Development of 5G CHAMPION Testbeds for 5G Services at the 2018 Winter Olympic Games

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Abstract— **This paper describes the first available 5G testbeds as designed by 5G CHAMPION, a collaborative research project undertaken by over twenty consortium members and targeting the provision of 5G services at the 2018 Winter Olympics in Korea. In order to provide 5G services such as augmented reality (AR), virtual reality (VR), high quality, interactive multi-player video games, the testbeds shall fulfill the challenging requirements such as ultra-high data rates, ultra-reliable low latency, and mass connectivity. To meet such requirements, revolutionary testbed architectures are proposed, designed to be flexible, cost- and energy-efficient, through adopting state-of-art multi-radio access technologies (RAT) in client devices and in the network. The testbeds will also provide mmWave wireless backhaul, an interoperable and seamless connection between two different access networks located in Europe and on the site of the Korean Winter Olympic Games.**

Inedex terms—5G Services; 5G Mobile Communication; 5G Testbed; 5G CHAMPION; multi-RAT; Heterogeneous Network.

I. Introduction

While 2G, 3G, and 4G mobile communication systems primarily evolved in order to obtain higher data rates and/or broader bands, the 5G system, currently under definition, will need more diversified key performance indicators (KPIs) to fulfil the key 5G use cases of enhanced mobile broadband (eMBB), ultra-reliable low latency communication (URLLC), and mass connectivity for emerging services [1]. In order to demonstrate those services in conjunction with worldwide events, such as the 2018 Winter Olympic Games in Korea, the collaborative funded research project 5G CHAMPION [2] began its work on June 1, 2016. More than twenty consortium members, located in the European Union (EU) and Korea (KR), have been developing the first 5G testbeds with heterogeneous, agile mobile networks for the services mentioned above, specifically designed to provide services at the Winter Olympic Games. The testbeds have been developed following the overall setup described in [3] with enabling technologies such as beamforming-based mmWave and satellite service provisioning, virtualized infrastructure, software reconfiguration across the entire protocol stack, accurate positioning, and high speed access.

This paper presents the 5G CHAMPION testbeds currently being developed focusing on the following three main assets. The first one is a new architectural approach that provides efficient end-to-end system performance. The second one is the interoperable and seamless connections between two different access networks (i.e. the access network in Europe and the one on the site of Korean Olympic Games). The third one is the merging of leading mmWave and sub-6 GHz 5G radio accesses, core network, and satellite technologies [3].

The availability of flexible and powerful 5G testbeds is an important asset for the whole telecommunication ecosystem, as such testbeds can provide researchers and SMEs with a clear understanding of the challenges and issues that future 5G systems will introduce, such as data rates in the order of tens of gigabits per second (Gbps), sub-millisecond service latency, and reliability in the packet loss rates of at least 10^{-9} [1]. Some 5G testbeds that partially fulfill those requirements have already been introduced [4-6]. In [4], the authors introduced 5G testbeds for mmWave systems with high bandwidth analog front ends, parallel and interleaved analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) for giga-samples per second (GS/s). However, those testbeds are proof-of-concept (PoC) systems for mmWave radio technology, while the 5G CHAMPION testbeds embrace these mmWave technologies and sub-6 GHz 5G radio access, core network, and satellite technologies. In [5], the authors introduced a virtual Wi-Fi testbed and virtualization tools in order to support hundreds of virtual Wi-Fi nodes. Other notable testbeds have been developed by the 5G project "Integration of Broadcast and Broadband in LTE/5G" (IMB5) [6], which leverages on evolved multimedia broadcast multicast service (eMBMS) testbeds. Embracing these features and technologies, the 5G CHAMPION testbeds aim to provide 5G services with interoperable and seamless connection between two different access networks across the world in conjunction with the Winter Olympic Games.

The remainder of the paper is organized as follows: Section II details the testbed architecture, Section III treats the test plan and the preliminary test results, Section IV finally draws the conclusion and hints at the next steps.

II. 5G CHAMPION Testbed Architecture

The testbeds architectural building blocks are being developed with the overall configuration of the 5G CHAMPION high-level system architecture as depicted in Fig. 1.

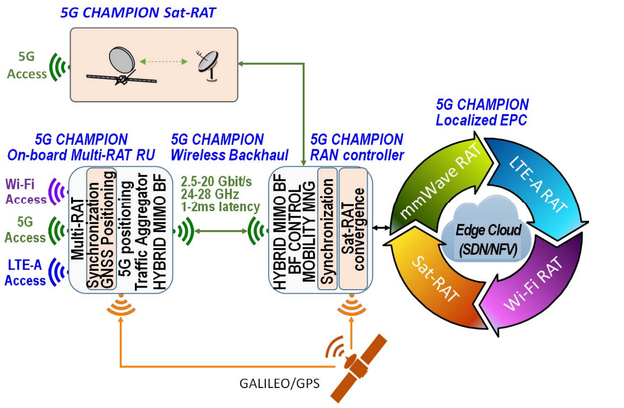


Fig. 1. 5G CHAMPION high-level system architecture.

The testbed is composed of five main units, two of them, i.e. the *5G CHAMPION Sat-RAT* and the *5G CHAMPION RAN Controller*, are out of scope of this paper and will be discussed in future works, whereas the other three units are described in the following:

- The *5G CHAMPION multi-RAT On-board RU*, comprises the access radio unit (ARU) for the link between the user equipment (UE) and the multi-RAT radio unit (RU);
- The *5G CHAMPION wireless backhaul*, includes a backhaul radio unit (BRU) for the link between the on-board multi-RAT RU and the RU in the base station connected to a digital processing unit (DU) with a radio access network (RAN) controller;
- The *5G CHAMPION localized EPC*, mainly made of the virtualized evolved packet core (vEPC).

In the system architecture described above, the EU companies have undertaken the development of the multi-RAT, the 5G positioning technology with accuracy of less than one meter error, and satellite access technologies, while the KR companies have been developing the high speed mobility service with the broadband terminals using mmWave access and distributed mobile core network technologies.

A. Access Radio Unit (ARU)

In order to implement the multi-RAT enabling accesses such as WiFi, LTE-A, and 5G, suitable software and the related virtualization techniques must be employed across both the entire network and the client devices. For the sake of brevity, to better understand the 5G CHAMPION testbed ARU with the multi-RAT function, this paper just describes the client device side as it is more interesting due to the fact that it has more information and the communication structure between the client devices and the network is almost symmetrical.

For the multi-RAT client devices of the testbeds, we adopted the European Telecommunications Standards Institute (ETSI) reconfigurable radio system (RRS) technology that provides a general concept for software defined radio (SDR) or cognitive radio (CR) [7-12]. ETSI RRS is the software reconfiguration framework that can be efficient thanks to the fact that it allows either the addition or replacement of entire RATs, or the upgrade of specific components across any layer. In order to be power efficient and flexible, the ETSI RRS adopts the radio virtual machine (RVM) concept, which presents two innovative functions. First, instead of inefficiently using middleware to execute a generic code on a specific target platform, the ETSI RRS allows the generic code to be optimized for the accelerators or for specific available hardware resources of the target platform. Second, following the back-end compilation, the executable code is optimally tailored to the execution environment using the RVM.

The fundamental architecture of a RRS is defined in [8], and consists of a communication services layer (CSL), a radio control framework (RCF), a unified radio application (URA), and a radio platform (RP) as illustrated in Fig. 2. Among these, the CSL with the multi-radio interface (MURI) is the key component that provides a minimum set of reconfiguration capabilities. The CSL is the layer related to the communication services supporting both generic (e.g., Internet access) and specific multi-radio applications.

The RRS enables the provision and usage of third party software components in a standardized way. A target radio application, i.e. a software code that alters part of an existing RAT or implements an additional air interface (e.g., CDMA, HSPA, LTE, WiFi, etc.), can be downloaded from the RadioApps store to the target RRS in the form of a radio application package (RAP). Because all radio applications exhibit common behaviors from the RRS perspective, those radio applications are called URAs once they are downloaded into the target RRS (see lower right side of Fig. 2).

B. mmWave Backhaul Radio Unit (BRU)

The basic architecture of the KR BRU testbed is similar to that of the mobile hot spot network (MHN) illustrated in [13], and entails two main components. The first, on the network side, is made of the MHN NodeBs (mNBs), consisting of MHN digital units (mDUs), and the MHN radio units (mRUs) (see Figure 7). The second, on the client- or the moving hot spot cell-side, is made of the MHN terminal equipment (mTEs) mounted on vehicles, which are primarily responsible for mobile wireless backhauling between the mTE and the mRU in a mNB. mTEs have the connection for the onboard access links (e.g., Wi-Fi) for the terminals inside a car.

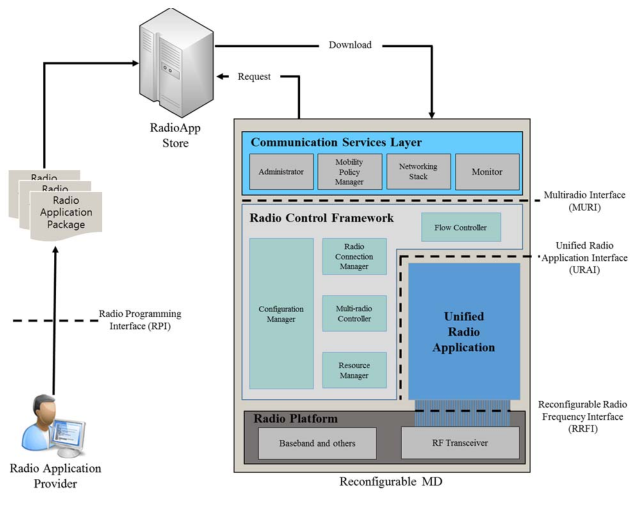


Fig. 2. Reconfigurable radio system architecture components [9].

The KR BRU testbed aims to allow the aggregation of a maximum of eight component carriers (CCs) in order to obtain a total transmission bandwidth of up to 1 GHz. The baseband boards (BBs) of both the mDU and mTE testbeds will be implemented on Xilinx FPGAs capable of providing a data-rate exceeding 2.5 Gbps.

In order to support the digital MIMO technology for improving spectral efficiency, dual-polarized array antennas are implemented in both transmit (TX) and receive (RX) antennas, as illustrated in Fig. 3. In particular, 4x4 and 8x8 vertical/horizontal arrays are configured for the TX and RX antennas, respectively. As for the used frequency band, because the KR BRU is designed to operate in unlicensed frequency bands in the range of 25–26 GHz, which is referred to as the Flexible Access Common Spectrum (FACS) in Korea, it is mandatory to meet the effective isotropic radiated power (EIRP) requirement regulated by the Korean government, where the maximum EIRP allowed is 36 dBm. Therefore, the maximum antenna gains designed for the TX and RX are approximately 16 dBi and 21 dBi, respectively, considering the maximum transmit power of 20 dBm. To reduce costs, only fixed RF beamforming is considered for each array antenna.

The EU BRU will be developed in the frequency band of 26.5–29.3 GHz, and consists of a baseband unit (BBU), an RF digital front-end (DFE), and an antenna module (Fig. 4). The BBU has a data rate of around 2.5 Gbps and implements classical OFDM signal processing and digital MIMO. With the RF-DFE, the BRU can be used for single or multi-beam transmissions. In contrast with the KR architecture, the EU BRU will include analogue beam-forming capabilities and gain control. Two different antenna architectures, which are based on planar phased array and electronically reconfigurable 'transmitarray' technologies [14], will be designed. The possible interface 'transmitarray' antennas with electronic beam-steering capabilities are composed of a focal source and a flat-lens array of unit cells. The proposed solution is based on a tunable unit cell [15, 16] with p-i-n diodes that are used to locally control the transmission phase on the flat-lens array.

With regard to the link budget and to the achievable distance, Fig. 5 shows that the testbed platform is capable of long range communications. However, it is sensitive to small multipath interferences. Moreover, the dashed lines relative to the solid ones say that the performance with ground reflections and several hundreds of meters can be lost for higher modulations. Finally, the results related to the beam misalignment demonstrate that the side lobes are strong and are a potential source of interference. Thus, new challenges arise w.r.t. the design of beamforming weights that can provide strong side-lobe rejection.

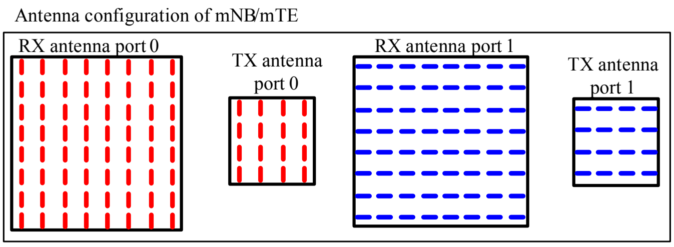


Fig. 3. Antenna configuration of the KR BRU.

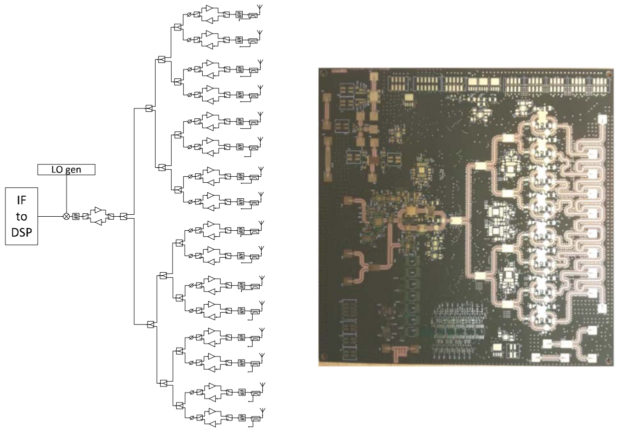
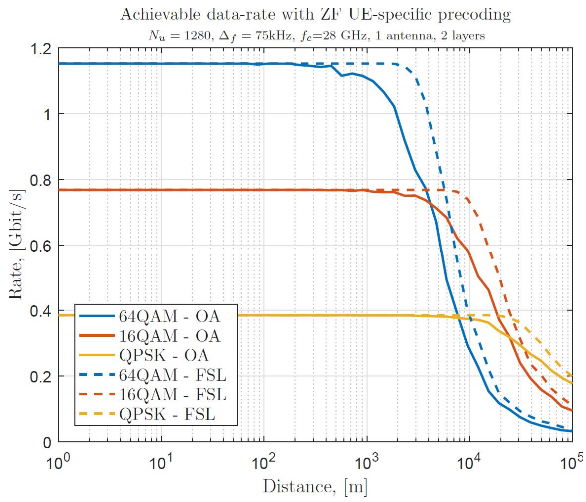
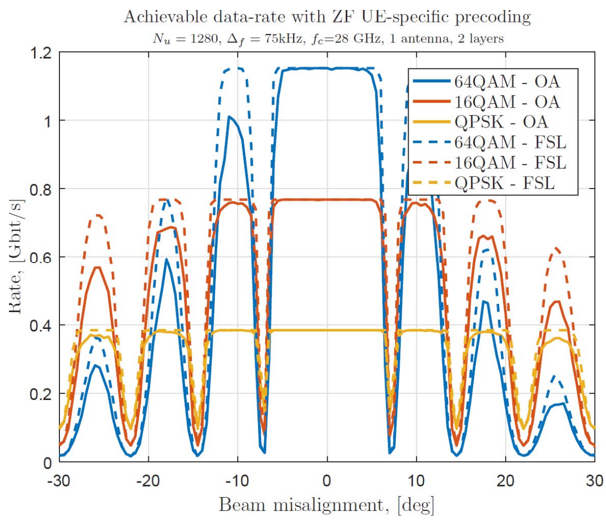


Fig. 4. Schematic of the EU BRU with the phased array antenna module and a photograph of the RF digital front-end module.



(a)



(b)

Fig. 5. (a) The maximum data rate as a function of the distance and (b) the maximum rate as a function of the beam misalignment at 100 m. (OA: open air with floor reflection, FSL: free space)

C. vEPC

The vEPC aims at delivering better proximity and flexibility, and 5G networks will distribute the mobile core functions to the edge nodes for enhanced real-time accessibility as illustrated in Fig. 6. In addition, the 5G core network functionality is divided into two parts: the user plane (UP), in charge of the bearer delivery, and the control plane (CP) in charge of signaling and controlling the 5G core. These are depicted in the high scalable vEPC (HS vEPC) section in the lower part of Fig. 6. The 5G network can also provide ultra-real time (low latency) services. In order to achieve this, it is possible to relocate the core functions closer to the end users and place real-time servers where the core functions are located.

It is possible to deploy different types of virtual mobile packet cores (MPCs) based on the demand or network access environment in the HS vEPC network architecture, in order to take advantage of the ‘softwarized’ networking technologies, such as software-defined networking (SDN) and network functions virtualization (NFV). In particular, in the MHN, a fast handover mechanism is required even in high-speed movements in order to maintain the user data rate for application services. In order to achieve this, the designated handover scheme using policy-based SDN technologies is exploited and used for the PoC of the mobility management for the testbeds.

III. 5G CHAMPION Testbed Plan and First Results

As depicted in Fig. 7, during the Pyeongchang Winter Olympics Games, the KR wireless moving-backhaul will be demonstrated for the services that use the testbed near the ‘IoT Street’ in the Gangneung Coastal Cluster (GCC) of the Olympics venues. Some RUs will be deployed along the roadside where buses equipped with mTEs on the front roof pass by. The clients on the bus can experience the 5G services, and two classes of use cases are considered, i.e. short-latency and broadband with mobility.

The key aspect of the short-latency application demonstrator is that two users will be connected to different 5G networks (EU’s and KR’s implementations) and will share a latency-critical application such as remote gaming or remote control. The fundamental challenge is to enable reliable real-time transmission of control messages from both sides of the network to the server, and vice-versa. Messages will be transferred over mmWave links, performing functions as radio access to the core network.

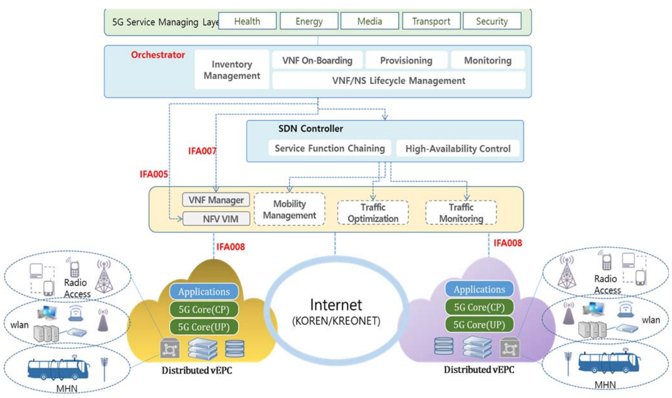


Fig. 6. High-level architecture of the KR vEPC.

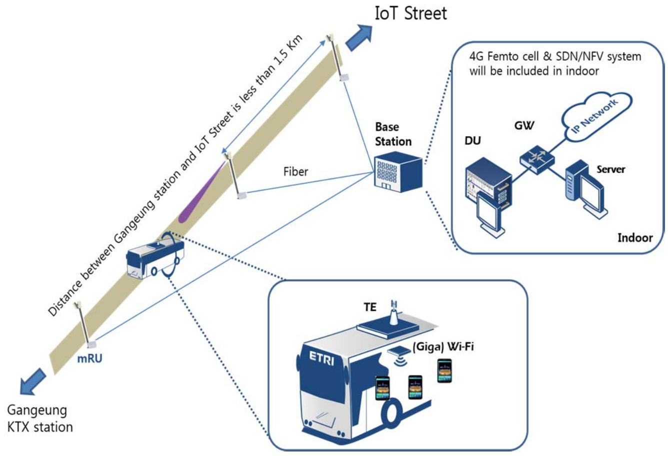


Fig. 7. KR moving wireless backhaul testbed for PoC.

The other key aspect of the use case of broadband applications in stationary and dynamic scenarios is that two users will be connected to different 5G networks (EU’s and KR’s implementations), and they will use the network for broadband applications such as ultra-high definition (UHD) content delivery, VR, AR with 3D multimedia, etc. The overall target KPIs and the key 5G CHAMPION technologies for the service scenarios are summarized in Table I. According to the chosen 5G CHAMPION technologies, handover with high mobility is the most important network function under analysis. In order to test such function in mmWave networks, we used the KR MHN PoC commercial prototype implemented in Seoul’s subway line 8, as depicted in Fig. 8. Five mRUs are connected with one mDU (see section II-B in this paper for the KR MHN architecture), and four handovers occur with a success rate of over 0.95 as a train travels along the testbed, while the handover success rate is 0.9 in the LTE system (see Table 3 in [17]).

Although the handover test was performed in a wireless environment in a city subway tunnel, the achieved high success rate of the handover function gives high hopes that promising similar results can be also achieved in different set-ups, that is, the wireless environments of the open roads planned for the Olympic site, by just optimizing the parameters related to the handover region or overlapped coverage that mmWave beams make.

TABLE I. Target KPIs and 5G CHAMPION technologies

Target KPI	*5G CHAMPION technology*
- Intersystem interoperability - 2 ms end-to-end latency	- Reliable internetwork connectivity (latency and rate to be verified)
- 100 Mbps user experience - Min. 2.5 Gbit/s mmWave wireless backhaul	- mmWave radios and multi-RAT - mmWave backhaul platforms
- SDN/NFV in vEPC	- Gaming server - SDN/NFV

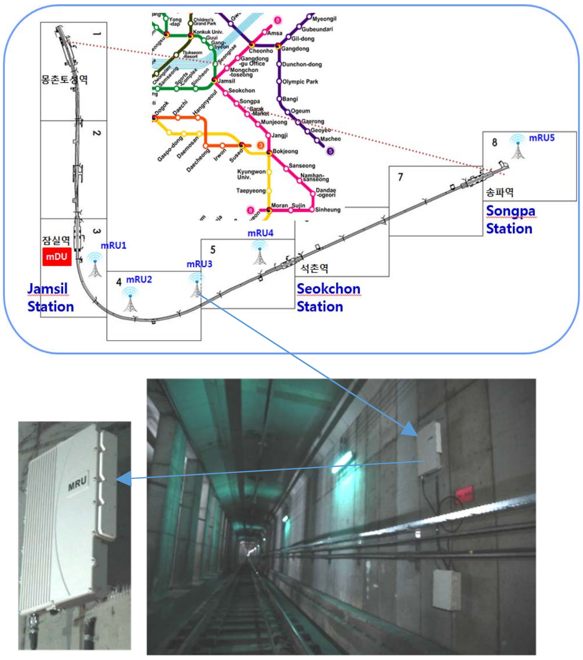


Fig. 8. The KR MHN PoC implemented in Seoul's subway. This PoC is instrumental to give guidance on the handover performance of the 5G CHAMPION testbed that will be used outdoor in the Olympic site.

IV. Conclusion

In this paper, three (ARU, BRU and vEPC) out of the five 5G CHAMPION testbeds units are addressed. The multi-RAT ARU structure is described with the client devices and the ETSI RRS. It is shown that the KR BRU allows the aggregation of a maximum of eight CCs in order to obtain a total transmission bandwidth of 1 GHz with a data rate of 2.5 Gbps and that dual-polarized array antennas will be implement for both TX and RX. On the other hand, the EU BRU consists of the BBU, the DFE, and the antenna module, and can be used for single or multi-beam transmissions. Moreover also two different antenna structures, based on the planar phased array and electronically reconfigurable 'transmitarray', are described. For the mmWave link, the link budget was analyzed; and some challenges were found in designing beamforming weights that could provide strong side-lob rejection. In vEPC, the HSvEPC network architecture with the 'softwarized' networking technologies such as SDN and NVF for fast handover are used, with main focus on the proximity for ultra-low latency services. Two classes of use cases are considered: short-latency oriented and broadband with mobility. The services that will be considered include, among others, remote gaming, UHD content delivery, VR, AR with 3D multimedia. For the handover test, the KR MHN PoC testbed for commercial prototype implemented in Seoul's subway line 8 was used, proving evidence of a predicted high success handover rate also for the future outdoor 5G CHAMPION testbeds. However, there still remains the problem of optimizing the parameters related to the handover region made by mmWave beams.

Future works will focus on describing the remaining two blocks in the 5G CHAMPION architecture and on providing more accurate results, especially for the outdoor case.

Acknowledgment

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