5G-MiEdge
Millimeter-wave Edge Cloud as an Enabler for 5G Ecosystem

EU Contract No. EUJ-01-2016-723171

Abstract
The EU-Japan funded research project 5G-MiEdge (Millimeter-wave Edge cloud as an enable for 5G ecosystem) is targeting the ambitious goal of contributing to the realization of a 5G cellular network infrastructure in Berlin and Tokyo for the 2020 Olympic Games Olympics through concept validation of advanced and novel 5G technology components. This deliverable unveils the vision of 5G-MiEdge project and identifies use cases and scenarios where technologies considered in the 5G-MiEdge project makes substantial benefits for 5G users.

Keywords
ultra high speed & low latency communications, location specific applications, millimeter-wave access, mobile edge cloud, liquid RAN C-plane, user/application centric orchestrations, 5G ecosystem, spectrum regulation

All rights reserved.
The document is proprietary of the 5G-MiEdge consortium members. No copy or distribution, in any form or by any means, is allowed without the prior written agreement of the owner of the property rights.

This document reflects only the authors’ view. The European Community is not liable for any use that may be made of the information contained herein.

Authors

<table>
<thead>
<tr>
<th>Fraunhofer- Heinrich-Hertz-Institut</th>
<th>Kei Sakaguchi</th>
<th><a href="mailto:kei.sakaguchi@hhi.fraunhofer.de">kei.sakaguchi@hhi.fraunhofer.de</a></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thomas Haustein</td>
<td><a href="mailto:thomas.haustein@hhi.fraunhofer.de">thomas.haustein@hhi.fraunhofer.de</a></td>
</tr>
<tr>
<td></td>
<td>Richard Weiler</td>
<td><a href="mailto:richard.weiler@hhi.fraunhofer.de">richard.weiler@hhi.fraunhofer.de</a></td>
</tr>
<tr>
<td>CEA-LETI</td>
<td>Antonio De Domenico</td>
<td><a href="mailto:antonio.de-domenico@cea.fr">antonio.de-domenico@cea.fr</a></td>
</tr>
<tr>
<td>ENEL</td>
<td>Valerio Frascolla</td>
<td><a href="mailto:valerio.frascolla@intel.com">valerio.frascolla@intel.com</a></td>
</tr>
<tr>
<td>Telecom Italia</td>
<td>Sergio Barberis</td>
<td><a href="mailto:sergio.barberis@telecomitalia.it">sergio.barberis@telecomitalia.it</a></td>
</tr>
<tr>
<td></td>
<td>Valerio Palestini</td>
<td><a href="mailto:valerio.palestini@telecomitalia.it">valerio.palestini@telecomitalia.it</a></td>
</tr>
<tr>
<td></td>
<td>Flavio Muratore</td>
<td><a href="mailto:flavio.muratore@telecomitalia.it">flavio.muratore@telecomitalia.it</a></td>
</tr>
<tr>
<td>Sapienza University of Rome</td>
<td>Sergio Barbarossa,</td>
<td><a href="mailto:sergio.barbarossa@uniroma1.it">sergio.barbarossa@uniroma1.it</a></td>
</tr>
<tr>
<td></td>
<td>Andrea Baiocchi,</td>
<td><a href="mailto:andrea.baiocchi@uniroma1.it">andrea.baiocchi@uniroma1.it</a></td>
</tr>
<tr>
<td></td>
<td>Antonio Cianfrani</td>
<td><a href="mailto:antonio.cianfrani@uniroma1.it">antonio.cianfrani@uniroma1.it</a></td>
</tr>
<tr>
<td>Tokyo Institute of Technology</td>
<td>Khanh Tran Gia</td>
<td><a href="mailto:khanhtg@mobile.ee.titech.ac.jp">khanhtg@mobile.ee.titech.ac.jp</a></td>
</tr>
<tr>
<td>Panasonic</td>
<td>Takinami Koji</td>
<td><a href="mailto:takinami.koji@jp.panasonic.com">takinami.koji@jp.panasonic.com</a></td>
</tr>
</tbody>
</table>
Table of contents

Abbreviations .................................................................................................................. 6

Executive Summary .......................................................................................................... 7

1 Introduction .................................................................................................................... 9
  1.1 5G Applications and Use Cases .............................................................................. 9
  1.2 5G-MiEdge – Vision, related Use Cases and KPIs ................................................. 13
    1.2.1 Fusion of mmWave Technology and MEC .................................................. 14
    1.2.2 5G-MiEdge key technologies and related KPIs ....................................... 15
    1.2.3 5G-MiEdge Specific Use Cases for uHSLLC ......................................... 16
  1.3 Structure of the document ..................................................................................... 18

2 State-Of-The-Art ........................................................................................................... 18
  2.1 KPI definition .......................................................................................................... 18
    2.1.1 KPIs from IMT2020 and 3GPP ..................................................................... 18
  2.2 Standardization bodies .......................................................................................... 19
    2.2.1 3GPP ............................................................................................................ 19
    2.2.2 ETSI MEC .................................................................................................. 24
    2.2.3 IEEE802.11ay ............................................................................................ 24
  2.3 Research projects landscape .................................................................................. 25
    2.3.1 METIS ......................................................................................................... 26
    2.3.2 METIS II .................................................................................................... 26
    2.3.3 TROPIC ...................................................................................................... 27
    2.3.4 MiWEBA .................................................................................................... 28
    2.3.5 MiWaveS .................................................................................................... 29
    2.3.6 mmMAGIC ................................................................................................. 30
    2.3.7 CHARISMA ................................................................................................. 31
    2.3.8 5G Champion ............................................................................................... 32
    2.3.9 5GPPP ......................................................................................................... 33
    2.3.10 MIC Research & Development of Spectrum Usage for Wireless Access Networks at Millimeter-Wave Band (2012-2016) ................................................. 34
    2.3.11 MIC: Research & development of advanced multiplexing and interference management technologies for millimeter-wave frequency bands .......................................................................................................................... 35
3 Definition of Use Cases ................................................................................................. 39

3.1 Omotenashi services ................................................................................................. 40
  3.1.1 Use case .............................................................................................................. 40
  3.1.2 Omotenashi specific applications ......................................................................... 40
  3.1.3 Scenario Description ............................................................................................ 41
  3.1.4 Expected traffic .................................................................................................... 42
  3.1.5 Added value of mmWave and MEC Technologies .................................................. 44
  3.1.6 Requirements for 5G systems .............................................................................. 44
  3.1.7 Similarity & difference with other projects .......................................................... 45

3.2 Moving Hotspot Scenario ......................................................................................... 45
  3.2.1 Use Case .............................................................................................................. 45
  3.2.2 Moving hotspot specific applications ................................................................. 45
  3.2.3 Scenario Description ............................................................................................ 46
  3.2.4 Expected traffic .................................................................................................... 47
  3.2.5 Added value of mmWave and MEC Technologies .................................................. 49
  3.2.6 Requirements for 5G systems .............................................................................. 50

3.3 2020 Tokyo Olympic ............................................................................................... 51
  3.3.1 Use Case .............................................................................................................. 51
  3.3.2 2020 Tokyo Olympic specific applications ......................................................... 51
  3.3.3 Scenario Description ............................................................................................ 52
  3.3.4 Expected traffic .................................................................................................... 54
  3.3.5 Added value of mmWave and MEC Technologies .................................................. 57
  3.3.6 Requirements for 5G systems .............................................................................. 58
  3.3.7 Similarity & difference with other projects .......................................................... 58

3.4 Dynamic crowd ........................................................................................................ 59
  3.4.1 Use Case .............................................................................................................. 59
  3.4.2 Dynamic crowd specific applications .................................................................... 61
  3.4.3 Expected traffic .................................................................................................... 62
  3.4.4 Added value of mmWave and MEC technologies .................................................. 63
  3.4.5 Requirements for 5G systems .............................................................................. 64
  3.4.6 Similarity & difference with other projects .......................................................... 64

3.5 Automated Driving ................................................................................................. 65
  3.5.1 Use case .............................................................................................................. 65
  3.5.2 Scenario Description ............................................................................................ 66
3.5.3 Automated Driving specific applications ........................................... 66
3.5.4 Expected traffic ............................................................................. 67
3.5.5 Added value of mmWave and MEC Technologies ....................... 68
3.5.6 Requirements for 5G systems ....................................................... 70
3.5.7 Similarity & difference with other projects ................................... 70
3.6 Summary of use cases selected in 5G-MiEdge project .................. 71

- Traffic density: >12.5 Tbit/s/km² ......................................................... 72
- MEC in the stadium media room ....................................................... 72
- Traffic density: >12.5 Tbit/s/km² ......................................................... 72
- MEC in the stadium media room ....................................................... 72

4 References ......................................................................................... 73
### Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>eMBB</td>
<td>enhanced Mobile Broadband</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>JP</td>
<td>Japan</td>
</tr>
<tr>
<td>MEC</td>
<td>mobile edge cloud (computing)</td>
</tr>
<tr>
<td>mmWave</td>
<td>millimeter-wave</td>
</tr>
<tr>
<td>RaaS</td>
<td>RAN as-a-service</td>
</tr>
<tr>
<td>UDN</td>
<td>Ultra Dense Network</td>
</tr>
<tr>
<td>uRLLC</td>
<td>ultra Reliable &amp; Low Latency Communications</td>
</tr>
<tr>
<td>uHSSLLC</td>
<td>ultra-High-Speed and Low Latency Communication</td>
</tr>
<tr>
<td>WP</td>
<td>Work Package</td>
</tr>
</tbody>
</table>
Executive Summary

The EU-Japan funded research project 5G-MiEdge (Millimeter-wave Edge cloud as an enable for 5G ecosystem) is targeting the ambitious goal of contributing to the realization of a 5G cellular network infrastructure in Berlin and Tokyo for the 2020 Olympic Games Olympics through concept validation of advanced and novel 5G technology components. The project will develop a feasible 5G ecosystem by combining mmWave edge cloud, liquid RAN C-plane, and user/application centric orchestration through standardization works in 3GPP and IEEE. At the end, the project will demonstrate a joint 5G Testbed in the city of Berlin (5G Berlin Testbed) and at the Tokyo 2020 Olympic Games. The Work Package 1 (WP1) runs throughout the lifetime of 5G-MiEdge project and is in charge of some key aspects of the project. First it fosters and ensures that an effective collaboration between the Japanese and the European teams takes place, creating a common vision that maximizes the synergies, reduces the risks and finally avoids all possible deviations from the common targets. Then it defines the use cases and scenarios relevant for the project objectives and capable of showing the advantages of the proposed novel technologies. Moreover, WP1 defines an extended 5G architecture and derives related requirements to be worked out in the other WPs. Finally, it analyses the impact of the project on the existing business models in the wireless communication markets.

This deliverable unveils the vision of 5G-MiEdge project and identifies use cases and scenarios where technologies considered in the 5G-MiEdge project makes substantial benefits for 5G users. Compared to the current understanding of 5G applications, i.e. enhanced Mobile Broadband (eMBB), ultra Reliable & Low Latency Communications (uRLLC), and massive Machine Type Communications (mMTC), the 5G-MiEdge project tries to achieve both eMBB and uRLLC at the same time in order to address new use cases and create additional values for 5G users. This new application is called Ultra High Speed Low Latency Communications (uHSLLC) that can be realized by combining mmWave access and Mobile Edge Computing (MEC). The combination of mmWave and MEC is a perfect couple of technologies to complement each other, since mmWave access benefits of the distributed computation and storage capabilities of MEC to optimize the communication strategies, incorporating cache prefetching, and orchestration of access points at the edge, while MEC greatly benefits from mmWave to provide high data rate proximity access to the edge cloud, thus reducing latency and improving quality of experience, especially in delivering context aware applications or exploiting cache prefetching. Combining mmWave and MEC and developing its enabling technologies is the distinguishing feature of 5G-MiEdge project and it represents its unique vision.

In this deliverable, the 5G-MiEdge project identifies five different use cases and scenarios as listed below where mmWave and MEC add significant values. In each use case, specific applications, their expected traffic, and requirement for 5G in terms of Key Performance Indicators (KPIs) and functionalities are described:

1. Omotenashi Services at airport, station, and shopping mall;
2. Moving Hotspot at train, bus, and airplane;
3. Tokyo 2020 Olympic at gates and stands & sports areas in Olympic stadium;
4. Dynamic Crowds at dense urban areas like around Shibuya train station;
5. Automated Driving especially in complex urban city environments.

In all selected scenarios, the use cases require large volume of data within limited latency in specific areas to enjoy scenario-specific applications.
1 Introduction

1.1 5G Applications and Use Cases

Future generations of wireless systems will have to support new features, far beyond basic wireless internet access with mobility support, in order to meet the 5G requirements discussed in the NGMN White Paper [NGMN5G][TR22.891], which provides an overview on use cases, scenarios, the associated architecture and Key Performance Indicators (KPI). In the attempt to cluster the large variety of use cases and scenarios to be supported by the new 5G system into a manageable number of categories, three major clusters as shown in Figure 1 are the current basis for discussion in research and standardization bodies. Enhanced Mobile Broad Band (eMBB), targeting mainly higher area capacity; massive Machine Type Communication (mMTC), targeting massive number of devices; and ultra-Reliable and Low Latency Communication (uRLLC), targeting a wide range of application enabling the so-called Tactile Internet and Industry 4.0 applications. Looking beyond the current scope of work in these three clusters, new applications and services can be envisioned requiring a combination of ultra-High-Speed and Low Latency Communication (uHSLLC), which will require new technology components to be combined in a holistic approach.

![Figure 1: 3 key use cases of 5G defined in IMT2020.](image)

The three main application categories highlighted in Figure 1 are characterized by different KPIs, as illustrated in Figure 2. Designing a common platform satisfying such diverse requirements in an effective way is one of the biggest challenges of 5G. At the physical layer, 5G builds on a significant increase of system capacity by incorporating massive MIMO techniques, dense deployment of radio access points and wider bandwidth. All these strategies are facilitated by the use of mmW communications. However, the improvement achievable at the physical layer could still be insufficient to meet the challenging and diverse requirements depicted in Fig. 2. To provide a common and efficient platform serving such different
applications, 5G foresees a paradigm shift that puts applications at the center of the system design. Virtualization of network functionalities and mobile edge computing (MEC) are the key tools of this application-centric networking. The goal of MEC is to bring cloud-computing capabilities, including computing and caching, at the edge of the mobile network, within the Radio Access Network (RAN), in close proximity to mobile subscribers. Mobile edge applications run as virtual machines on top of a virtualization infrastructure provided by the mobile edge (ME) host.

**RAN as a Service and location specific applications for vertical industries**

The ambition of 5G roadmap is to foster an application/user centric design, where the operators are expected to provide networks on a RAN as-a-service (RaaS) basis, to meet the wide range of use cases through the design of *network slices*. A key element is the softwarization of many network functionalities, to have the flexibility to allocate resources dynamically, within a common framework, in line with the current (or expected) demand and to tailor network slices to specific needs. These ambitions match well with the use cases of NGMN and are well in line with the trends highlighted in a recent study [5GMNOSurvey] interviewing MNOs worldwide. The main findings across all continents and regions have been found the following:

Network densification using Small Cells requires broadband connections to the network. Optical fiber is highly preferred wherever possible, but mmWave technology is considered the most promising and economically viable wireless option for backhaul and fronthaul.

Operators have diverse options of data off-loading in unlicensed spectrum, most of them prefer tight integration of 3GPP and non-3GPP RATs, following the frameworks of LAA and LWA. This includes high capacity RATs like e.g. 802.11ad/ay/ac. Therefore, managing access points and spectrum in unlicensed bands will become a central task for network performance optimization and energy and spectrum efficient inclusion of UDN into the macro-cellular infrastructure.

Among the verticals identified in 5G roadmap, 71% of operators consider autonomous cars / automated driving as the biggest vertical market to emerge, requiring combinations of ultra-reliable and low latency communication for applications with a wide range of data rate requirements.

Furthermore, telemedicine for remote areas is concluded to be only feasible if low latency and very high data rates can be realized through the 5G networks.

Many of these scenarios and more specifically many of the targeted 5G use cases require a very service / user centric orchestration of the particular required 5G network resources starting from air-interface configuration /selection through backhaul and core network configuration and provisioning of communication and computation resources and the right place and time. Such demanding requirements can only be met by a holistic approach as proposed by the 5G-MiEdge consortium. Focusing on the use cases and scenarios in need of uHSLLC 5G-MiEdge targets the Tokyo 2020 Olympic Games as a short term venue to demonstrate the feasibility of the overall novel concept combining high speed mmW communication with Mobile Edge Computing.
As mentioned before, the main idea of 5G-MiEdge is to merge MEC and mmW communications in order to design a very effective application-centric architecture, while building on the potentials of mmW communications, with the goal of delivering information technology (IT) services with very low latency and/or high reliability, *when and where required*. Under this new paradigm, radio, computing and storage resources may be seen as components of a truly pervasive (liquid) computer that follows the mobile user on the infrastructure side.

In the following, we will describe how this fusion of mmW-Comm and MEC will help to fulfil the requirements of the three major application categories, as illustrated in Fig. 1.

![Figure 2: 8 KPIs for 5G defined in IMT2020.](image)

A) mmWave and MEC for eMBB applications

eMBB use cases target higher peak data rates or higher area capacity. In order to achieve the requirements of eMBB, the following technology enablers are considered: aggregation of more spectrum chunks and traffic offloading in non-IMT bands, increased bandwidth per carrier at higher frequencies above 6 GHz, increased spatial reuse of radio resources by deployment of denser cell topologies and improved spectral efficiency using *massive MIMO* technologies. Since mobility is important for most of the eMBB use cases, heterogeneous network support and separation of control and user plane are considered key enablers to embed high capacity small cells into an existing cellular network, wherever they are needed. For example, hot spots provided by mmWave small cells can provide effective mobility support even with patchy coverage, when appropriately embedded in the existing cellular network [MiWEBA D1.1] operating at frequencies below 6 GHz. Other relevant scenarios, like mobile hot spots in busses or trains, are in urgent need of mmWave high capacity wireless links to backhaul the hot spot traffic from the moving vehicle.
Building on the potentials of this advanced physical layer fabric, further improvements are achievable by introducing MEC technologies. Augmented reality (AR) is an example of application benefiting from MEC and mmW. These applications need to be aware of the user’s position and the direction they are facing through, for example, their camera view. Starting from such information, AR applications create additional information, in the form of video, sound, etc., and deliver it to the user in real-time. If the user moves, the information is refreshed and follows the user. This is a service, which is naturally localized; it requires high computational capabilities and needs to be delivered with very low delay. Hosting such AR services on a MEC platform associated to an mmWave Access Point (AP) is a key strategy to create this computationally demanding, supplementary information near the mobile user and deliver it satisfying the user experienced latency requirements.

B) mmW and MEC for URLLC applications

URLLC use cases are mainly covered by the so-called Tactile Internet applications, e.g. industrial automation or remote control of vehicles over the networks. Such applications require very stringent KPI fulfillment regarding reliability of successful packet deliveries or very low end-to-end round trip delays of 1ms, or even less, requiring concerted latency targeted optimization across all protocol layers. Running these applications, especially those targeting industrial automation or autonomous driving, as close as possible to the radio access points is the key strategy to meet the severe requirements of uRLLC applications in terms of latency and reliability. Merging MEC with mmW is then the ideal solution to deliver these context-aware applications requiring ultra-low latency and/or high reliability, as it enables fast access to MEC services while avoiding the problems associated to latency control over wide area networks.

In the autonomous driving scenario, the orchestration of multiple MEC servers gives rise to a distributed car cloud that receives local messages directly from applications in vehicles and roadside sensors, analyzes them and then propagates hazard warnings and other latency-sensitive messages to other cars around at extremely low latency.

In the Industry 4.0 scenario, powerful data analytics algorithms, learning the behavior of production process components and predicting potential failures, can be implemented very close to the production chain, by local processing of data coming from multiple sensors. This may be extremely useful to prevent any interruption of the production cycle and/or to optimize productivity. Furthermore, many of these industrial local networks can be designed from scratch and optimized for the purposes they have to serve.

C) mmW and MEC for mMTC

Most of the sensors interconnected in a Smart City scenario have very limited computation capabilities and energy resources. Computation offloading is then the key strategy to enable these sensors to supporting sophisticated applications resorting to nearby computers. This is made possible by proximity access to MEC servers instantiating virtual machines running the required applications as close as possible
to the sensors. Proper orchestration of these virtual machines gives rise to a distributed control system that overcomes the bottleneck of centralized systems.

In this scenario, merging mmW and MEC is an effective strategy to provide fast access to IT resources, thus facilitating computation offloading, and to orchestrate the work of nearby MEC servers through mmW backhaul links.

The description of the potential exploitable from a combination of mmW communication and MEC for the three main use case clusters targeted in 5G development phase 1 are foundation of the uHSLLC use case as the focus of the 5G-MiEdge project to be addressed in standardization of 5G technologies in phase 2 at a later stage, see Figure 3.

![Figure 3: New use case challenges targeted in 5G-MiEdge project.](image)

### 1.2 5G-MiEdge – Vision, related Use Cases and KPIs

The 5G-MiEdge vision and the focus of this project is the investigation and analysis of the fusion of MEC with mmWave communications, as an effective way to support applications requiring at the same time extreme high data rates, low latency end-to-end service provisioning and full mobility support. Among the partners of 5G-MiEdge [8], a joint Japanese / European research project, it is a shared belief that it is precisely the merging between MEC and mmWave communications that enables the design of an application-centric scalable system. There mobile applications can run at the mobile side, if resources are sufficient, or in the nearest MEC server, or in a cluster of MEC servers, properly interconnected by high capacity wired or mmWave backhaul links, 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 radio access links. At the same time, proactive strategies like data caching are to be put in place to meet the demanding end-to-end (E2E) latency requirements of some applications foreseen in some 5G verticals, such as Industry 4.0 or e-Health. The identification of scenarios/use cases requiring uHSLLC and benefiting from it is main objective of this deliverable.

1.2.1 Fusion of mmWave Technology and MEC

The 5G-MiEdge vision builds on two technologies, which are standing up in the ongoing standardization rush to enable 5G systems by 2020: the use of mmWave for access and ubiquitous deployment of enhanced Mobile Edge Computing (MEC). The latter is a very effective way to bring cloud services at the edge of mobile networks, the former is one of the key enabler of 5G, thanks to its effectiveness in handling interference and its capability to make possible data rates much higher than any existing cellular standard. Those technologies well integrate each other into a single holistic 5G ecosystem, enabling highly efficient network operations, real-time service delivery, and the ultimate user experience. The main idea is that a fully effective deployment of MEC is only possible by relying on a very high data rate radio access and backhauling. mmWave technology is the perfect technology to enable not only high data rate traffic, but also wireless backhauling, to complement wired backhauling, when and where necessary. At the same time, a fully effective exploitation of mmWave technologies can greatly benefit from the distributed computing capabilities offered by MEC, enabling a joint optimization of communication, computation and caching resources.

Therefore, the main goal of the 5G-MiEdge project is to design, develop and demonstrate a highly innovative 5G architecture, with its associated novel signaling and functionalities, which manages to smartly and smoothly combine mmWave access/backhauling with MEC. This will enable two of the most important 5G use cases, namely eMBB services and mission critical URLLC applications (see Figure 1), via cost-efficient Radio Access Networks (RANs), while taking into account global interoperability issues.

To achieve this goal, 5G-MiEdge proposes a newly defined ultra-lean and inter-operable control-signaling plane, called liquid RAN C-plane, where liquid stems from its capability to enabling services and connections able to follow and adapt to users’ needs, like a liquid adapts to the form of its container. Such a liquid RAN C-plane is meant to provide ubiquitous liquid allocation of communication and computation resources, within a user/application-centric perspective. Acquisition of context information and forecasting of service requests are key steps to enable a proactive orchestration of radio and computation resources of 5G-MiEdge based 5G networks.

This set of proposed innovations will bring important advantages and new system capabilities, as it will:

1) Enable to relax the capacity and latency constraints that characterize the backhaul of mmWave access technology,
2) Limit CAPEX and OPEX for Mobile Network Operators (MNOs) by adapting available resources to traffic forecast and user context awareness,

3) Provide instantaneous, reliable, and ultra-broadband services by taking advantage of content prefetching and caching, wide spectrum availability, insight into the network conditions, and the user proximity to the mmWave Access Points (APs).

1.2.2 5G-MiEdge key technologies and related KPIs

5G-MiEdge has to tackle three different, but inter-connected key technologies to make its vision a concrete and tangible success, as shown in the lower part of Figure 4:

![Figure 4: Technology components for uHS+LLC and related KPIs.](image)

The ‘**mmWave Edge Cloud**’ technology leverages mmWave APs and edge cloud, where data/applications reside in specific sites based on mobile user requirements and available radio and cloud resources. Additionally, deployed network and cloud infrastructure can be efficiently shared by different operators, and orchestrated to reach unprecedented energy and cost efficiency. These functionalities require user context awareness (such as habits, location, and action) and fine time-space traffic forecast, for instance, to decide when, where, and which content to cache. Providing such rich information is the key goal of the ‘**Liquid RAN C-Plane**’ technology, which uses multiple RATs, available at the terminals, to collect user specific data and elaborate a real-time, rich, and reliable map. Finally, the ‘**User/application centric orchestration**’ technology is introduced as a framework where robust, scalable and possibly distributed algorithms are used to manage computation, storage, and communication resources in real-time and in a flexible way.

In order to assess whether 5G-Mixedge will manage to deliver the promised enhancements to the 5G system architecture, some measurable KPIs of the 5G-
MiEdge key technologies are proposed in Table 1. The Technology Readiness Level (TRL) column is to be read as follows: the number on the left shows the state-of-the-art at the beginning of the project; the number on the right shows the expected advancement of the TRL level at the end of the project.

Table 1: 5G MiEdge technologies, KPIs and TRL

<table>
<thead>
<tr>
<th>Technology</th>
<th>Outcome and proposed KPIs to be used for the final evaluation</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>mmWave Edge Cloud</td>
<td>Outcome: Overall architecture and cross layer functions will be designed, evaluated, demonstrated, and disseminated. KPIs: see the 5G MiEdge KPIs in Table 2</td>
<td>1-&gt;5</td>
</tr>
<tr>
<td>Liquid RAN C-plane</td>
<td>Outcome: Definition of control plane and network interfaces. KPIs: accuracy of the produced resource maps; corresponding control protocols.</td>
<td>2-&gt;5</td>
</tr>
<tr>
<td>User/Application centric orchestration</td>
<td>Outcome: algorithms designed and assessed through simulation; selected key algorithms implemented as a proof of concept. KPIs: convergence, computational complexity and effectiveness of the proposed solution will be evaluated.</td>
<td>2-&gt;5</td>
</tr>
</tbody>
</table>

1.2.3 5G-MiEdge Specific Use Cases for uHSLLC

Three main use cases have been defined to demonstrate the effectiveness of the 5G-MiEdge proposal, as shown in the right side of Figure 5.

The Stadium: characterized by an extremely high user density and co-channel interference, which requires specific antenna design and advanced signal processing. Additionally, AP deployment in this use case is dimensioned to deal...
with major entertainment events, which likely attract thousands of people. Nevertheless, when the stadium is not overcrowded, service requests may vary a lot and capacity at both radio access and backhaul network might be underused. Self-organising cognitive mechanisms based on adaptation and learning are then required to adjust the network configuration to the load variations.

Figure 6: Stadium scenario at Tokyo 2020 Olympic Games.

**The Office:** A large portion of mobile traffic is nowadays originated from indoor users, demanding an exponentially growing data rate. Deployment of indoor APs is an efficient solution to deal with the unfavorable propagation environment (outdoor to indoor loss), by reducing the gap between the service provider and the terminal. In the office, stationary or slow-mobility users are likely to access to cloud services (up-/down-loading large files from/to the office cloud server) and virtual reality applications that enable, through the exchange of high-resolution 3D data, real-time interactions among people located in remote offices. Accordingly, the main challenges of this use case are to provide enough capacity to support these applications and to strongly limit the energy consumption during lightly loaded periods (e.g., lunchtime).

**The Train / The Station:** A significant number of users access mobile networks when using public transportation, where, due to the lack of dedicated infrastructure and unfavorable propagation losses, very limited wireless services is experienced. This use case characterized by a dedicated architecture where data/applications are proactively stored in relays and instantaneously transferred to the nodes mounted inside the vehicles, so to provide continuous coverage and low latency broadband services, such as gaming and HD video streaming.

Table 2 provides target values of the selected KPIs for each of the 5G-MiEdge use cases.

<table>
<thead>
<tr>
<th>Peak data rate [Mbps]</th>
<th>Latency [ms]</th>
<th>Area traffic capacity [Tbps/km²]</th>
<th>Reliability, Availability</th>
<th>Cost efficiency</th>
<th>Energy efficiency</th>
<th>Connection density [user/km²]</th>
</tr>
</thead>
</table>

Table 2: 5G-MiEdge use cases and associated preliminary KPI requirements
### 1.3 Structure of the document

Principle goal of deliverable D1.1 is two-fold:

- Identify use cases, scenarios, and applications suitable for the 5G-MiEdge vision described in Sect. 1.2;
- Define requirements for 5G to realize identified use cases and applications.

To achieve this goal, the deliverable D1.1 is organized as follows. Firstly, Sect. 2 makes a survey on the State-Of-The-Art (SOTA) of use cases, scenarios, and requirements defined in other research projects, industrial fora, and standardization bodies. One big difference of the 5G-MiEdge project from SOTA point of view is that we will identify more location (scenario) specific use cases as (vertical) services to be realized by 5G technologies. In Sect. 3, five typical location specific use cases suitable for the 5G-MiEdge project are identified as follows:

- “Omotenashi Services” at airports, stations, and shopping malls;
- “Moving Hotspot” at trains, busses, and airplanes;
- “Tokyo 2020 Olympic Games” at gates and stands & sports areas in Olympic stadium;
- “Dynamic Crowd” at dense urban areas like around Shibuya station;
- “Automated Driving”, especially in complex urban city environments.

These five use cases consume extreme data traffic while they require low latency as well, since they are location specific use cases. For example, the automated driving use case requires to exchange HD map information dynamically in real-time between surrounding vehicles and roadside units. That requires both high data rate and low latency at specific locations on traffic roads in the complex urban city environments.

### 2 State-Of-The-Art

#### 2.1 KPI definition

Even though many Key Performance Indicators (KPIs) are self-explaining, some of them may still need further clarifications. In this subsection, the most relevant KPIs are defined.

#### 2.1.1 KPIs from IMT2020 and 3GPP

The ITU has recently defined the objectives of the future development of the International Mobile Telecommunications (IMT) for 2020 and beyond, compared
them to the IMT-Advanced ones (see Figure 2), and identified their importance for different scenarios. Similar analyses have been carried out, providing comparable results, such as the NGMN, and by other collaborative research projects.

Based on those studies and the overall objectives of the project, the measurable **KPIs** for **5G-MiEdge** are:

**KPI 1: the peak user rate** is the maximum achievable data rate under ideal conditions per user/device;

**KPI 2: the latency** is the contribution by the radio network to the time from when the source sends a packet to when the destination receives it;

**KPI 3: the area traffic capacity** is the total traffic throughput served per geographic area;

**KPI 4: the reliability** is equal to $(1 - \text{service dropping rate})$; **the availability** is equal to $(1 - \text{service blocking probability})$;

**KPI 5: the cost efficiency** is the ratio of the Total Cost of Ownership (TCO) and the network capacity;

**KPI 6: the energy efficiency** refers to the quantity of information bits transmitted to or received from users, per unit of energy consumption of the radio access network (RAN);

**KPI 7: the connection density** indicates the total number of connected and or accessible devices per unit area.

### 2.2 Standardization bodies

The standardization process of mmWave and MEC technologies touches several standards bodies. Here below, the most relevant ones, for the scope of 5G-MiEdge, are reported.

#### 2.2.1 3GPP

The 3rd Generation Partnership Project (3GPP) standardization bodies started the first 5G discussions in 2015. Among the several active groups, the 3GPP technical specification group Services and System Aspects (SA) Work Group 1 (SA1) is in charge of defining the so called Stage 1 of 3GPP specifications, which covers the specification of features, services and requirements of mobile and fixed communication technologies. The Stage 1 provides the first step of the specification process, which is then further refined and completed by the work of the Stage 2 (RAN and SA other work groups) and Stage 3 (CT work groups) in 3GPP. Now, the only stable work on 5G, relevant to this deliverable, is the work accomplished by the SA1 group.

It is worth noting that so far in no document it is explicitly mentioned the support of above 6GHz frequency bands. Such aspects will be the focus of the second set of 5G features, planned to be started under the 3GPP Release 16, from 2018 onwards.
2.2.1.1 Use cases as defined by SA1

In 2015, SA1 started under the 3GPP Release 14 the work on the first set of 5G features with the creation of the Feasibility Study “on New Services and Markets Technology Enablers (SMARTER)”. The scope was to “identify the market segments and verticals whose needs 3GPP should focus on meeting, and to identify groups of related use cases and requirements that the 3GPP eco-system would need to support in the future”. The work reached a milestone with the creation of the Technical Report TR 22.891 [TR22.891] “Feasibility Study on New Services and Markets Technology Enablers; Stage 1”, which contains more than 70 different use cases, categorized in four different groups:

- massive Internet of Things,
- Critical Communications,
- enhanced Mobile Broadband,
- Network Operation.

Each one of those groups spun the creation of a related new Technical Report with the same title, all approved at the 3GPP SA#72 meeting held in June 2016 in Busan, Korea. The four TRs are summarized in the table below.

<table>
<thead>
<tr>
<th>TR</th>
<th>Use Case Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.861: FS_SMARTER – massive Internet of Things</td>
<td>Massive Internet of Things focuses on use cases with massive number of devices (e.g., sensors and wearables). This group of use cases is particularly relevant to the new vertical services, such as smart home and city, smart utilities, e-Health, and smart wearables.</td>
<td></td>
</tr>
<tr>
<td>22.862: FS_SMARTER – Critical Communications</td>
<td>The main areas where improvements are needed for Critical Communications are latency, reliability, and availability to enable, for example, industrial control applications and tactile Internet. These requirements can be met with an improved radio interface, optimized architecture, and dedicated core and radio resources.</td>
<td></td>
</tr>
<tr>
<td>22.863: FS_SMARTER – enhanced Mobile Broadband</td>
<td>Enhanced Mobile Broadband includes a number of different use case families related to higher data rates, higher density, deployment and coverage, higher user mobility, devices with highly variable user data rates, fixed mobile convergence, and small-cell deployments.</td>
<td></td>
</tr>
<tr>
<td>22.864: FS_SMARTER – Network Operation</td>
<td>The use case group Network Operation addresses the functional system requirements, including aspects such as: flexible functions and capabilities, new value creation, migration and interworking, optimizations and enhancements, and security.</td>
<td></td>
</tr>
</tbody>
</table>

SA1 consolidated under the 3GPP Release 15 the four TRs into the a single document, the first Technical Specification TS 22.261 [TS22.261] for 5G requirements “Service requirements for the 5G system; Stage 1”, which was very recently approved in the SA#75 meeting held in March 2017 in Dubrovnik, Croatia. The TS provides the first normative text in 5G, i.e. the Stage 1 requirements for next generation mobile telecommunications, guiding the future work of the Stage 2 (RAN and SA) and Stage 3 (CT) work groups in 3GPP.
The following figure shows the relation between the identified four use cases groups and the main vertical market segments of future 5G systems, together with the related 3GPP documents that can provide more information.

![Figure 4: Use cases/scenarios in 3GPP SA1 (SMARTER).](image)

**TR22.861**

**TR22.862**

**TR22.863**

2.2.1.2 Requirements and KPIs as defined by SA1

It is important to note that each one of the identified four groups of use cases has its own long list of new requirements, targeted at and refined for a specific vertical industry and new services.

It is possible however to extract from TS 22.261 a set of defined and interesting requirements and scenarios, which are the most relevant aspects for the work of 5G-MiEdge, and to cluster them in two main streams of activities, ‘High data rates and traffic densities’ and ‘Low latency and high reliability’, as described in the following. For a more detailed information, it is possible to download TS22.261 [TS22.261].
High data rates and traffic densities

Several scenarios require the support of very high data rates or traffic densities of the 5G system. The scenarios address different service areas: urban and rural areas, office and home, and special deployments (e.g., massive gatherings, broadcast, residential, and high-speed vehicles). The scenarios and their performance requirements are summarized in the following Table.

Table 1 Performance requirements for high data rate and traffic density scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Experienced data rate (DL)</th>
<th>Experienced data rate (UL)</th>
<th>Area traffic capacity (DL)</th>
<th>Area traffic capacity (UL)</th>
<th>Overall user density</th>
<th>Activity factor</th>
<th>UE speed</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban macro</td>
<td>50 Mbps</td>
<td>25 Mbps</td>
<td>100 Gbps/km²</td>
<td>50 Gbps/km²</td>
<td>10 000/km²</td>
<td>20%</td>
<td>Pedestrians and users in vehicles (up to 120 km/h)</td>
<td>Full network</td>
</tr>
<tr>
<td>Rural macro</td>
<td>50 Mbps</td>
<td>25 Mbps</td>
<td>1 Gbps/km²</td>
<td>500 Mbps/km²</td>
<td>100/km²</td>
<td>20%</td>
<td>Pedestrians and users in vehicles (up to 120 km/h)</td>
<td>Full network</td>
</tr>
<tr>
<td>Indoor hotspot</td>
<td>1 Gbps</td>
<td>500 Mbps</td>
<td>15 Tbps/km²</td>
<td>2 Tbps/km²</td>
<td>250 000/km²</td>
<td>note 2</td>
<td>Pedestrians</td>
<td>Office and residential</td>
</tr>
<tr>
<td>Broadband access in a crowd</td>
<td>25 Mbps</td>
<td>50 Mbps</td>
<td>[3,75] Tbps/km²</td>
<td>[7,5] Tbps/km²</td>
<td>[500 000]/km²</td>
<td>30%</td>
<td>Pedestrians</td>
<td>Confined area</td>
</tr>
<tr>
<td>Dense urban</td>
<td>300 Mbps</td>
<td>50 Mbps</td>
<td>750 Gbps/km²</td>
<td>125 Gbps/km²</td>
<td>25 000/km²</td>
<td>10%</td>
<td>Pedestrians and users in vehicles (up to 60 km/h)</td>
<td>Downtown</td>
</tr>
<tr>
<td>Broadcast-like services</td>
<td>Maximum 200 Mbps (per TV channel)</td>
<td>N/A or modest (e.g., 500 kbps per user)</td>
<td>N/A</td>
<td>N/A</td>
<td>[15] TV channels of [20 Mbps] on one carrier</td>
<td>N/A</td>
<td>Stationary users, pedestrians and users in vehicles (up to 500 km/h)</td>
<td>Full network</td>
</tr>
<tr>
<td>High-speed train</td>
<td>50 Mbps</td>
<td>25 Mbps</td>
<td>15 Gbps/train</td>
<td>7.5 Gbps/train</td>
<td>1 000/train</td>
<td>30%</td>
<td>Users in trains (up to 500 km/h)</td>
<td>Along railways</td>
</tr>
<tr>
<td>High-speed vehicle</td>
<td>50 Mbps</td>
<td>25 Mbps</td>
<td>[100] Gbps/km²</td>
<td>[50] Gbps/km²</td>
<td>4 000/km²</td>
<td>50%</td>
<td>Users in vehicles (up to 250 km/h)</td>
<td>Along roads</td>
</tr>
<tr>
<td>Airplanes connectivity</td>
<td>15 Mbps</td>
<td>7.5 Mbps</td>
<td>1.2 Gbps/plane</td>
<td>600 Mbps/plane</td>
<td>400/plane</td>
<td>20%</td>
<td>Users in airplanes (up to 1 000 km/h)</td>
<td>Along roads</td>
</tr>
</tbody>
</table>
Low latency and high reliability

Several scenarios require the support of very low latency and very high communications service availability, which implies a very high reliability. The overall service latency depends on the delay on the radio interface, transmission within the 5G system, transmission to a server which may be outside the 5G system, and data processing. Some of these factors depend directly on the 5G system itself, whereas for others the impact can be reduced by suitable interconnections between the 5G system and services or servers outside of the 5G system. The scenarios and their performance requirements can be found in the following table.

Table 2 Performance requirements for high data rate and traffic density scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>End-to-end latency</th>
<th>Jitter</th>
<th>Survival time</th>
<th>Communication service availability</th>
<th>Reliability</th>
<th>User experienced data rate</th>
<th>Payload size</th>
<th>Traffic density</th>
<th>Connection density</th>
<th>Service area dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete automation – motion control</td>
<td>1 ms</td>
<td>1 µs</td>
<td>0 ms</td>
<td>99,9999%</td>
<td>99,9999%</td>
<td>1 Mbps up to 10 Mbps</td>
<td>Small</td>
<td>1 Tbps/km²</td>
<td>100 000/km²</td>
<td>100 x 100 x 30 m</td>
</tr>
<tr>
<td>Discrete automation</td>
<td>10 ms</td>
<td>100 µs</td>
<td>0 ms</td>
<td>99.9%</td>
<td>99.9%</td>
<td>10 Mbps</td>
<td>Small to big</td>
<td>1 Tbps/km²</td>
<td>100 000/km²</td>
<td>1000 x 1000 x 30 m</td>
</tr>
<tr>
<td>Process automation – remote control</td>
<td>60 ms</td>
<td>20 ms</td>
<td>100 ms</td>
<td>99,9999%</td>
<td>99,9999%</td>
<td>1 Mbps up to 100 Mbps</td>
<td>Small to big</td>
<td>100 Gbps/km²</td>
<td>1 000/km²</td>
<td>300 x 300 x 50 m</td>
</tr>
<tr>
<td>Process automation – monitoring</td>
<td>50 ms</td>
<td>20 ms</td>
<td>100 ms</td>
<td>99.9%</td>
<td>99.9%</td>
<td>1 Mbps</td>
<td>Small</td>
<td>10 Gbps/km²</td>
<td>10 000/km²</td>
<td>300 x 300 x 50 m</td>
</tr>
<tr>
<td>Electricity distribution – medium voltage</td>
<td>25 ms</td>
<td>25 ms</td>
<td>25 ms</td>
<td>99.9%</td>
<td>99.9%</td>
<td>10 Mbps</td>
<td>Small to big</td>
<td>10 Gbps/km²</td>
<td>1 000/km²</td>
<td>100 km along power line</td>
</tr>
<tr>
<td>Electricity distribution – high voltage</td>
<td>10 ms</td>
<td>5 ms</td>
<td>10 ms</td>
<td>99,9999%</td>
<td>99,9999%</td>
<td>10 Mbps</td>
<td>Small</td>
<td>100 Gbps/km²</td>
<td>1 000/km²</td>
<td>200 km along power line</td>
</tr>
<tr>
<td>Intelligent transport systems – infrastructure backhaul</td>
<td>100 ms</td>
<td>20 ms</td>
<td>100 ms</td>
<td>99,9999%</td>
<td>99,9999%</td>
<td>10 Mbps</td>
<td>Small to big</td>
<td>100 Gbps/km²</td>
<td>1 000/km²</td>
<td>2 km along a road</td>
</tr>
<tr>
<td>Tactile interaction</td>
<td>0.5 ms</td>
<td>TBC</td>
<td>TBC</td>
<td>[99,999%]</td>
<td>[99,999%]</td>
<td>[Low]</td>
<td>[Small]</td>
<td>[Low]</td>
<td>[Low]</td>
<td>TBC</td>
</tr>
<tr>
<td>Remote control</td>
<td>[5 ms]</td>
<td>TBC</td>
<td>TBC</td>
<td>[99,999%]</td>
<td>[99,999%]</td>
<td>[From low to 10 Mbps]</td>
<td>[Small to big]</td>
<td>[Low]</td>
<td>[Low]</td>
<td>TBC</td>
</tr>
</tbody>
</table>
2.2.2  ETSI MEC

In September 2014, the ETSI MEC group published a white paper, which included a first set of scenarios relevant for the MEC technology [ETSIWP] (see Figure 5). The augmented reality use case described a consumer-oriented service, connected cars as third-party oriented service, intelligent video acceleration and IoT gateway are services oriented to improve the network performance.

![Use cases in ETSI MEC](image)

Figure 5: Use cases/scenarios in ETSI MEC.

2.2.3  IEEE802.11ay

IEEE802.11ay is the next generation standard of IEEE802.11ad to support data rates in excess of 20 Gbps by exploiting channel bonding, channel aggregation and MU-MIMO in 60 GHz unlicensed band established in Mar. 2015 [IEEE802.11ay]. Table 3 summarizes use cases and corresponding requirements selected in IEEE802.11ay standardization body. All selected use cases are relevant for the 5G-MiEdge project except the use case #4: data center. The IEEE802.11ay will support mmWave access and backhaul to enable eMBB applications for 5G. The PHY and MAC specifications will be standardized by 2019. IEEE802.11ad/ay will be integrated in 5G by using non-3GPP aggregation that will be specified in 3GPP.

<table>
<thead>
<tr>
<th>UC #</th>
<th>Indoor (I)/Outdoor (O)</th>
<th>Environment</th>
<th>Throughput</th>
<th>Topology</th>
<th>Latency</th>
<th>Security</th>
<th>Availability</th>
<th>Applications and Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOS/ NLOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Use cases and requirements selected in IEEE802.11ay
<table>
<thead>
<tr>
<th>Application</th>
<th>Use Case</th>
<th>Data Rate</th>
<th>Latency</th>
<th>Transmission</th>
<th>Bandwidth</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ultra short range communications</td>
<td>I</td>
<td>&lt;10cm</td>
<td>~10Gbps</td>
<td>P2P</td>
<td>&lt;100 ms</td>
<td>Static, D2D, Streaming/Download</td>
</tr>
<tr>
<td>2 8K UHD wireless transfer at smart home</td>
<td>I</td>
<td>&lt;5m</td>
<td>&gt;28Gbps</td>
<td>P2P</td>
<td>&lt;5ms</td>
<td>Uncompressed 8K UHD Streaming</td>
</tr>
<tr>
<td>3 Augmented reality</td>
<td>I</td>
<td>&lt;5m</td>
<td>~20Gbps</td>
<td>P2P</td>
<td>&lt;100 ms</td>
<td>Low Mobility, D2D, 3D UHD Streaming</td>
</tr>
<tr>
<td>4 Data center</td>
<td>I</td>
<td>&lt;10m</td>
<td>~20Gbps</td>
<td>P2P/P2 MP</td>
<td>&lt;100 ms</td>
<td>Indoor Backhaul with multi-hop*</td>
</tr>
<tr>
<td>5 Video-mass data distribution</td>
<td>I</td>
<td>&lt;100m</td>
<td>&gt;20Gbps</td>
<td>P2P/P2 MP</td>
<td>&lt;100 ms</td>
<td>Multi-cast Streaming/Download, Dense Hotspot</td>
</tr>
<tr>
<td>6 Mobile offloading and multi-band operation</td>
<td>I/O</td>
<td>&lt;100m</td>
<td>&gt;20Gbps</td>
<td>P2P/P2 MP</td>
<td>&lt;100 ms</td>
<td>Multi-band Multi-RAT operation, Hotspot</td>
</tr>
<tr>
<td>7 Mobile fronthauling</td>
<td>O</td>
<td>&lt;200m</td>
<td>~20Gbps</td>
<td>P2P/P2 MP</td>
<td>C/I</td>
<td>Fronthauling</td>
</tr>
<tr>
<td>8 Wireless backhaul</td>
<td>O</td>
<td>&lt;1km with single hop &lt;150m with multiple hops</td>
<td>~2Gbps</td>
<td>P2P/P2 MP</td>
<td>&lt;35ms</td>
<td>Small Cell Backhauling, Single hop or multiple hop</td>
</tr>
<tr>
<td>9 Office Docking</td>
<td>I</td>
<td>&lt;3m</td>
<td>~20Gbps</td>
<td>P2P/P2 MP</td>
<td>&lt;10ms</td>
<td></td>
</tr>
</tbody>
</table>

### 2.3 Research projects landscape

It is very important for a research project to be aware of the state of the art in the areas in focus of its research activities. That is the reason of this section, which summarizes what are, to the best of our knowledge, other research projects in both Europe and Japan that deal with topics related to 5G-MiEdge.
2.3.1 METIS

The METIS project has defined twelve test cases for the information society in the beyond 2020 [METIS D1.1], from which we have selected the six most relevant with respect to the technological challenges target by 5G MiEdge. These test cases are part of two scenarios referred to as “Amazingly fast” and “Great service in a crowd”, where the peak data rate and the traffic volume per area are the most stringent requirements, respectively. Table 4 summarizes all the KPIs of selected test cases and the related requirements.

Table 4 Main requirements and KPIs for the relevant test cases as defined by METIS [METIS D1.5]

<table>
<thead>
<tr>
<th>Use case</th>
<th>KPI</th>
<th>Requirement</th>
<th>Relevant for 5G MiEdge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual reality office</td>
<td>Traffic volume per subscriber</td>
<td>36[Tbyte/month/subscriber] in DL and UL</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Average user data rate during busy period</td>
<td>0.5 [Gbps] DL and UL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic volume per area</td>
<td>100 [Mbps/m²] DL and UL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experienced user data rate</td>
<td>1 [Gbps], UL and DL, with 95% availability (5 [Gbps] with 20% availability)</td>
<td>Yes</td>
</tr>
<tr>
<td>Dense urban information society</td>
<td>Traffic volume per subscriber</td>
<td>500[Gbyte/month/subscriber] (DL+UL)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Average user data rate during busy period</td>
<td>5 (1) [Mbps] DL (UL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic volume per area</td>
<td>700 [Gbps/km²] (DL+UL)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Experienced user data rate</td>
<td>300 (60) [Mbps] DL (UL) with 95% availability</td>
<td></td>
</tr>
<tr>
<td>Shopping mall</td>
<td>Traffic volume per subscriber</td>
<td>1.07 [Gbyte/subscriber] (DL+UL) during busy period</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Average user data rate during busy period</td>
<td>1.7 (0.7) [Mbps] DL (UL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic volume per area</td>
<td>170 (67) [Gbps/km²] (DL+UL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experienced user data rate</td>
<td>300 (60) [Mbps] DL (UL) under below availability (Mbps)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Availability</td>
<td>95% of indoor environment space of shopping mall area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>95% of time for commercial data traffic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>99.9% for safety-related sensor applications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed permanent infrastructure</td>
<td>Not existing within the open area</td>
<td></td>
</tr>
<tr>
<td>Stadium</td>
<td>Traffic volume per subscriber</td>
<td>9 [Gbyte/h] per subscriber DL+UL in busy period</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Average user data rate during busy period</td>
<td>0.3-3 [Mbps] (for UL+DL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic volume per area</td>
<td>0.1-10 Mbps/[m²] / (stadium area 50,000 [m²])</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experienced user data rate</td>
<td>0.3-20 [Mbps] DL+UL</td>
<td></td>
</tr>
<tr>
<td>Open air festival</td>
<td>Number of users and devices per area</td>
<td>3.6 [Gbyte/subscriber] DL+UL during busy period of the festival</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Average user data rate during busy period</td>
<td>9 [Mbps] (DL/UL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic volume per area</td>
<td>900 [Gbps/km²] (DL+UL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experienced user data rate</td>
<td>30 [Mbps] (DL or UL) at 95% availability</td>
<td></td>
</tr>
</tbody>
</table>

2.3.2 METIS II

Based on the results obtained in the METIS project [METIS D1.1] and the NGMN white paper [NGMN5G], the METIS II project is investigating defined five use cases described in Table 5 [METIS II D1.1]. These use cases are related to three main use case families, namely Extreme Mobile Broadband (xMBB), Massive Machine-Type
Communications (mMTC), and Ultra-reliable Machine-Type Communications (uMTC).

Table 5 Main requirements and KPIs for the relevant test cases as defined by METIS II [METIS II D1.1]

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Key Performance Indicator (KPI)</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban information society</td>
<td>Experienced user throughput</td>
<td>300 Mbps in DL and 50 Mbps in UL at 95% availability and 95% reliability</td>
</tr>
<tr>
<td></td>
<td>E2E RTT latency</td>
<td>Less than 5 ms (augmented reality applications)</td>
</tr>
<tr>
<td>Virtual reality office</td>
<td>Experienced user throughput</td>
<td>5 (1) Gbps with 20% (95%) availability in DL and 5 (1) Gbps with 20% (95%) availability in UL both with 99% reliability</td>
</tr>
<tr>
<td>Broadband access everywhere</td>
<td>Experienced user throughput</td>
<td>50 Mbps in DL and 25 Mbps in UL at 99% availability and 95% retainability</td>
</tr>
<tr>
<td>Massive distribution of sensors and actuators</td>
<td>Availability</td>
<td>99.9%</td>
</tr>
<tr>
<td></td>
<td>Device density</td>
<td>1,000,000 devices/km²</td>
</tr>
<tr>
<td></td>
<td>Traffic volume per device</td>
<td>From few bytes per day to 125 bytes per second</td>
</tr>
<tr>
<td>Connected cars</td>
<td>E2E one-way latency</td>
<td>5 ms (traffic safety applications)</td>
</tr>
<tr>
<td></td>
<td>Experienced user throughput</td>
<td>100 Mbps in DL and 20 Mbps in UL (service applications) at 99% availability and 95% reliability</td>
</tr>
<tr>
<td></td>
<td>Vehicle velocity</td>
<td>Up to 250 km/h</td>
</tr>
</tbody>
</table>

2.3.3 TROPIC

TROPIC project was an FP7 European Project dealing with distributed computing, storage and radio resource allocation over cooperative small cells. The use cases/scenarios analyzed in TROPIC are reported in Figure 6. The main idea was to empower small cell base stations with additional cloud computing functionalities in order to bring IT services closer to the mobile user, with the goal of improving user experience on latency and download/upload speed. TROPIC addresses this scenario by exploiting advanced MP2MP communications schemes, innovative virtualization procedures, and a cross-layer approach to the allocation of resources understood in a wide sense: radio, computational/storage capacity and energy. A new functional element, named Small Cloud Manager, was designed and implemented to instantiate virtual machines enabling computation offloading from mobile devices to access points endowed with this extra functionality. Alternative computation offloading schemes were proposed and tested. The project ended with a system level simulator analyzing the performance of these alternative offloading schemes, for different classes of applications, and a proof-of-concept testbed showing the energy saving and the end-to-end latency decrease resulting from offloading computations from the mobile device to a cloud enhanced eNodeB.
5G-MiEdge builds on the experience gained in TROPIC. The technical manager of TROPIC is now the technical manager of 5G-MiEdge. However, 5G-MiEdge plans to go well beyond TROPIC for several reasons. First, while TROPIC subsumed an LTE physical layer, while 5G-MiEdge builds on the much more powerful physical layer provided by mmW communications, which enable higher data rates for the radio access and for the wireless backhaul. This is fundamental to reduce latency and to facilitate the orchestration of virtual machines running over nearby access points. Secondly, 5G-MiEdge builds on all the work that is accumulating in these very last few years on Mobile Edge Computing, an idea that in TROPIC was still in its infancy.

2.3.4 MiWEBA

The MiWEBA project was a pioneer of integrating mmWave accesses to cellular networks as a heterogeneous network with C/U splitting to overcome the problem of limited coverage inherent in the mmWave accesses. Among the five use cases shown in Table 6 selected by the MiWEBA project [MiWEBA D1.1], all but the UMa are relevant for the 5G-MiEdge project. Compared to the MiWEBA project, the 5G-MiEdge project assumes practical backhaul networks and overcome the problem of end-to-end latency by combining mmWave access and MEC technologies.

<table>
<thead>
<tr>
<th>Use cases</th>
<th>Scenarios</th>
<th>Technology</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>UMi street canyon</td>
<td>Dense hot spot urban areas</td>
<td>High-rate areas</td>
<td>Increase distance and coverage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cell APs with beamforming antennas</td>
<td>Provide cooperation for interference coordination</td>
</tr>
</tbody>
</table>

Figure 6: Use cases/scenarios in TROPIC.
<table>
<thead>
<tr>
<th>Use Case</th>
<th>UMi open square</th>
<th>UMa</th>
<th>Indoor open office</th>
<th>Indoor shopping mall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UMi open square</strong></td>
<td>Dense hot spot in a square</td>
<td>High-rate areas</td>
<td>Larger areas</td>
<td>Dense hotspot shopping mall</td>
</tr>
<tr>
<td><strong>UMa</strong></td>
<td>Dense hot spot urban areas Mobility in the city Backhaul and fronthaul dense urban and metropolitan areas</td>
<td>Larger areas</td>
<td>Small cell APs and RRHs CRAN Densely small cells</td>
<td>Dense hotspot shopping mall</td>
</tr>
<tr>
<td><strong>Indoor open office</strong></td>
<td><strong>Indoor open office</strong></td>
<td>Isolated rooms</td>
<td>Small cell APs with beamforming antennas Some cooperation between APs</td>
<td>Increase capacity Provide cooperative beamforming and interference coordination Use typically LOS path C- and U-plane split</td>
</tr>
<tr>
<td><strong>Indoor shopping mall</strong></td>
<td>Dense hotspot shopping mall</td>
<td>Large public areas</td>
<td>Small cell APs and RRHs CRAN Different levels of cooperation between APs</td>
<td>Increase capacity Provide cooperative beamforming and interference coordination Use typically LOS path C- and U-plane split</td>
</tr>
</tbody>
</table>

### 2.3.5 MiWaveS

MiWaves (Beyond 2020 Heterogeneous Wireless Networks with Millimeter-Wave Small Cell Access and Backhauling) [MiWaveS] is an industry-driven large-scale integrating EU-funded FP7 project. MiWaveS will be finalized in April 2017 and is composed of 15 consortium partners, chosen among the key players in the telecommunication ecosystem, involving universities and research centers, SME, industry and operators.

The target of the project is to demonstrate how low-cost or advanced mmWave technologies can provide multi-gigabits per second access to mobile users and contribute to sustain the traffic growth. The project investigates and demonstrates key enabling technologies and functionalities supporting the integration of mmWave small-cells in future heterogeneous networks, particularly at the level of networking functions and algorithms, integrated radio and antenna technologies.

Five main use cases and related KPIs were defined, as shown in the following.

- **Use Case 1**: *Urban street-level outdoor mobile access and backhaul system*, in which 1000-times higher spatial data consumption is expected by 2020. Users expect to have multi-Gigabit low-latency connections almost anywhere,

- **Use Case 2**: *Large public events*, covering e.g., massive crowd gatherings and sports events. A great amount of users using data-hungry applications are served by the network, but just in some specific periods and in small areas,
Use Case 3: **Indoor wireless networking and coverage from outdoor**, including the increase of indoor networks capacity and versatility, using indoor or outdoor antennas, and connecting to the operator network by quasi-fixed links,

Use Case 4: **Rural detached small-cell zones and villages**, using mmWave wireless backhaul technologies standalone or combined with wired line connection, to overcome the deployment difficulties of wireline backhaul,

Use Case 5: **Hotspot in shopping malls**, considering ad-hoc deployment of small cells and mmWave backhaul as a cost efficient solution to enable high data rate services inside malls.

| Table 7: [MiWaveS D2.4] Summary of the KPIs for MiWaveS use cases. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| **High-level targets** | **KPIs** | **Use cases** |
| Capacity | End-user capacity | 1, 2, 3 |
| | Area throughput/system capacity | 1, 2, 5 |
| Service and reliability | Reliability (service/backhaul) | 2, 3, 4 |
| | System coverage | 2 |
| | Backhaul range | 4 |
| | QoS and QoE | 1, 4, 5 |
| Green radio | Energy efficiency / power consumption | 1, 2, 3, 4, 5 |
| Network flexibility / TCO reduction | Efficiency of installation and operation | 1, 4 |
| | HetNet capability | 1, 3 |
| | Network adaptation versatility | 3 |
| | Cost efficiency | 3 |

The most relevant MiWaveS use cases for 5G-MiEdge are Use Case 2 and Use Case 5. Both of them concentrate mainly on backhaul problems, whereas 5G-MiEdge focuses on access aspects as well.

2.3.6 mmMAGIC

mmMAGIC (mmWave based mobile radio access network for 5G integrated communications) [mmMAGIC D1.1] is an industry-driven large-scale integrating EU-funded FP8/H2020 project. mmMAGIC will be finalized in June 2017 and is composed of 18 consortium members, chosen among the key players in the telecommunication ecosystem, bringing together major infrastructure vendors, operators, measurement equipment vendors, universities and research centers and an SME.

The main objective of the project is to design and develop new concepts for mobile radio access technologies for deployment in the 6-100 GHz range, with particular focus on impacting the standardization of 5G systems.
In the following Table a summary of the use cases and the main KPIs taken into consideration is provided.

Table 8: [mmMAGIC D1.1] Summary of the mmMAGIC use cases and KPIs.

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Broadband access in dense Areas</th>
<th>High user mobility</th>
<th>E-real time communication and Ultra reliable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use Case 1</td>
<td>Media on demand</td>
<td>Cloud services</td>
<td>Dense urban Society with distributed crowds</td>
</tr>
<tr>
<td>Use Case 2</td>
<td>15</td>
<td>300</td>
<td>25 (up to 50)</td>
</tr>
<tr>
<td>Use Case 3</td>
<td>Very low</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Use Case 4</td>
<td>4000</td>
<td>2500</td>
<td>30000 (with peaks of 150000)</td>
</tr>
<tr>
<td>Use Case 5</td>
<td>60</td>
<td>750</td>
<td>7500</td>
</tr>
<tr>
<td>Use Case 6</td>
<td>50</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Use Case 7</td>
<td>50</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Use Case 8</td>
<td>50</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

The most relevant mmMAGIC use cases for 5G-MiEdge are UC3, UC5 and partially UC4. 5G-MiEdge follows a different approach to the problems highlighted by all those use cases, as the introduction of MEC technologies is not taken into consideration at all in mmMAGIC.

2.3.7 CHARISMA
CHARISMA (Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for intelligent and Secure Media Access) [CHARISMA] proposes an intelligent hierarchical routing architecture that combines two important concepts: devolved offload with the shortest path nearest to end-users, and E2E security service chain via virtualized open access physical layer security, all integrated via an intelligent mobile cloud.
The use cases considered in CHARISMA, chosen to particularly feature and require the 3 key defining functionalities of CHARISMA, namely low latency, open access, and security, are listed here below:

- UC1: Automotive – Trains
- UC2: Automotive – Platooning, Vehicle Collision Avoidance
- UC3: Automotive – Buses,
- UC4: Big Event,
- UC5: Emergency - Fire Fighters,
- UC6: Factory of the Future (IoT),
- UC7: Video Streaming,
- UC8: Remote Surgery,
- UC9: Smart Grid.

The most relevant for 5G-MiEdge CHARISMA use cases are UC4 and partially UC2.

CHARISMA concentrates mainly at PHY layer w.r.t. wireless-optical integration and security aspects, whereas 5G-MiEdge rather on enhancements to the system architecture exploiting the synergy between mmWave and MEC technologies as well bringing the mmWave access to the next level of exploitability, also taking into consideration upper layers of the wireless protocol stack.

2.3.8 5G Champion

Figure 8 illustrates the overall 5G CHAMPION system [5GChamp]. 5G CHAMPION will address key 5G requirements and use cases with the following key technological objectives:
1) Provide a mmWave high capacity backhaul link with 2.5 Gbit/s maximum data-rate using 400 MHz ~ 1 GHz bandwidth in the 24-29.19 GHz band;

2) Provide up to 20 Gbit/s user data rate over a mmWave indoor link;

3) Provide in the high mobility scenario a user-experience of 100 Mbit/s;

4) Provide a seamless access to satellite communications for 5G devices including narrowband IoT service to 5G UE ‘as is’ via a satellite component.

5) Demonstrate 1-2 ms latency over the 5G wireless backhaul link;

6) Demonstrate an agile management of the core network functionality and services through an SDN/NFV evolved packet core;

7) Ubiquitous (indoor-outdoor) location accuracy < 1 m;

8) Improved multi-link connectivity supporting simultaneous or adaptively selecting wireless backhaul to several entry points into the network.

The 5G CHAMPION project targets to demonstrate the interoperability of three enabling technologies (i) mmWave radio access for the wireless backhaul, (ii) heterogeneous access and (iii) localized EPCs (Evolved Packet Cores), (iv) satellite systems.

Figure 8. 5G CHAMPION System [5GChamp].

2.3.9 5GPPP

In April 2016, the 5GPPP issues a document providing an overview of the use cases developed from various 5G-PPP phase 1 projects related to the 5G radio access network [5G-PPPWP]. Although these different projects have defined their own use cases, they are mainly focusing on three services (xMBB, uMTC and mMTC). Therefore, the 5G-PPP grouped the different defined use cases into six families, as detailed in Table 9.

<table>
<thead>
<tr>
<th>Group</th>
<th>Comments</th>
<th>METIS-II</th>
<th>FANTASTIC-5G</th>
<th>mmMAGIC</th>
<th>SPEED-5G</th>
<th>SGNORMA</th>
<th>Flex5GWare</th>
<th>VirtuWind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban</td>
<td>Indoor</td>
<td>Dense</td>
<td>Dense</td>
<td>Dense</td>
<td>Dense</td>
<td>V2X +</td>
<td>Smart</td>
<td></td>
</tr>
<tr>
<td></td>
<td>outdoor</td>
<td>urban</td>
<td>urban</td>
<td>urban</td>
<td>massive</td>
<td>venues</td>
<td>Meters</td>
<td></td>
</tr>
</tbody>
</table>

Table 9: 5G-PPP use case families [5G-PPPWP].
### 2.3.10 MIC Research & Development of Spectrum Usage for Wireless Access Networks at Millimeter-Wave Band (2012-2016)

This project investigated 60 GHz and 40 GHz mmWave spectrum to be used for access and backhaul in cellular networks. The use case considered in this project is entertainment contents download at gates using 60 GHz access overlaid on the wide area networks. Figure 9 shows developed hardware prototypes for 60 GHz access, with developed CMOS devices and 32x32-element antenna array realizing 6.1GHz data rate at a smartphone, and 40 GHz backhaul with full duplex functionality.

<table>
<thead>
<tr>
<th>Dense Urban Environment</th>
<th>Information Society below 6 GHz</th>
<th>Society with Distributed Crowds</th>
<th>Cloud Services</th>
<th>Immersive 5G</th>
<th>Early Experience</th>
<th>MTC Communications in Urban Environments</th>
<th>Dynamic Hotspots and Secondary Substations in Dense Urban Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadband (50+Mbps) everywhere</td>
<td>Focus on suburban, rural and high speed trains</td>
<td>Broadband access everywhere</td>
<td>50 Mbps everywhere</td>
<td>High speed train</td>
<td>50+ Mbps everywhere</td>
<td>Media on demand</td>
<td>Mobile broadband in vehicles V2X communications for enhanced driving</td>
</tr>
<tr>
<td>Connected Vehicles</td>
<td>uMTC and/or xMBB on cars, V2V and/or V2X</td>
<td>Connected cars</td>
<td>Automatic traffic control/ driving High speed train</td>
<td>Moving hot spots; Traffic jam; Vehicular communication</td>
<td>Smart offices</td>
<td>Future connected office</td>
<td>Smart cities</td>
</tr>
<tr>
<td>Future Smart Offices</td>
<td>Very high data rates indoors and low latency</td>
<td>Virtual reality office</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Bandwidth IoT</td>
<td>A very large number of connected objects</td>
<td>Massive deployment of sensors and actuators</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Grid backhaul and grid backbone have reliable, ultra-low latency requirement</td>
</tr>
<tr>
<td>Tactile Internet / Automation</td>
<td>Ultra reliable communication with xMBB flavour</td>
<td>Tactile Internet</td>
<td>Tactile internet/ video augmented robotic control and remote robotic manipulation on surgery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

5G-MiEdge
Figure 10 shows a PoC system of 60 GHz and 40 GHz integrated heterogeneous networks demonstrated in Tokyo Institute of Technology in Mar. 2016. The PoC demonstrated seamless services of video data download over the mmWave integrated heterogeneous networks. This prototype hardware will be integrated into 5G-MiEdge project to be combined with MEC technologies. [ATN16]

(a) 60 GHz UE.  
(b) 60 GHz BS.  
(c) 40 GHz full duplex backhaul.

Figure 9: Developed hardware prototypes for 60 GHz access and 40 GHz backhaul.

2.3.11 MIC: Research & development of advanced multiplexing and interference management technologies for millimeter-wave frequency bands

The project aimed to develop technologies required for point-to-multipoint millimeter-wave access (Figure 11) that is applicable for public deployment use-case scenarios such as in stores and train stations. The project also developed the technology for co-existence of millimeter-wave systems. The project carried out system simulations, experimental demonstrations (Figure 12) and standardization activities (mainly in IEEE 802.11TGay), and successfully developed interference management technologies for efficient use of the 60 GHz frequency band.
2.4 NGMN

In March 2015, the NGMN Alliance published the NGMN 5G White Paper [NGMN5G], where the alliance, to support the future standardization process, described its vision on the operator requirements for 5G. NGMN has defined twenty-five use cases for 5G, grouped into fifteen categories and eight use case families. Amongst the fifteen categories, the most relevant for 5G MiEdge are five of them, which are summarized in Table 10.

Table 10: Main requirements and KPIs for the relevant test cases as defined by NGMN [NGMN5G].

<table>
<thead>
<tr>
<th>Use case</th>
<th>KPI</th>
<th>Requirements</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud</td>
<td>60GHz AP freq.</td>
<td>CH1 CH2 CH3 CH4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60GHz AP</td>
<td>2.4/5GHz AP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60GHz Area</td>
<td>60GHz Area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.4/5GHz Area</td>
<td>2.4/5GHz Area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AP Controller</td>
<td>Network Switch</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mobile Station (STA)</td>
<td>To LTE</td>
<td></td>
</tr>
</tbody>
</table>

2.4/5GHz Area

WiGig AP 2.4/5GHz AP

40Gbps

10Gbps

Figure 11: System architecture example.

Figure 12: Experimental demonstration of point-to-multipoint millimeter-wave access (at Narita international airport, Feb. 2016).
<table>
<thead>
<tr>
<th>Broadband access in dense areas</th>
<th>DL: 300 Mbps</th>
<th>UL: 50 Mbps</th>
<th>This data rate is motivated by ubiquitous support of Cloud services, video and other digital services, possibly combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2E latency</td>
<td>10ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>On demand, 0-100 km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device autonomy</td>
<td>&gt;3 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connection Density</td>
<td>200-2500 / km²</td>
<td></td>
<td>Total device density is 2000~25,000 / km², a 10% activity factor is assumed</td>
</tr>
<tr>
<td>Traffic Density</td>
<td>DL: 750Gbps / km²</td>
<td>UL: 125Gbps / km²</td>
<td>Connection density x User experienced data rate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Broadband Access in a Crowd</th>
<th>DL: 1Gbps, UL: 500Mbps</th>
<th>These data rates correspond to the Cloud storage service, which is the service with the highest data rates in the considered service mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2E latency</td>
<td>10ms</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Pedestrian</td>
<td></td>
</tr>
<tr>
<td>Device autonomy</td>
<td>&gt;3 days</td>
<td></td>
</tr>
<tr>
<td>Connection Density</td>
<td>75,000 / km² (75 / 1000 m²)</td>
<td>1 person per 4 m², 30% activity factor; typical area is 500~1000 m²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indoor Ultra-high Broadband Access</th>
<th>DL: 15 Tbps/km² (15 Gbps / 1000 m²)</th>
<th>UL: 2 Tbps/km² (2 Gbps / 1000 m²)</th>
<th>A mix of services is considered: 25% of active users use Cloud storage services with data rates DL: 1Gbps, UL: 500Mbps 30% of active users use Desk cloud services with data rates DL:20Mbps, UL: 20Mbps 5% of active users use Multiparty video conferencing with data rates DL: 60Mbps, UL: 15Mbps The remaining 40% of active users use less demanding services, neglected here. Within each service, an assumption is made on how much time is DL or UL. For cloud 67 storage, DL is 4/5 of time while UL is 1/5; for desktop cloud the ratio for DL and UL are 5/6 and 1/6; while for the multiparty video conference the ratio for DL and UL are 1 and 1 (always on during an active video conference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2E latency</td>
<td>10ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Pedestrian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device autonomy</td>
<td>&gt;3 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connection Density</td>
<td>150,000 / km² (30,000 / stadium)</td>
<td></td>
<td>Stadium: typical area 0.2 km², 100,000 persons, 30% activity factor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Broadband Access in a Crowd</th>
<th>DL: 25Mbps UL: 50Mbps</th>
<th>Main use case is HD video/photo sharing</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2E latency</td>
<td>10ms</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Pedestrian</td>
<td></td>
</tr>
<tr>
<td>Device autonomy</td>
<td>&gt;3 days</td>
<td></td>
</tr>
<tr>
<td>Connection Density</td>
<td>150,000 / km² (30,000 / stadium)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indoor Ultra-high Broadband Access</th>
<th>DL: 3.75 Tbps / km² (0.75 Tbps/stadium)</th>
<th>UL: 7.5 Tbps / km² (1.5 Tbps/stadium)</th>
<th>Connection density x User experienced data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Density</td>
<td>DL: 3.75 Tbps / km² (0.75 Tbps/stadium)</td>
<td>UL: 7.5 Tbps / km² (1.5 Tbps/stadium)</td>
<td>Connection density x User experienced data rate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mobile broadband in vehicles (cars, trains)</th>
<th>DL: 50Mbps UL: 25Mbps</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>E2E latency</td>
<td>10ms</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>On demand, up to 500km/h</td>
<td></td>
</tr>
<tr>
<td>Device autonomy</td>
<td>&gt;3 days</td>
<td></td>
</tr>
<tr>
<td>Connection Density</td>
<td>2000 / km²</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mobile broadband in vehicles (cars, trains)</th>
<th>DL: 50Mbps UL: 25Mbps</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>E2E latency</td>
<td>10ms</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>On demand, up to 500km/h</td>
<td></td>
</tr>
<tr>
<td>Device autonomy</td>
<td>&gt;3 days</td>
<td></td>
</tr>
<tr>
<td>Connection Density</td>
<td>2000 / km²</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mobile broadband in vehicles (cars, trains)</th>
<th>DL: 50Mbps UL: 25Mbps</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>E2E latency</td>
<td>10ms</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>On demand, up to 500km/h</td>
<td></td>
</tr>
<tr>
<td>Device autonomy</td>
<td>&gt;3 days</td>
<td></td>
</tr>
<tr>
<td>Connection Density</td>
<td>2000 / km²</td>
<td></td>
</tr>
</tbody>
</table>
2.5 5GMF

The 5th Generation Mobile Communications Promotion Forum (5GMF) is the Japanese governmental forum to promote 5G established in Sep. 2014. They have selected six usage scenarios in July 2016 related to 5G-MiEdge project as shown Table 11 [5GMFWP]. They have proposed several requirements for 5G including peak data rate more than 1 Gbps per user, functionality of content caching to reduce user experience latency, and dynamic network management with inter operable control signaling to reduce CAPEX/OPEX. Since these requirements are very close with 5G-MiEdge project, we (5GMF and 5G-MiEdge) have similar vision toward 5G.

Table 11: Usage scenarios and corresponding requirements proposed by 5GMF.

<table>
<thead>
<tr>
<th>Usage scenario</th>
<th>Category</th>
<th>Overview</th>
<th>KPI</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Enhanced real experience entertainment</td>
<td>Entertainment</td>
<td>Experience sharing, Simulated experiences, virtual reality, Omni-cam, 1 Gbps/user peak 400 Gbps/km^2</td>
<td>Peak data rate, Throughput, Mobility, Connection density, Spectrum efficiency, Area capacity</td>
<td>Peak data rate, Connection density, Spectrum efficiency, Area traffic capacity</td>
</tr>
</tbody>
</table>
3 Definition of Use Cases

5G-MiEdge proposes five core use cases that best show the need and the benefits of merging MEC- and mmWave-based technologies, namely 1) Omotenashi services, 2) Moving hotspot, 3) Tokyo 2020 Olympic Games, 4) Dynamic crowd, and 5) Automatic driving. Each use case is detailed and is then linked to relevant scenarios that exploit the advantages of the use cases and provide all details on their realistic and possible implementations in-the-field.
In each use case, the technical challenges that can be overcome via the joint use of mmWave and MEC technologies are explained, while the scenarios define all the constraints related to e.g. max number of users, max delivered bandwidth, etc.

It is worth to stress, that only a subset of these use cases and the associated scenario will be demonstrated at the end of the project. This subset will be chosen by the work packages that deal with the 5G MiEdge technology, to better reflect the advantages and the improvement of this technology.

3.1 Omotenashi services

3.1.1 Use case

Omotenashi is the Japanese style of hospitality. Its goal is to make the customers who come to Japan have fun and feel satisfied by providing a service adjusted to customer needs. On the way to their destination, visitors need to wait for a while on many occasions. For instance, tourists normally arrive at the airport two hours prior to departure of their flight. After check-in, they go shopping, eat food, etc. and then they continue to the waiting area at the departure gate.

After arrival at the airport of their destination, some passengers go to another gate for connecting flights, and others head for public transportations, such as a train or a bus, to go to their next destination. In any cases, they need to wait for a while at the waiting area until their next departure.

When tourists arrive at an airport or a station, they often download large volumes of content, such as tourist information, 3D virtual tour videos and games, before they leave for their next destination. They can enjoy these downloaded contents in flight/train/bus without worrying about availability of a high-speed network connection.

They can also download multi-language information, 3D indoor maps, shopping promotion video clips, 4K/8K live videos etc. for better shopping experience at airport/station/shopping malls.

Omotenashi services in 5G-MiEdge aim to offer ultra-fast wireless connection so that the visitors to Japan can enjoy high quality services such as video download, 3D virtual tour (VR), games etc. without suffering from throughput limitation.

3.1.2 Omotenashi specific applications

(a) Ultra-high-speed content download in a dense area

People download large volume contents while they stay at a waiting area. The maximum data size of the contents will be around 2 GB, which corresponds to a compressed two hour HD movie.

(b) Massive video streaming

People watch videos, such as 3D virtual tour videos, shopping promotion video clips and 4K/8K live videos, at their own preferred time. The challenge is to provide different videos for multiple users in a same location at the same time. The data rate
requirement depends on the quality of the video, but it is typically in the range of 15 to 50 Mbps, assuming a highly compressed video for a smartphone/tablet.

3.1.3 Scenario Description

3.1.3.1 The Airport

At the airport, there are several places for the passengers to visit or stay before their departure. Typical examples are waiting areas at the departure gate, airport lounges, retails, restaurants etc.

In Tokyo area, there are two primary airports, Haneda international airport and Narita international airport, which handled 80 million passengers and 39 million passengers in 2016 respectively. The density of travelers in these areas varies depending on the flight schedule or the season.

Fig. 4.1.1 shows a departure waiting area, which is one of the typical areas for passengers to stay at the airport. In this specific example, chairs are placed side-by-side, with a density of about 400 seats within 600 m², which is assumed as one of the most congested area.

The capacity of airplanes also varies depending on airline companies, routes etc., but there are typically around 300 seats in widely used airplanes such as Boeing 767 and Airbus A340. Therefore, it can be assumed that about 300 passengers wait at the waiting area at boarding announcement.

![Fig. 4.1.1 Departure waiting area at the airport](http://www.aviationwire.jp/)

3.1.3.2 The Train Station

E231-500 is the typical commuter train operated on Soubu line, which is passing by the main stadium of Olympic game. The train formation has 10 cars, each 20 m long. The capacity of passengers is about 1,500 at 100% ride rate. The nearest train station, Sendagaya, has a platform about 5 m wide with two tracks, east bound and west bound. During rush-hour, the ride rate goes up to 200%. Assuming 10% of passengers get on/off the train, 600 passengers may wait for coming trains, which is assumed as the most congested situation at the train station.
3.1.3.3 The Shopping Mall
At the shopping mall, there are many places crowded with people. One of the typical examples is a food court. The one shown in 4.1.3 occupies 680 m² with 450 chairs. Therefore, it can be assumed that the population density is similar to the waiting area at the airport.

3.1.4 Expected traffic
3.1.4.1 At the Airport
(a) Ultra-high-speed contents download in a dense area
Assumption:
- Average file size of a movie: 2 GB (2 hours, HD 720p, 30fps, H264)
- Average number of movies downloaded per passenger: 3 movies
- Number of passengers who download contents: 100 (30% of 300 total passengers)
- Waiting time before boarding: 30 min.
- Area: 600 m²
The assumption listed above gives 6 GB (2 GB x 3) data download per a passenger, and 600 GB (= 2 GB x 3 x 100) total data traffic.

If we assume 2 Gbps data rate for each mmWave access link, the required download time for 6 GB data download is 24 sec (=6GB x 8 / 2 Gbps).

By using only single 2 Gbps mmWave link, the download of 100 passengers will take more than 40 min. (= 24 x 100 / 60). In order to complete 100 passengers’ data download within 30 min., multiple mmWave links are needed. As an example, three concurrent mmWave links gives six Gbps system throughput, resulting in less than 15 min. for total download time.

(b) Massive video streaming
Assumption:
- Required data rate per passenger: 50 Mbps
- Average number of passengers who watch video streaming: 100 (30% of 300 total passengers)
- Area: 600 m²

The total system throughput is calculated as five Gbps (= 50 Mbps x 100). Assuming 100 passengers distribute in the 600 m² waiting area, 3 to 6 mmWave APs will be sufficient to cover the whole waiting area.

3.1.4.2 At the Train Station
At the train station, the shortest interval of trains could be only 3 minutes. Therefore, only contents download use case is discussed. From another point of view, the passengers in the train car will be considered later in the moving hotspot use case in more detail.

(a) Ultra-high-speed contents download in a dense area
Assumption:
- Average file size of a movie: 500 MB (30min, HD 720p, 30fps, H264. Note: short video clip will be preferred in the train.)
- Average number of movies downloaded per passenger: 3 movies
- Number of passengers who download contents: 200 (30% of 600 passengers on the platform)
- Waiting time before boarding: 3 min. (shortest interval of trains)
- Area: 500m² (5m x 10m)

Similar to the airport use case, the download data per passenger and the one per total system can be calculated as 1500 MB and 150 GB respectively.

Assuming 2 Gbps max. throughput, each passenger can download 1500 MB data within 6 sec.

In order to handle 150 GB data traffic within 3 min, at least 6.6 Gbps (= 150 GB x 8 / 3min / 60) system throughput is required.
If we install mmWave APs at every 10 m spacing along the 100 m long platform, the maximum system throughput reaches 20 Gbps (by 10 APs), which can handle 6.6 Gbps traffic estimated above with sufficient margin.

3.1.4.3 At the Shopping Mall

Since this use case is similar to the airport, detailed discussion is omitted.

3.1.5 Added value of mmWave and MEC Technologies

Since waiting areas are highly crowded with people, the network system needs to provide sufficient throughput even in a dense populated environment. In order to achieve ultra-high-speed throughput, the system combines mmWave access with MEC, which brings computation and storage at the edge of the network. In particular, MEC enables to pre-fetch the most popular or requested contents to the local edge server in order to prevent backhaul congestion. Furthermore, running analytics on the MEC servers makes possible to learn, locally, which are the most popular contents across time, such as breaking news, etc., in order to optimize the pre-fetching step.

The use of mmWave access also provides highly directional signal characteristic, which is suitable for avoiding interference in the dense area.

Since communication distance of mmWave access is relatively limited, it is reasonable to expect users to approach a dedicated download spot (like a mobile KIOSK) at initial launch of the download service. The mmWave shower, which will be discussed in the stadium gate use case, will be another choice. As the download service becomes popular, multiple mmWave APs will be adopted to extend the area coverage and offer better user experience. The orchestration of these multiple mmWave APs will be facilitated by the presence of MEC servers.

3.1.6 Requirements for 5G systems

- Peak user rate: 2 Gbps
- Area coverage: 100 (train platform) to 1000 m² (airport waiting area and shopping mall)
- Area peak system rate: more than 6.6 Gbps
- End-to-end latency: not critical (around 200ms will be acceptable)
- Mobile edge cloud: prefetching of download contents to avoid backhaul congestion and running local data analytics to learn most popular contents as a function of time
- HetNet: integration of unlicensed 60 GHz band
- User/application centric orchestration: delivering high-quality overall application experience
- Micro-operator: providing specific, localized services
- Traffic density: 10 Mbps/m² (= 6 Gbps/600 m² at airport waiting area and shopping mall), 13.2 Mbps/m² (= 6.6 Gbps/500 m² at train platform)
- Mobility: stationary to pedestrian (4 km/h)
3.1.7 Similarity & difference with other projects

The ultra-high-speed access in a dense area is considered as one of the most important requirements in 5G. Therefore, there are several projects targeting for similar use cases.

For example, mmMAGIC and NMGN describe broadband access in a dense area as a first use case example. METIS mentions “amazingly fast” scenario which provides very high data-rates for users to experience instantaneous connectivity without perceived delays. The project also lists several test cases such as a virtual reality office and a shopping mall.

5GMF also presents similar use cases such as content downloads by commuters as well as communications during the rush hour commute. Besides, 5GMF addresses the importance of MEC, which will play a central role in order to support end-to-end quality of applications and services.

The use case described in this section is similar to these prior examples, but MiEdge puts more focus on combination of mmWave access and MEC. It includes prefetching/caching as well as orchestration in order to get full benefit of mmWave ultra-high-speed access, which is the uniqueness of the project.

3.2 Moving Hotspot Scenario

3.2.1 Use Case

A moving hotspot describes a wireless communication system for passengers making a potential long trip on train, bus, or airplane. Moving hotspots require wireless link as a backhaul due to mobility of train/bus/airplane. Therefore, it is required to have communication measure 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 and/or passing some spots on the routes.

3.2.2 Moving hotspot specific applications

(a) Entertainment contents download

Passengers in flight/train/bus can download large volume contents, such as video and games which are stored in the local (edge) content server.

The downloaded contents are pre-fetched to the station/airport/bus-stop based on the users’ request history and their locations, and then they are transferred to the local server in the flight/train/bus while stopping at the station/bus-stop/airport and so on. These data are wirelessly delivered to passengers’ mobile devices.

(b) Upload and share sightseeing photos/videos in SNS

Passengers in flight/train/bus wirelessly upload sightseeing photos/videos to the local server instantaneously. The uploaded data are transferred to the cloud server afterwards while stopping at the station/bus-stop/airport and so on. These data are shared with their friends/families through SNS.
3.2.3 Scenario Description

3.2.3.1 The Train
The formation of JR (Japan Rail) Soubu line which is passing aside of the Olympic main stadium is assumed as the typical geometry for train. This train car is very general as similar train cars are used very much for commuter train around Tokyo.

Train car capacity: about 150 passengers
Train cars for a formation: 10

![Fig 4.1.4 Soubu line (JR)](https://www.jreast.co.jp/train/local/e231.html)

3.2.3.2 The Bus
Route bus capacity is about 30 for seating. If considering standing passengers, capacity is 50 more or less.

The capacity of long distance bus is 45 generally.

![Fig 4.1.5 General route bus in Tokyo](http://www.kotsu.metro.tokyo.jp/bus/)
3.2.3.3 The Airplane

The capacity of large airplanes from Airbus/Boeing is 250-350. It is different by airplane type, operating carrier, route, etc. Here, Airbus A340-600 is assumed for the typical geometry. It is general for routes between Europe and Japan.

![A340-600](image)

Fig 4.1.6 A340-600, example of seating layout

Source: http://www.lufthansa.com/jp/ja/Seat-maps_A340-600

Figure above is a seating layout example of A340-600, Lufthansa. There are 297 seats in total, first 8, business 44, premium economy 32 and economy 213. The cabin is divided into 6 compartments.

3.2.4 Expected traffic

3.2.4.1 In the Train

150 passengers are assumed for 100% full in each car of commuter train in Tokyo at the most congested hour. Assuming 30% of them to download 2GB contents from the local MEC server in the train during the station interval of 2 minutes, the required average bit rate for a train car is:

\[
2\text{[GB]} \times 8589934592\text{[bits/GB]} \times 150 \times 0.3 / (2 \times 60) = 6.442\text{[Gbps]} \quad \text{(downlink)}
\]

In order to moderate link blockage by human bodies, multiple IEEE802.11ad access points may be necessary inside a car. Considering 3 access points, the required bandwidth will be divided to them as 2.15Gbps (= 6.442 / 3).

The aggregate traffic of a train formation is: 6.422 x 10 = 64.22[Gbps] (downlink)

Assuming 30% of them to upload 500MB into SNS during the station interval of 2 minutes, the required average bit rate a train car is:

\[
0.5\text{[GB]} \times 8589934592\text{[bits/GB]} \times 150 \times 0.3 / (2 \times 60) = 1.611\text{[Gbps]} \quad \text{(uplink)}
\]

When considering 3 access points in a train car, upload traffic will be divided to 0.54[Gbps] for an access point.

And traffic summation of a train formation is: 1.611 x 10 = 16.11[Gbps] (uplink)

Traffic summation of downlink and uplink for a train formation is 80.33 [Gbps] (= 64.22 + 16.22). The dimensions of a train formation is 600 m² (= 200 x 3) approximately. So the traffic density is 134 Mbps/m² (= 80.33 Gbps/600m²).
Mobility is about 120 km/h for commuter train at the fastest. However, it is not necessary to consider mobility between user’s devices and the local server. Passengers are still inside a train car.

It is not so critical on latency between user’s devices and the local server. It is acceptable to have 100 ms latency at the worst because of content characteristics of this use case.

Regarding backhaul for synchronizing and sharing contents between the local MEC server on train and cloud servers, it may be sufficient to have 10Gbps link for transferring contents at stations. It can transfer data of 75GB (= 10G / 8 x 60) approximately in a minute. However, it depends on interval between spots for synchronization and algorithm of prefetching/caching. They will also affect the storage size of the local MEC server.

3.2.4.2 In the Bus

50 passengers are assumed for a bus at the most. Applying the same traffic model as the one for train, 1/3 traffic will be generated.

$$6.442 / 3 = 2.147 \text{ [Gbps]}$$ for downlink

$$1.611 / 3 = 0.537 \text{ [Gbps]}$$ for uplink

The traffic summation of downlink and uplink is 2.684[Gbps] (= 2.147 + 0.537). The dimensions of a bus is 25 m$^2$ (= 10 x 2.5) approximately. So the traffic density is 107Mbps/m$^2$ (= 2.684 Gbps/25m$^2$).

Mobility is about 50 km/h for bus at the fastest. However, it is not necessary to consider mobility between user’s devices and the local server. Passengers are still inside a bus.

It is not so critical on latency between user’s devices and the local server. It is acceptable to have 100ms latency at the worst because of content characteristics of this use case.

Regarding backhaul for synchronizing and sharing contents between the local MEC server on train and cloud servers, it may be sufficient to have 1Gbps link for transferring contents at stations. It can transfer data of 3.8 GB (= 1G / 8 x 30) approximately in 30 seconds. Coming-in/going-out of passengers is less dynamic than train. Frequency of content update to the local MEC server may be moderate. However, it depends on interval between spots for synchronization and algorithm of prefetching/caching. They will also affect the storage size of the local MEC server.

3.2.4.3 Inside the Airplane

It is around 30 minutes for mmWave access to be considered as the most congested minutes just after permission of radio emission from personal devices in the cabin after taking off.

Assuming one access point for a compartment, the densest compartment is economy class. There are 213 passengers in two economy class compartments. Assuming 100% of them to download 2GB content in 30 minutes, the required average bit rate in a compartment is:
2 [GB] x 8589934592 [bits/GB] x 213 / 2 x 1.0 / (30 x 60) = 1.016 [Gbps] (downlink)

Traffic summation of the entire cabin: 1.016 x 297 / (213 / 2) = 2.833 [Gbps]

Assuming just 1 hour available for mmWave access during domestic flight, passengers can upload their contents of sightseeing pictures or videos to SNS within the time. Their upload will be random and disperse. In such situation, the required average rate for the entire cabin is:

0.5 [GB] x 8589934592 [bits/GB] x 297 / (60 x 60) = 354.3 [Mbps]

The traffic summation of downlink and uplink is 3.187 [Gbps] (= 2.833 Gbps + 354 Mbps). The dimensions of an airplane is 323 m$^2$ (= 61 x 5.3) approximately. So the traffic density is 10 Mbps/m$^2$ (= 3.187 Gbps/323m$^2$).

Mobility is 1000 km/h for airplane at the fastest. However, it is not necessary to consider mobility between user’s devices and the local server. Passengers are still inside an airplane.

It is not so critical on latency between user’s devices and the local server. It is acceptable to have 100 ms latency at the worst because of content characteristics of this use case.

Regarding backhaul for airplanes, there is no chance to have sufficient bandwidth during its flight except satellite link, except when flying over land with sufficient ground bound communication infrastructure. Considering these characteristics, download of local contents from the local MEC server is the main use case. Those downloads will occur only during flight. Therefore, it is not necessary to consider frequent updates of content on the local MEC server at airports. When considering that all passengers upload contents to SNS during flight, data of 149 GB (= 0.5 GB x 297) will be generated. Considering 2 Gbps link for backhaul at airport, all uploaded contents will be transferred in 10 minutes (= 149 x 8 / 2 / 60). It will be finished during passengers disembarking.

3.2.5 Added value of mmWave and MEC Technologies

The mobile hotspot consists of Wi-Fi/WiGig access point, local MEC server, and other components to deliver video content and games to passengers. Moreover, passengers upload sightseeing photos/videos into SNS. Uploaded contents will be stored in local MEC server temporarily and transferred to the cloud when backhaul bandwidth is sufficient. When a user starts wireless communication via mmWave inside the vehicle, its traffic flow will be transferred to the local MEC/content server. He can select/download favorite large volume contents like videos or games based on suggestions provided by 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. The users can enjoy contents without being conscious of the difference from regular Internet communication. At this time, it is important that MEC properly caches or pre-fetches content according to user/application demands.
Adding computation capabilities in the MEC servers in terms of capability to instantiate and run virtual machines, makes possible to learn the content popularity, across space and time, to optimize the cache pre-fetching step. Regarding upload, distributed server functions on the local MEC server will temporarily cache uploaded contents by users such as photos/videos. The users can upload their contents also without being conscious of the difference from regular SNS uploading. The uploaded contents temporarily cached on the local MEC server will be transferred to the cloud when the vehicle obtains sufficient bandwidth of backhaul at stations/bus stops/airports and so on.

3.2.6 Requirements for 5G systems

3.2.6.1 Train
- High peak data rate for user link: DL: 2.15 Gbps, UL: 0.54 Gbps
- High peak data rate (e.g. 10Gbps) for backhaul at stations for synchronizing with cloud servers
- mmWave (WiGig) access inside train cars for high data rate with counter-measures for link blockage by passengers
- Area coverage: 10 – 20m
- MEC server(s) in a train formation for data prefetching/caching
- Distributed server function of SNS on the local MEC server
- Traffic density: 134 Mbps/m² (80.33 Gbps/600m²)
- Mobility: 120 km/h, but passengers are still inside a train car

3.2.6.2 Bus
- High peak data rate for user link: DL:2.147 Gbps, UL:0.537 Gbps
- High peak data rate (e.g. 1 Gbps) for backhaul at bus stops for synchronizing with cloud servers
- mmWave (WiGig) access inside buses for high data rate with counter-measures for link blockage by passengers
- Area coverage: 10m
- MEC server in a bus for data prefetching/caching
- Distributed server function of SNS on the local MEC server
- Traffic density: 134 Mbps/m² (2.684 Gbps/25m²)
- Mobility: 50 km/h, but passengers are still inside a bus

3.2.6.3 Airplane
- High peak data rate for user link: DL:2.833 Gbps, UL:354.2 Mbps
- High peak data rate (e.g. 2 Gbps) for backhaul at airports for synchronizing with cloud servers
- mmWave (WiGig) access inside airplane for high data rate with counter-measures for link blockage by seat backs and passengers
- Area coverage: 10m for a compartment of the cabin
- MEC server in an airplane for data prefetching/caching
- Distributed server function of SNS on the local MEC server
- Traffic density: 10 Mbps/m² (3.187 Gbps/323m²)
- Mobility: 1000 km/h, but passengers are still inside an airplane
3.3 2020 Tokyo Olympic

3.3.1 Use Case

![Image of entrance ports equipped with mmWave showers]

Figure 13: Entrance ports equipped with mmWave showers

In the 2020 Tokyo Olympic stadium, a visitor may be expected to pass under the 6 entrance gates (see Figure 13) with a very high frequency (see section 4.3.3. for further details). The six entrance gates are subdivided in a large number of multiple access ports (typically equipped with turnstiles), to enable an efficient filling of the stadium. To accelerate the flow rate, spectator electronic tickets may be read from fixed access points. Whenever a visitor passes the gate, he can download event-specific applications together with the associated large volume of data e.g. event schedule, related videos in the past events, player’s profile etc. to enjoy the unique applications e.g. AR/VR while watching the game. Regarding the hot spot antenna two possible solutions can be considered: a single hot spot antenna that serves all the access ports of a gate or multiple antennas (one information shower per each entrance port).

3.3.2 2020 Tokyo Olympic specific applications

The 2020 Tokyo Olympic represents one of the most challenging use cases of extreme mobile broadband due to both the very high bit rate requirements per single connection and the very high user density. In addition to the requirements affecting the total system capacity, the very low latency required by some of the advanced multimedia services (e.g., immersive communications) makes even more difficult to design an adequate communication system.

These applications will require a combination of ultra-high connection density, high data rate and low latency.

3.3.2.1 Stadium gates

(a) Olympic game application/data download

At the stadium gate, visitors download specific application of the event and large data (related videos in the past events, player’s profile etc.) to enjoy the unique applications, such as AR/VR, while they are watching the game.

Visitors can also download the 4K/8K premium videos of the game when they leave the stadium, in such a case is assumed that downloaded content size is about 1~5 min. compressed video clip.
3.3.2.2 Stand and sports arena

(a) 4K/8K multi camera video capturing, 4K/8K video download (video analytics)

At sports events, the videos from multiple 4K/8K video cameras are collected to the edge server, and then multi-viewpoint live videos are created in real-time for TV broadcast. The multi-viewpoint videos are also shared with spectators wirelessly to enjoy 360° high-definition live videos on their smartphone/tablet. The edge server also creates AR/VR videos for the spectators to enjoy unique user experience.

(b) Massive SNS sharing

A large number of users share pictures/videos at the same time, for example at the moment of goals of a soccer match, grand slam of a baseball etc. The massive data from many users are instantaneously uploaded to an edge server and user specific contents are created and shared with other fans at the stadium wirelessly as well as with fans in other locations through internet.

3.3.3 Scenario Description

Typical geometry of a stadium is based on the plan of the new National Stadium for Tokyo Olympics 2020. The stadium will be built above an area of about 7.24 ha with totally 7 levels (2 underground) containing of 3 layers of stands and seats for more than 60,000 audiences. This stadium has six gates each might be supported by multiple entrance ports to accommodate all the audiences attending the events.

![Figure 14: New National Stadium for Tokyo Olympics 2020.](Source: Japan Sport Council)

The new stadium is distinguished for its wood structure and green spaces based on the concept of the harmonization with nature. The building whose roof height is...
below 50 m was designed as an oval structure with a huge oculus above the track. Seating stands will be sheltered below the latticed larch and steel canopy, and circulation areas around the edge of each level will feature plants and trees, to respect the surrounding park. A system of natural wind will control the temperature of the stadium to counteract high temperatures of Summer time in Japan. The stands and sports arena was designed to be easily accessible for everyone including handicapped, where routes are equipped with block sign and voice guidance. Considering evacuation in case of disasters, audience at everywhere inside the building can access to emergency exits by less than 15 minutes. Downloading information about the stadium in advance at the entrance gates might facilitate the enjoyment of audiences during the Olympic Games.

3.3.3.1 Stands and Sports Arena

Within the stadium the stands and sports arena are characterized by a number of high definition video cameras connected to a stadium media room, as depicted in Figure 15.
Figure 16: Reference architecture for video production and distribution within the stadium.

According to Figure 16, the high definition video cameras convey the video signal toward the media room of the stadium where all the required video processing is carried out. The logical connections depicted in the picture can be implemented both via optical fiber or wireless.

The goal is to enable the users to enrich their experience through augmented/virtual reality (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 augmented reality 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. A further important point is that, to prevent that computationally intensive applications will discharge the mobile device batteries too fast, it is necessary to resort to computation offloading from the mobile devices to the edge servers.

### 3.3.4 Expected traffic

3.3.4.1 Stadium gates

Both when entering and when going out through the gates, the time elapsed within the radio coverage of the “information shower” located at the gates or at the entrance ports is likely to be short.

a) Entering in the stadium

According to [FIFA] the entry capacity is the number of people that can pass through the turnstiles and/or other controlled entry points within a period of one hour. This is the same definition reported also in [Guide to safety at sports grounds of the UK Department for Culture, Media and Sport, ed. 2008]. According to the latter document, it is set un upper limit of 660 persons per turnstile per hour that cannot be exceeded. This means that the higher allowed entry flow rate is 0.183 persons/s, i.e., one person every 5.45 s. Rounding this number at 1 person every 5 s it is assumed a worst case situation. This is then the time available to download information/applications when entering the stadium. If the mmWave antenna covers only the single person passing through the turnstile, the required average bit rate to download a document with a peak size of 1 GB ($2^{30}$ B = 8589934592 bit) is:

$$ R_{\text{entering gate}} = \frac{8589934592}{5} \approx 1.718 \text{ Gbit/s} $$

Since the information shower is a “user oriented” information shower, the above value has to be considered as a peak value.

In case the antenna at the entering gate footprint is larger, the above bit rate has to be increased according to the number of users covered simultaneously.

In particular, when a unique antenna serves the overall set of the entrance ports associated with one of the six stadium gates, the overall traffic to be served increase significantly. Assuming 20 entrance ports for each gate, the above bit rate have to multiplied by 20, (so the required capacity increase to $R=1.718*20= 34.36 \text{ Gbit/s}$)
The operating assumptions is that the download of information starts automatically when entering in the coverage of the antenna (e.g., based on a user profile or on a prior request).

The mobility level of the users when passing through the entrance ports is very low.

b) Leaving the stadium

The provision of videos with the highlights of the event when the people is leaving the stadium is more challenging because the available time is shorter and the user density is higher.

According to [DCMS-Guide], it is recommended that, for a width of 1.2m, on a level surface, 100 people can reasonably exit in 1 minute (equal to 82 spectators per 1m width per minute). Assuming a 1 m wide gate, it means that 82/60 = 1.37 persons/s are passing through an exit gate (we round this value to 2 persons/s). Assuming a maximum video clip size of 500 MB, the information has to reach more than one person simultaneously.

Since two people have to be served simultaneously in one s (and, even if with the same size, not necessarily with the same information content) the following bit rate is required at each port:

\[
R_{\text{exit gate}} = 2 \times 500 \times 2^{20} \times 8/1 = 2 \times 500 \times 1048576 \times 8 = 8.4 \text{ Gbit/s (i.e., 4.2 Gbit/s per person)}
\]

Again, the number of persons served simultaneously can be modified according to the area covered by the information shower. In the case of a single antenna covering the 20 ports the required bit rate is:

\[
R_{\text{exit gate}} = 8.4 \times 20 = 168 \text{ Gbit/s}
\]

The above figures can be modified according to a coefficient that takes into account the percentage of subscription to this kind of service. At the moment, 100% of subscription is assumed.

The mobility level of the users when going out is higher with respect to the entrance case.

Assuming that the 20 ports cover an area about 30 m x 1 m, the higher user density occurs when leaving the stadium: 40 persons/30 m² = 1.33 users/m² (when entering is one half).

3.3.4.2 Stands and sports arena

(a) 4k/8k multi camera video capturing, 4k/8k video download (video analytics)
(b) Massive SNS sharing

Concerning the spectators, both the situations related to cases (a) and (b) can be summarized in a unique table where the traffic data and the transmission direction are modified according to the phase of the event. The assumed reference data are derived from those of use case 3 of NGMN “Broadband access in a crowd”. 

---

5G-MiEdge
It is reasonable to assume, that 20,000 spectators out of 60,000 at the stadium (about 30%) are connected (that is they have a control plane connection). The activity factor for the user plane traffic is variable according to the phase of the event. This means that, during the normal phases of the event, a low percentage of the active spectators is originating traffic (e.g., 10%). During the breaks it is likely that a significant (e.g., 50%) part of the active spectators will send/receive information. Immediately after special moment of the event (e.g., a goal scored), it is likely that a large percentage of the active spectators (e.g., 40%) will receive information and 30% of them will resend it to someone else. Of course, the activity factors can be modified according to specific references. The considered stadium surface is 0.072 km².

Table 12 reports the aggregated traffic [Gbit/s] to be served within the stadium.

<table>
<thead>
<tr>
<th>Phase of the event</th>
<th>Active Connections in the stadium</th>
<th>DL (50 Mbit/s per connection)</th>
<th>UL (50 Mbit/s per connection)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Activity</td>
<td>Traffic</td>
</tr>
<tr>
<td>Normality</td>
<td>20000</td>
<td>10%</td>
<td>100</td>
</tr>
<tr>
<td>Exceptional (e.g., goal, …)</td>
<td></td>
<td>40%</td>
<td>400</td>
</tr>
<tr>
<td>Break</td>
<td></td>
<td>50%</td>
<td>500</td>
</tr>
</tbody>
</table>

The above bit rates reflect the situation when both the connections between the high definition video camera-media room/MEC server and media room/MEC server-mmWave access points are realized by fiber. On the contrary, if the connection between video camera and media room/MEC server is an in-band wireless connection at mmWave, the impact on the uplink can be very different depending on the compression degree of the video signal provided at the output of the video cameras. Two possible extreme situations can be considered:

- **Uncompressed video signal at the video camera output.**

  According to the literature (for example [https://www.nttdocomo.co.jp/english/info/media_center/pr/2016/0524_00.html]), the uncompressed video signal is characterized by a very high bit rate: 48 Gbit/s for 8k video and 12 Gbit/s for 4k video. Assuming that a 4k video stream is sent to the media room by each of the 50 video cameras, a value of 50x12 = 600 Gbit/s has to be added to the uplink load already reported in the above table.

- **Highly compressed video signal at the video camera output**
It does not appear very likely that a highly compressed video stream is sent from the video cameras to the media room because, the video signal has to be further processed before its distributions. A low extra load on the uplink air interface represents the benefit of such a choice. If 50 Mbit/s is the assumed bit rate for highly compressed 4k video, the overall extra load on the uplink is 0.05 x 50 = 2.5 Gbit/s (to be added to the value of the above table).

In order to enable VR/immersive communications experience, the delay requirement has to be very low (not exceeding 5 ms [Seam]). At this regard, a MEC server co-located with the stadium media room should allow those requirements to be satisfied.

The additional uplink traffic originated by few mobile video cameras for security reasons is likely to be negligible. This because, it appears reasonable to assume that the stadium is already well covered by fixed video cameras installed for security.

Besides, if the backhaul connections between media room/MEC server and mmWave access points are in –band wireless connections at mmWave again such an extra load has to added to the value on the table.

Concerning the users density, assuming that the stands cover an area of 40,000 m², the user density is 60,000 spectators/40,000 m² = 1.5 users/m².

The users in the viewing area can be considered static (no mobility).

Concerning the traffic density in the access segment the peak value is 500 Gbit/s/40,000 m² = 12.5 Tbit/s/km².

### 3.3.5 Added value of mmWave and MEC Technologies

To cope with such a challenging use case, it is straightforward to make use of 5G wireless communications including both the main enablers necessary to provide very high bit rates jointly with low latency i.e., mmWave access and MEC servers. In the following, the details related to the geometry of the scenarios and of the use cases are shown.

In summary, to make the delivery of AR/VR applications possible, it is necessary to have:

a) Dedicated high capacity links between the fixed high definition cameras and the MEC servers of the media room (the MEC servers, are responsible for running the computationally intensive applications providing the immersive augmented reality experience to the mobile users)

b) High data rate mmWave download links serving a large number of users;

c) The development of dedicated applications, running on the mobile devices, handling the exchange of data between the mobile device and the hot spot 5G antenna, necessary to enable user navigation throughout the scene.

The MEC servers play a key role in offloading intensive computations from mobile devices to powerful servers, to overcome the battery bottleneck.
3.3.6 Requirements for 5G systems

- User rate: Minimum rate 50 Mbit/s (value arising from the assumptions we have done for the users on the stands)
- Area coverage (range): The minimum cell range is the one required by the information shower at each turnstile (i.e., 0.5 m radius).
- Area (system) rate: Total of 500 Gbit/s to serve the stands area of the stadium, radio access segment
- End-to-end latency: 5ms (for immersive reality)
- Requirements on backhaul: 1.718 Gbit/s + required overhead (single information shower per turnstile when entering)
- Requirements on computation: For applications using MEC functionality

3.3.7 Similarity & difference with other projects

The stadium scenario has been considered by several projects/international bodies as one of the most challenging for significant 5G use cases as those previously described (e.g., extreme mobile broadband for video content download/sharing/streaming and virtual/immersive reality). The challenge is mainly represented by the very high traffic density to be served. This scenario has been taken into account by projects like mmMAGIC, METIS-I/II and by international fora like 5GMF, NGMN, 3GPP.

The use cases/scenarios provided by those projects/fora, show a high-level general alignment with respect to what came out within 5G-MiEdge. Some differences can be noticed in the traffic density that, in 5G-MiEdge is higher (this because 5G-MiEdge assumes that many spectators ask for services based on very high definition video contents). The assumed minimum latency appears aligned with METIS-I/II. The international fora 5GMF is the one describing the usage scenario most aligned with the 5G-MiEdge/Olympic Game Stadium when talking about Entertainment/Enhanced real experience entertainment (shared experiences and virtual reality experience). It has to be highlighted that in 5G-MiEdge Olympic game stadium the very challenging requirements are not uniformly spread over the overall stadium area but are concentrated at the gates/entrance ports areas and on the stands inside the arena. Moreover, the MEC related considerations concerning running context aware data analytics and implementing effective caching strategies are a characterizing element of this project.
3.4 Dynamic crowd

3.4.1 Use Case

![Figure 17 Dynamic crowd use case.](image)

This use case focuses on a medium outdoor area located in the metropolitan city centre where thousands of people may spend part of their daily life (see Figure 17). The area is characterized by a several possible outdoor hotspots like bus stops, stations and recreation parks. Users at such outdoor hotspots might download large volume contents, such as tourist and shopping information, high definition 3D live broadcast of a game happening at a stadium nearby, or upload and share through SNS photos and videos recently taken near the place.

They can also download multi-language information, 3D indoor maps, shopping promotion video clips, 4K/8K live videos etc. for better shopping experience at the next destination nearby e.g. shopping departments around Shibuya station.

The significant difference of these scenarios is that the traffic pattern changes dynamically throughout a day (see Figure 18) in accordance to users’ activities e.g. changing from light to very busy traffic in specific hours of a day as seen in Figure 19.
Figure 18: An example of traffic variation at a station in Tokyo (2013).

Figure 19: Time varying user density in Tokyo area.
3.4.2 Dynamic crowd specific applications

3.4.2.1 Public video surveillance

4K/8K videos are uploaded from multiple surveillance cameras through wireless high-speed backhaul, which enables to lower installation cost. The collected videos are analyzed in the edge server in order to detect suspicious activity, find lost child etc.

3.4.2.2 3D live video broadcast of Olympic Games

People can watch 3D live video, such as sold-out games, in a public space. The population density and data traffic dynamically change depending on the event schedule, number of broadcast programs etc.
3.4.3 Expected traffic

Shibuya station is one of the most crowded stations in Tokyo. The station and its surrounding areas are depicted in the above map. At the central of this map, there is one nearby hotspot at Hachiko exit, where there is one of the crowded scramble crossroads in the world. The central area of highly dense traffic is of the size around 40 m x 40 m square. At this square, it is expected to have more than 1000 people in the peak hour, among them 300 people are stopping. However, if we take into also the surrounding area with shopping stores and entertainment buildings, the size of this dynamic crowd might be estimated as 2 km x 2 km where some traffic peaks which represent the hotspots can be observed in the below figure.
(1) Public video surveillance
6 video surveillance camera are assumed around the square.
50[Mbps] x 6 = 300[Mbps]

2) 3D live video broadcast of Olympic Games
50% of users are assumed to watch video broadcast of 50Mbps out of 300 waiting people.
50[Mbps] x 300 x 0.5 = 7.5[Gbps]

3.4.4 Added value of mmWave and MEC technologies

Associating a MEC server to a radio access point enables a pervasive security system, where the (cloud) computing capabilities of the MEC server make possible to rapidly analyse videos from mobile users or from fixed cameras locally, to raise early warnings about suspicious or anomalous behaviours, without the need to send all data to a centralized security agency. MmWave links from radio access points associated to these MEC servers located in the hotpots 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. For instance, a set of user lining up in a queue may be better served by multiple APs that see the users with a wider angle, to facilitate the use of spatial multiplexing.

Due to the variability of this environment and the high data rate requirements for multimedia broadband services, beside the traffic is dynamically changed throughout a day due to users’ activities, the introduction of ultra-broadband mmWave access and topology-flexible mmWave meshed backhauling are preferable. Some typical location specific applications for these scenarios are public surveillance and high definition video broadcast services.
3.4.5 Requirements for 5G systems

In such a dynamic crowd environment, network densification with many number of mmWave APs overlaid on the current LTE cells is effective to accommodate traffic in peak hours. However, many number of APs leads to the problem of high CAPEX and OPEX. One solution to relax the problem is to use mmWave meshed network for the backhaul network of APs. By using the mmWave meshed network, the CAPEX can be reduced by removing deployment cost of wired backhaul. Furthermore, the OPEX can also be reduced by introducing dynamic ON/OFF and flexible path creation in the backhaul network in accordance with the time variant and spatially non-uniform traffic distributions. Such flexible control of the backhaul network is enabled by Software Defined Network (SDN) technology using out-band control interface over the LTE. In summary, mmWave meshed backhaul with SDN comes into place as one suitable candidate for dynamic crowd scenarios owing to its ultra-wide bandwidth and deployment flexibility with low cost.

The above figure shows an example of mmWave meshed network proposed in [REF] to be used in the dynamic crowd scenario. In this figure, mmWave APs are overlaid on a LTE macro cell to play a role of integrated backhaul and access with three or four sectors in both access and backhaul. The LTE macro BS plays a role of mmWave gateway as well in the cell to accommodate time-variant and spatially non-uniform traffic by forming a mmWave meshed network. [OTSH2017]

Based on the above traffic prediction of 3D live video broadcast of Olympic games, 2 mmWave APs of peak data rate of about 6Gbps are required for the crowded 160 m² square area (at Hachiko statue). Therefore, to cover the complete dynamic crowd area of 4 km² area, maximally 5000 mmWave APs are necessary.

3.4.6 Similarity & difference with other projects

The dynamic crowd has been considered by several projects as one of 5G use cases of dynamic user traffic. This scenario has been taken into account by several projects like mmMAGIC (moving hotspots) and international fora like 5GMF (mobile broadband in vehicles), NGMN (dynamic hot-spot services).
Unfortunately, most of the considered cases assumed a crowd dynamic in terms of space, i.e. moving crowd like moving vehicles; but what is of interest is a crowd dynamic in terms of time, like in MiEdge or NGMN, where dynamic network management or soft network establishment are required.

<table>
<thead>
<tr>
<th>NGMN</th>
<th>Entertainment applications</th>
<th>Dynamic crowd, 10,000 devices, 100 Mbps/device</th>
<th>Throughput, Connection density, Area capacity</th>
<th>Dynamic network management, scalability, CAPEX/OPEX</th>
</tr>
</thead>
</table>

The most related scenario is the dynamic hot-spot services defined by NGMN. However, this international forum lacks to describe about the dynamicity of traffic, or to clarify detailed requirement for 5G as shown in the above table. On the other hand, MiEdge considers dynamic crowd as one of its most important use cases/scenarios where we clearly define mmWave meshed backhaul network management against dynamic daily traffic at one of the most typical place i.e. Shibuya station in Tokyo. We also further emphasize the importance of introducing MEC and associating MEC to an underlying mmW physical layer to reduce latency under limited backhaul capacity.

### 3.5 Automated Driving

#### 3.5.1 Use case

Automated driving is considered as one of the three most important use cases of future 5G systems [5GPPPWP AV]. The 1st 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 [3GPP22885]. These messages are transmitted in case of an emergency or as so-called awareness messages, which contain information such as location, speed and heading direction. However, the 2nd phase of 5G V2X aims for automated driving applications, where automated control software become primarily responsible for monitoring the environment and the driving vehicles, referred to as Levels of Automation (LoA) in the range 3 to 5 [SAE].

Automated driving systems require highly resolved and dynamic maps in order to maneuver safely. Since the resolution of current maps used for car navigation is definitely not sufficient, high resolution and real-time maps, also called dynamic High Definition (HD) maps, become indispensable [SH16]. Fig. 4.5.1 shows an example of an HD map generated with a LiDAR (Light Detection And Ranging) sensor, which is used to monitor the car surroundings and display the same as a high-resolution and real-time point cloud.
3.5.2 Scenario Description

Target scenarios for automated driving considered in this project are complex urban city environments as in Fig. 4.5.2, where many invisible hidden objects exist behind buildings and tracks as well as unexpected and unequipped bicycles and pedestrians. In such a complex environment, it is with high likely Roadside Units (RSU) exist to monitor the latest traffic conditions by cameras and LiDAR sensors, however, this information in the RSU are not fully utilized to assist driving for safety purpose so far.

3.5.3 Automated Driving specific applications

Cooperative perception of HD maps using extended sensors

In such a complex scenario, self (egocentric) perspective based automated driving as in [Ang13] cannot work anymore due to many invisible hidden objects. Therefore, automated vehicles require helps from sensors located at RSUs as electrical mirror in
addition to the sensors equipped in the surrounding vehicles. Cooperative perception is realized by exchanging sensor data between vehicles and Roadside Units (RSUs) and is necessary in order to widen or enhance the visibility area of HD maps \cite{KQC15} \cite{HFL15}. This concept allows a more accurate localization of objects and more important, due to a superior bird's eye view, prevents that objects remain not visible and undetected, due to the ego-perspective of the sensors mounted on the vehicle. This external object detection capability is particularly critical for a safe realization of automated driving in complex urban environments.

Fig. 4.5.3 shows an HD map example because of cooperative perception from multiple RSUs continuously monitoring the road conditions. In this case, the RSUs are located on the street lamps at a height of 6 m and a distance of 40 m between the street lamps. These cooperative perception RSUs seem indispensable in complex urban city environments, in order to detect hidden objects, unequipped vehicles, bicycles, pedestrians, etc.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{hd_map_example.png}
\caption{Cooperative perception created by multiple RSUs on a road.}
\end{figure}

3.5.4 Expected traffic

It is reported in \cite{SH16} that the total data volume of such an HD map collected for the duration of one hour is about 1 TB, which corresponds to a 2.2 Gbps data output for the LiDAR sensor. It is reported in \cite{Ang13} that Google’s automated car gathers a total of about 6 Gbps of sensor data, which includes LiDAR and other sensors, in order to bring automated driving into practice. \cite{Kzr16} summarizes in general for automated driving the required data rates of automobile sensors, i.e. 80-560 Mbps for LiDAR sensors or 160-320 Mbps for cameras sensors. Even though the final values depend on the resolution of the actual HD map, an estimation of 1 Gbps appears reasonable as a typical data rate requirement for exchanging HD map information via V2V link. On the other hand, since a RSU supports multiple OBUs at the same time, the required data rate of V2X is much higher than that of V2V. Assuming average traffic density as 0.2 vehicles/m/lane and totally three lanes at one side of a road, the RSU
located every 40 m should support average 24 Gbps data rate. This data rate can be relaxed by introducing multicast transmission within a group of vehicles close to each other. If eight vehicles in the same lane are grouped, the required data rate becomes 4 Gbps/group.

The communication range supported by a cooperative perception system can be determined by the braking distance of vehicles. As an example, [GB01][Tra07] estimate 100 meters as a braking distance (including a safety increment distance) for the emergency stop of a generic sedan car at 70 km/h, which can be seen as the maximum speed in urban city environments. This braking distance estimate could be raised to 150 meters for buses or trucks. Hence, the HD map exchange system should support a communication range of at least 150 meters for emergency braking applications. This number is to some extent comparable to the numbers given by [Gic15].

At the end, latency is the most crucial communication system parameter in order to realize a stable control. It’s well known that latency and data rate are a tradeoff for the case of video or LiDAR data transmission. The latest video data compression technique reduces the data rate to one-tenth of the raw data rate. However, these video compressions inevitably lead to higher latencies than the 10 ms required for automated driving [5GPPPWP AV]. Furthermore, raw (or nearly raw) data is also needed for liability reasons in case of an accident [KQC15].

3.5.5 Added value of mmWave and MEC Technologies

Based on the discussion in Sect. 3.5.4, the enhanced V2V/V2X communication targeting at automated driving requires a data rate of 1Gbps per link, end-to-end latency of less than 10 ms per link and a communication range of more than 150 m, in order to put safe automated driving into practice by exchanging raw (or lightly processed) sensor data. Such high requirements cannot be realized with current technologies [3GPP22885]. Hence, 3GPP initiated related work in Release 15 and beyond, which is named eV2X (enhanced V2X) [3GPP22886]. As a consequence, the utilization of mmWave and MEC technologies are becoming increasingly important for the field of automated driving.

Figure 4.5.4 shows an example of a system architecture for mmWave based V2V/V2X in order to realize a real-time exchange of HD maps between On-Board Units (OBUs) mounted in vehicles and RSUs. All communication links between OBUs and RSUs are directly connected through proximity-based services, namely Device-to-Device (D2D) communication, as specified in [3GPP23303]. However, differently from standard D2D, this V2V/V2X system uses mmWave channels to fulfill the requirements of 1 Gbps data rate and less than 10 ms latency. The communication range of mmWave links can be extended to more than 150 m, if highly directional antenna beams are used. One challenge in this system might be the antenna beam alignment between OBUs and RSUs, however [VSB16] [CVG16] show the feasibility of using mmWave in vehicular scenarios. The system coexists with the conventional V2X system [3GPP22885], which supports cloud-based services such as traffic jam forecast and long-range traffic navigation.
A block diagram of OBU and RSU is shown in Fig. 4.5.4, where the difference between a OBU and a RSU is solely the automated driving unit. The OBU/RSU receives the HD maps from surrounding OBU/RSUs via mmWave V2V/V2X links and fuses them with its own HD sensor data in the HD map processing unit. This process is called cooperative perception as described in Sect. 4.5.2. This combined HD map with its widened visibility area is used for automated driving decisions and in addition is transferred to neighboring OBU/RSUs. However, before transmitting the fused HD map, the HD map processing unit selects the area of interest (or control resolution of HD map area by area) dependent on the location of receiver OBU/RSUs to avoid exponential increase of data rate. The OBU/RSU is a unification of mmWave and MEC, since the HD map processing unit is considered as MEC to compute cooperative perception at the edge of the network.

From our point of view, the described V2V/V2X system and therefore mmWave will play an important role in Intelligent Transport Systems (ITS) in addition to the current frequency bands below 6 GHz. In systems beyond 5G, Unmanned Aerial Vehicles (UAV) may use a similar concept for automated flying at low altitude, as shown in Fig. 4.5.4.

Fig. 4.5.3 mmWave based V2V/V2X to exchange HD maps.

Fig. 4.5.4 RSU and OBU composed of mmWave and MEC.
3.5.6 Requirements for 5G systems

In summary, the following requirements are needed in 5G and beyond to support automated driving use cases.

- High data rate in enhanced V2V/V2X link to exchange HD map information: > 1 Gbps
- Traffic density of vehicles: 0.2 vehicles/m/lane
- Low end-to-end latency in enhanced V2V/V2X links to realize safe maneuvering: < 10 ms
- Communication range of enhanced V2V/V2X links to guarantee safe stop of vehicles: > 150 m
- High reliability on enhanced V2V/V2X links to avoid accidents: 99.99%
- OBU-to-OBU, RSU-to-RSU, OBU-to-RSU relay to extend coverage of cooperative perception
- RSU-to-Network relay (tethering) to be connected with cloud data server
- Mobile edge computing in RSU and OBU to process cooperative perception in real-time
- (Vehicle) user and (automated driving) application centric orchestration of RSUs deployed either by cities, governments, or mobile operators
- Control plane over LTE/NR for radio resource management of enhanced V2V/V2X side-links
- Dedicated control plane in enhanced V2V/V2X links to realize standalone operation of V2V/V2X without connection of LTE/NR
- Micro-operator to deploy and operate RSUs by either cities, governments, or highway/traffic public corporations
- Heterogeneous usage of enhanced V2V/V2X, to be used for short range safety, and legacy V2V/V2X, to be used for awareness message and long range route decision
- Dedicated carrier for enhanced V2V/V2X at frequency band above 24.25 GHz to support wider bandwidth without unnecessary interference

3.5.7 Similarity & difference with other projects

The 5GPPP white paper [5GPPWP AV] gave a high level vision about engagement of automotive industry and telecom industry through 5G. They pointed out the change of business model after by 5G by picking up typical use cases such as automated driving, road safety and traffic efficiency services, digitalization of transport and logistics, intelligent navigation, information society on the road, and nomadic nodes. Therefore, they triggered the discussion about automated driving use case to be included in 5G and beyond.

The ETSI MEC white paper [ETSIWP] has studied usage scenarios of MEC and selected a connected vehicle service scenario as one of four reasonable scenarios for MEC. The main purpose of MEC is to reduce end-to-end latency of services by introducing computation capability at 5G base stations. This system architecture with
MEC will increase the safety efficiency and convenience of transportation system by the exchange of critical safety and operational data. However, detail parameters for design have not been discussed yet.

3GPP TR22.886 [3GPP22886] has studied use cases and requirements to be considered in enhanced V2X services targeting semi-automated or full automated driving. The selected use cases include; vehicle platooning, information exchange within platoon, automotive sensor and state map sharing, remote driving, cooperative driving for short distance grouping, collective perception of environment, information sharing for full automated driving, information sharing for full automated platooning, video data sharing, intersection safety information provisioning for urban driving, video composition for V2X scenario, etc. Since these studies well match with the automated driving use case written in this section, outcomes from the 5G-MiEdge project will contribute to future 3GPP standards.

### 3.6 Summary of use cases selected in 5G-MiEdge project

The following table summarizes all use cases selected in the 5G-MiEdge project. Detailed references for the other projects mentioned in the table can be found in Section 2 of this document.

<table>
<thead>
<tr>
<th>Use cases</th>
<th>Scenarios</th>
<th>Requirements for 5G</th>
<th>Relevance with other projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Omotenashi service</td>
<td>Ultra-high-speed wireless access in a dense area such as an airport, a train, a shopping mall, etc.</td>
<td>- Peak user rate: &gt; 2 Gbps &lt;br&gt; - Area coverage: 100 (train platform) to 1000 m² (airport waiting area and shopping mall) &lt;br&gt; - Area peak system rate: &gt; 6.6 Gbps &lt;br&gt; - Mobile edge cloud: prefetching of download contents to avoid backhaul congestion &lt;br&gt; - HeteNet: integration of unlicensed 60 GHz band &lt;br&gt; - User/application centric orchestration: delivering high-quality overall application experience &lt;br&gt; - Micro-operator: providing specific, localized services &lt;br&gt; - Traffic density: &gt; 10 Mbps/m² (airport waiting area and shopping mall), &gt; 13.2 Mbps/m² (train platform) &lt;br&gt; - Mobility: stationary to pedestrian (4 km/h)</td>
<td>mmMagic, NGMN, METIS, 5GMF</td>
</tr>
<tr>
<td>2. Moving hotspot</td>
<td>High-speed wireless communication for passengers in a vehicle (train, bus, airplane, etc.)</td>
<td>- Data rate: &gt;2.15/0.54 Gbps/user (DL/UL), &gt;80 Gbps/total (in train case)</td>
<td>mmMagic, NGMN, 5GMF</td>
</tr>
</tbody>
</table>

Table 13: Summary of identified scenarios/use cases in 5G-MiEdge project.
<table>
<thead>
<tr>
<th>3. 2020 Tokyo Olympic</th>
<th>Olympic Stadium area and stands</th>
<th>File download, high definition content download and sharing, Immersive reality</th>
<th>4. Dynamic crowd</th>
<th>Outdoor hotspot areas like bus stops, stations and recreation parks, with dynamic changes of traffic pattern</th>
<th>Public video surveillance and 3D live video broadcast of Olympic games</th>
<th>Access Gates</th>
<th>mmMagic, NGMN, 5GMF</th>
</tr>
</thead>
</table>
| MEC server on vehicle | • E2E latency: < 100 ms  
• Range: > 10 m  
• Reliability: 99.99%  
• Local MEC with large cache memory on vehicle  
• Distributed server function of SNS on local MEC server  
• WiGig/Wi-Fi standalone operation  
• Contents' synchronization between cloud servers and local MEC servers  
• High speed backhaul on vehicle's route, stations, bus-stops, airports: > 10 Gbps (in train case)  
• Traffic density: > 134 Mbps/m² (train)  
• Mobility: 120 km/h, but passengers inside are still | Viewing area  
• User data rate > 50 Mbit/s  
• E2E latency: < 5 ms  
• Cell radius: depends on access point/beam capacity  
• Area system rate: > 500 Gbit/s (to serve the access segment of the area stands)  
• User density: > 1.5 users/m²  
• Traffic density: > 12.5 Tbit/s/km²  
• MEC in the stadium media room  
| Access Gates  
• User data rate: > 4.2 Gbit/s  
• User density: > 1.33 users/m²  
• Traffic density: > 5.6 Gbit/s/m²  
• Cell radius: > the footprint has to cover the 20 entrance ports area (30 x 1 m²) | mmMAGIC, METIS-I/II, 5GMF, NGMN, 3GPP |
| 3. 2020 Tokyo Olympic Stadium area and stands | File download, high definition content download and sharing, Immersive reality | Viewing area  
• User data rate > 50 Mbit/s  
• E2E latency: < 5 ms  
• Cell radius: depends on access point/beam capacity  
• Area system rate: > 500 Gbit/s (to serve the access segment of the area stands)  
• User density: > 1.5 users/m²  
• Traffic density: > 12.5 Tbit/s/km²  
• MEC in the stadium media room | 4. Dynamic crowd | Outdoor hotspot areas like bus stops, stations and recreation parks, with dynamic changes of traffic pattern | Public video surveillance and 3D live video broadcast of Olympic games | Access Gates  
• User data rate: > 4.2 Gbit/s  
• User density: > 1.33 users/m²  
• Traffic density: > 5.6 Gbit/s/m²  
• Cell radius: > the footprint has to cover the 20 entrance ports area (30 x 1 m²) | mmMagic, NGMN, 5GMF |
5. Automated driving

<table>
<thead>
<tr>
<th>Automotive traffic environments in urban city</th>
<th>Cooperative perception by exchanging HD dynamic map information between vehicles &amp; roadside units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data rate: &gt; 1 Gbps / link</td>
<td>Traffic density: 0.2 vehicles/m/lanes</td>
</tr>
<tr>
<td>E2E latency: &lt; 10 ms</td>
<td>Range: &gt;150 m</td>
</tr>
<tr>
<td>Reliability: 99.99%</td>
<td>UE-UE, UE-network relay</td>
</tr>
<tr>
<td>MEC in roadside units &amp; on-board units</td>
<td>User/application centric orchestration</td>
</tr>
<tr>
<td>RRM via LTE/NR</td>
<td>Standalone operation without LTE/NR</td>
</tr>
<tr>
<td>Micro-operator to be deployed by government</td>
<td>Combination with legacy V2V/V2X</td>
</tr>
<tr>
<td>Dedicated carrier above 24.25 GHz</td>
<td>5GPPP, ETSI MEC, 3GPP TR22.886</td>
</tr>
</tbody>
</table>

4 References

[CHARISMA] The CHARISMA project website. Available online at: www.charisma5g.eu.
[ETSIWP] Yun Chao Hu, et al. “Mobile edge computing—A key technology towards..."

6G.


[METIS II D1.1] METIS II D1.1 “Refined scenarios and requirements, consolidated use cases, and qualitative technoeconomic feasibility assessment,” Jan. 2016. Available: https://metis-ii.5g-ppp.eu/


[mmMAGIC D1.1] mmMAGIC Deliverable D1.1 « Use case characterisation, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz». Available online at: https://5g-mmagic.eu/results/#deliverables.

[mmMAGIC] The mmMAGIC project website. Available online at: 5g-mmagic.eu.


[SH16] Heiko G. Seif, Xiaolong Hu, “Autonomous Driving in the iCity – HD Maps as a Key


