



Summer School on

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

Day 1		Monday June 29th
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	Luise	16-18
Day 2		Tuesday June 30th
Security and privacy in 5G systems	Garroppo	9-11
Cloud/Edge Computing for 5G Networks	Vallati	11-13
Optics for 5G and Beyond	Andriolli	14-16
Artificial Intelligence for 5G Networks and Applications	Ruffini	16-18
Day 3		Wednesday July 1st
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 2nd
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 3rd
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
 - Non-geostationary systems (Iridium, Globastar, AST Mobile, Apple, Starlink direct to cell)
 - Geostationary systems (Inmarsat, Thuraya, Sirius-XM, Solaris)
 - Open Issues and Future Directions
- Commercial fixed broadband communication systems
 - Non-geostationary systems (SES O3B, OneWeb, SpaceX Starlink, Amazon Kuiper)
 - Geostationary systems (Eutelsat Ka-sat and HTS Konect, Viasat 2 e 3, Hughes Networks Jupiter 3)
 - 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 and Beyond - Prof. N. Andriolli

- Optical transport in 5G architectures: role and requirements
- X-Haul networks

- Optical technologies for 5G X-Haul
- Open and cloud-native fronthaul
- Outlook toward Beyond-5G and 6G transport

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)
- Dynamic Deployment Ability
- UAV-Based Swarm Networks
- Computing Communication and Caching/Storage in the sky
- Network Softwarization and Virtualization in UAV Communications
- Real field trials towards 6G

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
 - Overview of the Simu5G simulator
 - Simulating 5G network scenarios
 - Simulating Mobile Edge Computing (MEC)-based applications
- Fast prototyping of 5G applications
 - Configuring Simu5G as a real-time network emulator
 - Running real-time MEC-based applications in emulated 5G networks

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

- 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
- Challenges 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