Wireless Communications I

1. Introduction

Overview An introduction and overview to the course topic and contents are given.

Source The material is mainly based on Chapter 1 of the course book.

Outline of the Lecture

- Motivation
- Course Overview
- Communications Systems
  - Block diagram, channel, capacity, methods
- Course Objectives
- History of Wireless Communications
- Technical Challenges
- Current Wireless Communication Systems
- Spectrum Regulation
- Trends for Future Systems and Networks
- 6G Flagship

Motivation

- **Why wireless communications?**
  - Reasons for no wires are manyfold.

- Flexibility
- Mobility
- Robustness?
  - Yes and no.
- Faster to deploy than wired

Course Overview

1 Introduction
2 Radio Channels
3 Digital Modulation and Detection
4 Coding for Wireless Channels
5 Performance over Wireless Channels
6 Diversity Techniques
7 Wideband Systems
8 Cellular System Principle

Block diagram of communications system

Format

Source coding

- Infor
  remo
- Comp
- Digita
- Sourc

Synchron
- To find
  received
  - Fre

Information

Encryption: two goals
- privacy (sanoman yksityisyys):
  - prevents the inappropriate users to get the infomation (useless to intercept)
- authentiation (sanoman luotettavuus):
  - prevents the inapropriate users to sent information (prevents false alarms)

- cannot be efficiently used to detect/correct errors

Multiple access
- Also sharing of channel cap
- Not necessary fixed but it c
  requirements of the users

code word of length *n* => amount of redundance is *n*/*k*, inverse *k*/*n* is code rate
- Channel coding increases signals' distance in signal space, therefore error probability decreases
- Errors should be usually randomized using interleaving

Spectrum spreading (spread spectrum systems
- Signal spectrum is spread by a factor of
- Goals, e.g.,
  - Increase interference resistance c
  - Decrease propability of intercepti
  - Tolerate multipath propagation
  - Multiple access (CDMA = code di
    access)
  - Distance measuring
- Spreading is done using special spreading code

one in frequency or time domain
ality)
cy division multiplexing (FDM)
- Time division multiplexing (TDM)

Information
sink

symbols

destination

Block diagram of communications system

Format

- Operation to convert signal into digital form (digital symbols)
    - E.g., A/D-conversion
- Does not remove redundancy

Source coding

- Information signal's (from source) redundancy is removed (e.g., HUFFMAN-coding)
- Compressing the message
- Digital symbols have redundancy,
    - if symbols have not the same probability or
    - if symbols are not independent of each others
- Source symbols inherent redundancy is nonsystematic
    - wastes channel capacity
    - cannot be efficiently used to detect/correct errors

Encryption: two goals

- privacy (sanoman yksityisyys):
    - prevents the inappropriate users to get the infomation (useless to intercept)
- authentiation (sanoman luotettavuus):
    - prevents the inapropriate users to sent information (prevents false alarms)

Block diagram of communications system

Channel coding

- Redundance is increased in a way, that the receiver can use it efficiently to detect and correct errors -> parity check bits (e.g., repetition codes, block codes, convolutional codes)
- Every sequence of *k* bits is presented as code word of length *n* => amount of redundance is *n*/*k*; inverse *k*/*n* is code rate
- Channel coding increases signals' distance in signal space, therefore error probability decreases
- Errors should be usually randomized using interleaving

Multiplexing

- Sharing of transfer capacity of channes to different users
- Is usually fixed
- Can be done in frequency or time domain (orthogonality)
  - Frequency division multiplexing (FDM)
  - Time division multiplexing (TDM)

Block diagram of communications system

Modulation
- To match the signal spectra in the band pass channel
- Can be changed carries wave amplitude, phase or frequency
- Line coding is corresponding process in low pass channel

Spectrum spreading (spread spectrum systems)
- Signal spectrum is spread by a factor of 100-1000
- Goals, e.g.,
  - Increase interference resistance of the receiver
  - Decrease propability of interception (LPI)
  - Tolerate multipath propagation
  - Multiple access (CDMA = code division multiple access)
  - Distance measuring
- Spreading is done using special spreading code

Block diagram of communications system

Multiple access

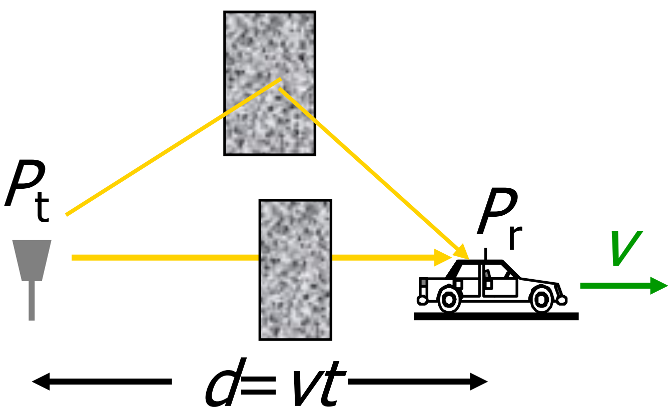
- Also sharing of channel capacity
- Not necessary fixed but it can be changed based on requirements of the users
- Access is controlled
- Examples
  - Frequency division multiple access (FDMA)
  - Time division multiple access (TDMA), e.g., GSM
  - Code division multiple access (CDMA), e.g., WCDMA
  - Space division multiple access (SDMA)
  - Polarization division multiple access (PDMA)

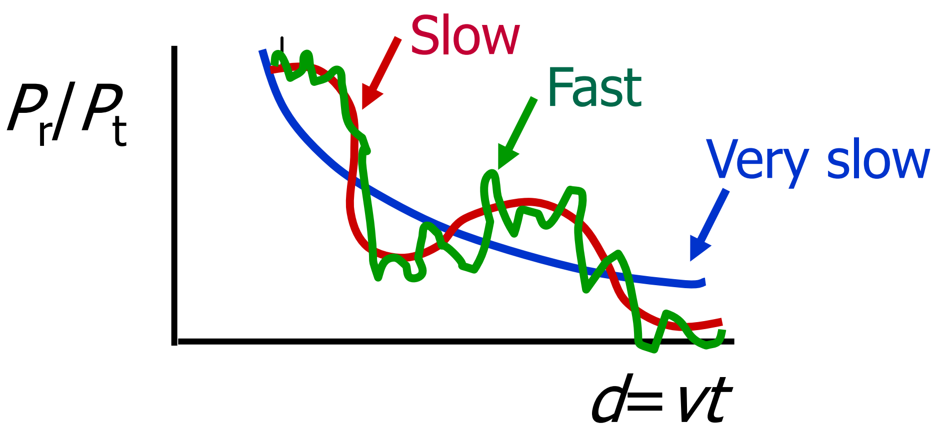
Synchronization

- To find meaningful time instants of the received signal time axis
  - Frequency (carrier synchronization) and time (symbol synchronization) estimation

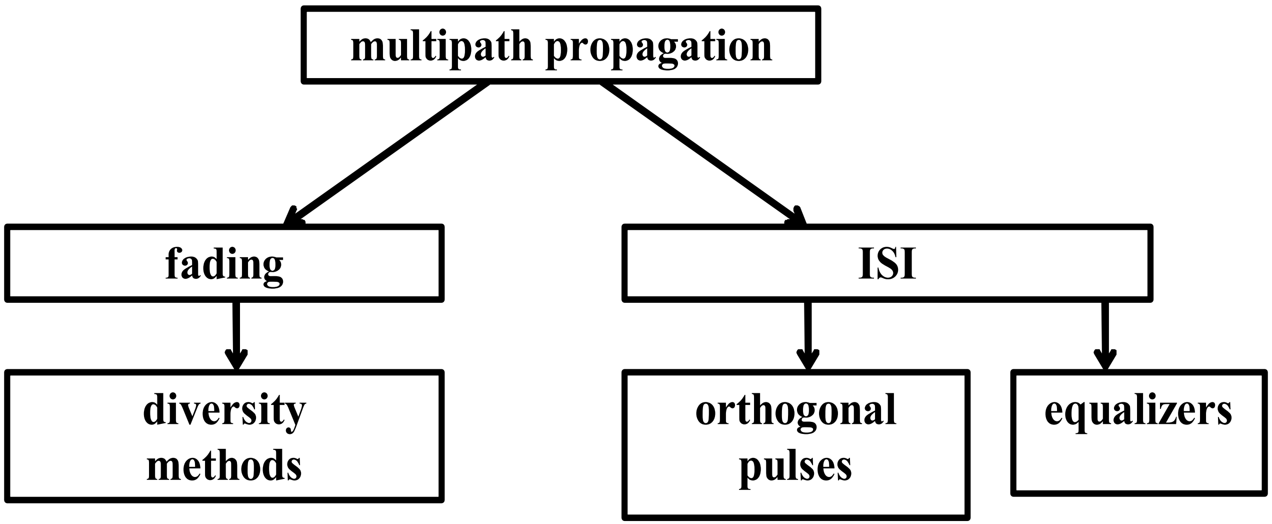
Propagation Characteristics

- Path loss (includes average shadowing)
- Shadowing (due to obstructions)
- Small scale multipath fading





Multipath Propagation



- time (coherence time)
- frequency (coherence bandwidth)
- space (distance 0,5…10 λ)
- polarization (orthogonality)
- FEC (channel coding)

- parallel transmission
- spread spectrum

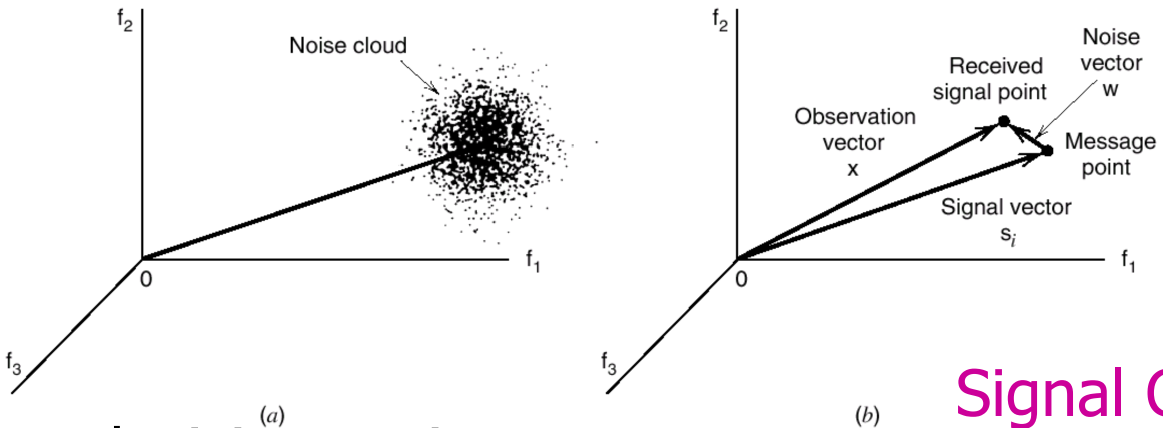
- linear
- nonlinear (DFE)
- Viterbi algorithm

Channel Capacity

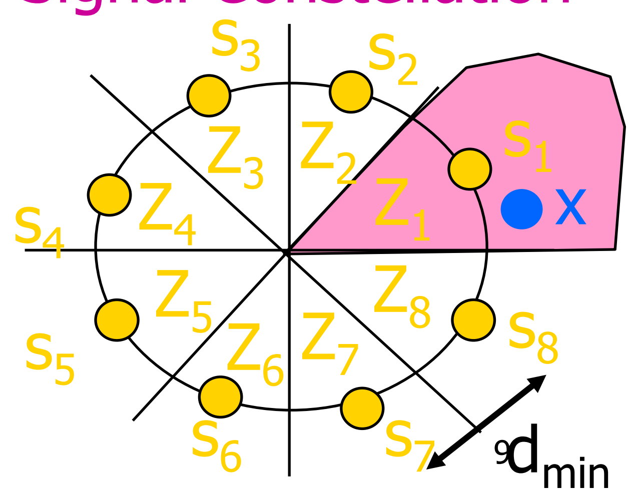
- Capacity defines theoretical rate limit
  - Maximum error free rate a channel can support
  - Depends on what is known about channel
- Unknown fading
  - Worst-case channel capacity
- Fading statistics known
  - Hard to find capacity
- Fading known at receiver only
- Fading known at transmitter and receiver
  - For fixed transmit power, same as with only receiver knowledge of fading
  - Transmit power $S(\gamma)$ can also be adapted
  - Leads to optimization problem

Decision Regions and Error Probability

- ML (maximum likelihood) receiver decodes s_i closest to x



Signal Constellation

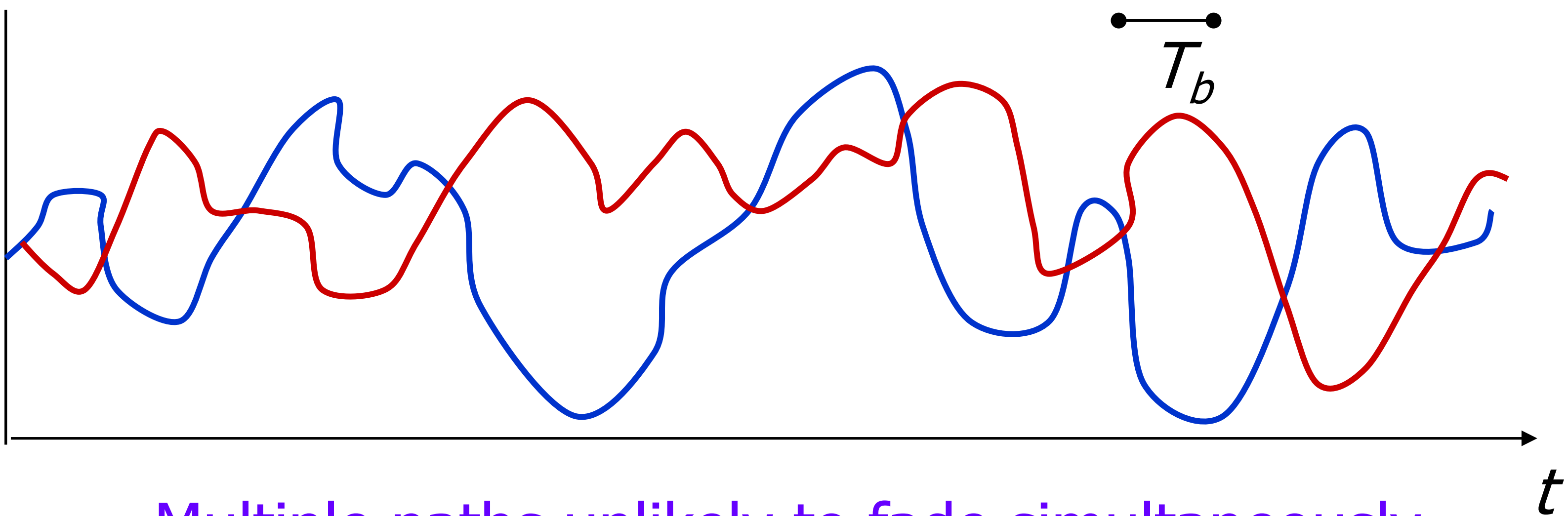


- Assign decision regions:
  - $Z_i = (x: |x-s_i| < |x-s_j| \text{ all } j)$
  - $x \in Z_i \Rightarrow m = \underline{m}_i$
  - P_e based on noise distribution

$$P_s \leq (M-1) Q\left(\sqrt{d_{\min}^2 / (2N_0)}\right)$$

Diversity

- Basic Idea
  - Send same bits over independent fading paths
    - Independent fading paths obtained by time, space, frequency, or polarization diversity
  - Combine paths to mitigate fading effects

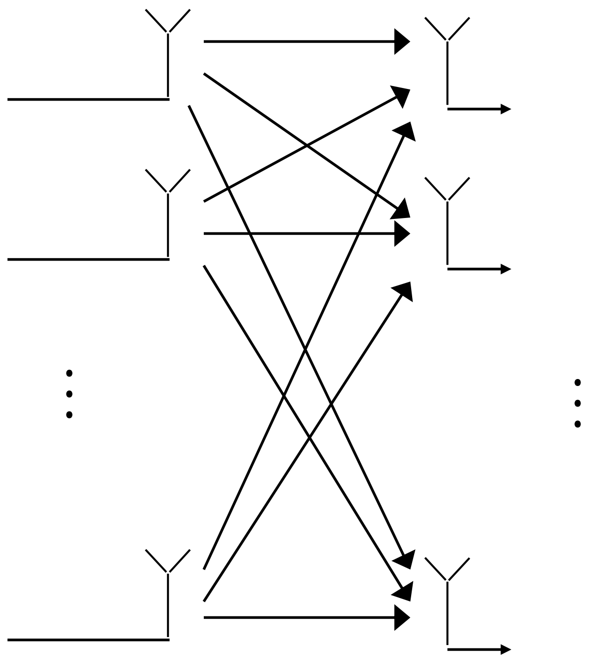


Multiple paths unlikely to fade simultaneously

Multiple–Input Multiple–Output (MIMO) or Multiantenna Communications

multiple–input

- Beamforming (adaptive antennae)
- Antenna diversity
- Spatial multiplexing



channel

multiple–output

Course Objectives

Core contents:

- Radio channel models and basic phenomena causing fading
- Digital modulation and detection
  - Signal space analysis, modulation principles, symbol and carrier synchronization
- Performance of digital modulation over wireless channels
  - In AWGN, in Fading
- Diversity
- Coding for wireless channels

Additional knowledge

- Multicarrier systems and spread spectrum systems

Special knowledge

- Cellular system principle

Resources

- Basic resources of the communication system:
  - bandwidth and
  - transmit power

  – Error probability depends on symbols' average energy, noise power density and symbols' distance in signal space (measured by Euclidean distance)
  – Tradeoff: increasing distance by signal design, error probability decreases but bandwidth increases
  – Bandwidth is estimated using **power spectral density of the modulation method**
  – Needed transmit power is estimated by **error probablity of the modulation method**

System division

- In bandlimited system, there is enough **transmit power**, but lack of spectrum (e.g., radio spectrum in general)
  - Need to be used signals having small distance (e.g., QAM)
- In power limited systems, there is lack of **transmit power**
  - Need to be used signals having large distance (e.g., channel coding in FEC systems, FEC = forward error correction)
- Use of channel coding to detect errors (ARQ = automatic repeat request) can be usefull both in bandlimited and power limited systems

Performance evaluation

- Performance evaluation methods for communication system
  - Mathematical analysis
    - **Simplified assumptions, linear systems, Gaussian noise**
  - Computer simulation
    - **Complicated systems possible**
    - **Can be concentrated into one problem at a time, because nonidealities of the equipments need not to be taken into acccount**
    - **Easy to make changes**
    - **Simulation times can be a problem**
  - Building equipments
    - **Slow and expensive, difficult to make changes**
    - **However, are necessar, because models are always incomplete**
- Choice of the system is bounded by cost and complexity
  -> need to investigate also suboptimal systems

GIVEN		IDEAL SYSTEM
Bandwidth SNR	→	Lowest error prob. Highest bit rate
Error probability Sigal energy	→	Minimum bandwidth Highest bit rate

History of Wireless Communications

- Ancient systems: smoke signals, carrier pigeons, semaphore flags at yards, flashing mirrors etc.
- Wireline electrical communications
  - Telegraph by Samuel Morse in 1838
  - Telephone by Alexander Graham Bell in 1875 (patent 1876)
- Radio and electromagnetism
  - Maxwell's equations by James Maxwell in 1873
  - Radio waves by Heinrich Hertz in 1888
- Radio communications
  - Nikolai Tesla in 1892 (patent in 1898)
  - Guglielmo Marconi in 1895 (patent in 1900)
    - Better public relations
    - Nobel prize 1909

The first half 20th Century

- Audio broadcasting over radio
- Video broadcasting over radio (television)
- Government radio systems
  - Police radio
  - Military radio
- World War II
  - Secure communications and spread spectrum
- Theoretical breakthroughs
  - Wiener filter
  - Matched filter
  - Information theory

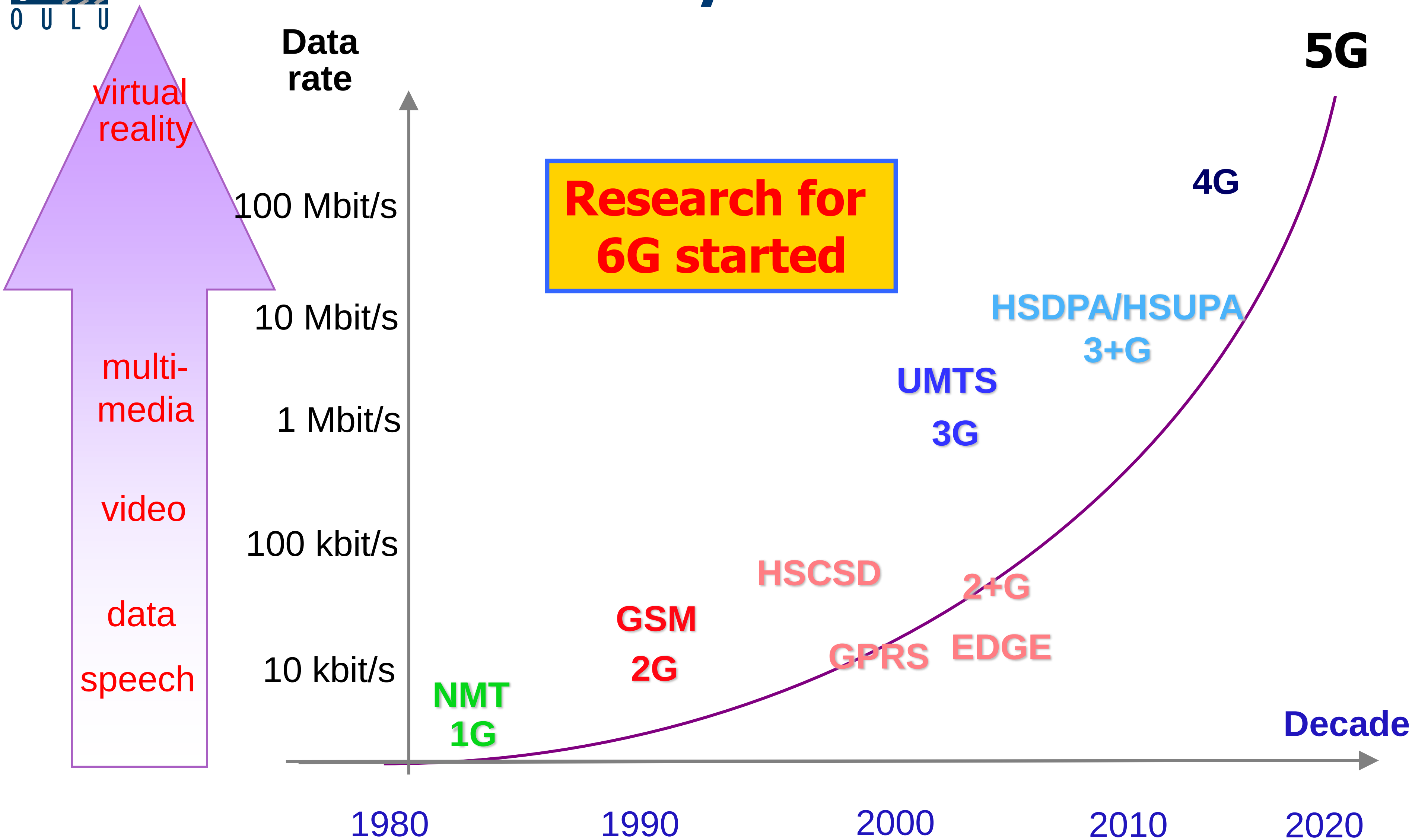
Mobile Communications

- Voice transmission between New York and San Francisco in 1915
  - convergence of telephone and radio started.
- Public mobile telephone introduced by AT&T in USA in 1946
  - FM radio transmission, 120 kHz per voice channel, limited to 80 km from base station, operator-assisted dialing.
- Mid-1960s: AT&T's IMTS (Improved Mobile Telephone Service) uses 30 kHz voice channels, narrowband FM and direct dialing
- Cellular concept introduced by AT&T in 1950s.
  - Spatial frequency reuse.
  - Concept designed completed in late 1960s.

Cellular System Evolution

Decade	1980s	1990s	2000s	2010s	2020s	2030s
Generation	**1G**	**2G**	**3G**	**4G**	**5G**	**6G**
Access	NMT, AMPS, TACS,…	GSM, GPRS, EDGE, D-AMPS, …	UMTS, CDMA	LTE, WiMAX	5G	6G
Platform	Analog	Digital	Packets	Broadband	Cloud	AI?
Application	Voice	Voice, SMS	WAP, Web	Web, Facebook, Youtube	IIoT, Verticals	?

Cellular System Evolution



Technical Challenges

- Wireless or radio communications pose a number of distinct technical and scientific challenges related to the fact that communication need to be *wireless* due to
  - radio propagation issues
  - power limitations if the terminal is also wireless in power supply sense.
- A wireless channel is inherently more difficult and fluctuating than a wired one.
  - Wireless connection is not always the best choice.

Technical Challenges (2)

- Terminal challenges:
  - Power limitations in portable terminals
    => power efficiency is a crucial issue.
  - Multitude of system standards
    => need for flexible and reconfigurable terminals.
- Radio spectrum is a scarce resource.
  - Bandwidth efficiency is a critical design issue.
  - Frequency spectrum sharing and allocation is a big political/economical issue.
    - International standardization bodies and national regulators need to co-operate.
- Security concerns due to radio transmission.

Wireless Channel

- Wireless channel distorts the signal in several manners:
  - free-space path loss (attentuation)
  - shadowing (large scale fading)
  - (small scale) fading due to multipath propagation.
- Wireless channels are always unpredictable to some extent.
- Wireless channels pose a main technical / theoretical design / research challenge for wireless communications.
- Understanding the channels is crucial.

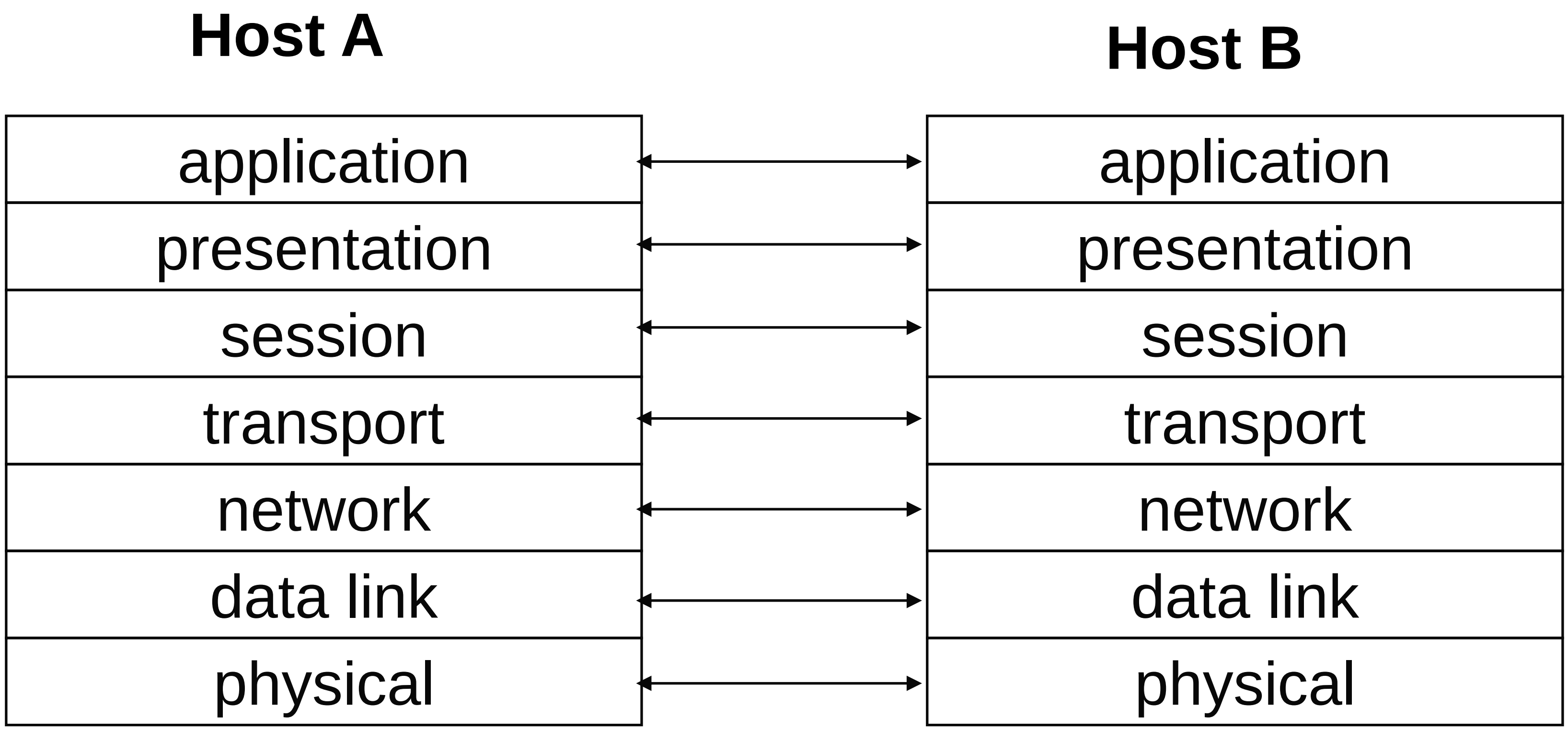
Examples of Quality of Service (QoS) Requirements

	Voice	Data	Live video
Delay	< 100ms	-	< 100ms
Packet Loss	< 1%	0	< 1%
BER	10^{-3}	10^{-6}	10^{-6}
Data Rate	8-32 kbps	1-100 Mbps	1-20 Mbps
Traffic	Continuous	Bursty	Continuous

Wireless Networking

- Locating the users and routing the signal is not always trivial in mobile communications.
- The traffic patterns, user (also interfering ones) locations and service needs (data rate, delay requirements, reliability etc.) vary over time and space.
  - High mobility poses particularly significant challenges.
- Challenges to wireless networking protocols, media access, routing etc.
- *Cross-layer optimization* is needed for performance optimum.

OSI Protocol Reference Model (1)

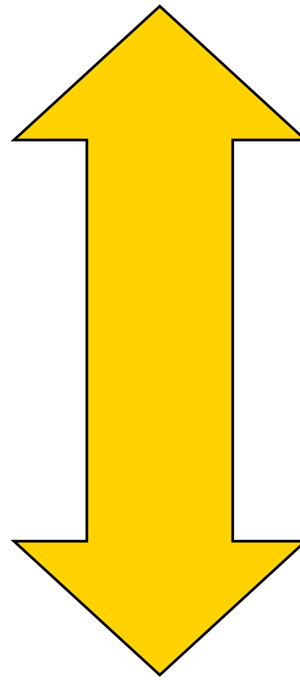


OSI Protocol Reference Model (2)

- Application layer: user program that generates data.
- Presentation layer: changes syntax (data format) if necessary.
- Session layer: synchronizes sessions (dialogues).
- Transport layer: end-to-end connection management, error recovery.
- Network layer: routes data through network.
- Link layer: framing, error recovery on links, including MAC.
- Physical layer: point-to-point medium-dependent transmission.

Crosslayer Design

- Hardware
- Link
- Access
- Network
- Application



Delay Constraints
Rate Constraints
Energy Constraints

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

Current Wireless Communication Systems

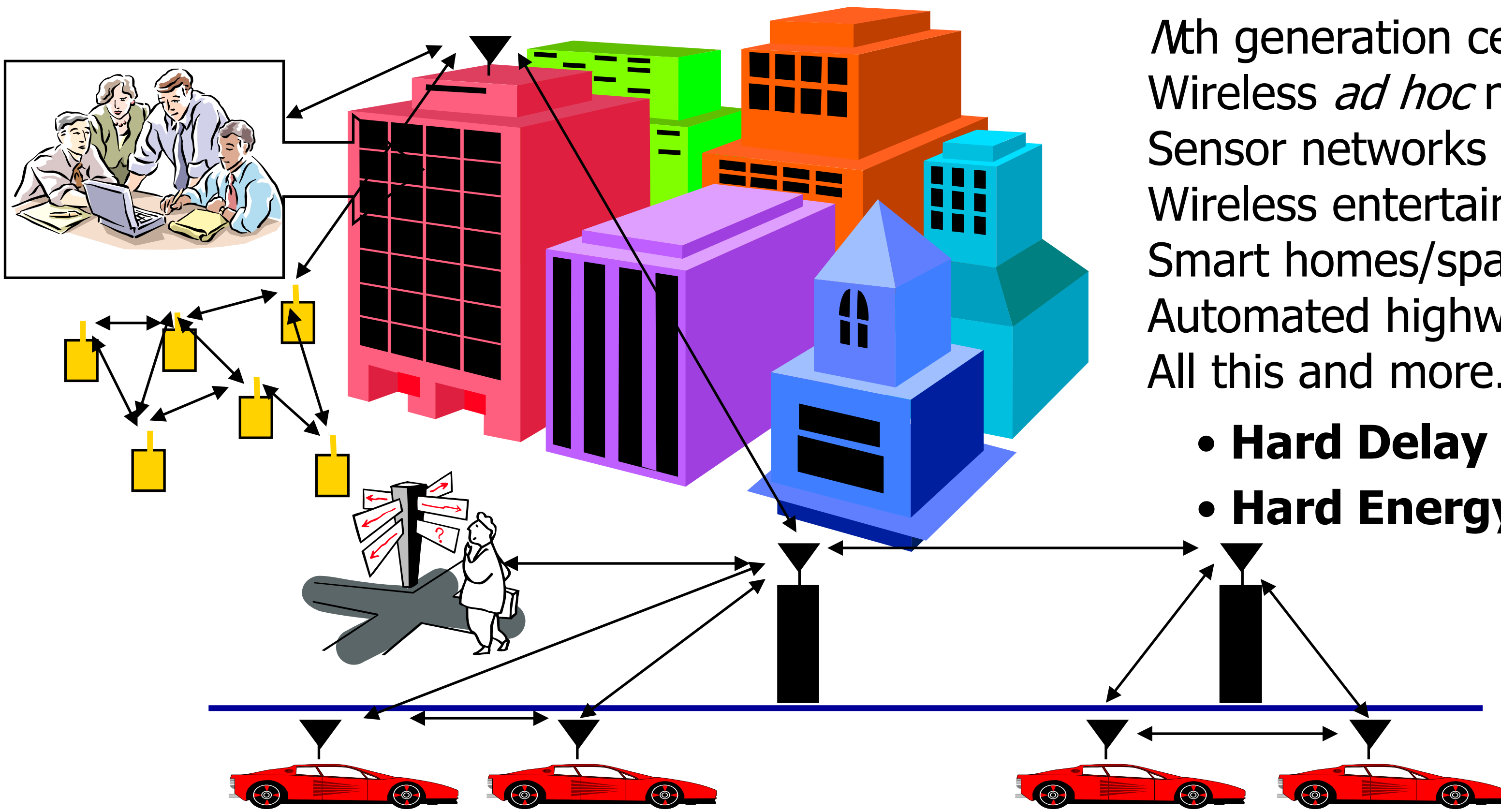
- Cellular communication (telephone) systems
- Cordless phones
- Wireless local area networks (WLAN’s)
- Wireless metropolitan area networks (WMAN’s)
- Wireless body area networks (WBANs)
- Fixed wireless access
- Paging systems
- Satellite networks
- Short range connectivity
- Emerging systems and technologies
  - *Ad hoc* wireless networks
  - Sensor networks
  - Distributed control networks

Spectrum Regulation

- Radio spectrum is regulated by government offices.
  - Finland: Ministry of Transportation and Communications
  - USA: Federal Communications Commission (FCC) or OSM.
- Regulation utilizes system (international) standards:
  - International Telecommunication Union (ITU)
  - European Telecommunications Standadization Institute (ETSI)
  - FCC
  - Association of Radio Industries and Businesses (ARIB) in Japan.
- *De facto* standards by companies.

Trends for Future Systems and Networks

Convergence of heterogeneous networks to enable ubiquitous communication among people and devices



Wireless internet access
*N*th 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**

6G
Flagship
UNIVERSITY OF OULU
Radio City
OULU
6G FLAGSHIP PROGRAM 2018-2026,
TOTAL BUDGET 251 MILLION €,
OVER 300 RESEARCHERS
Web:www.6genesis.com
Twitter: @6Genesis

UNIVERSITY of

Flagship

Basic pillars enabling future smart society

6G SYSTEMS:
WIRELESS COMMUNICATION
AI DISTRIBUTED AT THE EDGE
LARGE IOT NETWORKS

Flagship focuses on 5G & 6G

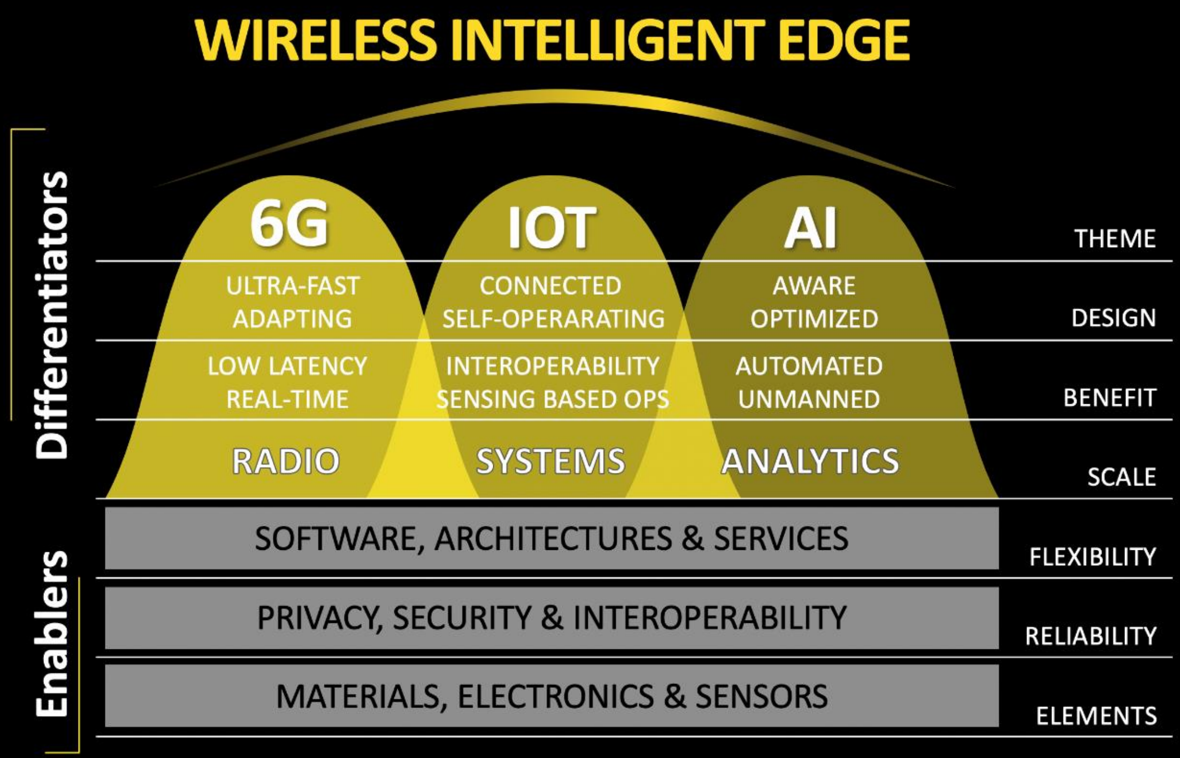
- **Now:** Utilize benefits of 5G
- **Next:** Develop 6G enablers

Wireless intelligent edge

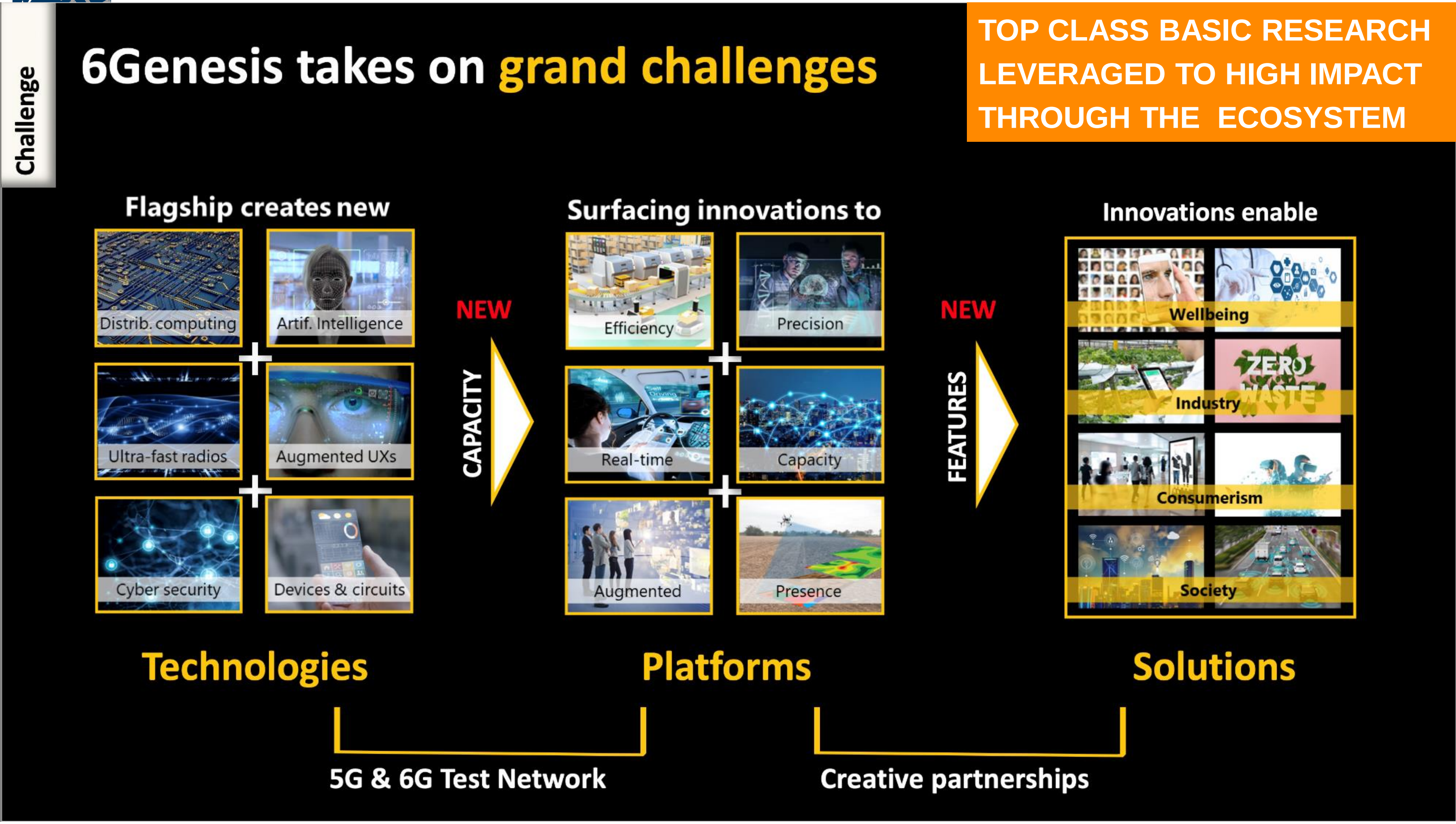
- Technology convergence
- Enablers for speed, experience, performance & security

Next gen requirements

- Real-time
- Sensing-based
- Edge intelligence
- ..list goes on!



TOP CLASS BASIC RESEARCH LEVERAGED TO HIGH IMPACT THROUGH THE ECOSYSTEM



ITEE RESEARCH FORMS A SOLUTION CREATION VALUE CHAIN

BASIC RESEARCH