FANTASTIC-5G: 5G-PPP Project on 5G Air Interface Below 6 GHz

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***Abstract*—5G will have to cope with a high degree of heterogeneity in terms of services, device classes, deployment types, environments and mobility levels. Consequently, diverse and often contradicting Key Performance Indicators (KPIs) need to be supported, such as high capacity/user-rates, low latency, high reliability, ubiquitous coverage, high mobility, massive number of devices and low cost/energy consumption. 4G is not designed to meet such a high degree of heterogeneity efficiently. Moreover, having multiple radio access technologies for multi-service support below 6GHz will be too costly. FANTASTIC-5G is a European project which will develop a new multi-service Air Interface (AI) for below 6 GHz through a modular design. To allow the system to adapt to the anticipated heterogeneity, the pursued properties are: flexibility, scalability, versatility, efficiency and future-proofness. To this end, the project will develop the technical AI components and integrate them into an overall AI framework where adaptation to the above described sources of heterogeneity will be accomplished. The work will also comprise intense validation and system level simulations. The consortium possesses the main stakeholders for innovation and impacting standardization, maintaining Europe at the forefront.**

Keywords—5G air interface, 5G-PPP, FANTASTIC-5G, H2020

I. INTRODUCTION

With 4G being currently massively rolled-out, it becomes apparent, that while it is very well suited to serve the wireless communication needs of today, it will quickly reach its limits. This is obvious due to the following observable trends:

Increase in capacity: The demand for wireless data is predicted to increase significantly, resulting in 1000x higher mobile data volumes and 10-100x higher end user data rates.

Increase in the number of connected devices: The number of connected devices is predicted to increase by a factor of 10-100, which means that up to 300,000 devices need to be served per access point.

Increase in reliability: Wireless connectivity will be applied to new use cases that require extremely reliable connections (typically 99.999% availability) and mission-critical communications, such as vehicle-to-vehicle coordination, critical control of the power grid, etc.

Decrease in latency: Remote presence and tactile Internet that impose stringent latency constraints on the end-to-end connection, including the wireless part. Forecasts indicate that the latency should be decreased by a factor of 5 in order to enable such services.

Increase in efficiency: Efficiency in terms of resource utilization (e.g. energy, spectrum) is becoming more and more pronounced. It is seen as an indispensable ingredient for a healthy/sustainable (1) ICT market/business and (2) environment.

These trends are originating from the fact that future communication systems are not only to deliver **Mobile BroadBand (MBB)** services. With enabling 5G to support **Massive Machine Communications (MMC)** and **Mission Critical Communications (MCC)** efficiently, we expect operators to be able to capitalize on new revenue streams. Similarly, supporting **Broad- and Multicasting Services (BMS)** in 5G helps widen the market and potentially free parts of the spectrum. Finally, **Vehicle-to-vehicle and vehicle-to-infrastructure communications (V2X)** will also play a crucial role in future communication networks, to more efficiently support mobile services while on the move and to enable new use cases such as traffic safety. These services are each linked to different sets of Key Performance Indicators (KPIs) to be optimized. In a later section we will provide more details on this aspect.

Someone could argue that designing different Air Interfaces (AIs) for the different service types described above might be the simpler approach than designing a single AI being able to be parameterized in different ways to concurrently accommodate all use cases on a per need basis. However, we do not see the first option to be competitive and profitable.

So, FANTASTIC-5G (Flexible Air iNTerfAce for Scalable service delivery wiThin wIreless Communication networks of the 5th Generation) targets to design a single modular air interface allowing the concurrent support of this wide range of use cases. Naturally, this cannot be achieved by following a ‘one-fits-all’ approach. Instead, we will design the air interface in a modular manner, allowing for parameterizing different parts of the band and related functionalities to satisfy the needs of the respective service being targeted.

The paper is structured as follows: we start with carving out the project vision and its objectives followed by a section describing our approach to tackle the problem. Then, we trace out the project innovations beyond the State-of-the-Art (SotA). We continue with a quick review of the project structure together with the consortium. To conclude, we finish the paper by indicating the positioning of the project within the ecosystem and the anticipated impacts.

II. PROJECT VISION AND OBJECTIVES

Driven by the trends, observations and the motivations presented in Section I, FANTASTIC-5G sets out a **vision** on a new 5G air interface below 6 GHz with the following **key characteristics**:

1. ***flexibility*** to support the *broad class of services* with their associated (broad class) of KPIs,
2. ***scalability*** to support the high number of devices,
3. ***versatility*** to support the diverse device types and traffic/transmission characteristics,
4. ***efficiency*** to support the requirements on energy consumption and resource utilisation, and
5. ***future-proofness*** to support easy integration of new features.

In order to make this vision a reality, FANTASTIC-5G is committed to conduct work towards the achievement of the following high level measurable objectives:

- **Objective 1**: To develop a highly ***flexible, versatile and scalable*** air interface to enable the in-band coexistence of highly differing services, device types and traffic/transmission characteristics.
- **Objective 2:** To design an air interface enabling ***ubiquitous coverage*** and ***high capacity*** where and when required.
- **Objective 3:** To develop an air interface being highly efficient in terms of energy and resource consumption.
- **Objective 4**: To render 5G more ***future-proof*** than former generations through easier introduction of new features.
- **Objective 5:** To ***evaluate and validate the developed concepts*** by means of system level simulations and hardware proof of concepts for selected components.
- **Objective 6**: To ***build up consensus*** on reasonable options for 5G standardization among the major industrial partners of the project that are also voting members in 3GPP[1] and to ***push the innovations*** of the project for ***standardization*** (through study items).

Thus, essentially the FANTASTIC-5G research project is targeting at pre-standardization development of a new 5G air interface to influence future 3GPP 5G standardization. As will be further motivated in the coming sections, fulfilling the project objectives present an interesting set of research challenges on how to most efficiently *adapt* the design of AI components and related physical layer procedures to the requirements of the multiple sources of heterogeneity. Our hypothesis is that this is possible through *re-configuration* of *flexible* solutions for the AI components and related procedures.

III. CONCEPT

A. Design principles

The main design principles of FANTASTIC-5G are: 1) A satisfied customer base 2) Cost efficiency 3) Future-proofness (forward compatibility).

[1] ALUD, Orange, HWDU, NOK, IMC, SEUK, TI

A satisfied customer base is achieved by providing ubiquitous access to a rich service mix with Quality-of-Service (QoS) guarantee. At the AI level, the project will propose mechanisms to easily adapt the air interface according to all the sources of the above mentioned heterogeneity.

Cost efficiency implies reduction in CAPital Expenditures (CAPEX) and Operational EXpenditures (OPEX) at a high level, part of which is provided at the AI level by high efficiency in energy and resource (esp. spectrum) utilization. Spectrum efficiency should be maximized because spectrum is a very valuable/expensive resource. Energy consumption (both at the network and at the terminal side) has to be reasonably low for cost as well as ecological reasons.

Future-proofness implies more degrees of freedom to introduce new features in the future. Parts of the AI will have to be redesigned to more easily introduce new features while maintaining backwards compatibility with devices not compliant with the new release. One example is the definition of the downlink control channel (PDCCH – Physical Downlink Control CHannel). In 4G, this channel is used by all users and has to follow strict guidelines. So, to ensure future-proofness, FANTASTIC-5G will design new flexible/reconfigurable control channel concepts which are adaptable to different services, device types and traffic/transmission characteristics.

B. Services and KPIs

FANTASTIC-5G will consider the following 5 core services as the baseline for the 5G ecosystem:

Mobile BroadBand (MBB), including multimedia streaming, Voice-over-IP (VoIP), internet browsing, videoconferencing, file downloads etc.

Massive Machine Communications (MMC), assuming a massive amount of actors and sensors/meters that are deployed anywhere in the landscape

Mission Critical Communications (MCC), requiring very low response times and very high reliability.

Broadcast/Multicast Services (BMS), involving simultaneous content delivery in a “one-to-many” or “many-to-many” mode. Typical examples are mobile TV, software updates/downloads etc.

Vehicle-to-vehicle and vehicle-to-infrastructure communications (V2X), which implies direct wireless connectivity (1) between vehicles (Vehicle-to-Vehicle, V2V) and (2) between vehicles and the roadside/beyond (Vehicle-to-Infrastructure, V2I).

Every service has its own specific set of KPI values, in terms of which the service requirements are defined. For each service, requirements on some KPIs are stricter than some others, e.g. reliability and latency are essential KPIs for MCC whereas – although required – high data throughput is not. Figure 1 below depicts these KPIs for each core service as well as a summary of related requirements with a color-code. The dark blue-colored KPIs are the so-called primary KPIs, which are essential/defining features that are very strict and challenging. The medium blue-colored KPIs are secondary KPIs which have lower priority. The light blue-colored KPIs are tertiary KPIs that are not so relevant.

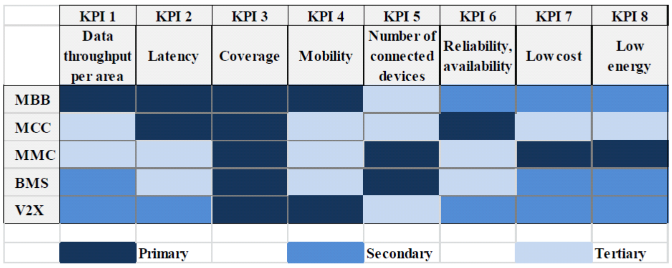

Figure 1: Core services and related KPIs with different requirement levels

C. Service Integration Drivers (SIDs)

The project will perform dedicated research activities on service-specific AI components for each one of the 5 core services. Then, we will use the concept of **Service Integration Drivers (SIDs).** The main role of the core service SIDs is to collect different components optimized for each service and to integrate them into a service-specific air interface solution (including waveform, frame, control signalling, coding, modulation, procedures, retransmission schemes, MIMO etc.). In addition we introduce a 6th SID (named as "Overall SID") that will ensure that the *co-existence* of different services will be achieved. Figure 2 below depicts the role of the SIDs in the air interface design.

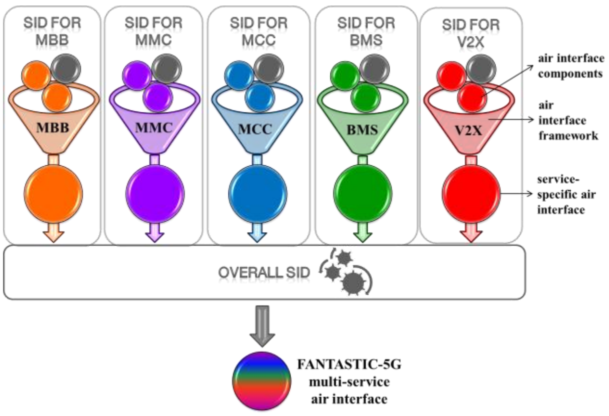

Figure 2: The role of Service Integration Drivers in FANTASTIC-5G air interface design

IV. Project Innovations Beyond the SotA

FANTASTIC-5G new air interface targets 3GPP Rel-14 and beyond and will break the backward compatibility towards LTE-A 4G by introducing new waveforms, new frame designs and new control signaling in PHY and MAC. This fundamental step is required to meet the foreseen trends and drivers. The core of the FANTASTIC-5G new AI is a ***unified frame structure*** in up- and downlink [1] handling a variety of traffic classes with virtually "contradicting" requirements and characteristics in the same time slot [2].

FANTASTIC-5G will provide ***a full PHY/MAC specification*** taking evolved OFDM, UF-OFDM aka UFMC [3], FBMC [4] and single-carrier modulation as the candidate waveforms thereby building up on the results of METIS and 5GNOW (the majority of FANTASTIC-5G partners are also partners in these projects and will use their gained expertise). Notably, this refers to the required physical layer procedures (channel estimation, synchronization, PAPR reduction, adaptive modulation and coding, low latency, reliability etc.) with emphasis on reasonable complexity versus performance trade-offs. The project will be the first to specify scalable MIMO and cooperation modes for the consolidated new waveforms including respective feedback and control signalling strategies in TDD and FDD.

In addition to multi-cell connectivity, FANTASTIC-5G will provide solutions with varying levels of macro-cell assistance ***for small cell deployment*** exploring network. Examples of the former include victim aware rank and modulation scheme selection. In order to unleash the potential of all the former techniques, a flexible MAC/RRM design is required, which takes all these feature enhancements into account from the start. Together with the evolving possibilities for local caching, we can foresee a very significant amount of shared content in 5G networks. Since the wireless medium is by nature a shared one, its full potential can only be exploited by ***incorporating broadcast and multicast mechanisms at the PHY layer*** of the air interface.

Eventually, FANTASTIC-5G aims at a ***highly scalable solution to support massive uncoordinated access of MMC devices*** exploiting the sporadic traffic patterns of MMC particularly in the "high overload situation" where resources can no longer be orthogonal [5]. A highly advanced cross-layer approach is targeted using, e.g., code division random access on PHY layer together with sparse signal processing (or compressed sensing) and advanced, scalable lower layer MAC protocols. Native integration of novel concepts such as ***wireless network coding and multicast*** improves throughput and reliability when various information flows, such as D2D and cooperative communications are in place [6]. In FANTASTIC-5G, we will address a lacuna in D2D communications, namely of the support of ultra-reliable and low latency communications, while leveraging the varying degrees of network assistance, in localized scenarios with focus on public security, emergency and vehicular communications.

V. Project Consortium and Structure

A. Consortium

The consortium of FANTASTIC-5G consists of 18 partners in total. It includes partners from both industry and academia (Figure 3). There are 11 partners from industry covering all relevant parts of the value chain for wireless cellular communications:

- Network equipment vendors: Alcatel-Lucent Deutschland AG, Nokia Networks (with 3 branches), Huawei Technologies Duesseldorf GmbH
- Chipset vendors: Intel Mobile Communications GmbH, Sequans Communications
- Device/user equipment vendor: Samsung Electronics UK
- Operators: Orange SA, Telecom Italia S.p.A.

- Provider of network management and optimization solutions: WINGS ICT Solutions

Academia is represented by 7 key contributors to wireless research both from research institutes and universities:

- Research institutes: Fraunhofer Gesellschaft zur angewandten Forschung - Heinrich Hertz Institut (HHI), Centre Tecnològic de Telecommunications de Catalunya (CTTC), Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)
- Universities: Politecnico di Bari, Aalborg University, University of Bremen, Telecom Bretagne

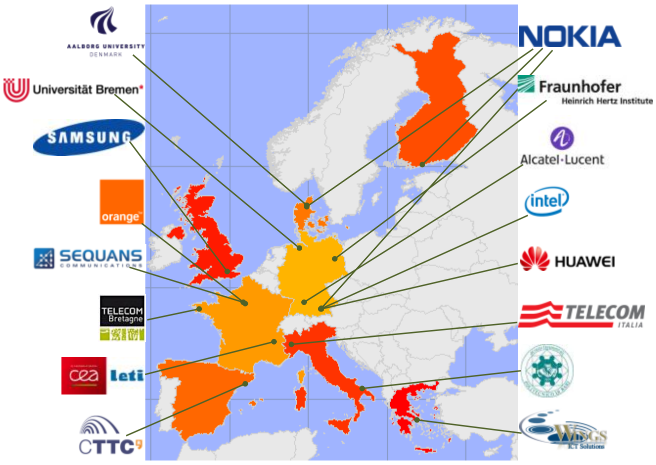

Figure 3: Partners of FANTASTIC-5G

B. Project Structure

The project is subdivided into Work Packages (WP), dealing with the major research areas and administrative issues. The work packages are further broken down into tasks, responsible for dedicated technical activities. FANTASTIC-5G also appoints an Innovation Manager (IM) who is a member of the project management team (PMT) and whose role is to look for opportunities of successfully implementing appropriate creative ideas emerging from FANTASTIC-5G, with a view on both market and technical aspects. In addition, FANTASTIC-5G will install an Advisory Board (AB) with external partners from related industries such as telecommunications, vehicular, electronics, satellite communications, broadcast etc.

The technical work of FANTASTIC-5G is structured around 6 WPs (Figure 4):

1. WP1: Management
2. WP2: System Requirements, Integration, and Evaluation
3. WP3: Link Design
4. WP4: Network Design
5. WP5: Proof of Concept
6. WP6: Dissemination, Exploitation and Standardization

WP1 is responsible for the overall management, administration, coordination and IT support of the project in order to enable a professional and constructive project progress. This work includes all the legal, contractual, financial areas of the project as well as marketing activities to enable the best possible project visibility.

WP 2 will identify use cases, KPIs, and requirements, based on the existing SotA and recommendations from the Advisory Board. It will also define the overall air interface framework as a high level description detailing interfaces and how it is embedded in an overall system concept. This provides the basis for all other tasks. WP2 is responsible from the integration of the technical solutions from WP3 and WP4 into an air interface that supports the co-existence of diverse 5G services. Finally, WP2 will be also responsible from the alignment of the system level simulators from different partners in order to make the results comparable and show system level gains over the current LTE system by numerical simulations.

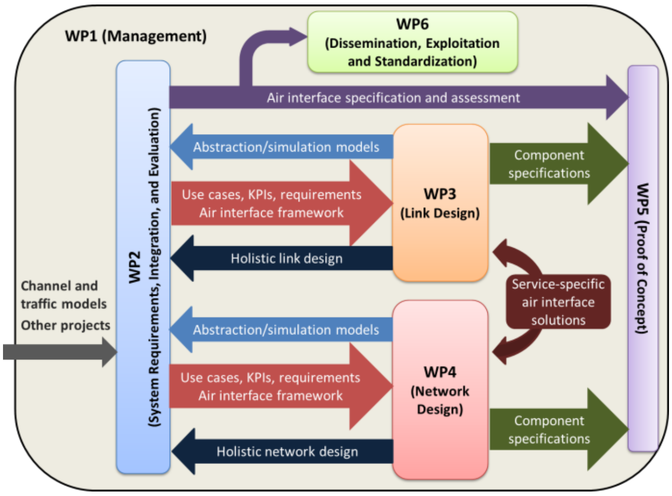

Figure 4: Interactions and dependencies between the WPs

WP3 deals with the link design which focuses on the PHY and MAC layer research. Its objective is to provide a holistic link solution that can be flexibly adapted to five core services (MBB, MMC, MCC, BMS and V2X). This flexible adaptation to different services works under the assumption that the air interface has knowledge on the service type of each data flow, paving the way for efficient cross layer optimization. As for the link solution, we aim at narrowing down the list of the waveform candidates to a minimum number, e.g., ideally one waveform; but nevertheless, the option for multi-waveform co-existence is not excluded. Furthermore, the main focus of this WP will be on the technical aspects that are tightly related to future 5G standardization, rather than a general algorithmic investigation. WP3 will also provide PHY-MAC layer abstraction models to WP2 to be used in system level simulations.

WP 4 will focus on the multi-user/multi-cell aspects such as design of the MAC, Radio Resource Management (RRM), support for higher layer functionalities, as well as efficient cross-layer optimization and integration with physical layer functionalities. This includes how to most efficiently control and use the functionalities offered by the physical/link layer (developed in WP3). The main topics covered in the work package include multi-antenna concepts with/without cooperation, advanced multiuser detection, a flexible MAC/RRM framework (resource allocation, link adaptation, power control, multi-cell/node connectivity, interference coordination), random access schemes (comprising scheduled and non-scheduled transmissions), service classification techniques (context awareness, service identification and class formation), support for broadcast and multicast transmissions (including techniques such as network coding) and device-to-Device (D2D) communications with varying levels of assistance from the cellular network.

WP 5 deals with the proof-of-concept (PoC) and demonstration of identified key technical components provided by WP3 and WP4. Software and hardware prototypes are implemented, aimed at validating the feasibility and the superiority of promising components of the proposed 5G air interface concepts. The main objectives of this work-package are to implement and evaluate the promising technical solutions proposed by the project. They include waveform design, coexistence aspects, broadcast / multicast transmission and coding techniques.

WP 6 will create awareness about the FANTASTIC-5G project and its specific research areas. The several activities will ensure that the project objectives and the advances achieved during the implementation of the project are properly presented across various communication channels. Thereby this WP will address expert networks, companies, and organizations within the wireless community.

VI. POSITIONING OF THE PROJECT AND ITS IMPACTS

Within the pre-structuring model defined by the 5G Infrastructure PPP Association (5G-PPP), FANTASTIC-5G covers the areas of “P2: Air Interface and Multi-Antenna, Multi-Service Air Interface below 6 GHz” of the Radio Network Architecture and Technologies Strand. The composition of the pre-structuring model indicates interactions between FANTASTIC-5G and other projects, as well as their natures and intensities (Figure 5).

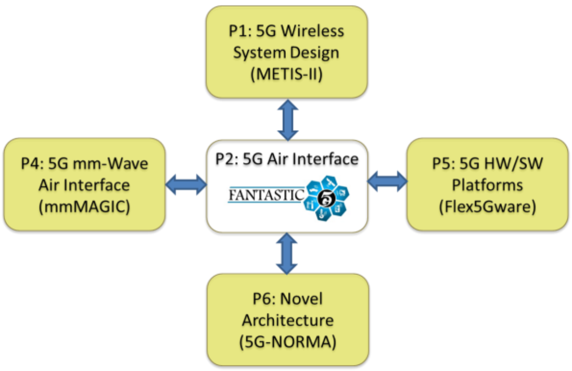

Figure 5: FANTASTIC-5G interactions within the 5G PPP pre-structuring model

The new AI design of will meet the requirements on the identified KPIs with increased flexibility, reliability, future-proofness as well as cost and energy efficiency. Notably, devices will be designed to support one common AI for all services and more devices will be produced applying similar/common chip sets thus achieving economy of scale for vendors. Also, the wireless system is expected to be more scalable and thus better suited to follow load variations between the services both temporal and in different locations. Moreover, FANTASTIC-5G will push its innovations to future standardization activities and will influence them as it gets apparent with its sixth key objective. Finally, the focus of FANTASTIC-5G on technologies requiring standardization such as waveform and frame design, MIMO for new waveforms, PHY layer procedures, RRM etc. is the evidence for the target of FANTASTIC-5G to have impact on standardization (Figure 6).

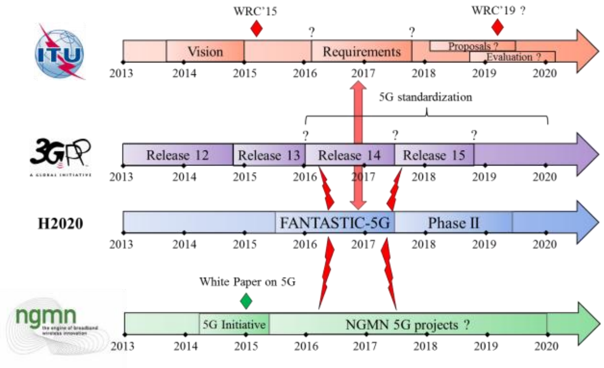

Figure 6: Positioning of FANTASTIC-5G with respect to ITU, 3GPP and NGMN

FANTASTIC-5G is one of the core/indispensable elements of the 5G project portfolio, thus filling a crucial gap in the overall structure; the consortium is ready to cooperate with other projects and be engaged in a set of actions which will make the whole programme a huge success in EU and beyond.

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