

# 5G-MiEdge: Design, Standardization and Deployment of 5G Phase II Technologies

*MEC and mmWaves joint development for Tokyo 2020 Olympic games*

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**Abstract**—This paper presents the vision of 5G-MiEdge, a research project leveraging the benefits of merging MEC and mmWave technologies. Based on that vision, the most relevant use cases and services for the forthcoming Tokyo 2020 Olympics are proposed. The focus is on showing how integrating MEC and mmWave into the 5G network architecture can offer a much more effective system. That is achieved by means of an edge cloud and the introduction of an ultra-lean and inter-operable signaling, called ‘liquid control plane’, capable of providing ubiquitous allocation of computation and communication resources, in an application-/user-centric framework. Finally standards-related aspects like the 5G-MiEdge impact on the ongoing 3GPP work and the services that compose the 5G phases are discussed.

**Keywords**—MEC, mmWave, 2020 Tokyo Olympics, 5G Phases.

## I. INTRODUCTION AND STANDARDIZATION STATUS

The convergence of different technologies, a key aspect of the forthcoming 5G networks, paves the way to new services and business models. Though, those new opportunities come at the cost of increased complexity and more stringent or new requirements. The ongoing standardization [1] of the 5G Phase 1 features (see Figure 1) introduces some new services, like massive Machine Type Communications (mMTC), enhanced Mobile BroadBand (eMBB) and ultra-Reliable and Low Latency Communications (uRLLC), which can only partially address all those new needs. In fact additional enhancements are needed to fulfil other more complex as well as more appealing services, like Augmented-/Virtual-Reality (AR/VR) or the spread availability of 1 Gbps wireless connections. 3GPP has recently defined the 5G Phase 2 to accommodate such advanced services, like the combination of eMBB and uRLLC into a new class, called Ultra High Speed Low Latency Communications (uHSLC) [2] (see Figure 2).

In particular, a key transformation of the communication architecture is represented by the deployment of the Multi-access Edge Computing (MEC) [3], a technology that brings cloud services at the edge of mobile networks, together with the millimeter-wave (mmWave) technology. The latter is identified as a key enabler of 5G systems [4], due to its very high data rate and effectiveness in handling interference. Moreover, since the accessibility of MEC services from terminals increases the uplink traffic [5], uplink mmWave connectivity is foreseen to be essential for effective service provisioning in 5G networks.

Leveraging on those two enabling technologies, this paper unveils the vision of 5G-MiEdge (*Millimeter-wave Edge Cloud*

*as an Enabler for 5G Ecosystem*) a 3-years EU-Japan co-funded research project [6] focusing on 5G Phase 2, and identifies services and use cases where such technologies can provide substantial benefits for wireless system users.

Figure 1. Timeline of 3GPP Releases and 5G Phases [1]

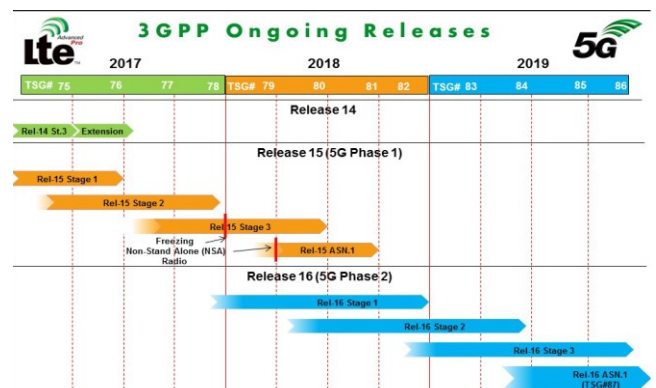
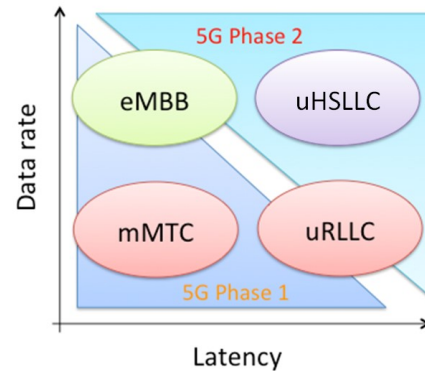


Figure 2. 5G Phase 1 and Phase 2 main services and key system KPIs [2]

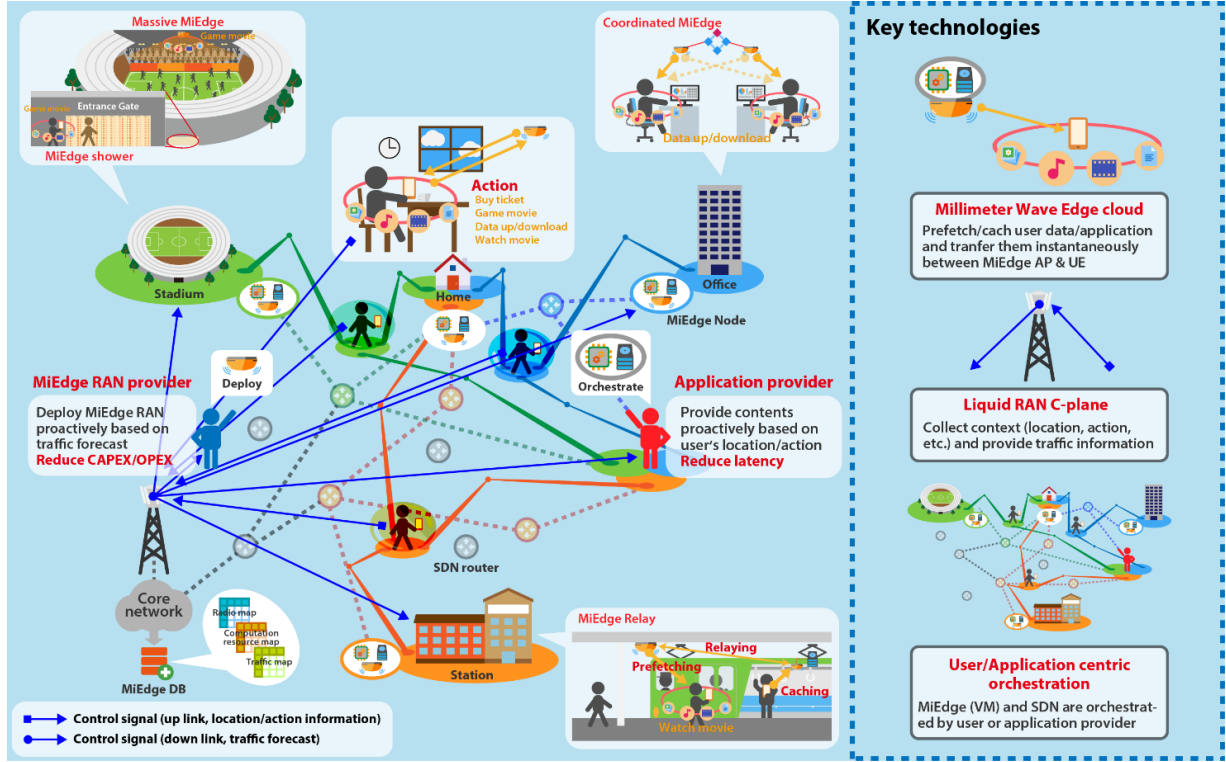


The rest of the paper is organized as follows: Section II details the 5G-MiEdge vision, Section III presents the addressed technologies, Section IV describes the defined use cases, and finally Section V draws conclusions and hints at next steps.

## II. THE 5G-MIEDGE VISION

5G-MiEdge has the ambitious goal of looking beyond the current scope of 5G, focusing on the uHSLC services, so to address new use cases and create additional values for 5G users. The distinctive feature of the 5G-MiEdge vision is to exploit the benefit of combining mmWave edge cloud, liquid RAN control-plane (C-plane), and user/application centric orchestration

Figure 3. Ultra High Speed Low Latency Communications use cases (left), and key 5G-MiEdge technologies (right) [10]



techniques. The final target is to demonstrate a first 5G implementation through testbeds in the city of Berlin [7] and at the 2020 Tokyo Summer Olympics.

Current 5G enhancements build on a radical increase of system capacity by incorporating massive MIMO techniques, dense deployment of radio access points (AP), and much wider bandwidth (new spectrum), all aspects facilitated by the use of mmWave communications. However, the improvements that can be achieved at the access stratum will still be insufficient to meet the challenging new 5G requirements. Therefore, to provide an efficient platform serving several different new applications, a paradigm shift is needed, putting applications at the center of the system design. Virtualization of network functionalities and MEC are key tools of this application-centric networking, where mobile edge applications run as virtual machines (VM) on top of a virtualization infrastructure, provided by the mobile edge host. MEC and mmWave technologies complement each other well: mmWave access benefits from the distributed computation and storage capabilities of MEC to optimize the communication strategies, incorporating cache prefetching [8], and orchestration of APs at the edge. MEC benefits from the high data rate proximity access to the edge cloud of mmWave, thus reducing latency and improving the Quality of Experience (QoE).

### III. KEY TECHNOLOGIES FOR 5G PHASE 2

The fusion of MEC with mmWave access is seen as an effective way to support applications requiring at the same time extreme high data rates, low latency end-to-end (E2E) service provisioning, and full mobility support [9]. Indeed, it is such

merging that enables the design of an application-centric scalable system. Mobile applications can run in terminals, if resources are sufficient, in the nearest MEC server, or in a cluster of MEC servers, depending on latency constraints and energy availability. Effective traffic and computation offloading mechanisms are made possible by enabling fast access to the edge cloud, through high capacity mmWave APs. At the same time proactive strategies like data caching are used to meet the demanding E2E latency of applications foreseen in 5G verticals like Automotive, Industry 4.0, and Media & Entertainment.

Figure 3 and Table 1 summarize the use cases and the key technologies developed by 5G-MiEdge so to make uHSLLC a reality. A newly defined ultra-lean and inter-operable control-signaling plane, called ‘liquid RAN C-plane’, is proposed, where ‘liquid’ stems from its capability of enabling services and connections that follow and adapt to users’ needs, like a liquid adapts to the form of its container. The liquid C-plane is meant to provide ubiquitous allocation of communication and computation resources in a user-/application-centric perspective. Acquisition of context information and service requests forecast are key steps to enable a proactive orchestration of radio and computation resources in 5G-MiEdge enhanced 5G networks.

Table 1. 5G-MiEdge key technologies [10]

Technology	Description
mmWave Edge Cloud	Pre-fetch and cache user data/applications /computation results and provide them to <i>MiEdge AP</i> and users
Liquid RAN C-Plane	Collect context info (location, habits) to provide traffic forecast to users and application providers
User/Application Centric Orchestration	Network orchestration fulfilling the applications requirements/specifications

### A. MmWave Edge Cloud

The mmWave Edge Cloud leverages mmWave APs and edge cloud, where data/applications reside in specific sites based on mobile user requirements and available radio and cloud resources. Deployed network and cloud infrastructure can be efficiently shared by different operators and orchestrated to reach improved energy and cost efficiency. 5G-MiEdge aims to extend the capabilities of the combination of ultra-high data rate and edge cloud resources for improved efficiency by two new network elements, the *MiEdge shower* and the *MiEdge relay*.

The first element is the *MiEdge shower*, a dedicated AP positioned where terminals pass by or stand for a reasonably long period of time to benefit from higher data rates. MiEdge showers can be deployed at ticket boxes, stadiums entry gates or other neuralgic points, where users are directed along specific narrow paths or are waiting at well-known location. User and/or location specific content will be pre-fetched to the edge cloud inside the MiEdge shower and transferred to users at very high data rate. In case of broadcast-like content, the mmWave shower efficiency can be further increased by using broadcast schemes, for users requesting the same content. Such mechanism could also be used, e.g., to update content on terminals, which are passing by on a conveyor belt using a series of MiEdge showers.

The second element is the *MiEdge relay*, a data forwarding entity where at least one of the links strongly benefits from the in-built edge cloud capability inside the unit. Such MiEdge relay can be used as a mmWave based concatenated and/or meshed backhaul link node, where content can be aggregated, stored and forwarded/rerouted so to balance between bursty data rate demand for content delivery and link capacities or latencies along certain path elements of the backhaul network. MiEdge relays are also perfectly suited for content delivery to moving small cells in trains/buses, where content is pre-fetched at the next station and/or buffered in another edge cloud inside the trains/buses, so to provide larger buffering capacity, while users stream content at lower speed from the moving small cells.

Thanks to these two elements 5G-MiEdge will manage to enable significantly better service perception and a more balanced data flows in both the backhaul and the access network.

### B. Liquid RAN C-Plane

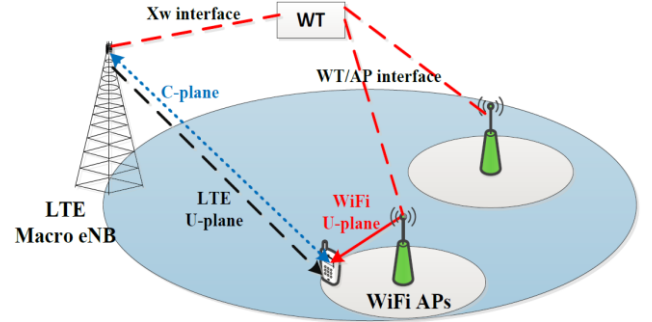
The functionalities exploited by the mmWave Edge Cloud require user context awareness (e.g. habits and location) and fine time-space traffic forecast, so to decide when, where, and which content to cache. Providing such rich information is the key goal of the *Liquid RAN C-Plane*, which uses multiple Radio Access Technologies (RAT) available in terminals to collect user data and elaborate a real-time and reliable map of users' habits.

A key feature of the Liquid RAN C-Plane is the control/ user-plane (C/U) splitting mechanism, introduced in 3GPP Release 12 [9], where radio resources of both LTE macro and small cells are controlled by macro eNBs. The small cells only serve UE with U-plane data traffic. This C/U plane splitting mechanism not only reduces signaling overhead towards the core network, but also enhances mobility robustness and reduce the handover failure rate, by maintaining the macro cell C-plane connection.

To achieve the above mentioned benefits for 3GPP/WLAN heterogeneous networks, the C/U splitting mechanism is applied

for a RAN-level 3GPP/WLAN aggregation [11]. The 3GPP architecture, i.e. the data radio bearer (DRB) splitting at the PDCP (Packet Data Convergence Protocol) layer, is considered to be a baseline for LTE-WLAN radio level integration. According to 3GPP, WLAN Termination (WT) connects both LTE macro eNB and WLAN APs, controlling several WLAN APs in the same mobility group [12], as shown in Figure 4, where the WT can be viewed as a MiEdge AP.

Figure 4. 3GPP defined LTE-WLAN aggregation architecture [12]



An enhancement of the dual connectivity framework is the so-called “Multi-Connectivity” [13], where a single terminal is simultaneously connected to multiple APs, which potentially use different access technologies like WiFi, LTE, and 5G New Radio (NR). Multi-Connectivity is a key enabler to satisfy the requirements of uHSLC services, as it can improve the system capacity (by using carrier aggregation), and service reliability and coverage (e.g. by supporting connection to multiple macro and small cells).

In 5G-MiEdge, users' context information including location and traffic data is collected, through multiple links and RATs, stored and processed. It is also expected that users provide traffic forecast to the MiEdge application providers, and RAN providers. Combining all this data, it is possible to generate a radio/computation resource map for all mmWave 5G RAN users under the control area of the MiEdge AP. However, even though the LTE-WLAN aggregation architecture including the WT and Xw interfaces was standardized in 3GPP Release 13, still the afore-mentioned expected functionalities cannot be supported, as WT was defined as a terminal node without any computing capabilities. Hence, it is necessary to newly define an mmWave edge cloud, a new liquid RAN C-plane and an enhanced mobility management, different from the LTE-WLAN aggregation one.

As a new C-plane to enable the 5G liquid edge cloud is needed, 5G-MiEdge focuses on the following functionalities:

- Collect context information of multi-users;
- Create multi-users radio/computation resource maps;
- Provide traffic information to MiEdge, application providers, and RAN providers;
- Support multi-layer, multi-RAT, and ultra-dense small cells deployment;
- Enable joint radio resource optimization and intelligent interference mitigation;
- Enable seamless mobility support for multi-layer multi-connectivity mmWave 5G RAN.



### C. User/Application Centric Orchestration

The User/Application Centric Orchestration technology is introduced as a framework where robust, scalable, and distributed algorithms are used to manage computation, storage, and communication resources in real-time and in a flexible way.

A new trend recently advocates a paradigm shift from network-centric to user/application-centric design [14], where terminals can combine multiple flows from different RATs. This trend becomes even more important considering the provision of cloud services (computation, storage) to mobile users. These services pose additional demands and create new network KPIs, which cannot be measured on packet delivery only anymore. Within this context, the application-centric networking recently advocated by Cisco [15] goes exactly in this direction by empowering network devices, e.g., routers, with the capability of handling applications in a different way.

5G-MiEdge goes beyond this concept and proposes a new architecture as a scalable and distributed system, where radio access, computing, and contents are all considered parts of a unified pool of resources that need to be allocated jointly, and dynamically, depending on users/applications' requests, in a truly user/application centric vision. The key tool for handling this difficult problem is again the proper combination of MEC and mmWave technology. With MEC, computing resources are brought closer to terminals. Virtualization is the key technology to instantiate computing VM when and where needed. Hence, if APs are endowed with the capability of handling VMs, there is the possibility of bringing cloud resources much closer to terminals. However, in a mobile context, these VMs need to follow the user movements to ensure the required latency in provisioning the required service. But the migration of VMs may be viable, within the required latencies, only in the presence of very high data rate backhauling. In some contexts, this might not be possible. This is where the combination of MEC with mmWave technology can play a fundamental role.

The further key feature in designing an effective MEC is the capability to predict users' behaviors or traffic demands. An effective prediction can in fact help implementing a proactive resource allocation or VM migration, able to anticipate the requests. According to 5G-MiEdge's vision, resources (caching, communication, or computation), will try to follow, and possibly anticipate, the users adaptively, as a liquid, depending on context and application requirements.

### IV. USE CASES, APPLICATIONS AND REQUIREMENTS

5G-MiEdge proposes five use cases [10] that best show the benefits of merging MEC and mmWave technologies:

- Tokyo 2020 Olympic Games;
- Omotenashi services;
- Moving hotspot;
- Dynamic crowd;
- Automatic driving.

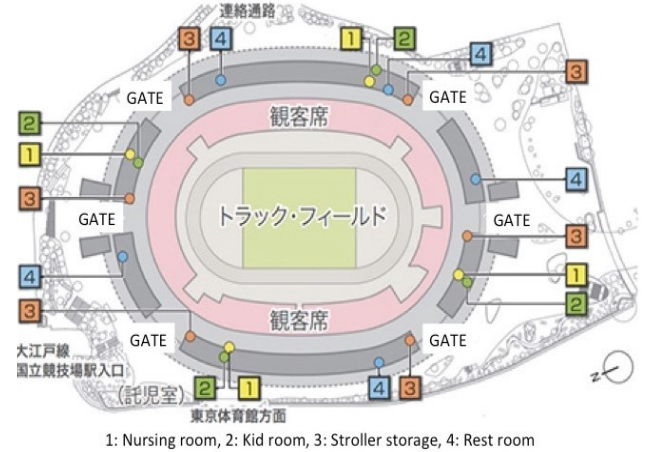
In the following only the first use case is detailed, the others are only briefly mentioned. More information on the 5G-MiEdge use cases can be found in [10] and in the recent 5G-MiEdge 3GPP contribution [16], which raised the attention of

the SA1 group on some not yet touched aspects of uHSLC, thus paving the way to more contributions along the lifetime of the 5G-MiEdge project.

### A. Tokyo 2020 Olympic Games

The new national stadium for Tokyo Olympics 2020 (shown in Figure 5) will contain seats for more than 60,000 people.

Figure 5. Stadium Tokyo 2020 Olympics (Source: Japan Sport Council)[10]



In the stadium visitors are expected to pass under the six entrance gates (see Figure 6) with a very high frequency. Each gate is subdivided in a large number of multiple access ports, equipped with turnstiles. To accelerate the flow rate, spectator electronic tickets may be read from fixed APs. When passing through a gate, the visitor can download data hungry event-specific applications, e.g., event schedule, related videos of past events, players' profiles, etc., so to enjoy new unique applications of AR/VR while watching the game.

Regarding the hot spot antennas, two possible solutions can be considered: a single hot spot antenna that serves all the access ports of a gate, or multiple antennas (one MiEdge shower per port). In the stadium, the stands and the sports arena will be covered by a number of high definition video cameras connected to a stadium media room (see Figure 7 and Figure 8), where all the required video processing is carried out.

Figure 6. Entrance gates equipped with MiEdge showers [10]

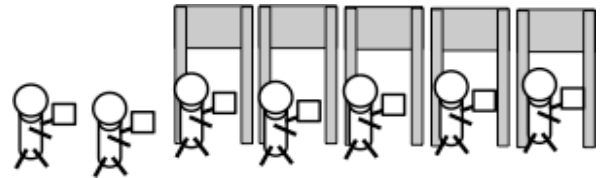


Figure 7. Stands and sports arena [10]

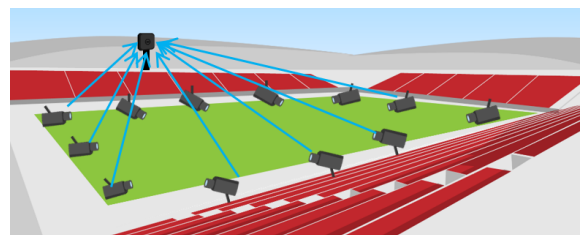
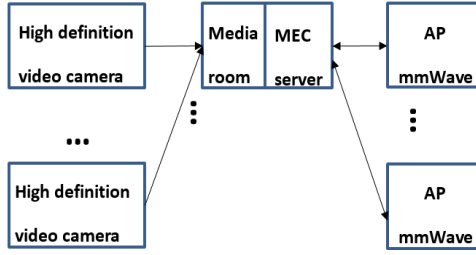


Figure 8. Architecture for video production/distribution in stadium [10]



The logical connections depicted in Figure 8 can be implemented either via optical fiber or wirelessly. The final goal is to enrich users' experience through AR/VR applications. A user may want, for example, to look at the game as if it were in a desired position within the field. This kind of AR can be created by combining the videos coming from multiple cameras in order to reconstruct a visual experience as required by the user who interacts with the system by (virtually) navigating through the field. The MEC servers play a key role in offloading intensive computations from terminals to powerful servers, hence overcoming the battery bottleneck.

To cope with such a challenging use case, 5G wireless systems are to be enhanced with means that can provide very high data rates and low latency i.e., mmWave access and MEC servers. In summary, AR/VR applications can be enabled by:

- Dedicated high capacity links between fixed high definition cameras and MEC servers in the media room;
- High data rate mmWave download links;
- Dedicated applications running in terminals, handling the exchange of data with the hot spot 5G antennas, necessary to enable user navigation throughout the scene.

#### B. Omotenashi services

Omotenashi is a concept that describes the Japanese style of hospitality, i.e., make tourists have fun and feel satisfied by providing a service adjusted to their needs. On the way to their destination tourists may arrive at the airport two hours prior to departure of their flights and after check-in, they may go shopping before moving towards the departure gates. Usually, when tourists arrive at airports or stations, they may want to download large volumes of data, such as 3D virtual tour videos or games. Omotenashi services in 5G-MiEdge aim to offer ultra-fast wireless connections, so that visitors can enjoy high quality services without suffering from throughput limitation.

Since waiting areas are highly crowded, the currently deployed wireless networks cannot fulfil users' needs. In order to achieve ultra-high-speed throughput, the proposed MiEdge system combines mmWave access with MEC. In particular, MEC enables to pre-fetch the most requested contents to the local edge server in order to prevent backhaul congestion. Furthermore, running analytics on the MEC servers makes it possible to learn, locally, which are the most popular contents across time, in order to optimize the pre-fetching step. The use of mmWave access provides highly directional signal characteristic, suitable for avoiding interference in a dense area. Since the range of mmWave APs is relatively limited, it is reasonable to expect users to approach a dedicated download spot (like a mobile KIOSK). As the download service becomes

popular, multiple mmWave APs will be adopted to extend the area coverage and offer a better QoE. The orchestration of these multiple APs will be facilitated by the presence of MEC servers. The use of the MiEdge shower is another possible different approach, as previously described.

#### C. Moving Hotspot

A moving hotspot describes a wireless communication system for passengers making a long trip on train/bus/airplane and requires wireless link as a backhaul. Therefore, it is needed to have communication measures for synchronizing and sharing contents between the local server on train/bus/airplane and service servers in the cloud, while stopping at train station/bus stop/airport or while passing some spots along the way.

The mobile hotspot consists of (legacy) WLAN/mmWave APs, local MEC servers, and other components to deliver video content and games to passengers. Often passengers upload to social network servers (SNS) photos/videos, which are temporarily stored in local MEC server and will be transferred to the cloud when suitable backhaul bandwidth becomes available. When a user starts communicating via mmWave inside a vehicle, the traffic flow will be transferred to the local MEC/content server. The user can select/download favorite large volume contents based on suggestions provided by the portal page on the local MEC server. General web browsing and SNS communications could be realized by the local MEC server behaving as a proxy content server. In this way, users can enjoy contents without being conscious of the difference from regular Internet communication. To make that happen, it is crucial that MEC properly caches or pre-fetches content according to user/applications demands. Adding computation capabilities to MEC servers, in terms of capability to instantiate and run VMs, makes it possible to learn the content popularity, across space and time, and to optimize the cache pre-fetching step. Regarding upload, distributed server functions on the local MEC server will temporarily cache uploaded contents by users (photos/videos).

#### D. Dynamic Crowd

This use case focuses on a metropolitan city center area where thousands of people spend part of their day. The area is provided with several outdoor hotspots. Users close by such outdoor hotspots might download large volume contents, such as tourist information, high definition (HD) 3D live broadcast of events happening at a stadium, or upload and share through SNS photos/videos. Typical location specific applications for this use case are public surveillance and HD video broadcast services.

The key difference of this use case compared to the other ones is that the traffic pattern changes very dynamically, during a day, in accordance to users' activities, e.g., from light to heavy traffic in specific hours.

Associating a MEC server to an AP enables a pervasive security system, where the (cloud) computing capabilities of the MEC server make it possible to rapidly analyze videos from mobile users or from fixed cameras, so to raise early warnings about suspicious behaviors, without the need to send all data to a centralized security agency. MmWave links from APs associated to such MEC servers located in hotspots enable a very high data rate delivery from and to mobile users. MEC servers can also help to orchestrate multiple APs in order to identify the

set of APs most suitable to serve a set of users, depending on users' distribution across space.

### E. Automated Driving

Automated driving is considered as one of the three most important use cases of future 5G systems. The initial (1<sup>st</sup>) phase of 5G Vehicle-to-Vehicle (V2V) and Vehicle-to-Everything (V2X) communications aims at driver assistance systems and exchanges messages either directly between vehicles or via appropriate infrastructure. These messages are transmitted in case of an emergency or as awareness messages, containing data such as location, speed, and heading direction. However, the subsequent (2<sup>nd</sup>) phase of 5G V2X aims at automated driving applications, where automated control SW become responsible for monitoring the environment and the driving vehicles.

Automated driving systems require highly resolved and dynamic maps in order to maneuver safely. The resolution of current maps is definitely not sufficient for autonomous driving, hence high resolution and real-time maps, also called dynamic HD maps, become indispensable. Examples of such HD maps are the ones generated through a LiDAR (Light Detection and Ranging) sensor used to monitor the car surroundings. The enhanced V2V/V2X communication targeting automated driving requires a data rate of 1 Gbps per link, E2E latency < 10 ms per link, and a communication range > 150 m. With the use of mmWave technology the latency between two links goes below 0.5 ms and, due to the proximity of mobile edge cloud computing, the data can be sent to the MEC for processing and delivered to the destination without exceeding the 10 ms latency constraint. The high density of cars on a highway requires highly focused beams, easily generated by small mmWave antenna arrays which also provide positioning data with few millimeters accuracy. With MEC the HD maps are stored locally, reducing latency be continuously updates with the latest sensor data. The current state of the art technology simply cannot fulfill these crucial requirements. 3GPP has just recently initiated related work in Release 15 under the enhanced V2X feature. As a consequence, mmWave and MEC technologies become increasingly important for the field of automated driving.

### F. Brief overview of requirements for uHSLLC

Table 2 reports key requirements associated to the uHSLLC family of use cases. Due to the lack of room in this paper no more information can be provided, but a detailed description of new requirements as defined by 5G-MiEdge can be found in [10] and will be further elaborated in future publications.

Table 2. uHSLLC main requirements for key identified use cases [16]

	Peak data rate [Mbps]	Latency [ms]	Area traffic capacity [Tbps/km <sup>2</sup> ]	Reliability, Availability	Cost efficiency	Energy efficiency	Connection density [user/km <sup>2</sup> ]
<b>Stadium</b>	DL: 25 UL: 50	10	DL: 3.75 UL: 7.5	95% 95%	100x vs. LTE-A	>100x vs. LTE-A	150,000
<b>Office</b>	DL: 1000 UL: 500	10	DL: 15 UL: 2	99% 99%	100x vs. LTE-A	>100x vs. LTE-A	75,000
<b>Train Station</b>	DL: 50 UL: 25	10	DL: 0.1 UL: 0.05	95% 99%	100x vs. LTE-A	>100x vs. LTE-A	2000 (500 users per train)

## V. CONCLUSIONS

This paper introduces the vision of the 5G-MiEdge project, focusing on 5G Phase 2 features and uHSLLC applications. The synergy between MEC and mmWave access is proposed as the main technology enabler for new use cases, applications, and

services to appear beyond the 2020 horizon. The Tokyo Olympic 2020 is the target venue to demonstrate the main project outcomes. Selected relevant use cases and a hint on currently defined requirements are provided, together with several 3GPP standardization references, which give readers with the needed background to understand the current status and the envisioned next steps of 5G deployment.

The next steps in 5G-MiEdge will focus on further refine and finally assess the identified new system requirements, on implementing the key proposed technology enablers, and on proposing, also in relevant standards bodies, 5G Phase 2 definitions of MEC servers interfaces and architectural blocks.

## ACKNOWLEDGMENT

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