Summer School on
Beyond 5G: ENABLING TECHNOLOGIES, OPPORTUNITIES AND RESEARCH CHALLENGES AHEAD

6 ECTS

Day 1		Monday June 30th
Introduction to 5G: Long story short	Luise	9-11
PHY-layer Technologies for 5G and B5G (i)	Bacci	11-13
PHY-layer Technologies for 5G and B5G (ii)	Moretti	14-16
Non-terrestrial networks for 5G	De Gaudenzi*	16-18
Day 2		Tuesday July 1st
Security and privacy in 5G systems	Garroppo	9-11
Cloud/Edge Computing for 5G Networks	Vallati	11-13
Optics for 5G networks	Giorgetti	14-16
Artificial Intelligence for 5G Networks and Applications	Ruffini	16-18
Day 3		Wednesday July 2nd
Network programming with eBPF	Procissi, Lettieri	9-13
5G and UAV applications	Giordano	14-16
Quantum computing impact on B5G security	Garroppo	16-18
Day 4		Thursday July 3rd
System-level simulation and real-time emulation of edge-enabled 5G/B5G networks	Stea, Nardini	9-13
Network Automation, SDN and NFV in 5G and B5G	Virdis*	14-16
Hands-On Network Programming with SDN for Network Slicing	Giorgetti	16-18
Day 5		Friday July 4th
Electromagnetic methodologies for 5G	Monorchio	9-11
Industrial IoT in B5G	Garroppo	11-13
Electromagnetic Systems for Automotive Applications: from 5G to Terahertz Communications	Michel	14-16
Electronic circuits and systems for 5G Automotive V2X scenarios	Saponara	16-18

1. **Introduction to 5G: Long story short** - Prof. M. Luise

   - Communications: a Person's Fundamental Right

   - Mobile/Wireless Communications and the Internet

   - Generations of Mobile Networks: From 2G to 3G to 4G to 5G

   - Searching For Efficiency: the 5G 10 x 10 x 10 Equation

   - Challenges in 5G Deployment: where are we now?

2. **PHY-layer Technologies for 5G and B5G(I)** - Prof. G Bacci

   - 5G propagation channel modeling and its implications for B5G, including dynamic and high-mobility scenarios

   - NR (New Radio) numerology: flexibility and scalability toward sub-THz B5G bands

   - Enhanced Mobile Broadband (eMBB) as a foundation for immersive applications (e.g., XR, holographic communications) in B5G

   - Ultra-Reliable Low-Latency Communications (URLLC) in critical industrial and vehicular B5G contexts

   - Massive connectivity challenges in B5G: supporting billions of heterogeneous devices with stringent energy and reliability constraints

3. **PHY-layer Technologies for 5G and B5G (II)** - Prof. M. Moretti

   - Multiple antenna technologies, including massive MIMO evolution for extremely high spatial resolution and 3D beamforming in B5G

   - Millimeter-wave (mmWave) and sub-THz communications: challenges and opportunities in wideband high-frequency transmission for B5G

   - Dense and ultra-dense networks, including coordinated small cells, intelligent reflecting surfaces (IRS), and cell-free architectures for seamless, high-capacity B5G connectivity

4. **Non-terrestrial networks for 5G** - Prof. R. De Gaudenzi

- The space market
- Commercial mobile communication systems
  - o Non-geostationary systems (Iridium, Globastar, AST Mobile, Apple, Starlink direct to cell)
  - o Geostationary systems (Inmarsat, Thuraya, Sirius-XM, Solaris)
  - o Open Issues and Future Directions
- Commercial fixed broadband communication systems
  - o Non-geostationary systems (SES O3B, OneWeb, SpaceX Starlink, Amazon Kuiper)
  - o Geostationary systems (Eutelsat Ka-sat and HTS Konect, Viasat 2 e 3, Hughes Networks Jupiter 3)
  - o Open Issues and Future Directions

5. **Security and privacy in 5G systems** - Prof. R. Garroppo

- Security and privacy evolution in LTE networks.
- The 5G security architecture.
- Privacy and security issues in 5G: main approaches, threats and challenges
- Reference to the security-by-design approach, authentication and subscriber's privacy.
- Open security issues and risks in the 5G eco-system.

6. **Cloud/Edge Computing for 5G Networks and Applications** – Prof. C. Vallati

- Cloud computing: general introduction to Cloud Computing and basic concepts. Virtualization as enabling technology for cloud computing.
- Mobile Edge Computing: general introduction to MEC as extension that moves computing and storage at the edge of the network.
- The role of MEC in 5G networks

7. **Optics for 5G networks** - Prof. A. Giorgetti

- Overview of optical communications and networks
- 5G-oriented optical networks: requirements and main features
- Front-haul / Mid-haul / Back-haul networks
- Optical transmission technologies for 5G X-haul

- Solutions for the mobile front-haul

8. **Artificial Intelligence for 5G Networks and Applications** – Prof. F. Ruffini

- Artificial Intelligence: intro
- Artificial Intelligence in 5G technology
- Artificial intelligence applications supported by 5G technology
- Explainable AI and future trends in AI

9. **Network programming with eBPF** – Prof. G. Procissi, Prof. G. Lettieri

- Introduction to eBPF
- eBPF program types, kernel hooks, maps and helpers
- eBPF for end host networking: eXpress Data Path (XDP) and Traffic Control
- Kernel bypass with AF_XDP
- Development of simple user/kernel space example applications

10. **5G and UAV applications** - Prof. S. Giordano

- Space-based networks, Air-based Networks, Ground-based Networks
- UAV-assisted communications
- Cellular-connected UAVs
- Flying Ad Hoc Networks (FANETs)
- Aerial Hetnets; Combined UAV and D2D Communications
- Dynamic Deployment Ability
- UAV-Based Swarm Networks
- Low- and high-altitude platforms
- Energy harvesting in UAV Networks
- Computing Communication and Caching/Storage in the sky
- Network Softwarization and Virtualization in UAV Communications
- Networks in a box

11. **Quantum computing impact on B5G security** - Prof. R. Garroppo

- Cryptographic algorithms and quantum computing
- Quantum computers impact on 5G security architecture
- Quantum and Post-Quantum Cryptography
- The NIST PQC algorithms and their potential usage in B5G

- The transition phase: the hybrid approach

12. System-level simulation and real-time emulation of edge-enabled 5G/B5G networks - Prof. G. Stea, G. Nardini

- Introduction to discrete-event simulation

- Open-source tools to simulate 5G: link-level vs. application-level

- Introduction to the OMNeT++ framework

- Modelling the 5G protocol stack and network components

  - o Overview of the Simu5G simulator

  - o Simulating 5G network scenarios

  - o Simulating Mobile Edge Computing (MEC)-based applications

- Fast prototyping of 5G applications

  - o Configuring Simu5G as a real-time network emulator

  - o Running real-time MEC-based applications in emulated 5G networks

13. Network Automation, SDN and NFV in 5G and B5G - Prof. A. Virdis

- SDN Principles: Control- and data-plane Separation, SDN general architecture and components, Northbound and Southbound interfaces.

- The evolution of SDN: from openflow to modern SDN views.

- Network softwarization and slicing: SDN architecture for 5G

- NFV: virtual network functions and orchestration, architecture overview, relation with SDN

- Network Automation concepts for 5G and beyond.

14. Hands-On Network Programming with SDN for Network Slicing - Prof. A. Giorgetti

- Emulation of an SDN network

- Interaction with the SDN controller

- Development and deployment of NetApps

- A practical NetApp example: network slicing

15. Methodologies for electromagnetic propagation in 5G - Prof. A. Monorchio

- E.M. Propagation Phenomenology at 5G bands

- Short introduction to high-frequency techniques

- Ray Tracing procedure

- Applications and validation

- Limitations and efficiency improvement
- Comparison with empirical propagation models
- Phased Array Antenna modelling
- Decoupling of antennas
- E.M. field level evaluation

16. **Industrial IoT in B5G** - Prof. R. Garroppo

- Classifications, Requirements and Performance Indicators of IIoT services.
- Technologies and architectures for supporting IIoT URLL and Massive IoT Services.
- Time Sensitive Communication and its integration in B5G systems
- 5G Non-Public Networks and support for a 5G-LAN type service.
- Integration of non-3gpp technologies in B5G systems.
- Technical Challenges for B5G-based IIoT services.

17. **Electromagnetic Systems for 5G Automotive Applications** – Prof. A. Michel

- Sensors and Wireless Systems integrated on vehicles: applications and requirements
- Evolution of Electromagnetic Systems for Cellular Communication: from GSM to 5G mmWave and beyond
- Challanges and future trends on Automotive Electromagnetic Systems for Cellular Communications

18. **Electronic circuits and systems for 5G Automotive V2X scenarios** - Prof. S. Saponara

- Introduction about HW enabling technologies for 5G
- RF/mmW transceiver circuits for 5G
- 5G digital baseband processors
- Safety and HW security for on-board 5G vehicle connectivity
- Circuit solutions for 802.11p WLAN and 5G C-V2X vehicle to everything connections
- Analysis of devices and application examples to autonomous and connected vehicles