CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF ELECTRICAL ENGINEERING

DEPARTMENT OF TELECOMMUNICATION ENGINEERING

B(E)2M32BTSA - Wireless Technologies

Wireless technologies

Introduction and fundamentals

Zdeněk Bečvář

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Faculty of Electrical Engineering
Department of Telecommunication Engineering

6G mobile RESEARCH LAB
http://6Gmobile.fel.cvut.cz

Outline

Overview and plan of the course

- Lectures & labs
- Exam

Fundamentals of wireless communications

- Classification of wireless technologies
- Wireless channel, signal propagation
- Medium sharing
- Topologies of wireless networks

Course overview

Lecturers

doc. Ing. **Zdeněk Bečvář**, Ph.D.
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doc. Ing. **Lukáš Vojtěch**, Ph.D.
room no. 903/B3, FEL
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Ing. **Pavel Mach**, Ph.D.
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Ing. **Zbyněk Kocur**, Ph.D.
room no. 601/B3, FEL
zbynek.kocur@fel.cvut.cz
tel. 2 2435 4054

In case of any questions, complains, or problems related to lectures, send an email as soon as possible (do not wait till end of semester) to zdenek.becvar@fel.cvut.cz

You can also use MS Teams channels in the course to provide a quick feedback

Labs

Ing. **Zbyněk Kocur**, Ph.D.
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Ing. **Pavel Mach**, Ph.D.
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Ing. **Ján Kučerák**
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machp2@fel.cvut.cz
tel. 2 2435 4050

In case of any questions, complains, or problems related to labs, send an email as soon as possible to both zbynek.kocur@fel.cvut.cz and zdenek.becvar@fel.cvut.cz

You can also use MS Teams channels in the course to provide a quick feedback

Lectures

Week	Date	Topic	
1.	21. 2.	Introduction to wireless networks (Z. Bečvář)	
2.	28. 2.	Medium access for wireless networks (Z. Bečvář)	Basics of wireless
3.	7. 3.	Routing in wireless sensor networks – metrics and protocols (Z. Bečvář)	
4.	14. 3.	Wi-Fi – topology, physical layer, medium access control and data transmission (P. Mach)	Medium/Long-range technologies
5.	21. 3.	Communications of autonomous systems (P. Mach)	
6.	28. 3.	LPWAN/LPN protocols for IoT (LoRa/LoRaWAN , etc.) (Z. Bečvář)	
7.	4. 4.	IoT communication in mobile networks (Z. Bečvář)	
8.	11. 4.	RFID – basic principles & physical layer (L. Vojtěch)	Short-range technologies
9.	18. 4.	RFID – evolution, technologies, communication chain (L. Vojtěch)	
10.	25. 4.	Short range low power communication (Bluetooth, ZigBee, 6LoWPAN, etc.) (L. Vojtěch)	
11.	2. 5.	Wireless system design (L. Vojtěch)	
12.	9. 5.	No lecture (teaching acc. to Monday's timetable)	
13.	16. 5.	Integration of wireless networks into TCP/IP environment (Z. Kocur)	Practical aspects
14.	23. 5.	Wireless communications in industry, Industry 4.0. (L. Vojtěch)	

Labs

Week	Date	Topic
1.	24. 2.	Introduction (Z. Kocur)
2.	3. 3.	Medium access methods (P. Mach)
3.	10. 3.	Wireless routing protocols (P. Mach)
4.	17. 3.	Assessment of Matlab tasks, Introduction to labs (P. Mach, Z. Kocur)
5.	24. 3.	LAB 1. – group A – Configuration and hacking of WiFi (Z. Kocur, J. Kučerák)
6.	31. 3.	LAB 1. – group B – Configuration and hacking of WiFi (Z. Kocur, J. Kučerák)
7.	7. 4.	Holidays
8.	14. 4.	LAB 2. – group A – V2X communication (Z. Kocur, J. Kučerák)
9.	21. 4.	LAB 2. – group B – V2X communication (Z. Kocur, J. Kučerák)
10.	28. 4.	LAB 3. – group A – LoRaWAN telecommunication chain (Z. Kocur, J. Kučerák)
11.	5. 5.	LAB 3. – group B – LoRaWAN telecommunication chain (Z. Kocur, J. Kučerák)
12.	12. 5.	LAB 4. – group A – Evaluation of NB-IoT operating parameters (Z. Kocur, J. Kučerák)
13.	19. 5.	LAB 4. – group B – Evaluation of NB-IoT operating parameters (Z. Kocur, J. Kučerák)
14.	26. 5.	Assessment, lab replacement (Z. Kocur, P. Mach, J. Kučerák)

Theoretical work in Matlab

Practical experiments

Two weeks per lab + preparation

Preparation for labs in advance is required!

If **anything is unclear in materials** for lab, **send an email to zbynek.kocur@fel.cvut.cz BEFORE the lab so that he can clarify it.** You can also use MS Teams channels in the course

Grading and Exam

Grade		Points
A	Excellent	50 – 45
B	Very good	44 – 40
C	Good	39 – 35
D	Satisfactory	34 – 30
E	Sufficient	29 – 25
F	Fail	< 25

Classification and grading

- **Semester/labs** (max 20 points)
  - Two labs in Matlab – 8 points
    - 4 points per lab (2 points for the assignment, 2 points bonus)
    - Possibility to complete work at home (by week 4: March 17)
  - Four laboratory tasks – 12 points
    - 3 points per lab
    - **Preparation before labs is a must!**
      - **Instructions** available about **a week before the lab – let us know in Teams or via email if not available or something is not clear!**
      - **Home preparation**
      - **Physical measurement in lab**
      - Possibility to complete reports during a week after the lab
  - At least 8 points for assessment
  - **Details to be provided during the first lab**
- **Exam** (max 30 points)
  - **Written exam** - topics from lectures and labs
- **Extra points** during lectures (max 3 points)
  - **Activity** during lectures

Expected **knowledge** of all topics **from lectures and labs**

- **No need to memorize all numbers and abbreviations**
- **Important is to understand principles**

Literature and sources

Lectures/labs

- Slides will be available at: **https://moodle.fel.cvut.cz/**
  - Slides include all what you need to understand fundamentals (and pass the exam)

Books

1. O. Liberg, M. Sundberg, E. Wang, J. Bergman, and J. Sachs, “Cellular Internet of Things: Technologies, Standards, and Performance,“ Academic Press, 2018.
2. H.Y. Wei, J. Rykowski, S. Dixit, "WiFi, WiMAX and LTE Multi-hop Mesh Networks: Basic Communication Protocols and Application Areas," Wiley, 2013.
3. W.W. Dargie, C. Poellabauer, "Fundamentals of Wireless Sensor Networks: Theory and Practice," Wiley, 2010.
4. K. Townsend, C. Cufí, Akiba, R. Davidson, "Getting Started with Bluetooth Low Energy: Tools and Techniques for Low-Power Networking," O'Reilly Media, 2014.
5. V. Coskun, K. Ok, B. Ozdenizci, "Near Field Communication (NFC): From Theory to Practice," Wiley 2012.
6. K. Finkenzeller, D. Muller, RFID Handbook: Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication, 3rd Edition“, Wiley 2010.

Standards (optional, not needed to pass exam)

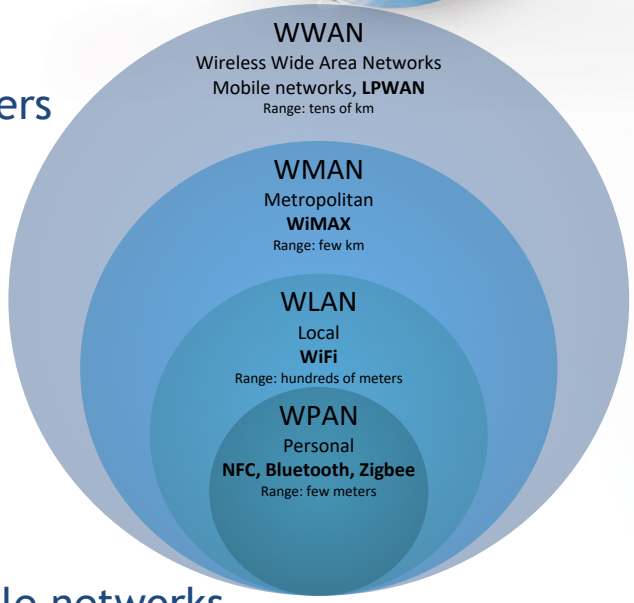
- ETSI (www.etsi.org)
- IEEE (www.ieee.org)
- …

Introduction to wireless technologies

Classification of wireless networks

Range

- **Personal** (WPAN) – neighborhood of a person, few meters
- **Local** (WLAN) – from meters to hundreds of meters
- **Metropolitan** (WMAN) – coverage of cities, few km
- **Wide** (WWAN) – global coverage – mob. nets, LPWAN



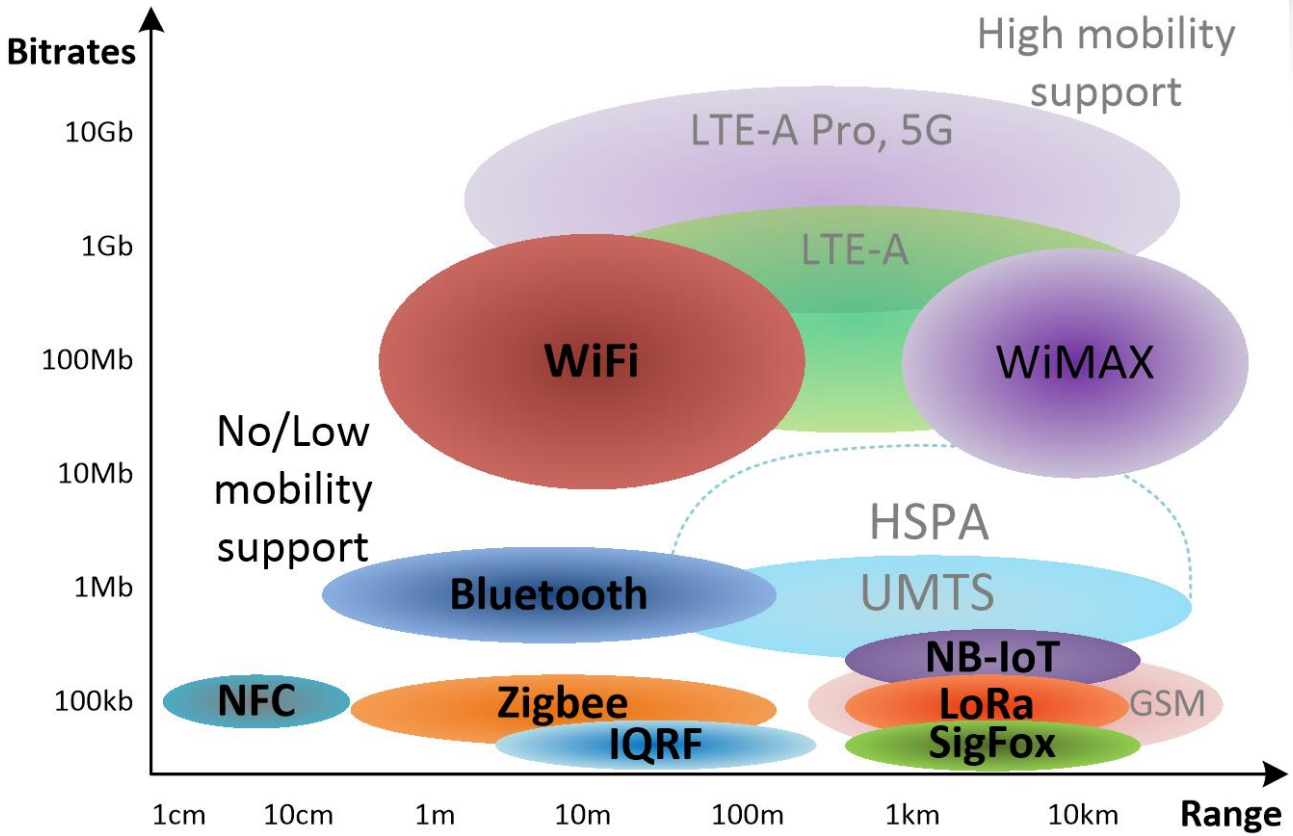
Mobility

- **Fixed** – no mobility at all
- **Nomadic access** – limited mobility (e.g., in a room)
- **Full mobility** – no limits on mobility (handover) – mobile networks

Topology

- **Infrastructure-based**
  - **Point-to-point** (P2P)
  - **Point-to-multipoint** (P2MP)
- **Infrastructure-less**
  - **Ad-hoc**
  - **Mesh**

Wireless technologies

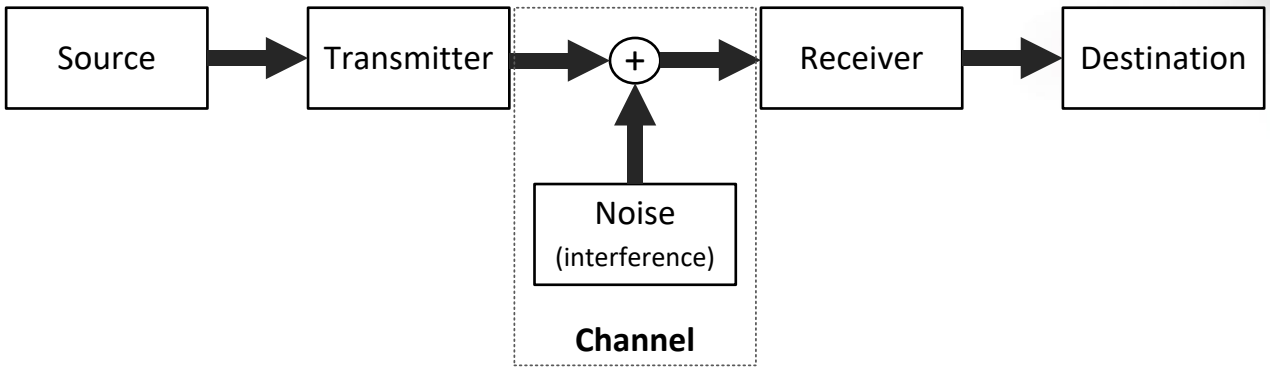


Simplified illustration

Scope of this course: **Wireless networks and technologies** except mobile networks

Mobile (cellular) networks in winter semester: B(E)2M32MKSA – "Mobile Networks"

Communication system



Wireline vs. Wireless

Channel:

- Wireless channel is **more prone to errors**, **interference** and **noise**, and it is **time varying**

Mobility:

- Wireless networks **allows mobility** of end devices

Flexibility and scalability:

- Wireless networks offer **more flexibility and topology is easy to change**

Deployment:

- **Deployment** of wireless networks is typically **faster, cheaper, and easier**

Hardware:

- Wireless HW is usually **more expensive**

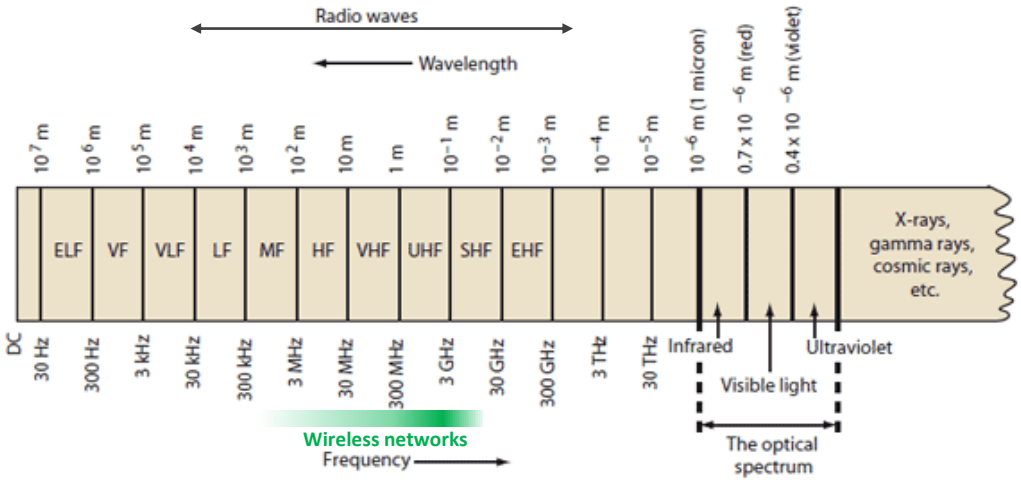
Radio waves

Radio waves: "electromagnetic waves of frequencies arbitrarily lower than 3 000 GHz, propagated in space without artificial guide"

- Definition by ITU in "ITU Radio Regulations – Article 1, Definitions of Radio Services"
  - http://www.ictregulationtoolkit.org/en/toolkit/notes/PracticeNote/2824
- Behavior like light (refraction, diffraction, …)

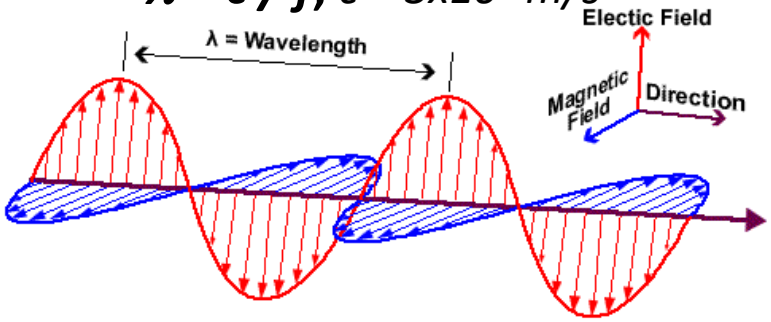
History

- Existence of electromagnetic waves postulated by J. C. Maxwell (1867)*
- Existence of waves demonstrated by H. Hertz – transmission over few meters (1887)**
- First long-range radio transmission by G. Marconi (18 miles) (1895)**



Wavelength (λ) vs frequency (f)

$\lambda = c / f$; $c = 3x10^{8}$ m/s



[A. Shenoy, "What is the difference between gravitational wave and electromagnetic wave? The same wave but the different initiator or totally different?,"]

*[A. Goldsmith, "Wireless Communications," 2005]
**[J. M. Sheam "History of Wireless Communication," 2011]

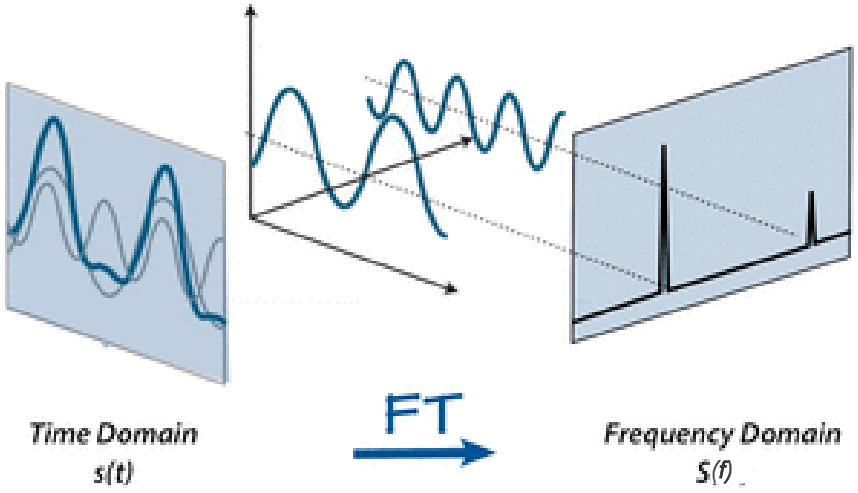
Spectrum of (radio) signal

Time domain – signal represented as a sum of ***sin*** signals

Frequency domain – signal represented by "**spectrum**"

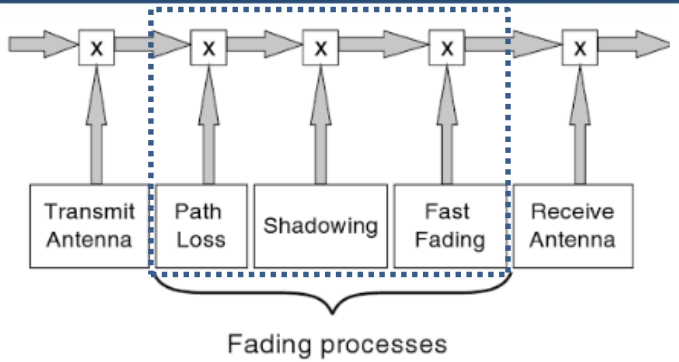
Transition between Frequency and Time domains:

- **Fourier Transform**, FT (**time** domain **to frequency** domain)
  - $S(f) = \int_{-\infty}^{+\infty} s(t) e^{-i2\pi f t} dt$
- **Inverse Fourier Transform**, IFT (**frequency** domain **to time** domain)
  - $s(t) = \int_{-\infty}^{+\infty} S(f) e^{i2\pi f t} df$



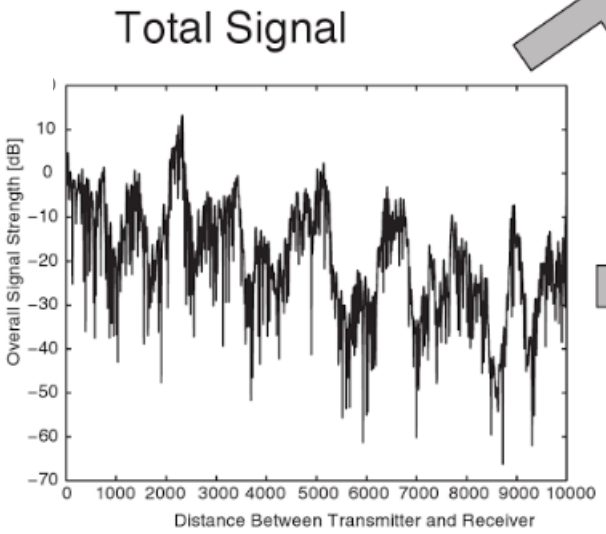
What is a Fourier transform? ,
http://mriquestions.com/fourier-transform-ft.html

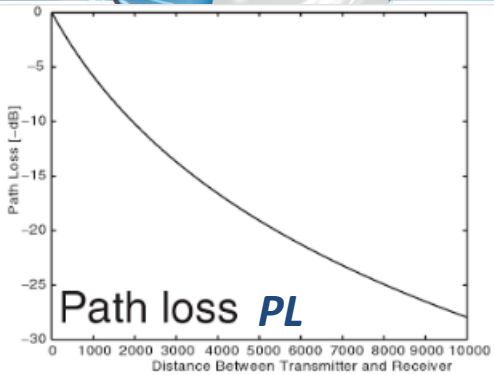
Wireless channel concept

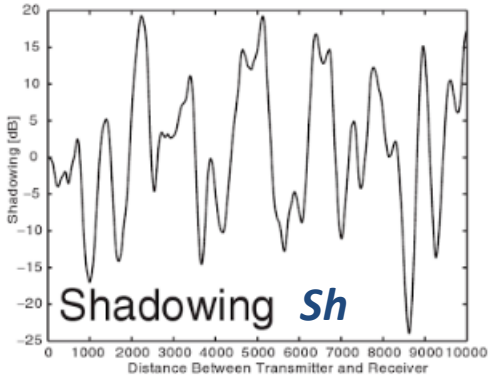


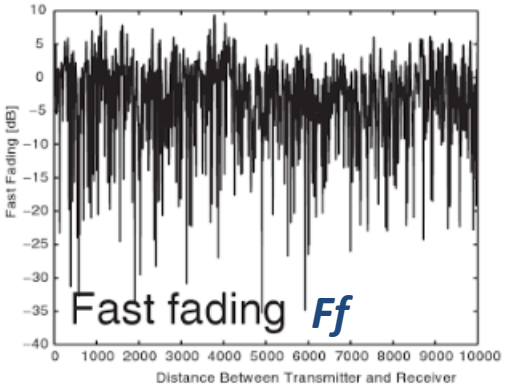
Channel attenuation:

- **Path loss**
  - Distance, frequency
- **Shadowing**
  - Obstacles (buildings, etc)
- **Fast fading**
  - Multipath propagation





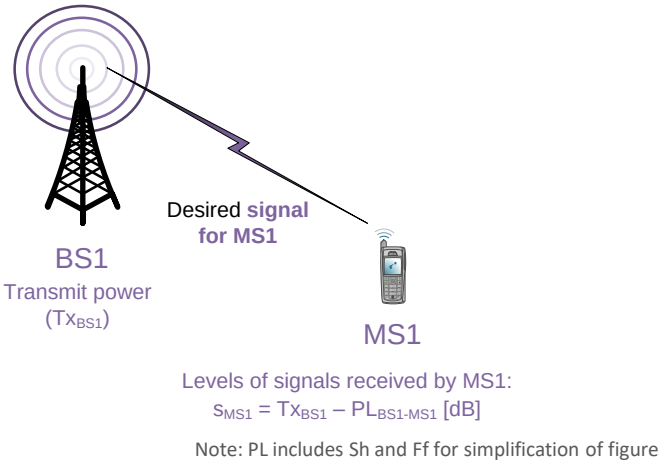




Overall attenuation of signal

PL + Sh + Ff

Signal propagation



dB ⇔ W

$P[\mathbf{mW}] = 10^{(P[\mathbf{dBm}]/10)}$

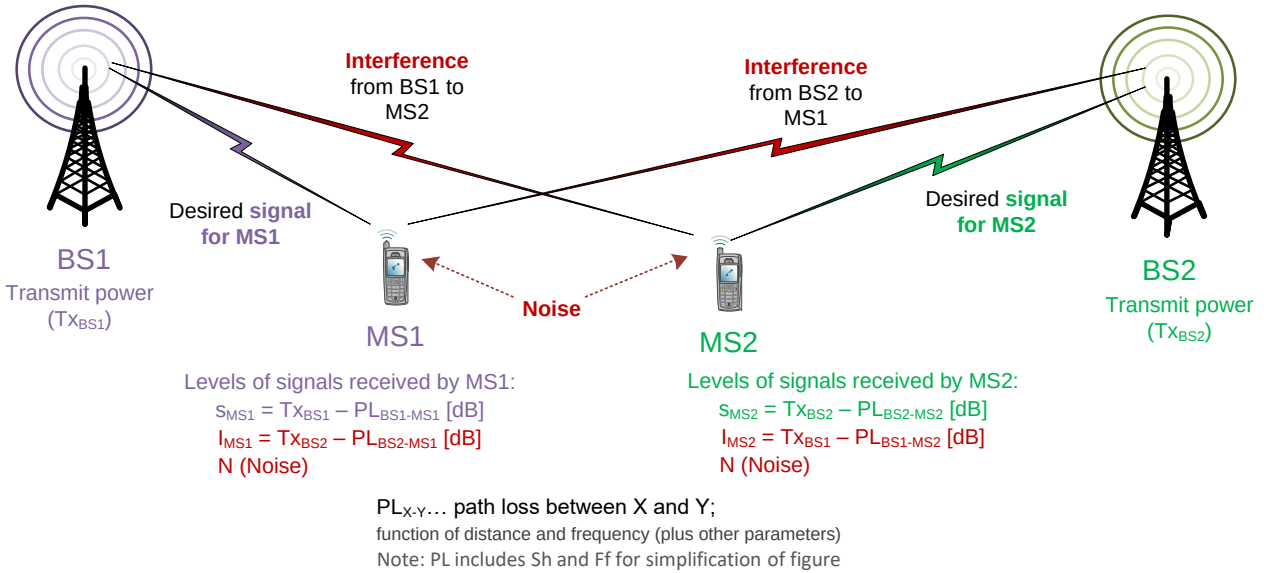
$P[\mathbf{dBm}] = 10*\log_{10}(P[\mathbf{W}]/1mW)$

Signal, *s* – desired signal carrying information

Transmitting power, *Tx* – power the base station transmits with

Received signal level/strength at the MS: ***s = Tx - (PL + Sh + Ff)*** [dB]

Interference and noise



dB ⇔ W

$P[\mathbf{mW}] = 10^{(P[\mathbf{dBm}]/10)}$

$P[\mathbf{dBm}] = 10*\log_{10}(P[\mathbf{W}]/1mW)$

Signal, *s* – desired signal carrying information

Noise, *N* – in general, any undesired signal; not carrying any information

Interference, *I* – undesired signal from neighboring communications at the same resources, $I = \sum I_i$, where I_i is the interference from the i-th source [W]

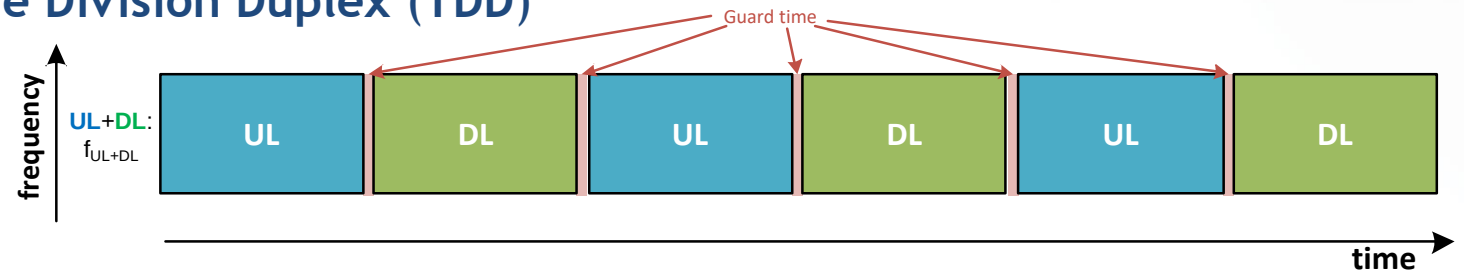
Signal to Interference plus Noise Ratio, $\boldsymbol{SINR = \frac{s}{I+N}}$ [W]; $\boldsymbol{SINR = s - IN}$[dB]

- Noise threated as interference (compute IN in W, $IN = N + \sum I_i$ [W], then convert to dB)

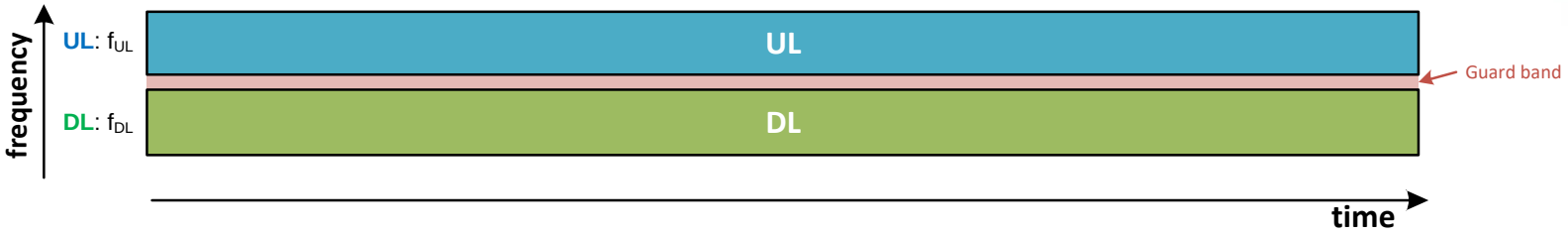
Duplexing
(Alternating Uplink and Downlink)

Half-duplex

- Time Division Duplex (TDD)



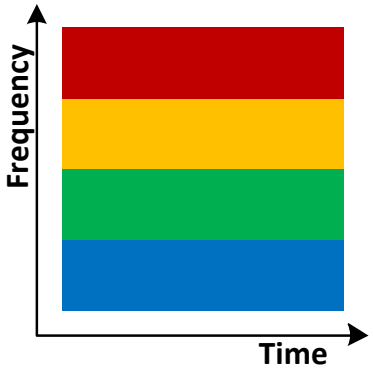
- Frequency division duplex (FDD)



Multiplexing
(Sharing resources among multiple users)

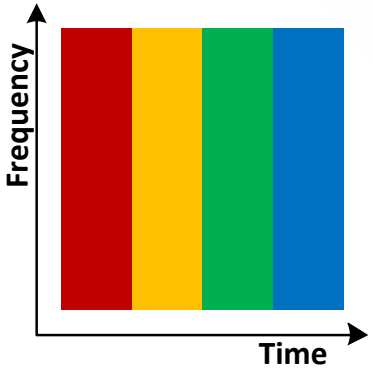
Frequency Division Multiple Access (FDMA)

Users allocated with different frequencies, but at same time



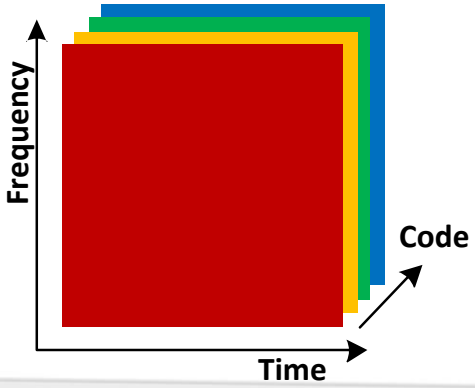
Time Division Multiple Access (TDMA)

Users allocated with same frequencies, but at different time



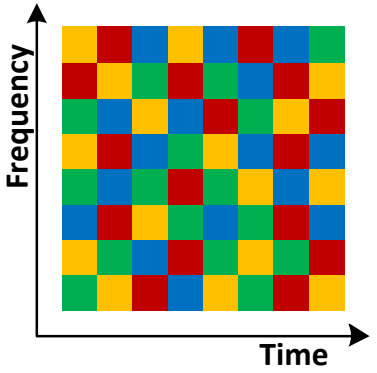
Code Division Multiple Access (CDMA)

Users allocated with same frequency and same time, but with different codes



Orthogonal Frequency Division Multiple Access (OFDMA)

Users allocated with different frequencies and different times; orthogonal carries



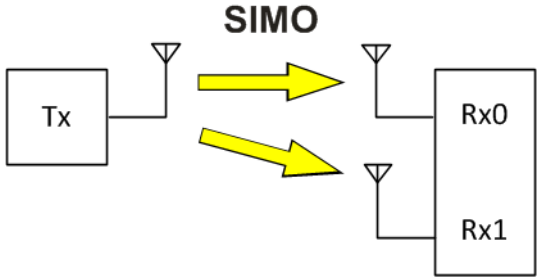
Multiple antennas

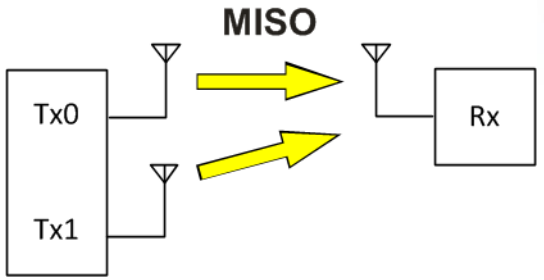
SISO (Single Input Single Output)

- Conventional communication

SIMO/MISO (Single/Multiple Input Multiple/Single Output) – same data

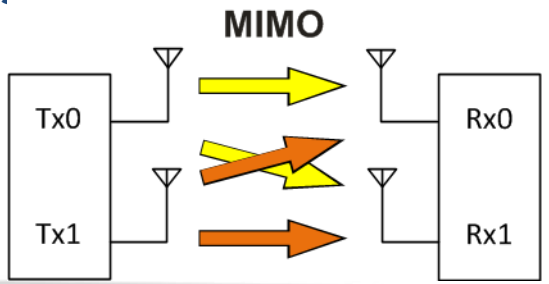
- Increase resistance against fading effects





MIMO (Multiple Input Multiple Output)

- **Capacity** (parallel transmissions) or **diversity** (fading robustness)
- Interference among parallel paths
  - Signal processing



Devices in wireless networks

Client/Terminal/User Device/User Equipment/...

- **Source/destination** for information communicated over network
- E.g., sensor, machine, tablet, PC, phone, …

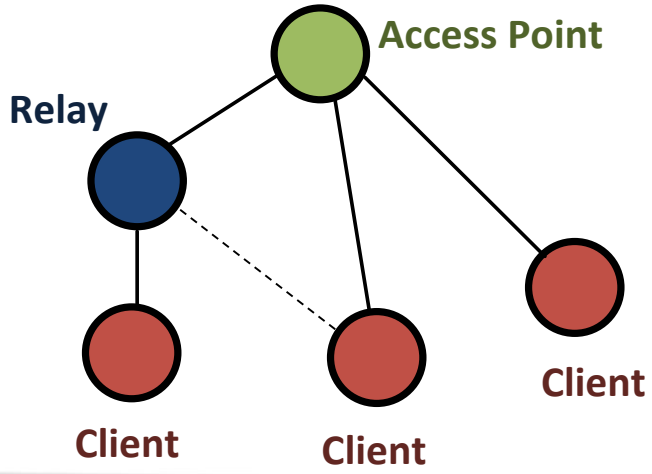
Access point (AP), Base Station (BS)

- Entity **controlling communication** and/or providing **interface to network**

Relay

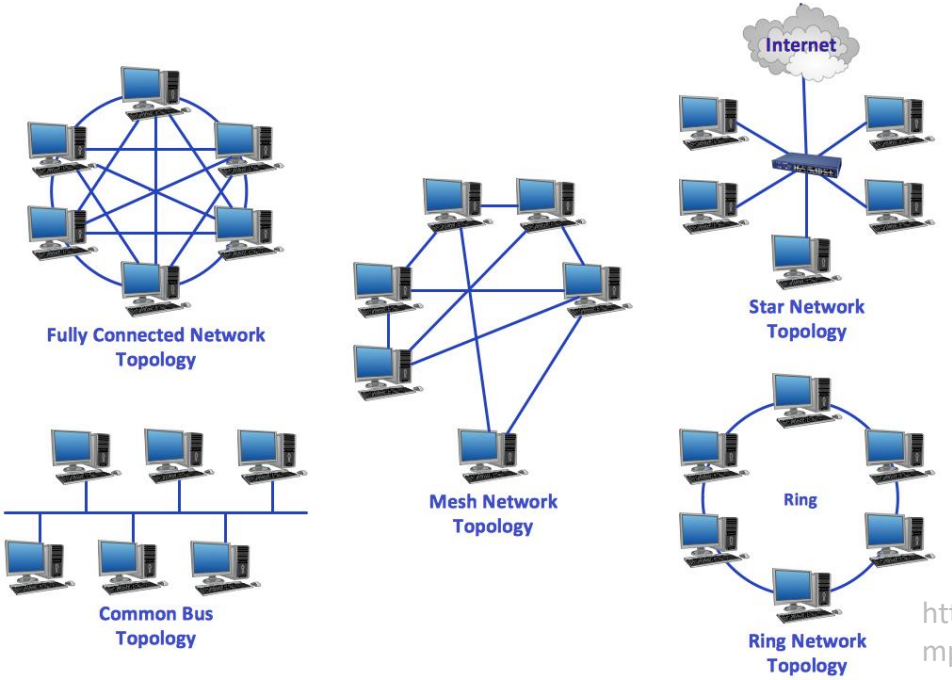
- **Forwarding** (relaying) **information** between two or more devices (Clients, APs)

Device in wireless network can act in more roles at the same time



Network topologies

Wireline (computer) networks – star, ring, bus, mesh, tree, …



http://www.conceptdraw.com/examples/wireless-network-topology

What is different for wireless?

Limits of wireline vs wireless network topologies

Wireless not limited by availability of a wire (cable, fiber)

- Cost of cable and its deployment avoided
- Higher scalability and flexibility

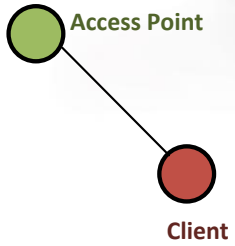
Wireless limited by:

- Signal propagation
  - Environment (walls, obstacles, weather,…)
  - Antennas (directional, gain,…)
  - Transmission power and receiver sensitivity
- Interference and noise
- Energy (critical in some scenarios and use-cases always)

Wireless networks topologies

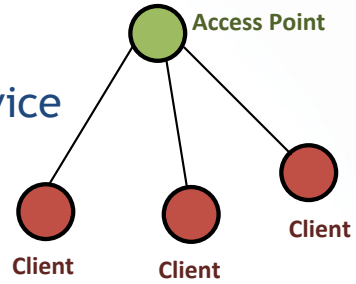
Point-to-point (P2P)

- Communication between two points (devices)
  - Access Point and Client, Client and Client
- Pair of communicating devices



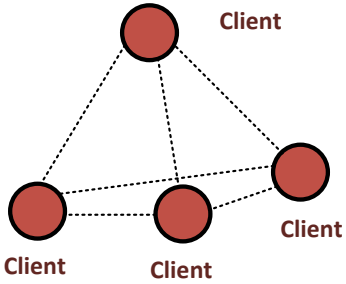
Point-to-MultiPoint (P2MP)

- Direct communication of many (multiple) devices with single AP/device
- Many communicating devices



Ad-hoc

- Communication channels between two points (devices, APs)
- Any device can communicate directly with another device in its communication range
- High dynamicity



Mesh

- Extension of ad-hoc
  - Relaying/routing of communication via intermediate nodes

Note: Ad hoc and Mesh overlap with each other and their definitions are often mixed

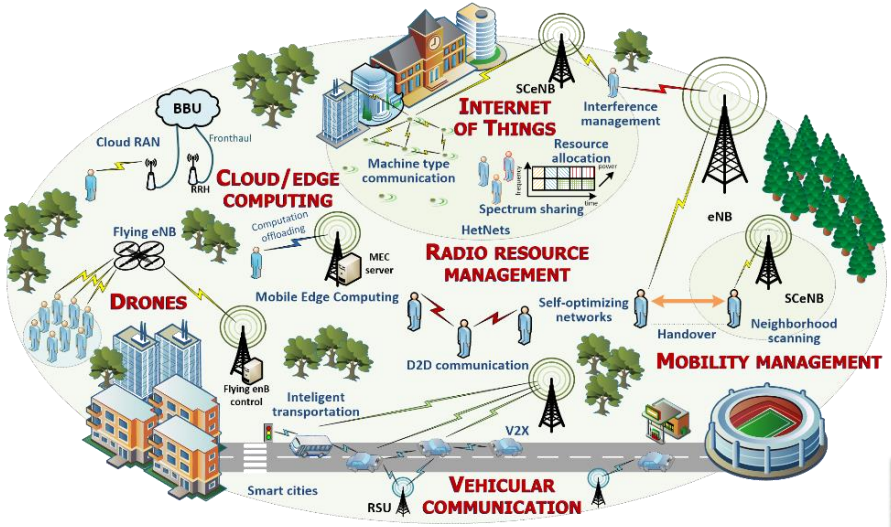
Projects and activities in wireless

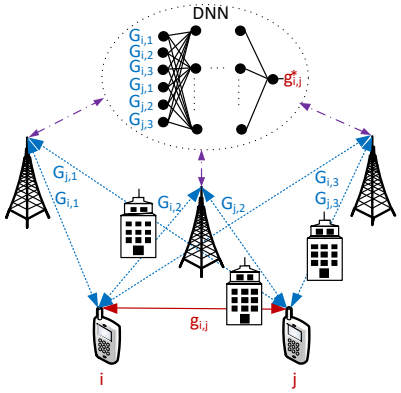
Projects and theses for students

Experiments and/or implementation in mobile/wireless networks

Prototyping Flying Base Station – UAVs and satellites

Experiments with Mobile Edge Computing





Testing machine learning in mobile networks

2-5 students

Scholarship 3.000-12.000 CZK/month
(subject to time availability)

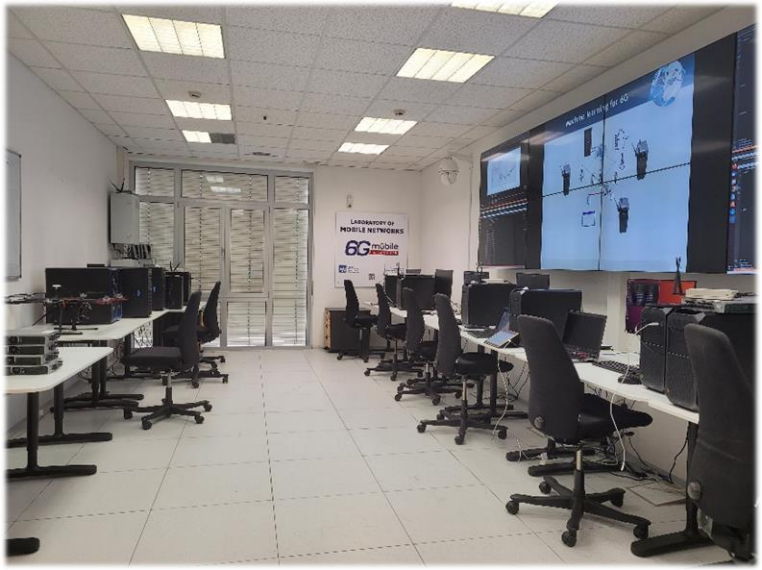
Diploma thesis (theory and practice)

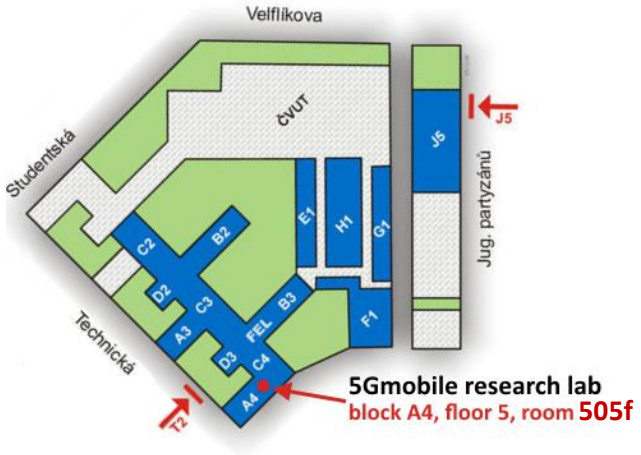
Prototyping vehicle (model) communicating via mobile networks

6Gmobile laboratory

HW and SW for emulation of 4G, **5G and beyond** networks

- **USRPs B210/B205mini/B310** running a Software Define Radio
- **OpenAirInterface** and **srsRAN** emulating 4G/5G/beyond 5G network
- **Edge computing servers** for Mobile Edge Computing applications
- **Drone** as a flying base station
- **Machine learning** for network control
- **GPU** for machine learning processing

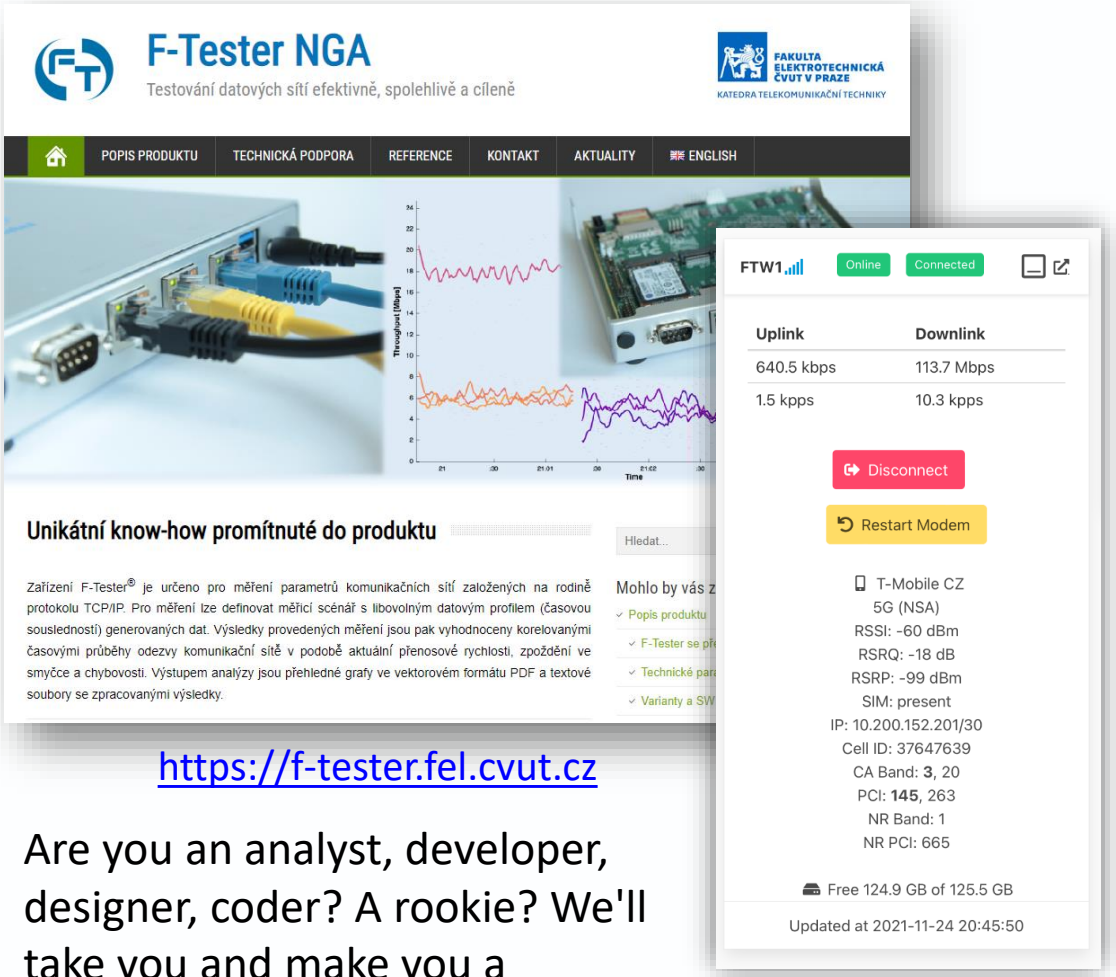




web: http://6Gmobile.fel.cvut.cz
twitter: @5Gmobile_CTU

Network Group Projects and Theses

Network Measurement Tools and Devices



https://f-tester.fel.cvut.cz

Are you an analyst, developer, designer, coder? A rookie? We'll take you and make you a hacker!!!

- Experiments with network performance measurement.
- Design and implementation of network devices.
- Various work with HW and SW with a focus on computer networks.
- Real working with the latest technologies (5G, LPWAN etc.).
- Work on projects with an overlap into the business.
- Do you know: x86, STM32, Arm, Linux, Windows, Mac OS, C, C++, Lua, Python, JavaScript, ubus, JSON, XML, http, users ☺?

zbynek.kocur@fel.cvut.cz

Project and theses for students

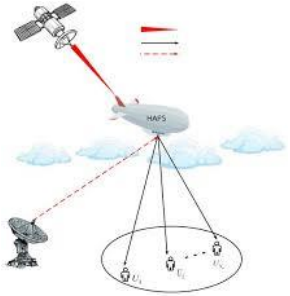
Scholarship

Simulator for emergency dispatch center

- Javascript (Node.js, Vue.js) – programming of individual functions
- Strong team to be learned from

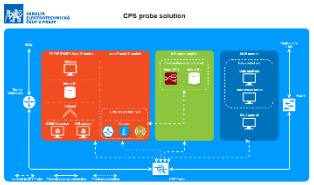
High-Altitude Pseudo-Satellite (HAPS) communication

- Satellite communication (HAPS – HAPS - GEO/LEO)
- Earth - HAPS communication
- HAPS – DRONES communication (for 6G network)
- Radio link, IDS/IPS security, HAPS data network



IDS/IPS security probe

- Embedded system configuration – adding new functions, sensors…
- IoT, Industry 4.0, network security, cyber – physical systems,



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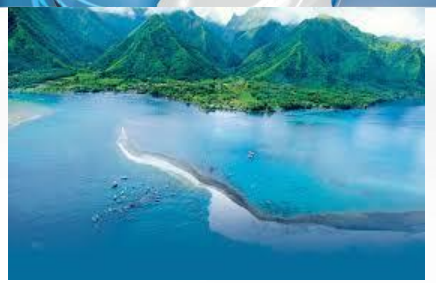
Study abroad

Double degree



NTUST (Taipei, Taiwan)

- **Top technical university** (#50 in Asia, #327 worldwide- QS ranking)
- Resides in the center of TaiPei
- **Conditions**
  - 3 semesters in Prague + 2 semesters in TaiPei
  - Diploma from ČVUT and from NTUST
  - Scholarship (covering travel and accommodation)
  - Only one diploma thesis (written and defended in English)
  - All branches of Electronics and Communications program
  - http://www.fel.cvut.cz/cz/education/abroad/taiwan.html

EURECOM (Sophia Antipolis, Cote d'Azur, France)

- **Top European institute in communication systems** (5★ in QS)
- French Riviera (Antibes, Cannes, Nice, St. Tropez,...)
- **Conditions**
  - 2 semesters in Prague + 2 semesters in France + 1 semester in company
  - Diploma from ČVUT and from EURECOM
  - Scholarship (covering travel and accommodation) **+5000 EUR** for an outstanding student(s)
  - Only one diploma thesis (if in company → **paid**)
  - KSI and IoT branches (extension to MK under preparation)
  - https://www.fel.cvut.cz/cz/education/abroad/eurecom.html

web: http://ek.fel.cvut.cz/cs/pro-studenty/double-degree-programy/
email: Zdenek.Becvar@fel.cvut.cz

CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF ELECTRICAL ENGINEERING

DEPARTMENT OF TELECOMMUNICATION ENGINEERING

Questions?

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6G mobile RESEARCH LAB

http://6Gmobile.fel.cvut.cz