

FANTASTIC-5G: Flexible Air Interface for Scalable Service Delivery within Wireless Communication Networks of the 5th Generation

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Abstract— 5th generation mobile networks will have to cope with a high degree of heterogeneity in terms of: services, mobility, number of devices, etc. Thus diverse and often contradicting key performance indicators need to be supported, but having multiple radio access technologies for multi-service support below 6GHz will be too costly. FANTASTIC-5G will develop a new multi-service Air Interface (AI) through a modular design. To allow the system to adapt to the anticipated heterogeneity, some properties need to be pursued, like: simplicity, flexibility, scalability, versatility, efficiency and future-proofness. Based on these properties a selected set of use cases and link and network design will be presented. The paper will also comprise validation and system level simulations through some indicative results; and will conclude with the overall impact to 5G standardization.

I. Introduction

Cellular technology has been renewed about every decade since the introduction of GSM, which can be considered as the main representative of the 2nd Generation cellular (2G) technology. In the 1990s, GSM became widespread and offered voice services all around the globe. With the rising success of the World Wide Web, data services became the key driver for the next generation of cellular technology. Around 2000, introduction of the 3rd Generation (3G) cellular technology enabled the rapid growth of mobile data services. In 2010, introduction of 4G (LTE - Long Term Evolution) has brought major improvements to wireless broadband access to Internet services. The next generation (5G) is expected to arrive around 2020. FANTASTIC-5G is a timely proposal set out to design the 5G air interface and prepare inputs for standardization whose time-frame is expected to start during the project lifetime. This development will lead to changes in the way mobile and wireless communication systems are utilized in various use case scenarios. Forecasts predict a total of 50 billion connected devices by 2020 [1][2][3]. In general 5G is the integration of several techniques, scenarios and use cases rather than the invention of a new single radio access technology. As technical requirements over currently existing technologies of 4G [4] lists the following:

- Increase in capacity: 1000 times higher mobile data volume per area,
- Increase in reliability: typically 99.999% availability,

- Increase in connected devices: up to 100 times higher number of connected devices,
- Increase efficiency: e.g. 10 times longer battery life for low power devices,
- Decrease in latency: 5 times reduced end-to-end latency.

The rest of the paper is organized as follows: Section II gives a detailed description of the vision and overview of FANTASTIC 5G project. Section III reviews all the services and use cases that are taken into account for the design of the Air Interface. Sections IV & V comprise of the detailed explanation of the link and network design for the FANTASTIC 5G AI. Then in Section VI evaluation methodology and indicative results are presented. The targeted impact to standardization is presented in Section VII and we conclude our paper in Section V.

II. Vision and Overview

FANTASTIC-5G will carry out a smart design of the air interface components and procedures to effectively deal with the issue of virtually conflicting requirements through such an adaptation. The project scope is limited to developing a new spectrum agnostic 5G air interface for carrier frequencies below 6 GHz. This is motivated by the fact that today's licensed bands for cellular usage are all below 6 GHz, and the World Radio Conference (WRC) in 2015 will also focus on below 6GHz spectrum. Furthermore, even if higher frequency spectrum bands are made available for 5G operation in the future, having effective means for utilizing 5G below 6GHz is still of relevance due to the more favorable radio propagation properties. Driven by the trends, observations and motivations, extensively studied solutions will be presented in this paper.

FANTASTIC-5G sets out a vision on the single 5G air interface with the following key characteristics:

- Flexibility to support the broad class of services with their associated (broad class) of KPIs,
- Scalability to support the high number of devices,
- Versatility to support the diverse device types and traffic/transmission characteristics,
- Efficiency to support the requirements on energy consumption and resource utilization, and
- Future-proofness to support easy integration of new features.

In order to make this vision a reality, FANTASTIC-5G is committed to conduct work on specific topics that directly lead to the accomplishment of the above 5 characteristics. For example, we achieve flexibility through highly adaptable/configurable PHY and MAC (Medium Access Control) layer mechanisms, scalability through efficient massive access protocols (e.g. connectionless access), versatility through tailored protection schemes, efficiency by keeping it as a leitmotif for any work in FANTASTIC-5G, and at last future proof-ness by assigning it as one of our main design principles.

A collaboration of a group of major stakeholders have come together in order to achieve 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 3GPP3 and to push the innovations of the project for standardization (through study items).

Figure 1 depicts how the first 4 (technical) objectives of FANTASTIC-5G are linked to its vision and to the trends presented above. Note that in this figure, there is not a one-to-one correspondence between the trends, the key characteristics and the objectives, i.e. Objective 1 is not an outcome of only the Key Characteristic 1 (Flexibility), which itself is not an outcome of only Trend 1.

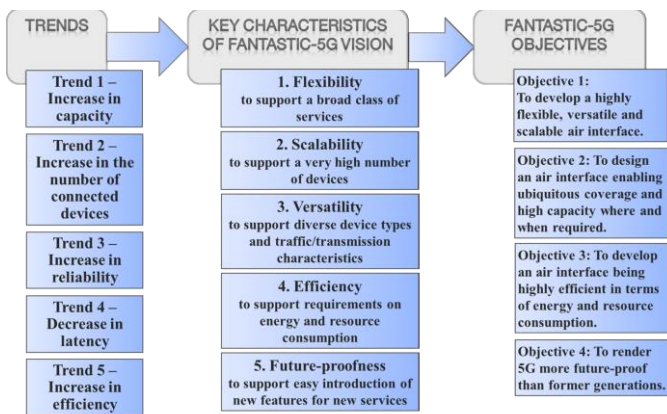


Figure 1: Trends to Objectives for the FANTASTIC-5G

All objectives are derived from the combinations of the Key Characteristics, which are the outcomes of the ensemble of the Trends.

III. Use cases

FANTASTIC 5G has analyzed the challenges regarding mobile and wireless infrastructure for beyond 2020 in detail. In order to tackle the development and evaluation of the proposed air interface, the following services have been specified:

- Mobile Broadband (MBB), with increased capacity, efficiency and data transmission rates.
- Massive Machine Communication (MMC). Robust, simple, efficient, and reliable communication for a massive amount of low-cost sensors/meters/actuators.
- Mission Critical Communication (MCC), with very low delay, and very high reliability and availability between nodes.
- Broadcast/Multicast Services (BMS), with simultaneous content delivery to a huge amount of users for better spectrum efficiency.
- Vehicular Communications (V2X), with direct connectivity between vehicles or vehicles to infrastructure, as an enabler for Intelligent Transport Systems (ITS).

Based on the above services, the resulting selected use cases for FANTASTIC-5G are illustrated in Table 1.

Table 1: Use cases for FANTASTIC-5G

USE CASE	DESCRIPTION	SERVICE
1	50 Mbps everywhere	MBB
2	High speed train	MBB + V2X
3	Sensor networks	MMC
4	Tactile Internet	MMC
5	Automatic traffic control /driving	MCC + V2X
6	Broadcast like services: Local, Regional, National	BMS
7	Dense urban society below 6GHz	MBB

It is worthwhile noting that the above 7 selected use cases represent all the core services either as a single core service (MBB, MMC, MCC, BMS) or as a combination of 2 core services (V2X in conjunction with either MBB or MCC).

Table 2: Core services and related KPIs

	KPI0	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8
Core Service	User rate	Through put	Latency	Coverage	Mobility	Connection Density	Reliability/ Availability	Complexity	Energy
MBB	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary
MMC	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary
MCC	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary
BMS	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary
V2X	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Primary

Requirement level: Primary (Dark Blue), Secondary (Medium Blue), Tertiary (Light Blue)

Table 2 depicts main KPIs for each service and the priorities that have been set so far. The *primary* KPIs are the essential features for the service and their requirements on these KPIs are very strict and also challenging. Next are the *secondary* KPIs for which the requirements still hold, but are relatively less strict. At last, we have the *tertiary* KPIs, which are also of relevance but they are not as essential either defining as the Primary and Secondary KPIs. Tertiary KPIs will be taken into account as long as they do not create any problems to other KPIs.

iv. Link-related aspects

One of the goals of the link design is to evaluate link adaptation techniques for the new waveforms designs and to identify possible enhancements and challenges that provide solution for a multiservice air interface. In particular, we have focused on features that are being considered as possible candidates for 5G air interfaces: the relaxation of the orthogonality properties of multicarrier schemes and the integration of multiple antenna schemes with new waveform designs. Several technical components such as modulation and coding, waveform, frame and control channel structure, physical layer procedure, etc. will be covered in 5G's link design. High variation of services and use cases that sometimes do not work together correctly have to coexist into the design, to fulfill the presumptions and challenges of the near future. For enabling future proofness, the 5G design shall possess high degree of flexibility and a minimum amount of fixed and predefined elements from the very beginning. Every item has to be open for configuration between a device and the network according to the actual needs, thereby relying on a given set of options. Thus, for achieving highest flexibility the only static/predefined element is the Initial Access Channel (IAC) [10][11] and all the other components that will be developed are required to be flexible and adaptable to the specified services and use cases.

Consequently, a flexible PHY layer has to be designed for a multi-service Air Interface, whose parameters can be individually configured according to the requirements of a specific service. Those PHY parameters encompass the subcarrier spacing, the configuration of a signal overhead like a cyclic prefix (if chosen to be used), specific filter coefficients and the particular frame structure.

Considering these features a multi-carrier waveform with filtering functionalities has to be enabled. Thus the waveforms will enable the in-band coexistence of different services, each of those will be assigned to its subband with tailored characteristics. The proposed candidates can be clustered into two categories:

- Subcarrier-wise filtered multicarrier, comprising FBMC with QAM/OQAM signaling [5], pulse shaped OFDM (P-OFDM) [8], and Flexibly Configured OFDM (FC-OFDM) [9]
- Subband-wise filtered multicarrier, comprising UF-OFDM [6] and F-OFDM [7]

Prototype filters with steep power roll-off in frequency domain for pulse shaping the subcarrier signal can be utilized. The steep roll-off is realized by allowing the time domain representation of the pulse to expand over the length of the symbol interval T ,

resulting in overlapping pulses if several multicarrier symbols are transmitted successively in time. These filters can be introduced into the development of the subcarrier-wise filtered multicarrier systems. Also an orthogonal or bi-orthogonal pulse design ensures that the overlapping pulses can be almost perfectly reconstructed without creating any mutual interference. In order to achieve maximum spectral efficiency, OQAM signaling has been proposed, yielding an FMBC/OQAM system. A redesign of the signal processing procedures is required for the utilization of orthogonality in the OQAM. This has to be done in order to successfully enable direct transfers of some algorithms developed for the OFDM protocol. Also QAM signaling enables the use of any scheme developed for OFDM systems, which ensures compatibility with all prevailing MIMO schemes. The signal structure of CP-OFDM, which can be considered that incorporates CP-OFDM and windowed-OFDM can be fully maintained, and pulse shaping/windowing is considered a free design parameter used to balance the robustness to time and frequency distortions. Last, simultaneous multi-service transmission building on distinct waveform technologies will be facilitated through the FC-OFDM scheme, that enables multiplexing of different waveforms in a given system bandwidth. For instance, we can generate two signals in two dedicated subbands which have FBMC-like and CP-OFDM-like characteristics, respectively.

On the other hand, Subband-wise filtered multicarrier systems (UF-OFDM and f-OFDM), employ FIR filtering per group of subcarriers after the classical OFDM modulation which conceptually ensures a close similarity (in fact actual implementations can apply the filtering functionality before the transformation to time domain for reduced complexity). The width of the single subbands and the time-frequency response of the respective filters are available design parameters. Subband-wise filtered multicarrier systems can be based on both CP-OFDM and ZP-OFDM (cyclic-prefix and zero-postfix, respectively). In some realizations filtering is only applied at the transmitter side (though it is not confined to this). The filters can be optimized according to selected KPIs, e.g. spectrum confinement, inband distortion, etc. These technologies maintain orthogonality in the complex field and thus any technology being developed for classical OFDM is easily applicable.

With respect to the frame structure in LTE/LTE-A systems, it should be mentioned that LTE frame structure does not possess high degree of flexibility which makes it inefficient to meet diverse requirements, e.g., to support both best effort MBB and low latency MCC. The frame design for 5G networks must be configurable according to service-specific requests, such as service/traffic type, latency constraint, target QoS etc. As a result it is assumed that the higher layer will make such information available to the lower layers. Then investigation of frame numerology and flexible TTI definitions such that they can be tailored to dedicated services both for TDD and FDD will take place. Regarding the latency and power consumption aspects, fast transitions between sleep and active modes, short active time with high data rate together with low sleep mode power consumption will be the main design objectives.

Figure 2 illustrates the envisaged multi-service frame structure.

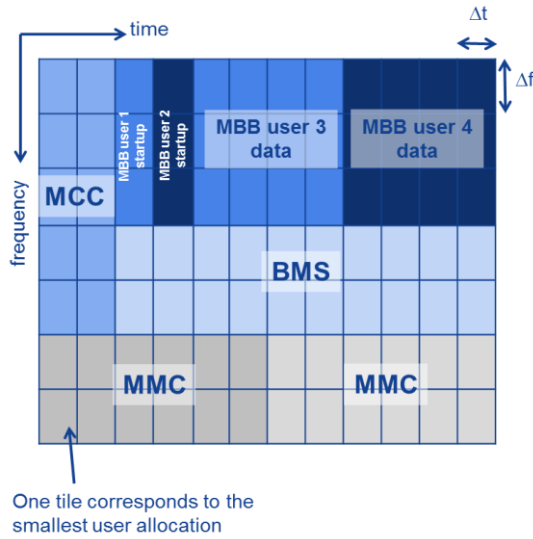


Figure 2: Multi-service frame structure

v. Network-related aspects

The project focuses on the multi-user/multi-cell aspects such as design of the MAC, 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 that we have already present in 0. In short, the main topics of the project can be summarized as follows:

- System level integration of multi-antenna concepts with/without cooperation, and advanced multiuser detection.
- Develop a flexible MAC/RRM framework for supporting a variety of link and system level requirements. Among others, RRM includes flexible and dynamic resource allocation, link adaptation, power control, multi-cell/node connectivity and interference coordination to accommodate different service mixes.
- Design a highly flexible and efficient random access scheme, comprising state-of-the-art collision resolution techniques, offering possibilities to support scheduled and non-scheduled transmissions.
- Explore opportunities for service classification techniques (context awareness, service identification and class formation) for improved performance.
- Flexible support for broadcast and multicast transmissions, including techniques such as network coding.
- Device-to-Device (D2D) communications with varying levels of assistance from the cellular network.

Figure 3 illustrates the 3 network-related aspects proposed by the FANTASTIC-5G project that will be presented here.

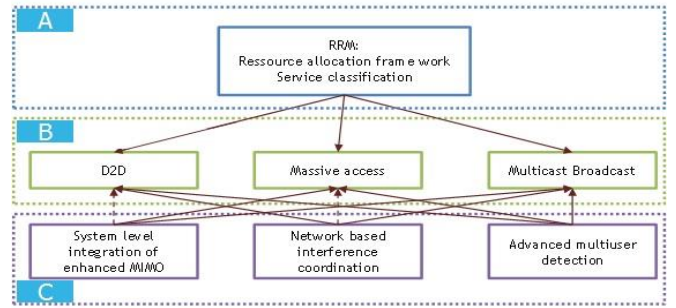


Figure 3: FANTASTIC-5G network related aspects (A: Basic RRM concept; B: Advance connectivity options; C: spectral efficiency)

A. Basic RRM concept

Allocation of radio transmission resources is one of the most essential RRM management tasks. This includes allocation of radio resources for scheduled unicast transmissions between network infrastructure base stations and UEs, scheduled multicast and broadcast transmissions, D2D, as well as resources for non-scheduled uplink access. The allocation of radio resources for different types of transmissions are by default assumed to be network controlled and to be conducted for each individual cell. The shared channel is assumed to offer an orthogonal time-frequency resource grid for multiplexing users within the cell.

It is well-known from communication theory that there are fundamental trade-offs between capacity, latency, reliability, and coverage [13]. From a system design point of view, this tells us that we should not optimize the air interface according to a given extreme case - e.g. low latency for any transmission, even if not required - as this will incur a loss in capacity (spectral efficiency), and vice versa. Instead, a flexible system design that allows optimizing each link in coherence with its service requirements is desirable.

Also machine learning techniques, reside in the area of statistical-based classification techniques have been especially considered (Figure 4) for this project, in order to improve performance for various types of traffic and service classification. For instance, mission critical traffic (MCC) should be prioritized compared to MBB (e.g., entertainment/youtube video). The reason to choose machine learning for the 5G communications [12] among other techniques is because it can automatically create the signatures for a service and automatically identify a service in the future traffic flow.

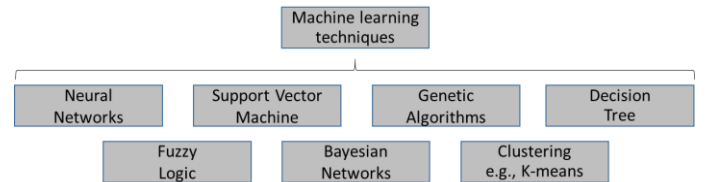


Figure 4: Overview of machine learning techniques

B. Advanced Connectivity Options

Traditional cellular connectivity is characterized by the downlink (DL) broadcast and uplink (UL) unicast of control plane signaling and DL/UL unicast of user plane data. Within FANTASTIC-5G, three new connectivity protocols are

explored to enhance cellular connectivity in both control and user plane, namely: (i) Device-to-Device; (ii) Massive Access; and (iii) Broadcast/Multicast. With (i) the cellular network becomes capable of supporting low latency links between proximate devices, extend network coverage and off-load cellular traffic via localized content caching and distribution [14]. Where one of the considered enablers is the leveraging of the network support to realize proximity discovery and access mode selection [15]. The goal of (ii) is to allow the cellular network to support a massive number of simultaneous transmissions originated from Machine-Type Devices (MTC), through the use of access protocols capable to take advantage of advanced multiuser receivers [16] and enhanced MIMO [17]. Finally, in (iii) traditional Broadcast/Multicast communications are enhanced through the use of non-orthogonal transmission schemes enabled via beam-forming and multilevel coding and spatial multiplexing; as well as broadcast communications integrated with uplink acknowledgement, enabling the retransmission to devices unable to decode the original broadcast transmission.

C. Spectral efficiency enablers

Different methods that mainly target at improving the overall spectrum efficiency, but also offering benefits for other KPIs are proposed in this project. In short, different techniques for interference mitigation are presented. System level integration of Multiple Input Multiple Output (MIMO) is naturally one of the important enablers for improved spectral efficiency, especially when considering massive MIMO with different degrees of cooperation and coordination [20][21]. Also there are included solutions for; improved network energy efficiency, protection of MCC, etc., in addition to improvements in the overall network spectral efficiency. Other different complementary options for network-based interference coordination are outlined, including both uplink and downlink solutions, as well as linear and non-linear approaches. For example, in the case of Non Orthogonal Multiple Access (NOMA), interference cancellation at the receiver is needed in order to fully exploit the potential of multiple access. Receiver complexity ranging from a “maximum likelihood” receiver to linear low-complexity receivers are taken into account. In the case of MMC, for example, the receiver complexity needs to be very low in order to be a viable solution for this kind of small devices with long battery life requirements.

MIMO techniques provide another powerful method to increase spectral efficiency like:

- Increase the data rate using spatial multiplexing
 - Increase the signal robustness
- by transmitting multiple independent/redundant streams with or without cooperation between base stations.

The challenges addressed in this project (e.g. complex techniques for massive MIMO) is to integrate these techniques into a common framework enabling the support of different use cases and facilitates adaptive mode switching between different transmission/reception methods.

VI. Evaluation Methodology and indicative results

The selected scenarios and use cases are dictating the environment models and KPI targets. Technology components (procedures) being developed during the project and indicating promising performance gains are to be implemented via certain system features. In a first phase during the development of the technology components first evaluations via system level simulations are to be executed. These results will be used to refine the concepts. Finally, in a second phase comprehensive system level simulations will be used to analyze the feasibility of the designs being developed in FANTASTIC-5G in achieving its goals and KPI targets.

High-level architecture of evaluation methodology takes into account:

- Environment models
- System features
- Analysis

Regarding environment models the impact of traffic, mobility and radio conditions are taken into account in the system-level simulators (e.g. 1000x more traffic, D2D connectivity, mobility etc.)

Regarding system features the usage of spectrum in frequency bands below 6GHz is taken into account (due to the fact that FANTASTIC-5G does not cover mm-wave research), dense network deployments, impact of modulation, coding, MIMO etc. Moreover, suitable abstractions of PHY and MAC layers in order to define system behavior models and limit complexity aspects of simulations will be taken into consideration. For instance, the project will model the PHY layer aspects on the simulator tools by utilizing pre-computed mapping curves e.g., of spectral efficiency versus signal quality indicators, block error rate versus signal to noise and interference ratio, physical data rate versus signal to noise and interference ratio, and so on. These lookup tables will be filled with values obtained from link level simulation results. Moreover, the simulation tools will provide the means for analyzing and providing results related to the targeted KPIs including throughput, latency, packet losses, bit error rate, low energy consumption etc.

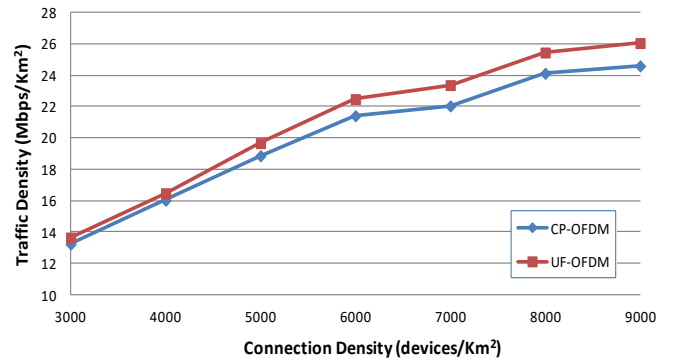


Figure 5: Traffic density vs. connection density

For the system-level scenarios a 10MHz uplink band is used around the central frequency of 2GHz in a given playground of

4km² including 19 3-sectorised base stations (57 cells). MMC traffic modelling is based on 3GPP TR36.888 [18] and TR 37.868 [19] models. Figure 5 shows the performance of CP-OFDM and UF-OFDM waveforms as the number of devices per km² increases.

VII. Demonstration

The demonstration aims at validating the feasibility and the superiority of the different components of the foreseen 5G air interface. The planned Proof-of-Concept (PoC) in FANTASTIC-5G are classified into three main categories: post-OFDM waveform prototyping, coexistence aspects evaluation and software defined radio (SDR) - based demonstration for broadcast and multicast transmission. Algorithms that are being developed in FANTASTIC-5G to tackle open issues like synchronization, channel estimation, equalization, efficient MIMO support and pulse shape adaptation will be addressed in the planned PoC. The transceivers will be tested in both vehicular, MMC and MCC scenarios. Additionally, MIMO transceiver will be developed to be tested in the MBB scenarios where the main focus is on relaxed synchronization and channel estimation in multi-antenna case. Broadcast and multicast transmissions are expected to have high importance in 5G networks and will be developed in FANTASTIC-5G to enable multicast transmissions to different multicast groups by the use of MIMO techniques but, at the same time, provide a common broadcast layer to all users will be demonstrated using software defined radio (SDR) platform. The different KPI to be evaluated with the different PoCs are specified to include power consumption, hardware complexity, error rate, power leakage, throughput, latency and robustness against Doppler, synchronization and also packet error rate and bit error rate, mobility, complexity and latency aspects.

VIII. Impact to standards

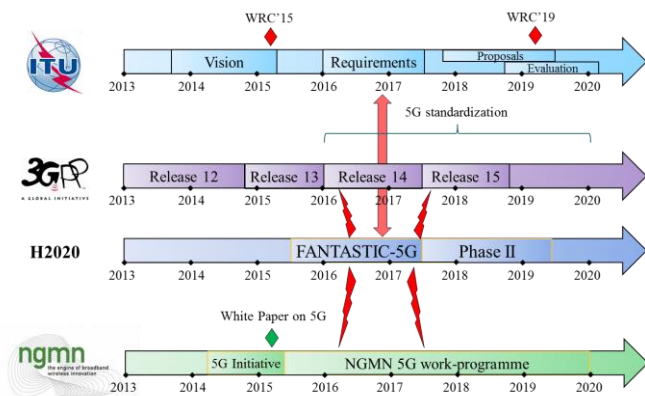


Figure 6: Positioning of FANTASTIC-5G with respect to ITU, 3GPP and NGMN

The project aims at extensively influencing pre-standardization and standardization activities in the future on 5G study items. This objective already can be perceived from the scope of

FANTASTIC-5G that is heavily composed of topics requiring standardization, e.g. waveform and frame design, PHY layer procedures, transceiver processing (interference management, multiuser reception, etc.), channel coding, adaptive coding and modulation etc. These are all topics that imply interfaces, messages, signaling, protocols (all of which are standardized in 3GPP) rather than proprietary algorithmic solutions. As one of the major outputs of the project, FANTASTIC-5G will lay out recommendations towards 3GPP using the innovative work carried out on such topics (Figure 6). The timing of this project is perfectly matched to interact with and influence 5G-related regulation, standardization and industrial fora that will strengthen the European position by allowing European-funded research to influence future standardization directions in 5G.

IX. Conclusions

In this paper, the 5G mobile communications use cases were identified which reflect the foreseen challenges. To target each case, research is carried out on technology components such as link-level and network-level design. The FANTASTIC-5G overall approach to 5G communications is to build an Air Interface which is flexible to efficiently enabling the utilization of all the arising diversification of services. This flexible air interface will allow support of the expected dramatic increase in the mobile data volume while broadening the range of application domains that mobile communications can support beyond 2020.

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