Multi RAT (WiFi/ LTE/ 5G) Mobile Network featuring RoF Fronthaul, 60 GHz Beam-Switching and Mobile IP

(invited paper)

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Abstract *We report on a public field trial demonstrating seamless handover in a multi Radio Access Technology mobile network supporting WiFi, LTE, and new 5G radio access in the 60 GHz band for full-duplex enhanced mobile broadband and 5G broadcast hotspots.*

Introduction

The fifth generation (5G) of mobile communications is expected to serve not only consumers but also multiple industries. Two performance features are often highlighted in that context to illustrate the expected technical advantageous of 5G against its legacy ancestors 3G and 4G which are the dominant mobile technologies today. These are a substantial increase in mobile data traffic as well as a reduction of latency down to the 1 ms threshold [1]-[4]. Recently, several field trials were conducted, demonstrating that the technology has been brought to a readiness level that allows reaching these technical performances. Supported by major standardization bodies which are working on the definitions for the new mobile radio, this pushes confidence that early versions of the new 5G mobile networks will become available around the year 2020.

In this paper, we report on the field trial of the European-Japanese RAPID5G consortium that publically demonstrated a 5G mobile network in the largest shopping mall in Warsaw, Poland. The technical targets for the RAPID5G field trial in Poland were to achieve high cell capacities for mobile users in dense user areas (shopping mall and stadium) and to demonstrate interoperability of the new 5G radio access with legacy 3G/ 4G services. Also, RAPID5G aimed at demonstrating low-latency 5G wireless service for the eMBB and the 5G hotspot use cases.

To achieve these technical performances, several physical layer innovations as well as new algorithms in the higher layers were carried out in the RAPID5G project. This includes new full-duplex 60 GHz SiGe transceiver chips featuring a Gigabit Ethernet interface [5], highly-directive beam-switching 60 GHz antennas and innovative 60 GHz beam-steering leaky-wave antenna technology [6]. Also, approaches for localizing the mobile user were tested and implemented in the field trial. Furthermore, a fiber-optic distributed antenna system (DAS) has been developed which provides analog RoF fronthaul as well as direct Gigabit Ethernet (GbE) connectivity to the new 5G radio access units (RAU) and thus supports the CRAN architecture. In addition, to provide low-latency seamless vertical handover between 3G, 4G and 5G, a Mobile IP algorithm including a fast initial link setup (FILS) protocol was developed and implemented [7].

Multi-RAT (3G/4G/5G) Network

For the field trial in the large Blue City shopping mall in Warsaw, a DAS has been developed and installed. It provides fiber-optic connectivity to all RAUs installed at the celling of the public area in the shopping mall as shown in Fig. 1.

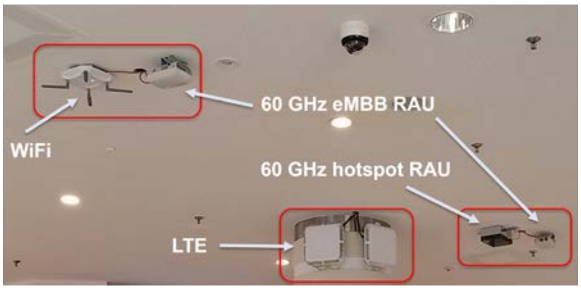

Fig. 1: RAU Installations for 3G/ 4G/ 5G mobile access.

Via its integrated head-end unit (IHU), the DAS system interconnects the shopping mall to a data center (DC) in Hala Mory providing the 5G BBU for the 5G hotspot RAU as well as the LTE BS. For being able to support LTE in the shopping mall, a LTE base station was implemented in the Mory DC which is connected to the MNO's DC evolved packet core (EPC) using a GbE transport network. Further, the Hala Mory DC is connected to another DC located in Perkuna. This DC hosts the server providing the data for the 5G hotspot, for WiFi, and for the 60 GHz 5G eMBB RAU. It also hosts the Mobile IP home agent.

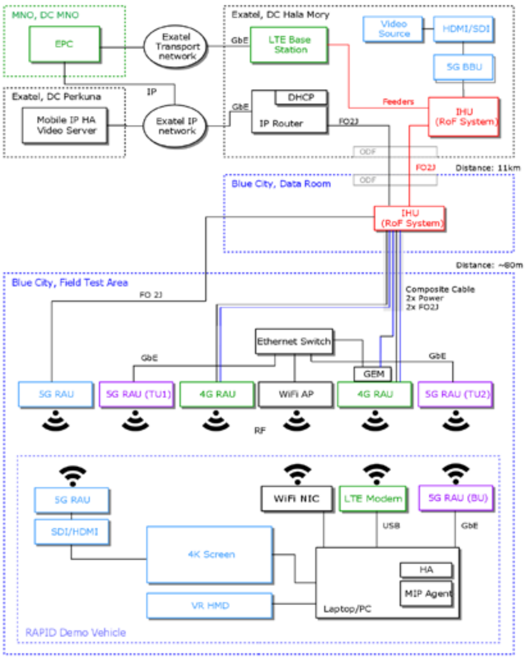

Fig. 2: Network architecture for the RAPID5G multi RAT field trial.

In the shopping mall, analog radio over fiber (ARoF) fronthauling was used for the LTE RAU and the 5G hotspo RAU. For the 5G eMBB RAU and for WiFi, the data was exchanged between the Mory DC and the RAUs in the Blue City shopping mall using GbE. For the field trial, a WiFi access point, two LTE RAUs, two 5G eMBB RAUs and one 5G hotspot RAU were installed at the celling (see Fig. 1) and are all connected by the DAS to the Blue City data room (see Fig. 2). The mobile terminal that was also developed in the project carried RAUs for supported wireless services, i.e. WiFi, LTE and 5G.

Mobile IP and FILS Implementation

To enable heterogeneous mobility allowing the mobile terminal (MT) to move freely inside the shopping mall and to dynamically attach itself to the most suitable wireless service, a Mobile IP algorithm has been developed and implemented. In detail, RAPID5G's Mobile IP system is based on a protocol and architecture defined in IETF's RFC 5944 [8]. It provides network layer roaming between the IP subsets. By assigning two types of IP addresses to the MT. The first is the home address, a virtual individual address that remains unchanged regardless of the RAT it is connected to. The second is the care-of address, which is associated with the physical network interface which changes whenever the mobile node roams to a different LAN segment. In such a configure-tion, the Mobile IP protocol is responsible for registering and de-registering and thus the Home Agent is always "aware" of the IP location of the mobile node and can act as an anchor point for incoming and outgoing traffic by creating Generic Routing Encapsulation (GRE) tunnels. Due to its versatile capabilities, Mobile IP was incorporated into the CDMA2000 network and nowadays plays a key role in the recent 3GPP LTE standards suite [9]. The software stack developed in RAPID5G consisted of the Mobile IP Agent responsible for Mobile IP registrations and GRE tunneling establishment, and the Handover Agent whose role was to gather network and radio condition parameters and make handover decisions based on that data. Whenever the RAPID5G MT was moving in shopping mall, the Handover Agent recorded RSSI level, signal quality, round-trip delay time (RTD) and other parameters. In case a threshold level is exceeded (e.g. 5G available and actual running service on MT requests high data rate), the Handover Agent requests the Mobile IP Agent to connect the MT to a more suitable radio link. On such a request, the Mobile IP Agent re-registered the MT with an updated care-of address and the incoming IP stream was redirected to the GRE tunnel established through the new radio link. This way, the RAPID5G mobile terminal was able to move and seamlessly switch between various RATs without breaking the service.

In addition to the seamless handover features, the Mobile IP protocol was furthermore designed with two additional features for improving the quality of service (QoS) in the multi-RAT environment. These two extensions are a Fast Initial Link Setup (FILS) based protocol and multi home support enabling the MT to connect to multiple RATs simultaneously. FILS, which had been standardized by IEEE802.11ai reduces the initial link setup time and is especially relevant for high data rate and low latency services. Furthermore, the RAPID5G mobile IP system can associate multiple care-of addresses to one home address. Thereby, the RAPID5G system is not only able to seamlessly handover between RATs, but it can also utilize several RATs at the same time, e.g. to increase the overall throughput or to use different RAT for different applications running at the same time.

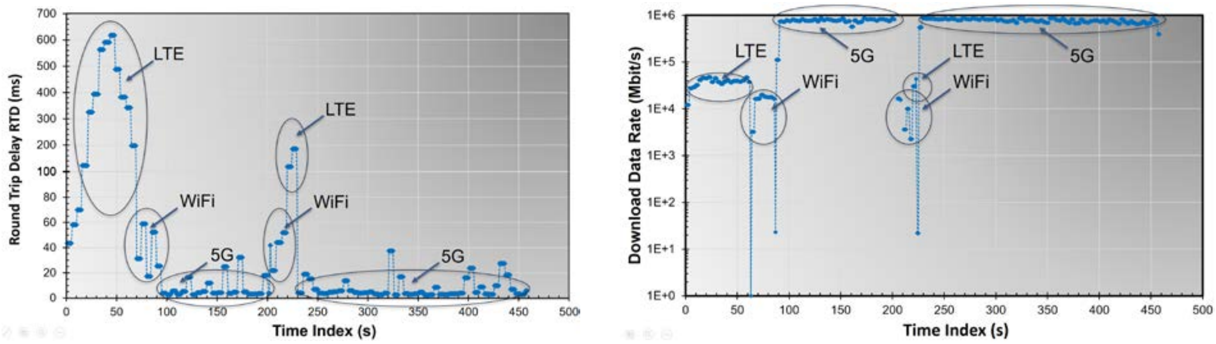

Fig. 3: Measured round trip delay (RTD) and download data rate for the different radio access technologies.

Field Trial Results

For demonstrating the seamless handover feature of the RAPID5G network, a video was streamed to the MT and displayed on its large 4K screen while the MT was moving in the shopping mall. Whenever the MT moved out of coverage it was switched automatically to the next available RAT. In this case, the user experience is that of an uninterrupted video. This is due to FILS and MOBILE IP which enabled short switching times and automatically re-initiates the streaming service as soon as the MT is connected to the new RAT. Of course, depending on the data rate provided by the new RAT, the video quality may have to be reduced.

For more quantitative experiments, a traffic generator had been employed and round-trip delay time (RTD) and downlink data rates were recorded. This was also done while the MT was moving with the high-directive 5G antennas following or when the MT was handed over to the next accessible RAT either because it left coverage or because it was forced to switch by the user. Fig. 3 shows the logged RTD and data rate versus time. They show a median and mean data rate of 16.4 and 13.7 Mbit/s for WiFi, 37.8 and 32.7 Mbit/s for LTE and 778.1 and 765.4 Mbit/s for 5G, respectively. It must be said in that context that the data rate of the 5G 60 GHz eMBB service is limited by the Gigabit Ethernet interface of the developed 5G eMBB RAU which allows a maximum data rate of 856 Mbit/s. Still, the throughput and latency during the field trial were always sufficient for streaming 8K 360° videos. It must be furthermore said that the comparably low LTE data rate was due to the fact that the LTE service covered the entire public field trial area and was accessible. Therefore, up to over 200 shopping mall customers were connected to the RAPID5G LTE service during the trials which led to a reduced speed of 47.1 Mbit/s maximum. In the lab, the LTE service reached 140 Mbit/s max.

The RTD is considered to be two times the experienced user latency. The median and mean values of the experienced user latency is 18.8 ms and 36.3 ms for WiFi, 61.1 ms and 122.3 ms for LTE and 2.2 ms and 5.2 ms for 5G, respectively.

Finally, the 5G hotspot RAU supported by analog RoF fronthaul was demonstrated to be capable of supporting multiple users with high-data rate stream simultaneously. During the field trial, two 1.5 Gbit/s uncompressed videos were streamed to two mobile users, simultaneously.

Conclusions

We reported a field trial of a multi RAT mobile network supporting 60 GHz mobile access with latencies down to 2.2 ms and maximum data rates of about 780 Mbit/s and 1.5 Gbit/s for the eMBB and 5G hotspot RAUs.

Acknowledgements

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