Estimation and Detection Theory

- Thomas Bayes (1702-1761)
- Mathematician (Bayesian Estimation)

- Detection Theory
  - The study of signal detection when corrupted by noise and other forms of distortion
  - Based on *signal-to-noise ratio* (SNR), and *hypothesis testing* (Bayesian estimation)

Information Theory



- Claude Shannon (1916-2001)
- Father of Information Theory

- Information Theory - Founding mathematical theory of communications
  1. *Source Coding Theorem* - removing redundancy from source signal
  2. *Channel Coding Theorem* - adding *controlled* redundancy to achieve arbitrarily low error rate, achievable maximum rate of transmission through a channel (*Capacity*)
  3. *Rate Distortion Theorem* - analysis of lossy data compression

Information Capacity

- Ultimate limit of communications: how much data can be reliably transmitted given some signal strength and bandwidth

$$C = B \log(1 + \text{SNR}) \text{ bits/second} \tag{1}$$

- this is referred to as *Shannon's limit*
  - C = capacity
  - B = channel bandwidth
  - SNR = signal-to-noise ratio (cannot control noise - can only control signal power)
- capacity increases *linearly* with bandwidth, but only *logarithmically* with signal strength
- Shannon's limit tells us what we can achieve it tells us nothing about how to do it!

Shannon's Limit

- ...then one day in 1993, Berrou, Glavieux, and Thitimajshima publish a research paper:

  "Near Shannon Limit Error-correcting Coding and Decoding: Turbo-codes"

- Powerful encoding technique that results in near capacity-achieving communications
- Cutting edge coding techniques in theory allow us to (almost) achieve the Shannon's Limit
- Not always practical (computational resources, battery power) or suitable for many operating environments (multiuser)
- While we have nearly reached the limit, we can 'invent a new channel' with higher capacity (MIMO)

Primary Communications Resources

- In designing communication systems the aim is to
  - maximize data rate
  - minimize error rate
- ... while *efficiently* utilize of two primary resources:
  - **Transmitted power** (SNR)- high transmit power means
    - able to combat propagation loss
    - diminish effects of noise and interference
    - high power (battery) consumption, interference to others
  - **Channel bandwidth** (B) - want to optimize the use of this precious (expensive) resource
    - fast signalling = high frequency content, requires high BW
    - distortionless transmission possible only if signal BW $<$ Channel BW
- Other considerations: computational complexity (delay), cost, interoperability...