# TeamUp5G: A Multidisciplinary Approach to Training and Research on New RAN Techniques for 5G Ultra-Dense Mobile Networks

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***Abstract*— This paper presents a summary of the main research directions being followed in TeamUp5G European Training Network. This project is teaming up a new generation of researchers and entrepreneurs ready to address complex engineering problems and innovation to work both at university and industry in the 5G field. Research is focused on radio access network (RAN) techniques for 5G, considering ultra-dense mobile networks as a key ingredient of the mobile networks and their evolution. It covers a wide spread of topics from physical layer and medium access control to applications, looking at spectrum sharing and energy efficiency as important features.**

***Keywords*— Small Cells, energy awareness, spectrum management, interference management, 5G Hetnets, IoT, massive MIMO, millimeter waves, visible light communication**

## I. Introduction to TeamUp5G

The global objective of the "New RAN TEchniques for 5G UltrA-dense Mobile networks" (TeamUp5G) European Training Network (ETN) project, started in January 2019, is to set up an international doctoral training network for inter-disciplinary and inter-sectoral research, knowledge sharing and training. We will team up a new generation of researchers and entrepreneurs ready to address complex engineering problems and innovation that are required to work both at university and industry. The TeamUp5G consortium includes academic and non-academic sectors and provides inter-sectoral and inter-disciplinary training for the researchers in their areas of expertise, ranging from mobile communications to video applications, from research to industrialization, operation, entrepreneurship, intellectual property and others. The network, coordinated by the Universidad Carlos III de Madrid, as a whole comprises 540 person-months of 15 early-stage researchers (ESRs), eight beneficiaries (Universidad Carlos III de Madrid, Aarhus University, International Hellenic University of Thessaloniki, Eclexys, Instituto de Telecomunicações, Nokia Spain, PDMFC and IS-Wireless) and partner organisations such as OEPM, Telefónica Investigación y Desarrollo, TELENOR, UNIAUDAX, and the Universities Nova de Lisboa, da Beira Interior, de Aveiro, ISCTE, and Western Macedonia.

With the continuous increase of data rates and the number of people using mobile communications, wireless connections are evolving towards 5G. The ultra-dense networks with small-cells (SCs) [1] are critical to fulfil the user satisfaction and subject of challenging requirements for the evolution to 5G. Nowadays, although there is a worldwide market of SCs, the network solutions have inherent technical limitations, e.g., limited available spectrum or the need to coexist within complex environments of multiple heterogeneous technologies and users. Possibly the most important challenge is the demand of increasing data rates per $km^2$.

In the new 5G context, UDN must be able to meet the requirements of two very different types of applications. On the one hand, in broadband mobile access, the capacity of the link is the most demanding factor. On the other hand, the ecosystem of the Internet of Things (IoT) demands intermittent or always-on hyper connectivity for machine-type communications [2] and promises a hyper connected smart world that could usher in many interesting opportunities and sectors of life such as healthcare, agriculture, transportation, manufacturing, logistics, safety, education, and many more. This leads to the explosion of SCs that will require new solutions to mitigate interference and optimise the network resources. Such solutions are being proposed in TeamUp5G, which is focused on new radio access network (RAN) techniques for 5G, considering UDNs. Research covers a wide spread of topics from physical layer (PHY) and medium access control (MAC) to applications, simultaneously looking at spectrum sharing and energy efficiency.

## II. Challenges in 5G New Radio Ultra Dense Networks

SCs are reduced-size, low-power wireless access points that operate in licensed spectrum and are operator-managed. The use of SCs, which are low-cost elements, has been proposed in different standards like 3GPP HSPA and LTE/LTE-A, 3rd Generation Partnership Project 2 (3GPP2) and IEEE802.16, to solve coverage and capacity problems

[3], [4]. Thus, SCs offer great advantages for operators and users, who get better coverage and higher data rate, high efficiency from a power consumption point of view and can offer / access new services. However, many open problems still exist in order to make the best possible use of SCs for both broadband and IoT. Some of the important aspects being tackled with respect to waveform design, interference, spectrum management, and optimisation for SC networks are described in the following sections.

### A. *Interference Management, waveforms and Massive MIMO (mMIMO)*

Interference management is a must in ultra-dense SC networks but has the drawback of the need for channel state information (CSI). With the aim to align the interference with no CSI knowledge, a technique called Blind Interference Alignment (BIA) has been developed [5], [6]. However, the performance of this technique under channel variations and its implementation in multi-tier networks are an open issue. Non coherent (NC) schemes [7] may be a way to avoid the CSI bottleneck, but they need to evolve to efficiently multiplex an adequate number of users.

In UDN, a very large number of transmitters are present in the coverage area and the concept of massive MIMO (mMIMO) comes into play; either in a centralized or distributed way, when large groups of neighbouring nodes actuate in a coordinated way and they are allowed to opportunistically form virtual antenna arrays for both transmission and reception. However, the realistic practical implementation of such a technology still entails many research challenges [8], [9]. Moreover, the use of the new millimeter-wave (mmW) frequency bands for cellular systems, combined with mMIMO, bring the advantage of compact antenna sizes that facilitate arrays with a very large number of antennas and very narrow beamforming. In turn, these frequency bands are subject to high propagation loss and lead to a high complexity of the transceivers. As an alternative, visible light communications (VLC) systems are characterized by a reasonable complexity and cost. The use of BIA is also proposed for VLC based on a novel architecture of the receiver [10].

In the process of defining the new 5G standards, the question aroused about what the optimal waveform in UDN is to combine with advanced MIMO and interference management. Providing a good balance between the different requirements of mobile broadband and IoT types of traffic remains a key question to solve. Moreover, actual research activities include the integration of radar and wireless communication technologies to improve spectrum management and pave the way for future IoT devices incorporating reflectometry-based sensing together with communication functionalities. Different types of waveforms have been considered, including orthogonal frequency-division multiplexing (OFDM) and its variants [11], [12].

### B. *Dynamic Spectrum Management and Optimisation*

Scheduling and resource allocation become essential components of wireless data systems because different users experience different fading conditions. Carrier Aggregation (CA) adds a new dimension for the scheduling of the users in 5G and raises an optimisation problem for the best use of the network resources [13]. Large portions of the assigned spectrum are used sporadically while other bands have an increase in spectrum demand. Then, unlicensed and licensed shared spectrum offer a set of possible advantages, which can potentially lead to greater spectral efficiency than exclusive access. Optimization of the access through the use of shared bands and cognitive radio (CR) allows the assignment of the underutilized spectrum resources, where spectrum can be shared between license holders and secondary users in a dynamic spectrum allocation way. Dynamic spectrum sharing licensed assisted access (LAA) has been adopted by 3GPP, and LAA has adopted CA as a mandatory function. In this context, SCs are the adequate candidate to accomplish the regulation in terms of limitation of the maximum transmitter power. Furthermore, drones and heterogeneous wireless communications may enhance the cellular coverage range [14]. The carrier-to-noise-plus-interference ratio has been modelled in scenarios where networks with secondary 3D drone small cells (DSCs) coexist with a primary 2D downlink cellular network in underlay spectrum sharing, and the optimal deployment density has also been studied.

### C. *Energy Consumption Reduction*

The spatial/temporal traffic characteristics in mobile networks are continuously changing and significant efficiency savings may be achieved by dynamically adapting the network resource provisioning, including energy, to changes in traffic characteristics [15]. Moreover, in cases where mixtures of macro and SCs are deployed, the potential of improving becomes even higher. Challenging traffic for emerging 5G applications, such as machine-to-machine (M2M), worsens the situation and requires different approaches to energy reduction due to solutions such as multi-connectivity. Actually, mobile network energy consumption is very significant. Further work is needed on mechanisms for energy consumption reduction in the context of “energy-challenged” scenarios such as IoT, particularly considering the increased durations of batteries [16].

## III. THE TEAMUP5G APPROACH

The main research objectives of TeamUp5G are focused on solving the three problems, which have been explained in the previous section, in a multidisciplinary way. These objectives can be summarized as follows:

- Design novel PHY/link/MAC algorithms and protocols to enhance capacity and user satisfaction.
- Propose new dynamic spectrum management, opportunistic optimisation of radio resources and CR techniques, together with self-organization capabilities, with different levels of collaboration.
- Devise techniques and methodologies to save energy that make the previously proposed optimisation techniques sustainable and environmentally friendly.
- Develop a proof of concept to demonstrate the feasibility of the proposed innovative techniques and encourage practical deployment, through prototyping and experimental research activities.

To accomplish those goals, the research programme is organized into eight Work Packages (WPs), four of them, the main scientific WPs, with the aim of meeting the main research objectives.

### A. Three Technical Pillars

Three are the technical pillars on which the project is based, each of them associated to one objective. These pillars can be summarized as follows:

1) *Advances in interference management, waveforms and mMIMO:* TeamUp5G is designing and evaluating new interference management and reduction (based on pre-coding for the downlink and cooperative equalization for the uplink) and joint scheduling mechanisms to mitigate interference through cooperation. The designed pre-coding techniques will require moderate (e.g. BIA) or none (e.g. NC) exchange of information, and will be used in combination with mMIMO in a cellular environment with traditional lower radio-frequency bands, mmW and also VLC. Advanced PHY-layer, new waveforms and multi-packet reception (MPR) techniques are under definition and particularly tailored for UDN.

2) *Advances in dynamic spectrum management with spectrum sharing and aggregation*: TeamUp5G is working to improve aggregation across a range of spectrum, with particular emphasis on increased densification of frequency and aggregation of opportunities involving UDN. Moreover, it considers aggregation also for the purpose of wireless backhaul and its joint optimisation with the cellular access. New multi-band schedulers with reduced implementation complexity that optimise both fairness and service-level parameters in a multi-service traffic scenario will be developed in the implementation of carrier aggregation in 5G Heterogeneous Networks environments with SCs within broader macro cells, as well as in cell free scenarios.

3) *Advances in energy-aware protocols:* The project proposes energy-aware MAC protocols with cognitive radio capabilities and optimisations in these protocols (e.g., packet concatenation, multi-channel-scheduled channel polling, and enhanced-two phase contention window mechanism). Energy-awareness will be studied for long-range radio technologies. Because of the different nature of the underlying PHY layer, the reuse of current protocols is not direct. Joint optimisation techniques will be designed to provision M2M traffic serving as backhaul of the network of sensors along with the own cellular traffic.

### B. Use Cases and Prototyping

TeamUp5G has to deal with a diversity of technologies which should be adequately adapted to the foreseen scenarios and end user requirements. The reference scenarios have been defined based on a state-of-the-art analysis and novel research visions provided by the beneficiaries, partner organisations and ESRs. Besides, key performance indicators (KPI's) are being defined to be linked to each scenario. Mixed scenarios with massive deployments for IoT applications considering vehicular and heterogeneous networks will be emphasized together with advanced video with high data rate and low latency.

Some of the most relevant scenarios and the developed techniques will also be used as test cases in the evaluation and proof-of-concept, which aims to be a cohesive element among all the research activities that will be carried out in TeamUp5G. Advanced immersive video applications and deploying wireless communications through drones will be used as show-cases to illustrate the novelty and applicability of the developed ideas.

### C. Transversal Integration: From Physical Layer to Application

Each ESR is being trained through research by means of an individual research project (IRP). The fifteen individual projects are integrated into the research work to pursue the common goals. The IRPs are multidisciplinary and contribute to achieving the objectives of the proposed joint research plan, working in several WPs. This allows us to address each of the three pillars from multiple points of view and a multilayer technological approach. The individual projects are listed in Table I.

## IV. Some Initial Results

TeamUp5G Training Network has overall progressed according to its first year planning. The first year main activities have been the selection and recruitment of the researchers, and to build up the management procedures, bodies and tools to start working. In addition, the technical work has begun and the first results are being obtained. In the following paragraph we summarize some of them.

### A. Scenarios

Research activity has begun with the definition of the reference scenarios and system requirements. A set of use cases that explore 5G features have been proposed, which can be classified into two broad categories: middleware applications (MWA) and commercial applications (CA).

TABLE I. Individual Research Projects

| Table Head | Table Column Head |
|---|---|
| ESR1 | New Scheduling Algorithms for Interference Management in Small Cells at Millimetre-Wave Frequencies |
| ESR2 | New Transmitter and Receiver Algorithms for mMIMO with Limited Channel State Information |
| ESR3 | Interference Management for Visible Light Communications in Radio-Frequency Hostile Environments |
| ESR4 | PHY/MAC Design of Future SCs adopting Multi-packet Reception and Full-Duplex Communications |
| ESR5 | Cell-less RAN and Cooperative Schemes for Interference Management |
| ESR6 | Opportunistic Gathering of Sensing Data |
| ESR7 | Licensed Shared Access in Heterogeneous Networks with Small Cells |
| ESR8 | Waveforms and Separation Algorithms for Joint Use in Radar and Communications |
| ESR9 | Architectures and Supporting Algorithms for Spectrum and CA for Small Cells and Ultradense Deployments |
| ESR10 | Coexistence of Small Cells and Low Power Wide Area Networks for Supporting IoT Connectivity |
| ESR11 | New Interference-Based Dynamic Channel Access Algorithms for Ultra-Dense Small Cell Deployments |
| ESR12 | Signal Processing Techniques for Massive MIMO Enabled mm Wave Communication |
| ESR13 | Design of Privacy Preservation Mechanisms and Secure Authentication in Small Cell Networks |
| ESR14 | Development and Production of Drone-Mobile Small Cell Station´s Prototypes |
| ESR15 | Application of 5G Ultra-Dense Networks for the Distributed Implementation of Immersive Media Rendering |

The goal of the first category of use cases is to propose a set of mechanisms and tools capable of minimizing latency and maximizing the resilience of a provided service. Despite the promise of lower latencies by 5G networks, it is important that the management of massive amounts of data produced by an application actively contributes to maintaining the same latency level. Consequently, this group of use cases shall address issues such as content distribution based on intelligent caching, traffic management by user profile, prefetching, dynamic resource allocation, intelligent algorithms for optimizing uplink connections, and security mechanisms based on the concept of network slicing.

On the other hand, the second category of use cases shall develop solutions in the fields of real-time virtual reality (VR), augmented reality (AR) and live video streaming (VS). In particular, in VR/AR, response times from communication networks are of the utmost importance for movement fluidity and to obtain a true sense of reality.

### B. *Use Cases*

TeamUp5G activities will focus on the following use cases, where the first three are middleware applications and the last two are commercial applications:

- Emergency Drone. A drone with capacity to transmit video images and other information about the environment in real time, as well as assuring the communications between the decision centres and crews and for the general population. It would allow a more effective response to an emergency event. Among the many possible scenarios where video streams from the disaster area and reestablishment of connectivity are critical to an adequate response to the emergency, TeamUp5G has defined step-by-step drone scenarios of large earthquake and forest fires.

- Predictive Maintenance in Manufacturing: Within the context of Industry 4.0, maintenance is one of the areas which attract more attention and investment due to the foreseen beneficial impact. The TeamUp5G approach will be centred on the use of analytic systems making use of AI to predict the optimal time instant for maintenance procedures and the use of augmented reality to assist and enhance the performance of technicians.

- Jump Travelling: Users at specific locations, let us say a theme park, would like to experience a new type of roller coaster - one in which they could enjoy jump travel, from one location to another around the world, and experience a 360-degree view from a flying drone, using immersive technology. This jump travelling between locations will be performed using a human-machine user interface based on sensors detecting hand movements coupled with augmented reality and voice recognition. These jumps can either be done to pre-recorded flight paths or to real-time flights in which the user will control, again using body movements tracked by sensors during the flight path experience.

- Multiplayer Game Using virtual reality (VR): This scenario consists of an online multiplayer game where a minimum of two opponents can perform virtual battles in a virtual arena. All players must be equipped with VR devices and interaction sensors that detect their movements. Each player makes use of a virtual melee weapon to attack or defend so that all players can react accordingly. The quality of the user experience is strongly correlated with the latency of the communication between players.
- Live Events using Virtual Reality (VR) / Augmented Reality (AR): Users at a venue, let us say a soccer stadium, can follow the game from different viewpoints, which can also change over time for each individual user. For that to be possible, an operator places several cameras around the stadium that capture images from multiple viewpoints. A user can select a viewpoint that is extrapolated, in real-time, by merging the angles captured from different cameras. However, the number of user-viewpoints (UVP) is limited, for a given event covered by a number of base stations (BS), so an operator determines a provision of a certain number of UVP. The increase and reduction of UVP are performed dynamically over time based on the users' demand and resource availability.

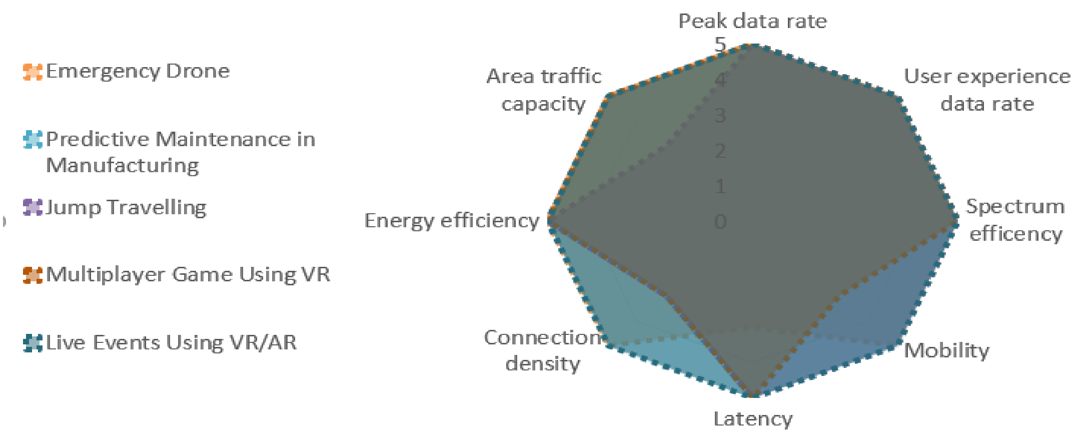


Fig. 1. Polygon describing the TeamUp5G scenarios and requirements.

The use cases described above have been used to provide some basic requirements to be considered in the more fundamental research done by ESRs. Each of them is related to one or more of the scenarios defined in 5G. These scenarios include Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (mMTC) and Ultra-reliable and Low Latency communications (URLLC). Figure 1 summarizes the requirements for the TeamUp5G scenarios, showing which is the most demanding performance in each of them.

### C. Some Research Examples

In the following, some examples of the initial results being obtained by the ESRs are provided:

*1) New scheduling algorithms for interference management:* In the frame of energy-efficient algorithms that satisfy the requirements of wireless networks while ensuring low power consumption, we developed an optimal sensing and scheduling policy to maximize the detection probability in a CR network, when energy from wireless sources is harvested. Our optimization problem is subject to an established false alarm probability, signal-to-noise-ratio, and energy constraints. In addition, recently we have extended our investigation to energy-efficient interference alignment (IA) algorithms with the aim of guaranteeing continuous coverage in 5G cellular networks. To achieve this objective, we have conducted a performance comparison of different IA algorithms to obtain the best trade-off between sum-rate and the amount of energy that could be harvested from interference signals.

*2) Advances in NC communications:* Related to interference management, waveforms and mMIMO, one of the first steps has been to design constellations for the uplink of NC M-ary Differential Phase-Shift Keying (MDPSK) massive MIMO systems for multiuser scenarios that outperform the constellations already available in the literature. When approaching the maximum, a posteriori detection of the constellations for their design, we found problems in terms of mathematical tractability. To overcome them we are using artificial intelligence (AI) techniques. For several different scenarios, these tools have found constellations outperforming the state-of-the-art. Besides this, it is found that a maximum of 3 users can be multiplexed at the same time and frequency for an acceptably large massive MIMO array (antennas in the order of hundreds) and an acceptable performance, unless additional dimensions are used to increase diversity.

*3) Advances on waveforms and separation algorithms for joint use in radar and communications:* We seek to achieve convergence of radar and communications on a common platform through the design of waveforms and algorithms optimized for cooperative schemes. As the first step, we consider a scenario with two transmit and receive antennas, where the integration of the two functionalities is achieved through the use of Alamouti coding and OFDM. It is shown that, by using the Alamouti scheme, the spatial diversity order is improved as in legacy communication systems, which has a favourable impact on the bit error rate (BER). Furthermore, as Alamouti is an orthogonal code the radar's angle resolution is improved through the use of the virtual array concept.

*4) Radio Resource Management*: For the management of the scarce resources in UDN, the spectrum-reuse can provide solutions for increasing the network capacity and link quality. Exploiting high frequency bands, techniques to achieve high spectrum efficiency, network throughput, energy efficiency, and signal-to-interference-plus-noise ratio (SINR), efficient algorithms to cater data rate needs, etc. can solve Radio Resource Management shortcomings largely in Heterogeneous Networks (HetNets) and UDN deployments.

*5) Application of 5G UDNs for the distributed implementation of immersive media rendering;* Augmented Reality offloading has become a key use case for 5G networks as it imposes severe throughput and latency requirements. Cutting-edge AR devices have an update rate of at least 60 Hz. As a consequence, all the sensor data has to be sent and processed in less than 16 ms, with an uplink and downlink data per frame of between 2.17 to 3.83 Mbit and 1.67 to 2.17 Mbit respectively. Solving a simple optimization problem for estimated processing times of between 7-9 ms, we concluded that the network should provide a peak throughput of 0.5 to 1 and 2 to 3 Gbps on the uplink and downlink respectively, and maximum round trip time latencies of 4 ms. Such requirements can be fulfilled, according to the 3GPP TS 38.306 standard, in a single component carrier network, with 11DL:1GP:2UL TDD configuration, subcarrier spacing (SCS) of 120 KHz (numerology 3) and a channel size of 400 MHz for a 256-QAM (Quadrature Amplitude Modulation).

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