



UNIVERSITÀ DI PISA

Università di Pisa

Doctoral Course

## **“5G, Beyond 5G and 6G: the next frontier”**

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### **Short Abstract:**

In the last years, information communication, computation and storage technologies are jointly reshaping the way we use technology, meeting the future needs of a wide range of big data and artificial intelligence applications and, paving the way for a full-customized autonomous user experience. In 2020 the 5G -Next Generation Communication Networks is expected to be operational and a global game changer from a technological, economic, societal and environmental perspective. 5G industry is intensively working today on designing, prototyping and testing fundamental technological advances to de-liver the promised performance in terms of latency, energy efficiency, wireless broadband capacity, elasticity, etc. Nevertheless, many experts say that the next big step for cellular networks is not 5G, it is the distributed support of the cloud and AI.

This set of lectures will cover the vision, the use cases, the architecture design and technical tools for understanding the key enabling technologies that will enable beyond 5G networks to meet its challenging performance targets and how ‘the cloud’ will play an operational role in future wireless networks. The lecture will also introduce and detail very innovative concepts freshly under investigation for future B5G/6G networks such as Reconfigurable Intelligent surfaces and the integration of non-terrestrial communication and edge intelligence with terrestrial communication systems. Moreover, dedicated lectures will promote the idea that including semantic and goal-oriented aspects in future 6G networks can produce a significant leap forward in terms of system effectiveness and sustainability. Semantic communication goes beyond the common Shannon paradigm of guaranteeing the correct reception of each single transmitted packet, irrespective of the meaning conveyed by the packet. The idea is that, whenever communication occurs to convey meaning or to accomplish a goal, what really matters is the impact that the correct reception/interpretation of a packet is going to have on the goal accomplishment. Focusing on semantic and goal-oriented aspects and, possibly combining them, helps to identify the relevant information, i.e. the information strictly necessary to recover the meaning intended by the transmitter or to accomplish a goal. Combining knowledge representation and reasoning tools with machine learning algorithms paves the way to build semantic learning strategies enabling current machine learning algorithms to achieve better interpretation capabilities and contrast

adversarial attacks. 6G semantic networks can bring semantic learning mechanisms at the edge of the network and, at the same time, semantic learning can help 6G networks to improve their efficiency and sustainability.

The lecture will offer a flora for interactive discussions on future research axes and open challenges on B5G/6G networks.

### **Course contents and schedule in brief:**

**Lecture 1 (3h)** - Introduction to evolution of Wireless Networks from 3G+ to 5G. Details on technologies enabling the revolution between 4G and 5G networks.

**Lecture 2 (1.5h)** – 6G, The next frontier: Visions, roadmaps, opportunities, issues, HW reality check

**Lecture 3 (3h)** – The quest for high spectrum bands: mmW, sub-THz and VLC communications. Issues and practical examples.

**Lecture 4 (3h)** – From the Mobile Edge Computing paradigm to network cloudification and Edge AI

**Lecture 5 (1.5h)** – Sustainable and energy efficient 6G Connect-Compute-Control Networks

**Lecture 6 (1.5h)** - 6G: The reconfigurable Intelligent Surfaces Opportunities for shaping the Environment as a Service. The RISE-6G case.

**Lecture 7 (1.5h)** - 6G: The non-terrestrial Communication integration and the on demand intelligent support for 3-dimensional services. The 5G-Allstar case.

**Lecture 7 (3h)** – Challenges in AI & Wireless Communications for 6G

**Lecture 8 (3h)** - 6G: The Semantic Communication opportunity and recent research results.

**Lecture 9 (1.5h)** - the Goal-Oriented Communications opportunity and recent research results.

**Lecture 10 (1.5h)** A strategy for future 6G research axes. Open discussions.

**Total # of hours:** 24

### **References:**

#### **Green Communications**

- *Enabling green cellular networks: A survey and outlook*, Antonio De Domenico, Emilio Calvanese Strinati, Antonio Capone,
- *Green framework for future heterogeneous wireless networks*, R Mahapatra, A De Domenico, R Gupta, EC Strinati – Journal on computer networks, 2013.
- *Base-station duty-cycling and traffic buffering as a means to achieve green communications*, R Gupta, EC Strinati, IEEE VTC 2012.
- Green communications: an emerging challenge for mobile broadband communication networks, E Calvanese Strinati, A De Domenico, L Herault - Journal of Green Engineering, 2011.

- *6G: The Next Frontier: From Holographic Messaging to Artificial Intelligence Using Subterahertz and Visible Light Communication*, E Calvanese Strinati, S Barbarossa, JL Gonzalez-Jimenez, D Ktenas, IEEE VT Magazine, Septembre 2019.
- *Air Interface Challenges and Solutions for future 6G Networks*, B Miscopein, JB Doré, E Strinati, D Kténas. January 2019. CEA-01986524v2
- *6G in the sky: On-demand intelligence at the edge of 3D networks (Invited paper)*, Emilio Calvanese Strinati Sergio Barbarossa Taesang Choi Antonio Pietrabissa Alessandro Giuseppi Emanuele De Santis Josep Vidal Zdenek Becvar Thomas Haustein, Nicolas Cassiau Francesca Costanzo Junhyeong Kim Ilgyu Kim. ETRI Journal, October 2020.
- *Design of cellular, satellite, and integrated systems for 5G and beyond*, Junhyeong Kim, Guido Casati, Nicolas Cassiau, Antonio Pietrabissa, Alessandro Giuseppi, Dong Yan, Emilio Calvanese Strinati, Marjorie Thary, Danping He, Ke Guan, Heesang Chung, Ilgyu Kim. ETRI Journal, October 2020.
- *6G Networks: Beyond Shannon Towards Semantic and Goal-Oriented Communications*, E Calvanese Strinati, S Barbarossa. To appear on Computer Networks Journal.

### **Mobile Edge Cloud**

- P. Mach and Z. Becvar, "Mobile Edge Computing: A Survey on Architecture and Computation Offloading," in IEEE Communications Surveys & Tutorials, vol. 19, no. 3, pp. 1628-1656, thirdquarter 2017, doi: 10.1109/COMST.2017.2682318.
- *D-MEC: Discontinuous Mobile Edge Computing*, Mattia Merluzzi, Nicola di Pietro, Paolo Di Lorenzo, Emilio Calvanese Strinati, Sergio Barbarossa, August 2020, arXiv preprint arXiv:2008.03508.
- *Resilient Design of 5G Mobile-Edge Computing Over Intermittent mmWave Links*, N di Pietro, M Merluzzi, EC Strinati, S Barbarossa, arXiv preprint, October 2019.
- *Proactive Computation Caching Policies For 5G-and-Beyond Mobile Edge Cloud Networks*, N di Pietro, EC Strinati, EUSIPCO 2018.
- *Enabling effective mobile edge computing using millimeterwave links*, S Barbarossa, E Ceci, M Merluzzi, E Calvanese-Strinati, IEEE ICC 2017.
- *Dynamic resource allocation exploiting mobility prediction in mobile edge computing*, J Plachy, Z Becvar, E Calvanese Strinati - 2016 IEEE WCNC.
- *Uplink traffic in future mobile networks: Pulling the alarm*, J Oueis, E Calvanese Strinati, Crowncom 2016.
- *The fog balancing: Load distribution for small cell cloud computing*, J Oueis, E Calvanese Strinati, S Barbarossa - 2015 IEEE VTC.
- *An architecture for mobile computation offloading on cloud-enabled LTE small cells*, F Lobillo, Z Becvar, MA Puente, P Mach, E Calvanese Strinati, IEEE WCNC 2014.
- Small cell clustering for efficient distributed fog computing: A multi-user case, J Oueis, EC Strinati, S Sardellitti, S Barbarossa - 2015 IEEE VTC.
- *Dynamic Traffic Management for Green Open Access Femtocell Networks*, A De Domenico, R Gupta, E Calvanese Strinati, IEEE VTC 2012.

## CV of the Teacher



Dr. Emilio Calvanese Strinati obtained his Engineering Master degree in 2001 from the University of Rome 'La Sapienza' and his Ph.D in Engineering Science in 2005. He then started working at Motorola Labs in Paris in 2002. Then in 2006 he joined CEA/LETI as a research engineer. From 2007, he becomes a PhD supervisor. From 2010 to 2012, Dr. Calvanese Strinati has been the co-chair of the wireless working group in GreenTouch Initiative which deals with design of future energy efficient communication networks. From 2011 to 2016 he was the Smart Devices & Telecommunications European collaborative strategic programs Director. Since December 2016 he is the Smart Devices & Telecommunications Scientific and Innovation Director. In December 2013 he has been elected as one of the five representative of academia and research center in the Net!Works 5G PPP ETP. From 2017 to 2018 he was one of the three moderators of the 5G future network expert group. Between 2016 and 2018 he was the coordinator of the H2020 joint Europe and South Korea 5GCHAMPION project. Since July 2018 he is the coordinator of the H2020 joint Europe and South Korea 5G-AllStar project. Since 2018 he holds the French Research Director Habilitation (HDR).

E. Calvanese Strinati has published around 120 papers in international conferences, journals and books chapters, given more than 100 international invited talks, keynotes and tutorials. He is the main inventor or co-inventor of more than 60 patents. He has organized more than 80 international conferences, workshops, panels and special sessions on green communications, heterogeneous networks and cloud computing hosted in international conferences as IEEE GLOBECOM, IEEE PIMRC, IEEE WCNC, IEEE VTC, EuCnC, IFIP, EUCnC and European Wireless.