Designing a Testbed Infrastructure for Experimental Validation and Trialing of 5G Vertical Applications

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Abstract. This paper describes the design of a testbed for experimental validation and trialing of 5G vertical applications. The paper introduces the challenges that 5G aims to solve with regard to the spectrum demand and the convergence of different wireless communication services. The European-level 5G research program 5G Public Private Partnership (5G-PPP) is a coordinated European approach to secure European leadership in 5G. The 5G-PPP has developed a 5G Pan-European Trials Roadmap, which includes a comprehensive strategy for coordinated international preliminary and pre-commercial trials. The objective in designing Turku University of Applied Sciences (TUAS) testbed infrastructure in Turku, Finland, has been in building a testbed that can be used to contribute to the development, standardization and trialing of wireless communications in a diverse selection of scenarios and vertical applications. In addition, the paper describes the spectrum monitoring capabilities at TUAS facilities.

Keywords: 5G · Testbed · Field trials · Experimental validation Field measurements · TVWS · LTE · DTT broadcasting · LSA · LoRa

1 Introduction

Designing a 5th generation mobile networks (5G) testbed infrastructure for experimentations and trials is far from a trivial task. It requires theoretical knowledge on wireless networks, engineering knowledge to build and operate the testbed and professional level measurement equipment and skilled personnel to operate them. 5G will not only be a New Radio [1], but also an umbrella under which the newly developed and existing technologies are converged to meet the requirements of 5G applications [2]. Thus, it is essential to know the limitations of the current technologies and to accurately define the requirements of the 5G applications.

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The 5G Public Private Partnership (5G-PPP) [3] funded by European Union is a major initiative aiming to secure European leadership in 5G. The public and private sectors in Europe work together to develop 5G in several different projects on different topics, such as overall architecture, physical layer, Network Function Virtualization (NFV), software-defined networking (SDN), and network slicing. European Commission has created a coordinated 5G action plan (5GAP) [4], which promotes preliminary trials under the 5G-PPP arrangement to take place from 2017 onward and pre-commercial trials from 2018 onward.

To address the key elements in 5GAP, a high-level 5G Pan-European Trials Roadmap [5] was released in May 2017. The main objectives of the Trials Roadmap are the following:

1. Support global European leadership in 5G technology, 5G networks deployment and profitable 5G business.
2. Validate benefits of 5G to vertical sectors, public sector, businesses and consumers.
3. Initiate a clear path to successful and timely 5G deployment.
4. Expand commercial trials and demonstrations as well as national initiatives.

The Finnish Funding Agency for Innovation (Tekes) [6] funds a 5thGear programme [7], which gathers Finnish companies and research institutes together with the aim to solve the challenges of next generation wireless communications, create new business and international collaboration. 5G Test Network Finland (5GTNF) [8] coordinates the integration of the 5G testbeds in 5thGear programme to create a joint open 5G technology and service development innovation platform to support the vision of 5G-PPP in Finland.

This paper introduces the approach chosen by Turku University of Applied Sciences (TUAS) for the evolution and design of testbed infrastructure, which will be used in the European 5G development through experimental validation and trialing of 5G vertical applications and is also a part of the 5GTNF.

The rest of the paper is organized as follows: Sect. 2 describes the previous TUAS research and available test networks, which form a basis of the TUAS testbed. Section 3 discusses the spectrum issues in 5G, while Sect. 4 describes the proposed testbed infrastructure on a high level. Section 5 describes the required spectrum monitoring capabilities and Sect. 6 concludes the paper.

2 TUAS Test Networks and Field Measurement Activities

As the 5G is expected to be able to provide optimized support for a variety of different services and applications [9], understanding the limitations in the current technologies is essential in building a converged 5G ecosystem. Depending on the use case and application, 5G should be able to simultaneously support multiple combinations of reliability, latency, throughput, positioning, and availability [10].

Testbed development requires knowledge on different use cases and vertical applications. TUAS has wide experience in the following vertical applications:

– TV content distribution and reception (broadcasting).
– IoT devices communicating data to the cloud service.
– Video surveillance streams in high definition.

The previous TUAS research and testbeds in digital terrestrial television (DTT) broadcasting, TV White Space (TVWS) and licensed spectrum sharing are described in Sects. 2.1 and 2.2, while Sect. 2.3 describes the recently planned industrial Internet of Things (IoT) testbeds.

2.1 Digital Terrestrial Television and TV White Spaces

TUAS radio laboratory has strong traditions in DTT broadcasting research during the past 10 years. Interoperability tests, mobility tests, verification and validation of rotated constellations and measurements of interference and coverage for DVB-T/H/T2 (Digital Video Broadcasting - Terrestrial/Handheld/Second Generation Terrestrial) have been conducted in several different projects, including EUREKA-Celtic projects WING-TV [11], B21C [12] and ENGINES [13].

Since 2010, the focus of TUAS research has been in spectrum sharing, especially in TVWS and LSA. In spectrum sharing, it is essential to study the technical protection conditions to enable the coexistence between secondary and primary (incumbent) users through field measurements in real test network environments. Field measurements are very time-consuming and expensive to conduct as they require substantial human resources, test network infrastructure, professional level measurement devices and radio licenses [14,15]. Field measurements are rare in the literature. Especially in spectrum sharing, the studies are typically based on simulations and laboratory measurements in controlled environments.

Turku TVWS test environment [16] was set up during in White Space Test Environment for Broadcast Frequencies (WISE), WISE2 and ReWISE (Reliability Extension to White Space Test Environment) projects (2011–2014) [17] to develop and validate technical solutions, accelerate commercial utilization of white spaces, and to contribute to the regulation and standardization work [18–29]. The test network and associated radio laboratory are located in Turku, Finland. TVWS equipment has also been installed and trialed in the use-case pilots of WISE2 project in different locations in Helsinki [16]. The test network was the first in Europe to have a full geolocation-based radio license for the TVWS frequency range 470 MHz–790 MHz [30] in the 40×40 km area shown in Fig. 1.

TUAS participated in Horizon 2020 Collaborative Spectrum Sharing competition with a proposal called DISTRIBUTE, which won the competition [31]. The highly innovative view on distributed spectrum sharing in DISTRIBUTE uses solutions involving licensed spectrum and is based on forms of geolocation databases. DISTRIBUTE adapted the geolocation database concept to be entirely decentralized, operating in a distributed way solely on the nodes or terminals that are sharing the spectrum. The approach is consistent with regulation

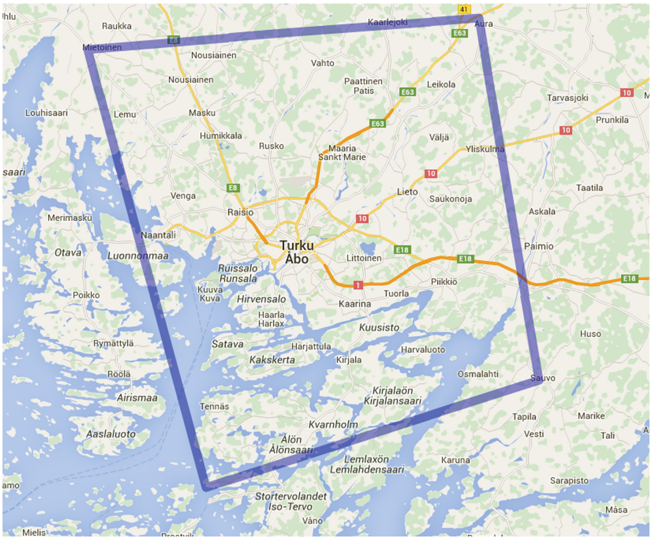

Fig. 1. 40 × 40 km Turku TVWS network radio license area.

and policy. Regulatory constraints might be even conveyed by the regulator at a higher level, and the distributed database solution will always operate within those local constraints. The approach is applicable to sharing of licensed spectrum, such as licensed devices operating in TVWS and Licensed Shared Access (LSA), and license-exempt spectrum sharing such as conventional TVWS and Spectrum Access System (SAS)-supported license-exempt access.

2.2 Licensed Spectrum Sharing

The Future of UHF Frequency Band (FUHF) project [32] continued to study spectrum sharing in ultra high frequency (UHF) TV band. The main focus was on field measurements [15] to study the feasibility of exclusive shared spectrum access through Long Term Evolution (LTE) Supplemental Downlink (SDL) concept [33–37]. The project also observed the regulatory and technical developments to determine the most feasible spectrum utilization methods for the UHF TV broadcasting band. The potential developments in the use of the band and candidate technologies such as WiB [38] and Tower Overlay over LTE-Advanced+ (TOoL+) [39–41] were considered in [15].

TUAS also co-operated with CORE+ project through WISE2 project and was a full project consortium partner in the follow-up project CORE++ [42]. These projects studied the LSA [43–51] and SAS [52–54] concepts by developing the framework, participating in the regulatory work and field trialing the developed systems. TUAS participated in the development of repositories for both LSA and SAS and in developing the spectrum sensing system fulfilling the requirements of Environmental Sensing Capability (ESC) in SAS. The European

Telecommunications Standards Institute (ETSI) work on defining LSA for 2300–2400 MHz band was recently finished [55–58] and is expected to evolve into a spectrum sharing method which could assist in meeting the spectrum demand for 5G [59].

2.3 Industrial IoT

There are two separate private networks for industrial IoT validation and trialing purposes in the TUAS test environment. The first network is a LoRa [60] low power wide area network (LPWAN) to study deep indoor propagation characteristics of a LoRa network. The network consists of two base stations at TUAS premises in ICT-City and Sepänkatu (locations are shown in Fig. 5), one base station at Kuusisto TV-mast and additional base stations operated by a private corporation. The network is operated on three 200 kHz channels at 868.1, 868.3 and 868.5 MHz. The transmissions have a 125 kHz bandwidth and a maximum duty-cycle constraint of 1%.

The second network consists of industrial radio modems, which provide a mission-critical communications solution and are based on private radio networking technology [61]. They provide reliable long-range data connectivity and very high availability for mission-critical applications under severe circumstances. The radio modems allow to build a private network that is not dependent on mobile network operators. The master base station is installed at ICT-city. The network consists of 5 base stations and is operated at 428 MHz.

3 Spectrum Issues in 5G

The main drivers for 5G are the constantly increasing requirements for higher bit rates, shorter latency, reliability, and support for a larger number of devices, as wireless services, especially video streaming and emerging massive IoT, are being adopted at an accelerating pace. The mobile network interface becomes more and more common not just in mobile phones, but also in laptops, tablets, and other end user equipment.

The quality of available content and services also improves and results in a rapid increase in the amount of traffic in mobile networks. The trend is predicted to continue [62–64] in the foreseeable future. Due to the existing base of end user equipment supporting only earlier mobile network generations, 5G systems cannot be allocated on the existing mobile network frequency bands, but they require new spectrum allocations. The increased demand of mobile network capacity can partially be solved by more efficient coding, though the main growth in capacity will take place by decreasing the average cell size and using higher frequency bands.

The European Commission Radio Spectrum Policy Group issued an opinion paper stating that the 5G pioneer bands in Europe are 700 MHz, 3.4–3.8 GHz (the 3.5 GHz band), and 24.25–27.5 GHz [65]. In the countries where the 700 MHz band can be cleared in the coming years, the band will mainly be taken into

LTE use. Otherwise and on longer term, the 700 MHz band, already allocated for mobile broadband (MBB), will be critical in providing nationwide and indoor coverage for 5G [4,65].

The bands above 24 GHz require a completely new radio access network (RAN) structure due to a large difference in propagation characteristics compared to the currently used mobile bands. Thus, the 3.5 GHz band will be the first strategic band for the 5G launch in Europe [4]. World Radiocommunication Conference 2019 (WRC-19) will decide about European 5G spectrum allocation above 24 GHz, including the pioneer 5G band above 24 GHz [66]. 5G operating in the frequencies between 24 and 86 GHz [4,67] can provide the large bandwidths and high data rates required by the increasing amount of MBB traffic. In addition to the 24.25–27.5 GHz band, also 31.8–33.4 GHz and 40.5–43.5 GHz are considered to be promising candidates for 5G in Europe.

The frequencies below 6 GHz are essential for 5G [68], as they can provide the needed coverage and reduce the cost of building mobile networks due to their better propagation characteristics. The current 3.5 GHz band allocation differs significantly in European countries. Some countries will be able to clear the band within a few years, but most of the countries have spectrum allocations which cannot be cleared in several years. Some of the countries which cannot clear the band completely consider making spectrum resources within the band available through static or dynamic spectrum sharing. Several European countries also consider regional radio licenses in addition or instead of nationwide radio licenses in the 3.5 GHz band. In general, spectrum sharing [69,70] methods may play a role in meeting the spectrum demand for 5G [59,71,72] especially in the frequencies below 6 GHz.

In the United States (US), a broadcast television spectrum incentive auction [73] was made to reorganize the DTT transmissions to the lower parts of the UHF TV frequency band and create contiguous blocks of cleared spectrum to the upper parts of the frequency band to be auctioned for the mobile network operator (MNOs). The process comprised of two separate auctions: a reverse auction for broadcasters to determine the price at which they would be willing to relinquish their spectrum usage rights and a forward auction to determine the prices MNOs are willing to pay for the spectrum. The auctions were interdependent and consisted of several rounds until the set goals regarding the economics and the amount of spectrum to be cleared were achieved. The auction was formally closed in April 2017 and resulted in a reallocation of 84 MHz of DTT spectrum and began a 39-month transition period, during which some television (TV) stations need to take their new channel assignments into use [74]. It is possible that Europe and the rest of the world could follow the US in reallocating the 600 MHz band for MBB to obtain more spectrum for 5G in frequencies below 1 GHz.

4 TUAS Testbed for 5G Vertical Applications

The current research activities at TUAS are largely focused on the development of a converged 5G ecosystem: Tekes-funded [6] WIVE (Wireless for Verticals)

[75], CORNET (Critical Operations over Regular Networks) [76], RAMP (Industrial Internet Reference Architecture for Medical Platforms) [77] and EU-funded 5G-PPP phase 2 project 5G-XCAST (Broadcast and Multicast Communication Enablers for the Fifth Generation of Wireless Systems) [78].

The TUAS testbed will support the following 5G verticals [79,80]:

– Smart cities [80].
– Media and entertainment [81].
– Factories of the future [82].

The TUAS 5G testbed focus will be on spectrum below 6 GHz. The frequencies of the current test network components are illustrated in Fig. 2. Radio licenses need to be acquired for each of the frequency bands, and permission from the MNOs is needed in the bands which have been allocated to LTE. As can be seen from Fig. 6, the 700 MHz band does not have any transmissions and is available for testbed use for the time being even though it has already been auctioned to the MNOs. The 5G candidate band 3.4–3.8 GHz is the main candidate for a future testbed extension, while the 2.5–2.69 GHz band is a backup frequency band if radio licenses cannot be obtained to the desired frequency bands.

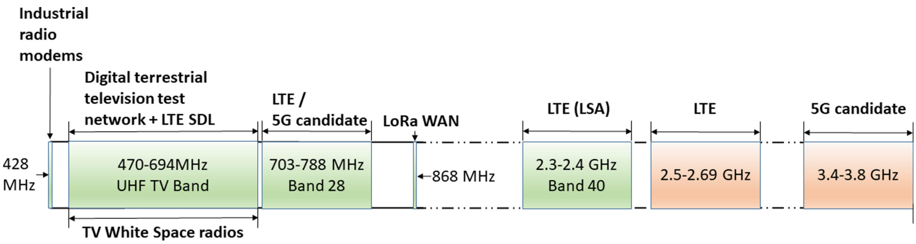

Fig. 2. TUAS testbed service frequencies.

The overall TUAS 5G testbed service architecture is illustrated in Fig. 3. The testbed infrastructure, backbone and the Operations, Administration, and Maintenance (OAM) are located in the TUAS radio laboratory at ICT-city building in Turku, Finland. The internal LTE virtual Evolved Packet Core (vEPC) and the LSA are operated on servers of the TUAS radio laboratory network. The ETSI LSA architecture reference model described in [57] is used. The blocks in grey color describe the equipment under the management of TUAS radio laboratory and the blocks in white the equipment outside TUAS control. Thus, the LSA controller is currently an external service. The Microsoft Azure portal and the external LTE Evolved Packet Cores (EPCs) are connected to the TUAS radio laboratory infrastructure through a firewall and a Virtual Private Network gateway (VPN-GW). The green blocks illustrate the air interfaces of different testbed services and the orange box the spectrum monitoring and sensing systems described in Sect. 5.

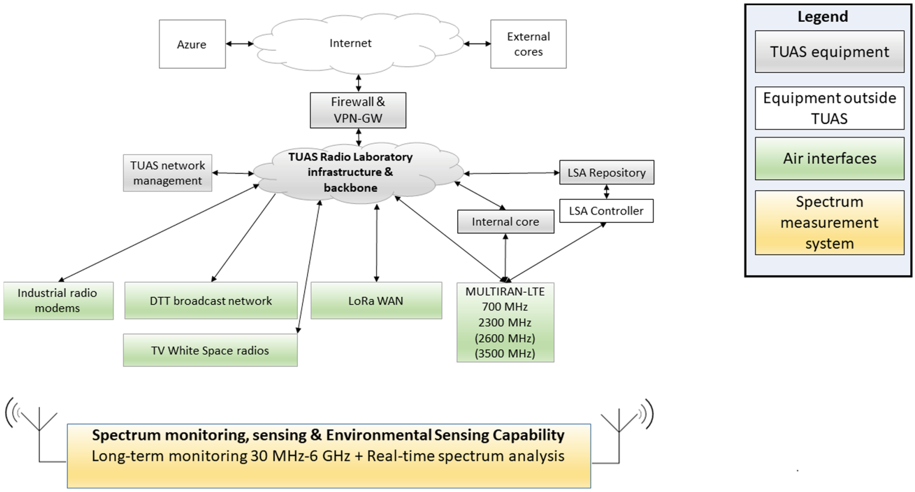

Fig. 3. Block diagram of overall TUAS testbed service architecture. (Color figure online)

One of the major challenges in the 5G experimentations and trials will be the user terminals. Especially the supported frequency ranges, the level of flexibility the terminals allow and the available software applications will largely determine for which purposes the terminals can be used for.

Figure 4 gives a more detailed description of the LTE part of the testbed along with a plan for the installation of first LTE Evolved Node Bs (eNBs). Two small-cell eNBs will be installed at ICT-city premises for indoor trialing purposes, one rooftop eNB will be installed at ICT-city and a second rooftop eNB at TUAS premises at Sepänkatu. The test network infrastructure includes an optical transport network (OTN) between the premises at ICT-city and Sepänkatu.

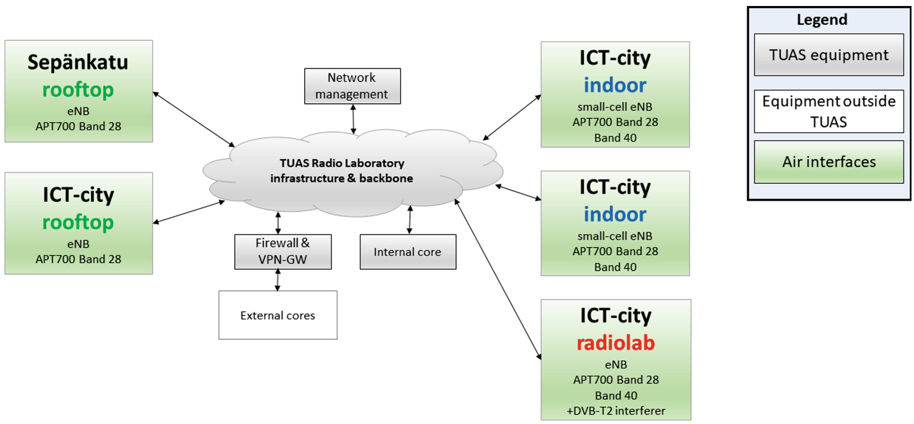

Fig. 4. LTE network architecture block diagram.

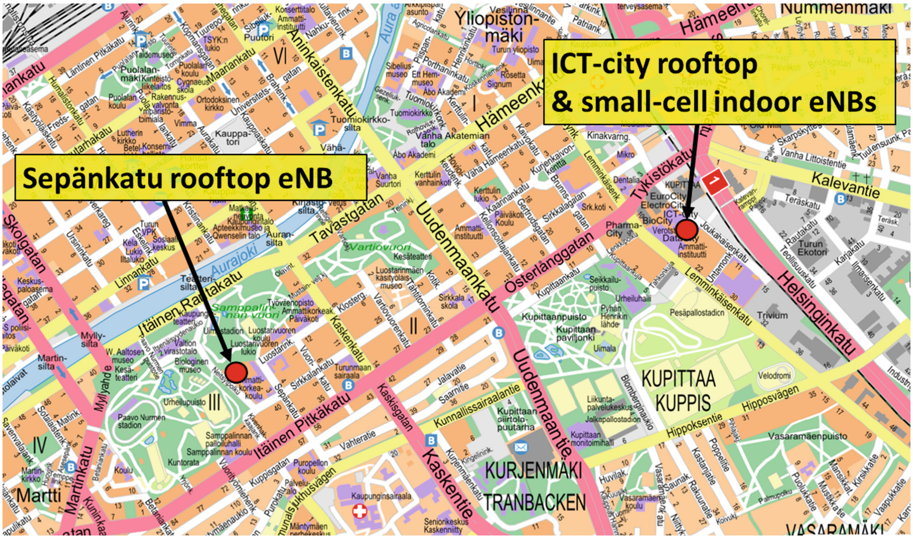

Fig. 5. LTE eNB geographical locations in Turku, Finland.

The geographical locations of the eNBs in Turku, Finland, are shown in Fig. 5. In addition to LTE eNBs, the locations have the following services:

– Sepänkatu: long-term radio spectrum observatory system, LoRa base station and industrial radio modem base station.
– ICT-city radio laboratory: on-demand real-time spectrum analysis, LoRa base station, industrial radio modem base station and DTT transmitter.

Instead of being only a new radio access technology for LTE, 5G will be an integration of several different services and networks. Thus, the overall system will be a completely redesigned programmable multi-service architecture [83–85] which uses network slicing. Network slicing means that the system can run multiple service instances (slices) on the same physical infrastructure. Network slices can be configured for each application, use case or service of 5G to meet its specific requirements and to serve different groups of users. The flexibility and programmability needed to create the network slices are provided by NFV and SDN.

5G-XCAST project [78] aims to design a dynamically adaptable 5G network architecture, which has layer independent network interfaces that are capable of dynamically and seamlessly switching between unicast, multicast and broadcast modes or using them in parallel. For example, the TUAS 5G testbed will be used for demonstrating point-to-multipoint Public Warning Systems (PWS) capabilities developed in the project.

The TUAS testbed can be flexibly extended as new network functionalities are developed and new equipment becomes available. The testbed infrastructure allows to test various Proof of Concepts (PoCs) from different 5G vertical applications.

5 Radio Spectrum Monitoring and Sensing

A spectrum observatory network was built in a GlobalRF Spectrum Opportunity Assessment project [86–92] in Wireless Innovation between Finland and the US (WiFiUS) program [93], which was jointly funded by the National Science Foundation (NSF) [94] and Tekes [6]. The project built an international network of radio frequency (RF) spectrum observatories continuously collecting long-term spectrum data to study the trends in spectrum utilization and to identify frequency bands where spectrum sharing could be feasible.

Three spectrum observatories are operational in Chicago, US, Virginia, US, and Turku, Finland. The measurement data from the spectrum observatories in Finland and the US is collected and stored into a single location at Illinois Institute of Technology [95] in Chicago. The RFeye nodes manufactured by CRFS [96] measure the whole frequency band from 30 MHz to 6 GHz in each of the locations.

Figure 6 shows the Turku spectrum observatory power spectral density (PSD) from June 26th 2017 for 470–900 MHz. The 700 MHz band was allocated to MBB [97,98] and in Finland the band has been cleared and auctioned for MNOs [99]. As can be seen from the figure, the 5 DTT multiplexes have been regrouped to the 470–694 MHz UHF TV broadcasting frequency range, but the 700 MHz MBB is not operational yet. Three 10 MHz blocks of frequency division duplex (FDD)-LTE downlink transmissions are active in the 800 MHz band [100].

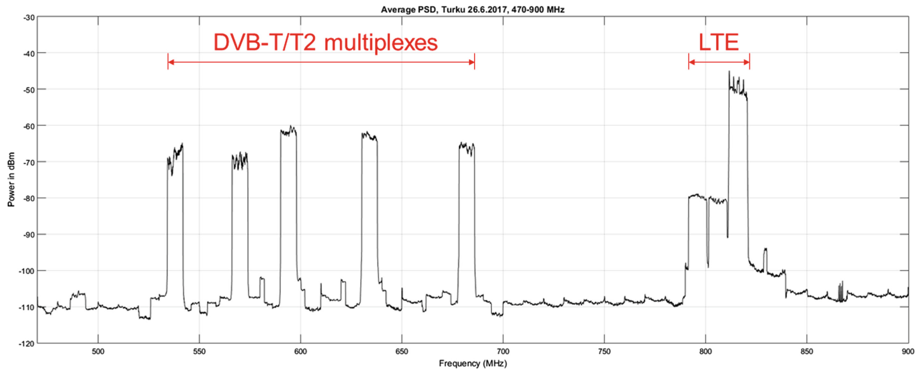

Fig. 6. 470–900 MHz UHF spectrum average PSD on June 26th 2017.

ICT-City site is equipped with several on-demand spectrum monitoring systems, which can distinguish different signals operating in the same frequency band [101], as shown in Fig. 7. The wideband signal in Fig. 7 is a 10 MHz LTE downlink signal and the two low-power transmissions are Programme Making and Special Events (PMSE) wireless microphones with 200 kHz bandwidth. The y-axis represents the signal strength in dBm and the x-axis the frequency. The center frequency is 783 MHz and the span 20 MHz. TUAS has also participated in the development of distributed spectrum sensing system with low cost hardware [102] and Environmental Sensing Capability (ESC) in SAS [54].

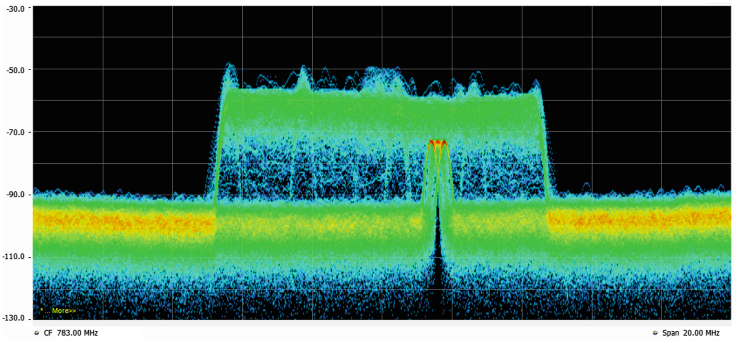

Fig. 7. On-demand spectrum monitoring is capable of distinguishing different signals operating in the same frequency band.

6 Conclusions

5G can be seen as an umbrella, which converges all the current wireless network systems, services and frequency ranges into one ecosystem. The ecosystem includes the evolution of the old technologies and completely new technologies and architectures, all of which need to meet the key performance indicators (KPIs) set in 5G-PPP for different vertical applications and services. The presented TUAS 5G testbed is a case study, which demonstrates how a testbed can be built for the purposes of the 5G research projects TUAS is involved in. The testbed allows to use different LTE ePCs and frequency ranges, which allows to support a range of different vertical applications.

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