Research Activities of Prof. Michele Zorzi's Group

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1 Connecting Everything

1.1 Master Theses on Vehicular Networks

1.1.1 Transport-protocol design in mmWave vehicular networks

Description: Traditional transport protocols (especially TCP) would not fit well in mmWave vehicular communication due to its unique performance characteristics (e.g., high bandwidth, frequent signal blockage, etc.). Some recent research works have started investigating innovative transport protocol designs tailored to vehicular networks, including those who can distinguish between packet loss due to network congestion and channel degradation/outage. A performance evaluation of such solutions, however, is still missing. In this thesis, you will evaluate the performance of traditional transport protocols in vehicular networks operating at mmWaves, highlight their main limitations and design new versions specifically tailored to the requirements of next-generation automotive systems. ns-3 will be used for the simulations.
Co-supervisor(s): Giordani, Polese

1.1.2 Requirement-aware attachment strategies for future millimeter wave vehicular networks

Description: Coexistence between mmWave and LTE communication systems has recently been considered in vehicular networks to guarantee increased capacity and robustness through heterogeneous networking. In this thesis you will:
1. Design and characterize new application source models which follow 3GPP standardization guidelines, in terms of end-to-end requirements.
2. Design innovative attachment policies in heterogeneous (mmwave + LTE) vehicular networks which avoid the overload of transmission links, e.g., by identifying the most appropriate destination cell as a function of the vehicle's individual requirements and traffic demands.
3. Compare the performance of the proposed schemes with that of traditional attachment strategies. ns-3 will be used for the simulations.
Co-supervisor(s): Giordani

1.1.3 Scheduling and Access Mechanisms in MmWave Vehicular Networks

Description: One of the main challenges of NR V2X networks is to efficiently share the same transmission medium among multiple vehicles. In this thesis, you will **design different access and scheduling algorithms** with the objective of minimizing the number of collisions and, at the same time, maximize the resource utilization. To this aim, you will **implement and test the performance of the selected algorithms with Millicar**, the ns-3-based module developed by our research group, that can be used to simulate NR V2X networks operating at mmWaves.
Co-supervisor(s): Drago, Polese, Zugno, Giordani

1.1.4 Hybrid V2V/V2I Communications in mmWave vehicular networks

Description: The design of communication protocols at mmWave bands is hindered by the high path and penetration loss of the signal at such high frequencies, that imposes line-of-sight (LOS) transmissions to be established. If LOS is not guaranteed, roadside infrastructures might be used to relay the traffic requests from the source to the destination vehicles (V2I connectivity). In this thesis you will **design network protocols that decide whether to establish V2V or V2I communications** depending on the instantaneous network performance (which is measured, e.g., in terms of throughput and latency). **The performance of the selected algorithms will be tested using Millicar**, the ns-3-based modules for mmWave vehicular networking developed by our research group.

Co-supervisor(s): Zugno, Drago, Giordani, Polese

1.1.5 Integrating communication protocols for connected vehicles at mmWaves

Description: Thanks to a large portion of bandwidth available at millimeter waves (mmWaves), a lot of studies have been carried out to demonstrate that not only we can communicate at such high frequencies, but in doing so we can improve the overall network performance. In this thesis you will **study how to integrate WAVE, the de-facto standard for V2V operations, with the new 3GPP NR V2X** standard that includes communications at mmWaves. You will **develop dedicated algorithms** to discriminate which packets need a more resilient yet less performing channel, i.e., they need to use WAVE, and which should be sent through a channel operating at higher frequencies. To this aim, you will **test the performance of the algorithms** with Millicar, the ns-3-based module developed by our research group, that can be used to simulate NR V2X networks operating at mmWaves.
Co-supervisor(s): Drago, Zugno, Giordani, Polese

1.1.6 Smart Protocols for Future Vehicular Networks

Description: The road towards **fully autonomous vehicles** goes along with the development of a robust and reliable network infrastructure, able to satisfy the strict requirements outlined by 3GPP and other standardization bodies. The safety and efficiency levels that self-driving vehicles promise to achieve demand (i) **low end-to-end latency**, (ii) **high reliability** and (iii) **high data rates**, which cannot be provided by the current communication technologies. Specifically, existing communication protocols at the application layer are not suitable candidates for this type of communication, and the research community is looking at the problem from new perspectives.
In this thesis, you will **study novel solutions** that have been proposed to deal with these challenges and carry out an extensive **comparison of the different protocols**. With the acquired expertise, you will be required to **design new** or **enhance existing protocols**, moving from their weakness or exploiting their advantages to achieve the required performance at the application level.
Co-supervisor(s): Giordani, Testolina (SCANLab)

1.2 Master Theses on Autonomous Driving and Sensors

1.2.1 Sensor-aided beam management in mmWave vehicular networks

Description: The millimeter wave (mmWave) bands have been investigated as a means to enhance automated driving, even though this requires the establishment of directional communications between the transmitting and the receiving vehicles. In this regard, mmWave systems can leverage information from sensors, including Light Detection and Rangings (LiDARs) and videocameras, that gather information about the surrounding environment and classify surrounding objects: acquisitions from automotive sensors can then be used to reduce the overhead associated with link configuration and beam management, since the transmitter can detect the position of the receiver and estimate the optimal direction of communication. In this thesis, you will design, test, and validate algorithms for performing beam management in mmWave vehicular networks based on automotive sensors' observations. Machine learning and deep convolutional neural networks, in particular, can be used to identify the optimal set of beams to be used for communication. Numerical comparisons with respect to state-of-the-art solutions for beam management should also be performed.
Co-supervisor(s): Giordani, Testolina (SCANLab)

1.2.2 Autonomous driving from the sky

Description: In a fully autonomous driving framework, where vehicles operate without human intervention, information sharing plays a fundamental role. In particular, autonomous cars need to exchange raw or processed

data gathered through local sensors, thereby enhancing their perception range beyond the capabilities of on-board instrumentation, which can be challenging to handle with standard (bandwidth-constrained) communication systems. One possible approach is to exploit unmanned aerial vehicles (UAVs). UAVs, in fact, operate from the sky and can provide users and their cars with an aerial bird's-eye view of the scene otherwise unavailable. This additional pair of eyes in the sky monitors the whole scenario from the top, thus guaranteeing a much wider perception of the scene than it would be possible from vehicles' (local) sensor acquisitions, thus achieving more efficient and centralized observations. In this thesis, you will evaluate whether it is possible to implement an autonomous driving framework by relying on UAV's sensory information, and how centralized driving decisions in the sky can be efficiently delivered to on-the-ground vehicles. To do so, you will leverage on the "Stanford Drone Dataset" that collects videos of various types of targets (including pedestrians, bikes, cars, buses, etc.) that navigate in a real world outdoor environment, recorded from UAVs.
Co-supervisor(s): Giordani (SCANLab)

1.2.3 Efficient data dissemination algorithms for automotive sensors

Description: Advances in the automotive industry have paved the way towards Connected and Autonomous Vehicles (CAVs) as a means to offer safer and more efficient driving. The potential of future CAVs can be fully unleashed through automotive sensors, including Light Detection and Rangings (LiDARs) and videocameras, as they can provide valuable information under conditions that human observers are not sensitive to. At the same time, the large volume of data generated by such sensors will likely saturate the capacity of vehicular communication technologies, making it challenging to guarantee the required quality of service. In this thesis you will design, test, and validate algorithms that dynamically adapts the transmission rate of the automotive sensors' observations depending on the characteristics of the specific scene and channel conditions. In particular, machine learning methods can be used to measure the mutual information of different combinations of the sensory readings and dynamically assign them value scores which depend on the degree of correlation. Real data from publicly available automotive datasets will be used during the evaluation process.
Co-supervisor(s): Giordani, Testolina (SCANLab)

1.2.4 Reinforcement-Learning-based data compression in autonomous driving scenarios

Description: The potential of future connected and autonomous vehicles can be fully unleashed through automotive sensors, including Light Detection and Rangings (LiDARs) and cameras, as they can provide valuable information under conditions that human observers are not sensitive to. In this context, efficient data compression is paramount to alleviate the burden of data transmission over bandwidth-constrained channels and to facilitate real-time communications. Compression techniques typically allow to define different quantization levels that trade off the compression efficiency against its speed. In this thesis, you will design, implement, and evaluate the performance of reinforcement-learning-based algorithms that try to identify the optimal compression level that balance compression accuracy and efficiency, based on channel conditions and available resources.
Co-supervisor(s): Giordani, Testolina, Pase (SCANLab)

1.2.5 Channel-aware autonomous driving

Description: In this thesis, you will design, implement, and evaluate possible mechanisms (e.g., based on machine learning) to **predict channel variations** in the vehicular environment and react accordingly (e.g., changing driving patterns or scheduling decisions) in case target performance requirements are not satisfied. The **ns-3 network simulator** and Python/MATLAB machine learning frameworks will be used to simulate accurate predictions in the vehicular environment and deliver preemptive driving/network decisions to the intended receivers.
Co-supervisor(s): Giordani, Drago, Zugno

1.2.6 Automatic radio map prediction of the environment in vehicular scenarios

Description: In this thesis, you will **create a customizable model** to collect diverse and heterogeneous channel datasets as a function of different parameters including (i) the network scenario (urban, rural), (ii) the antenna architecture, (iii) the vehicles' characteristics (speed, position, acceleration, etc.), (iv) the base stations' density and deployment configuration, and (v) the application characteristics (traffic source rate, QoS requirements, etc.), that can be used to generate radio maps of the environment. For **precise estimation of the radio maps**, you will use ns-3, which accounts for spatial consistency of mobility-based simulations, and supports the – deterministic or random – deployment of objects of different sizes to mimic humans, vehicles, and buildings.
Co-supervisor(s): Giordani, Drago, Zugno

1.2.7 How to apply artificial intelligence to facilitate UAV-deployment in traffic conditions

Description: Unmanned Aerial Vehicles (e.g., drones) can be deployed to assist existing base stations in providing high-capacity wireless coverage to users, e.g., in hot-spot areas with overwhelming traffic conditions. In this regard, it should be possible to estimate the probability of traffic congestion so as to schedule the optimal UAV deployment option accordingly. In this thesis, you will use real-world datasets containing trajectories of a very large number of vehicles to develop, test, and validate algorithms, e.g., based on machine learning, that are able to determine how to distribute UAVs in hot-spot areas leveraging only traffic profiles. The goal is to minimise the number of UAVs to be deployed while satisfying users' access requests, without saturating the capacity of fixed terrestrial infrastructures.
Co-supervisor(s): Giordani, Testolina, Pase (SCANLab)

1.3 Master Theses on IoT

1.3.1 Ultra-Reliable Low-Latency Communications for Industrial Internet of Things (IIoT)

Description: The Industrial Internet of Things (IIoT) will be the core infrastructure of Industry 4.0, where machines and devices will be connected to each other to collectively perform sensing and control tasks in smart factories and/or cities. Within this paradigm sensors, actuators and other general robot-devices will generate a new type of traffic with particularly stringent requirements in terms of reliability (up to 99.99999%) and latency (below 1 ms, or even 0.1 ms, in the radio part), demanding for what is known as Ultra-Reliable Low-Latency Communications (URLLC). This network service calls for a new design of wireless systems where fundamental trade-offs and solutions have to be deeply studied. The goal of this thesis is to design, implement, and evaluate possibel solutions, using analytical tools and/or simulation-driven analyses, to enable URLLC in IIoT scenarios
Co-supervisor(s): Giordani, Pase

1.3.2 Efficient information distribution in Internet of Medical Things (IoMT) Scenarios

Description: The Internet of Medical Things (IoMT) is playing a crucial role in the healthcare industry to improve the living conditions of individuals through suitable technological solutions. To this aim, the availability of heterogeneous, yet complex, physical signals (like EEG, EMG, ECG, SpO2, acceleration of different body segments) and environmental data is fundamental to continuously monitor the health conditions and behaviour of individuals and detect any critical situation (e.g., while driving or sleeping). However, the large volume of data generated by these sensors can saturate the capacity of communication networks, making it challenging to guarantee the required quality of service. In this thesis, you will design, test, and validate algorithms that select the most relevant sensors' acquisitions to be sent at each transmission opportunity so as to prioritize the transmissions that have the greatest value of information for the target applications. Machine learning, in particular, will be used to estimate the degree of correlation among consecutive observations and/or measure the mutual information of the sensory readings. Finally, you will acquire IoMT data from real physical and environmental sensors to evaluate the performance of the proposed

techniques.
Co-supervisor(s): Giordani, Cisotto

2 Future Cellular Networks

2.1 Master Thesis on Integrated Access and Backhaul

2.1.1 Quality of Service guarantees in 5G Integrated Access and Backhaul Networks

Description: 5G networks at mmWave frequencies will be deployed with a very high density, to increase the coverage probability. Each base station, however, will need to have a backhaul connection to the core network, and providing fiber access to all the nodes may be too costly or unfeasible. Therefore, the 3GPP has recently introduced Integrated Access and Backhaul as a possible solution for this problem: the base stations are completely wireless, and the backhaul link is wireless as well as the access. This thesis will focus on algorithms and protocols to control the Quality of Service in these kinds of networks, trying to guarantee some performance constraints (e.g., latency) for different classes of traffic.
Co-supervisor(s): Polese, Zugno, Giordani

2.1.2 Protocols and algorithms for efficient neighbor discovery in 5G Integrated Access and Backhaul Networks

Description: 5G networks at mmWave frequencies will be deployed with a very high density, to increase the coverage probability. Each base station, however, will need to have a backhaul connection to the core network, and providing fiber access to all the nodes may be too costly or unfeasible. Therefore, the 3GPP has recently introduced Integrated Access and Backhaul (IAB) as a possible solution for this problem: the base stations are completely wireless, and the backhaul link is wireless as well as the access. However, IAB relays need to both transmit and receive reference and synchronization signals, for example to detect other relays, or for being detected by the users. Given that, according to the 3GPP, IAB nodes are half-duplex, it is necessary to efficiently multiplex the measurements in time and frequency resources. This thesis will study algorithms and protocols to efficiently perform these measurements, proposing solutions that advance the state of the art with respect to 3GPP NR specifications.
Co-supervisor(s): Polese, Zugno, Giordani

2.1.3 Algorithms for dynamic Integrated Access and Backhaul topology setup in 6G nomadic networks

Description: 5G and 6G networks will foresee the dynamic placement of network nodes, in order to support varying traffic demands (e.g., because of events), or to provide coverage in case the fixed infrastructure is not available (e.g., in a disaster scenario). These nomadic nodes can be mounted, for example, on UAVs, vehicles, etc, and provide connectivity to the end users. However, as they are truly mobile, they will need a wireless backhaul, which can be provided with the 3GPP Integrated Access and Backhaul (IAB) technology. Currently, the 3GPP is considering only IAB support for fixed nodes in NR - but future releases will consider an extension to nomadic scenarios, once important challenges are addressed. In this thesis, you will work on one of these problems: the identification of a robust and efficient topology as node move and change their position with respect to the other neighbors in the network. You will propose algorithms to identify the best connectivity strategy as the topology evolves, and evaluate them using simulations in MATLAB or ns-3.
Co-supervisor(s): Polese, Zugno, Giordani

2.2 Master Theses on Channel Modeling and Ray Tracing

2.2.1 Modeling the small-scale fading in millimeter wave networks

***Description**:* Recent developments in software, hardware and communication technologies have opened the way towards the design of 5G communications systems operating at millimeter waves (mmWaves). At these frequencies, learning the statistics of the small-scale fading is vital to describe the fluctuations of the received power over time and to model deviations from the power predicted by the simple path loss. In this thesis, you will inspect a real small-scale fading measurement dataset and develop tools (e.g., based on machine learning) to provide a characterization of the fading statistics in the mmWave environment. Deep neural networks and generative adversarial networks, in particular, can be trained in an unsupervised manner to capture the effect of the small-scale fading and extract the channel statistics.
Co-supervisor(s): Lecci, Testolina, Giordani, Polese

2.2.2 Channel modeling in millimeter wave networks: ray tracing vs. stochastic vs. hybrid

***Description**:* To correctly assess the performance of mmWave systems, it is essential to have reliable channel models, based on a deep understanding of the propagation characteristics of the mmWave signal. On one side, stochastic and analytical models are easy to use but may be too simple to accurately characterize specific scenarios. On the other side, ray tracers characterize the propagation environment based on the geometry of the scenario and provide high accuracy, at the expense of a very significant computational complexity.
In this thesis, you will investigate whether the added cost of using a ray-tracer is really necessary over a simpler stochastic model, validating the results on a simulator such as ns-3. Furthermore, an environment-aware stochastic channel model could be designed to obtain the best of both worlds, validating its performance against the two baselines.
Co-supervisor(s): Lecci, Zugno, Polese, Testolina

2.2.3 Non-Line-of-Sight Vehicle-to-Vehicle communication via smart reflections

Description: Recently, millimeter wave (mmWave) bands have been investigated as a means to enhance automated driving and address the challenging data rate and latency demands of emerging automotive applications. Operations at mmWaves, in turn, suffer from severe penetration loss from local blockers and require communications to be in line of sight (LOS). In the vehicular scenario, however, on-board sensors like cameras and LiDARs can be used to determine surrounding objects' locations and their surface materials, and identify potential reflectors of the signal to avoid potential blockers. In this thesis, you will use ray tracers to characterize the propagation environment based on the geometry of the scenario, and assess whether the metallic nature of the vehicles be used to reflect the mmWave signal to avoid intermediate blockers, thus enabling *non-line-of-sight* (NLOS) communication.
Co-supervisor(s): Giordani, Lecci

2.2.4 Dual polarizationion in mmWave communications

Description: Antennas can be designed to emit and capture specific polarizations of the EM field, allowing to multiplex information across orthogonal types to increase the system throughput. The wireless medium, though, tends to mix different polarizations together especially when reflections occur, thus adding cross-polarization interference.
The goal of this thesis is to assess whether this phenomenon is predominant or not in typical mmWave scenario, first by adding this feature to an open source EM ray-tracer, and then validating the results on a full-stack simulator such as ns-3.
Co-supervisor(s): Lecci, Giordani

2.2.5 Effects of diffraction in mmWave communications

Description: Diffraction allows EM waves to "bend" around corners, reducing the sharp change between LoS and NLoS as well as reducing the impact of blockages.
For this thesis, diffraction will have to be implemented on an open source ray-tracer, followed by an analysis of its effects on the communication quality in a number of realistic scenarios and a comparison with against real-world measurements,
Co-supervisor(s): Lecci, Giordani

2.3 Master Theses on High-Frequency Communications

2.3.1 Multi-connectivity to the extreme: from 2 to 2000 GHz

Description: The millimeter wave (mmWave) bands – roughly between 10 and 100 GHz – have attracted considerable attention for 5G cellular wireless systems to provide very high transmission speeds. Operations at high frequencies, in turn, introduce severe path and penetration loss which might render the communication unreliable and discontinuous. Coexistence between mmWave and Long Term Evolution (LTE) communication systems has therefore been considered to guarantee increased capacity and robustness through multi-connectivity. Recently, researchers have started investigating terahertz (THz) bands too – roughly between 100 GHz and 10 THz – to satisfy the boldest requirements, e.g., in terms of data rates and latency, introduced by emerging 6G applications.
In this project, you will use the ns-3 LTE, mmWave and THz modules (which are already publicly available) to design and evaluate multi-connectivity solutions among the different radio technologies. The goal is to select the best network interface(s) as a function of the characteristics in which the user terminals are deployed.
Co-supervisor(s): Polese, Giordani

2.3.2 multi-RAT scheduling optimization in mmWave cellular networks

Description: The next generations of cellular networks will rely on the concept of multi-connectivity, i.e., the possibility of using multiple links, at different frequencies, for transmitting data and control. The goal of this thesis is to study algorithms to dynamically allocate user traffic over multiple links, with different characteristics and behaviors (e.g., a high-capacity but intermittent mmWave link and a low-capacity, stable LTE link). Different optimizations for different kinds of user traffic (low-latency, video, TCP, etc) will be proposed and evaluated using the ns-3 simulator.
Co-supervisor(s): Polese, Zugno

2.3.3 Public Safety Communications (PSC) scenarios with mmWave

Description: A reliable communication is a key in critical public safety scenarios. For example, PSC can be used to coordinate the actions of first responders and increase their awareness of the surrounding environment, or to enable remote monitoring and control of unmanned vehicles and robots. Recently, the interest in the application of mmWave wireless networks to PSC has increased in the research community: the huge amount of free spectrum available at such high frequencies would yield very high data rates, thus enabling high quality and/or 360 video streaming and ultra-low latency monitoring. However, it is challenging to provide reliability, given the harsh propagation environment and the sensitivity to blockage of mmWave links. In this project you will either (i) use the mmwave-psc extension of the ns-3 mmwave module to study the performance of cellular deployments in different reference public safety scenarios, or (ii) develop a new reference public safety scenario modeling communication of safety vehicles, flying UAVs and first responders. In particular, you will try to understand which are the key parameters that affect the mmWave network performance, and propose innovative solutions to guarantee a certain level of Quality of Service to the public safety communications while minimizing the number of base stations deployed.

Co-supervisor(s): Polese, Zugno, Giordani

2.3.4 Realistic mobility in 5G NR mmWave scenarios

Description: The use of directional antennas in mmWave networks worsens link stability as it becomes more susceptible to blockages and mobility, thus affecting the link quality and the higher-layer protocols such as TCP. In fact, both TX and RX need to periodically track each other's position requiring some overhead and a proper choice of tracking parameters, e.g., periodicity, duration, directions to test, beam characteristics, among others, which are still not well understood nor implemented in full-stack simulators.
The goal of this project is to support realistic beam tracking on top of a well-established full-stack mmWave simulator, then further study the problem of beam tracking under both pedestrian and vehicle mobility, especially in the likely event of sudden blockages, in a variety of realistic scenarios.
Given the non-trivial nature of the problem as well as the strong hidden correlation of the underlying process, smart heuristics as well as machine learning techniques will be used to improve the user performance over a wide range of possible scenarios.
Co-supervisor(s): Lecci, Zugno

2.3.5 Novel Adaptive Modulation and Coding (AMC) for WiGig protocols

Description: Adapting the Modulation and Coding Scheme (MCS) of a transmission is the first step towards high spectral efficiency. Choose an excessively aggressive scheme and no data will possibly be decoded, choose an excessively conservative scheme and resources will be wasted. The peculiarities of the mmWave channel together with the specific transmission opportunities given by the WiGig protocol offer the possibility to improve the state of the art on this topic.
The objective of this project is to design AMC schemes able to exploit these new characteristics to improve the communication efficiency. A python-based OpenAI Gym environment is ready to be used together with some state of the art algorithms already implemented for comparison. In a later moment, if seen fit, the newly designed scheme(s) could be ported into ns-3 to fully characterize their performance in a realistic setting.
Co-supervisor(s): Drago, Lecci

2.3.6 Characterization and modeling of VR/AR traffic

Description: The digitalization of our society is pointing towards telepresence, with the help of Virtual and Augmented Reality (VR/AR). Since close-to-real-time transmission is needed for a good user experience, extremely tight Quality of Service (QoS) requirements are needed, resulting in very peculiar traffic characteristics. Protocols for a proper support should be designed and validated, but the current literature lacks realistic traffic models for this types of application.
The goal of this thesis is to (i) collect and characterize AR/VR traffic traces using network analyzers, (ii) model their behavior using, e.g., statistical tools such as Markov Models or generative models such as GANs or RNNs.
Co-supervisor(s): Lecci, Drago

2.3.7 VR scheduling on WiGig devices

Description: Scheduling radio resources for modern applications such as Virtual and Augmented Reality (VR/AR) can be very challenging, as they require tight Quality of Service (QoS) and Experience (QoE) constraints. For example, ultra-low latency is required to yield a sufficient user experience, which common WiFi channel access is not able to guarantee.
The goal of this thesis is to extend a WiGig-based scheduling framework developed by our research group to improve and design smart scheduling solutions and communication strategies. Finally, the designed algorithms can be thoroughly tested on real traffic traces, making this research more effective and reliable.
Co-supervisor(s): Lecci, Drago

2.4 Master Theses on Simulations

2.4.1 Scaling ns-3 mmWave simulations

Description: ns-3 is a state-of-the-art open source network simulator that features a module for the simulation of 5G cellular networks at mmWave frequencies. One of the main burdens in the simulation of such high frequency scenarios is the modeling of the channel. ns-3 mmWave implements the 3GPP channel model for frequencies above 6 GHz, which is accurate but limits the scalability of the simulation. In this project, you will start from profiling of the ns-3 mmWave code base and identify which are the main bottlenecks related to the scalability of the simulation. Then, you will study and implement a solution to optimize the channel computation in such a way to speed up the simulations, for instance using optimized C++ libraries for scientific computing like IT++ or Armadillo.
Co-supervisor(s): Zugno, Lecci, Polese

2.4.2 5G mmWave Network Slicing in ns-3

Description: the next generation of mobile networks (5G) is currently being standardized by 3GPP as New Radio (NR). An important concept is network slicing, i.e., the ability to allocate a dedicated set of resources in the network in order to address some key performance indicators of a certain class of traffic (e.g., ultra-low latency, ultra-high reliability, high throughput). This thesis will study how different classes of traffic, with different requirements, can coexist in a 5G mmWave cellular network, and implement scheduling algorithms that can guarantee the effectiveness of the network slicing mechanism also for mmWave.
Co-supervisor(s): Polese, Zugno

2.4.3 Video streaming optimization techniques using network coding strategies on a multi connectivity infrastructure

The next generation of telecommunications networks are required to support higher bit-rates than today, in order to deliver ultra-high quality multimedia contents to the users. Nowadays, most multimedia applications such as Netflix, Youtube and so on, are accessed from mobile devices, prompting the provision of very high data rates by next generation (5G) cellular networks. Given the vast amount of available spectrum available at high frequencies (i.e. mmWave), this infrastructure has been studied as a key enabler for this type of services; however, the harsh propagation environment at such frequencies makes it hard to provide a reliable service. To provide high quality video streaming, besides the high data rate that can be obtained by working at mmWave frequencies, there is a need for reliability, low packet loss and stable performance. Moreover, live video streaming also demands low latency. Several works in the literature have demonstrated that the application of network coding strategies could provide feasible solutions to overcome these problems.
In this thesis you will:
1) integrate a video coding framework with the network simulator, so that it is possible to actually see the video received in simulation;
2) extend the possibility to use network coding solutions to enhance the performances of mmWave networks;
3) combine multi connectivity infrastructures (LTE + mmWave) and packet prioritization in order to define an optimal strategy for ultra-reliable video streaming applications.
Co-supervisor(s): Drago, Polese

2.5 Master Theses on 6G Networks

2.5.1 An ns-3 simulator for satellite operations at millimeter waves

6G research is focusing on the development of non-terrestrial communication to provide three-dimensional (3D) coverage by complementing on-the-ground infrastructures with aerial platforms, including satellites. In this context, the millimeter wave (mmWave) spectrum – roughly above 10 GHz – is being considered in an effort to maximize communication data rates through non-terrestrial links. The potential of mmWave technology to support satellite communications has also been recognized by the 3GPP which defines satellite network deployment scenarios and related system parameters, including channel modeling at above 10 GHz frequencies. In this thesis, you will develop an ns-3 module for the simulation of satellite communications in the mmWave bands which is compliant with the 3GPP standardization efforts in this domain.
Co-supervisor(s): Giordani, Polese

2.5.2 MAC schemes for 6G terahertz access

Terahertz communications are being discussed as a possible enabler of 6G networks. The high isotropic pathloss at such high frequencies, however, calls for the usage of highly directional antennas, which complicate medium access schemes. While similar problems have been dealt with in the mmWave band, the even harsher characteristics of terahertz frequencies, combined with the larger amount of bandwidth available, open new issues and call for innovative solutions. This thesis aims at studying the performance of different state-of-the-art MAC schemes and their applicability to terahertz use cases. The goal is to understand which are the major pitfalls and limitations, to identify novel solutions that provide improved performance in these challenging conditions.
Co-supervisor(s): Polese, Giordani

2.5.3 Full stack issues in 6G networks

The introduction of mmWaves communications in 5G networks has uncovered integration issues in the full networking stack, from the MAC layer (because of directionality) to the transport (TCP underperforms due to the highly variable physical layer rate) and application. 6G networks are expected to be more heterogeneous than 5G, with a combination of communications at sub-6 GHz frequencies, mmWaves, terahertz and in the visible light spectrum. The different characteristics of these bands may stress in different ways the higher layers of the protocol stack, which will need to be adapted to truly harness the benefits of the physical layer design in 6G. In this thesis, you will setup a simulation (using ns-3) that integrates different access technologies (mmWave, terahertz, VLC, LTE), evaluate how TCP and QUIC perform when combining these different links, and propose solutions to efficiently manage their integration with transport protocols.
Co-supervisor(s): Polese, Giordani

2.5.4 Edge Intelligence for future networks

Description: Due to the always increasing computational power of mobile devices, which are now equipped with intelligence capabilities, the cloud-based paradigm is shifting towards a more decentralized and distributed architecture, moving data processing to the edge of the network. In this context, the marriage between artificial intelligence and communications has to be properly studied to design the intelligent networks of future 6th generation (6G) networks. On the one hand, the burden of distributed training and inference processes needs a reliable network infrastructure to achieve the desired tasks in acceptable time. On the other hand, data-driven models can enhance communications protocols in different layers of the protocol stack, being a promising solution to achieve extreme communications even under uncertainty, dynamic network topology and bad channel conditions. In this thesis you will

study and design new algorithms/models for enabling fast and efficient distributed machine learning mechanisms for communication, and assess their performance through simulation and/or by using analytical tools.
Co-supervisor(s): Giordani, Pase

3 Underwater Networks

3.0.1 Design of an acoustic modem prototype equipped with an atomic clock for perfect synchronized MAC and OWTT-based ranging

Description: GPS does not work in underwater deployments, so it is extremely hard to keep the nodes of a network synchronized, and to measure the distance between nodes. For this reason, TDMA-based schemes are usually not used, and the classical way to calculate the distance between two nodes is to measure the round trip time between the transmission of a message and the reception of its acknowledgement. In the case all the nodes of the network are synchronized, this operation might be performed with the transmission of a single signal, by reducing significantly the network overhead. In this thesis the student has first to analyze the advantages of a chip-scale atomic clock (CSAC) in performing perfect synchronized MAC protocols and one way time travel (OWTT) ranging. Then it will design an acoustic modem with such capabilities.
Co-supervisor: Campagnaro

3.0.2 Design and field evaluation of a ping localizer for sport and work equipment, based on underwater to air cross-boundary radio links for shallow freshwater scenarios

Description: Although radio frequency (RF) cannot be used for long range communication in salty waters, it might be used for communication from devices deployed in shallow freshwater to in-air devices, thanks to its ability to cross the water-air boundary. In this Thesis the student will first analyze the RF propagation underwater, then he will test which RF devices can provide a longer communication link, and select the best performing one to be used for a localization device. This localization device can be installed in sport or work plastic-made equipment that are often lost in lakes and rivers, such as paddles, by helping people to recover the lost equipment and partially limit the plastic pollution.
Co-supervisor(s): Campagnaro, Francescon (W&M)

3.0.3 A game-theoretic and experimental analysis of energy-depleting jamming attacks in underwater acoustic networks with a learning counterstrategy

Description: Security aspects in underwater wireless networks have not been widely investigated so far, despite the critical importance of the scenarios in which these networks can be employed. For example, an attack to a military underwater network for enemy targeting or identification can lead to serious consequences. Similarly, environmental monitoring applications such as tsunami prevention are also critical from a public safety point of view. In this work, we assess a scenario in which a malicious node tries to perform a jamming attack, degrading the communication quality of battery-powered underwater nodes.

Co-supervisor(s): Campagnaro, Signori

3.0.4 Realistic Evaluation of Autonomous Underwater Vehicle (AUV) Swarm Formation Control

Description: AUV swarm formation control has been widely studied in recent years from the robotics community, however, there exists a crucial gap between theoretical research and practical situation in AUV formation. This gap is

due to the bad modeling of the underwater acoustic communication scenario, characterized by multipath, long propagation delay, and strongly affected by doppler, wind and shipping noise.
In this Thesis the student has to design and evaluate an AUV formation control distributed algorithm by employing the DESERT Underwater framework, a simulation, emulation and experimentation tool for underwater networks, that well characterize the acoustic channel.
Co-supervisor(s): Campagnaro

3.0.5 Design and development of a light-weighted and easy to deploy smart buoy for ocean connectivity

Description: The deployment of smart buoys typically requires the use of ships equipped with a big winch and the cost of this deployment is limited to military and oil and gas applications. In this thesis, the student needs to design and develop a light-weighted and easy to deploy battery-powered smart buoy equipped with both underwater and above the water long range communication devices.
Co-supervisor(s): Campagnaro, Francescon (W&M)

3.0.6 Modelling the underwater acoustic channel using a 2-state Markov model in the DESERT Underwater network simulator

Description: The characteristic of the underwater acoustic channel heavily depends on the area in which the networks are deployed (e.g., shallow vs. deep water scenario). One of the main challenges in the underwater network is to obtain an accurate and computationally efficient acoustic waves propagation model to be employed in the network simulators. The Urick model, used in many simulation tools, often leads to optimistic results in terms of packet error rate and does not consider the time varying behaviour of the acoustic channel. Ray tracer tools, such as Bellhop, allow to obtain more realistic results but are more computationally demanding. In this thesis, a new channel model based on a 2-state Markov chain will be implemented in the DESERT Underwater Network Simulator and the performance will be compared with the existing models.
Co-supervisor(s): Campagnaro, Signori

4 International Opportunities

4.0.1 International Opportunities at Northeastern University, Boston

Description: The Institute for the Wireless Internet of Things at Northeastern University allows you to study innovative concepts in the area of cellular networks, machine learning in networks, and mmWave/terahertz communications with an experimental approach. Through Northeastern, you can access testbeds and experimental facilities which are unique in the world: (i) Colosseum, an RF emulator with 128 software-defined radios that can be used for large-scale experimental evaluations; (ii) Arena, a software-defined-radio testbed with 64 antennas for cellular, wifi and MIMO studies; (iii) mmWave and terahertz radios; (iv) UAVs. If you are interested, please contact Prof. Zorzi or Michele Polese to discuss a specific topic. Notice that it takes a few months to organize a visit to Northeastern, so please plan ahead if interested. Remote access to the testbeds is also possible.
Co-supervisor: Michele Polese