Document Number: ICT-317669-METIS/D1.1

Project Name:
Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)

Deliverable D1.1

Scenarios, requirements and KPIs for 5G mobile and wireless system

Date of delivery:	29-04-2013	Version	1
Start date of Project:	01-11-2012	Duration	30 months

Deliverable D1.1
Scenarios, requirements and KPIs for 5G mobile and wireless system

Project Number:	ICT-317669
Project Name:	Mobile and wireless communications Enablers for the Twenty-twenty Information Society

Document Number:	ICT-317669-METIS/D1.1
Document Title:	Scenarios, requirements and KPIs for 5G mobile and wireless system
Editors:	Mikael Fallgren, Bogdan Timus (Ericsson AB)
Authors:	Petar Popovski (Aalborg University), Volker Braun, Hans-Peter Mayer (Alcatel-Lucent Bell Labs), Peter Fertl, Zhe Ren, David Gonzales-Serrano (BMW Group Research and Technology), Erik Ström, Tommy Svensson (Chalmers University of Technology), Hidekazu Taoka, Patrick Agyapong, Anass Benjebbour (DOCOMO), Gerd Zimmermann (Deutsche Telekom AG), Juha Meinilä, Juha Ylitalo (Elektrobit), Tommi Jämsä, Pekka Kyösti (Anite), Konstantinos Dimou, Mikael Fallgren, Yngve Selén, Bogdan Timus, Hugo Tullberg (Ericsson AB), Malte Schellmann, Yuxiang Wu, Martin Schubert (Huawei ERC), Du Ho Kang, Jan I Markendahl, Claes Beckman (KTH), Mikko Uusitalo, Osman Yilmaz, Carl Wijting, Zexian Li (Nokia), Patrick Marsch, Krystian Pawlak, Jaakko Vihriala (Nokia Siemens Networks), Alexandre Gouraud, Sébastien Jeux (France Telecom - Orange), Mauro Boldi, Gian Michele Dell'aera, Bruno Melis (Telecom Italia), Hans Schotten (University of Kaiserslautern), Panagiotis Spapis, Alex Kaloxylos, Konstantinos Chatzikokolakis (National and Kapodistrian University of Athens)
Dissemination Level:	PU
Contractual Date of Delivery:	01/05/2013
Status:	Public
Version:	1
File Name:	METIS_D1.1_v1.docx

Abstract:

This deliverable introduces generic scenarios based on fundamental challenges, and the specific problem description of test cases that will be relevant for beyond future radio access. Specific characteristics of each scenario and each test case include the key assumptions regarding requirements and key performance indicators. In order not to constrain the potential solutions, the requirements are specified from an end-user perspective. The deliverable will not only serve as the guideline for the technical work and system concept design in METIS, but also can serve in external research communities to help to harmonize the work towards the future radio access system including the new generation system of 5G.

Keywords:

Scenario, KPI, test case, requirement, challenge, end-user, electromagnetic field exposure, traffic volume density, experienced user throughput, E2E latency, reliability, availability, retainability, energy consumption, cost.

Executive summary

The overall goal of the METIS project is to lay the foundation for the beyond 2020 5G mobile and wireless system by providing the technical enablers needed to address the requirements foreseen for this time frame.

Deliverable D1.1 introduces five scenarios based on five challenges that will be relevant for the considered time frame and which are wide in scope. Those are

a) "*Amazingly fast*" focuses on *high data-rates* for future mobile broadband users,

b) "*Great service in a crowd*" focuses on mobile broadband experience even in the very crowded areas and conditions,

c) "*Ubiquitous things communicating*" focuses on efficient handling of a *very large number* of devices (including e.g. machine type of devices, and sensors) with *widely varying requirements*,

d) "*Best experience follows you*" focuses on *end-users on the move* with high levels of experience, and

e) "*Super real-time and reliable connections*" focuses on new applications and use cases with very strict requirements on *latency and reliability*.

To facilitate the work with more specific research questions D1.1 further defines twelve concrete test cases based on the above scenarios. Each such test case typically contains challenges from one or more scenarios. The aim of the test cases is to provide distinct problem descriptions, requirements, and Key Performance Indicators (KPIs) from the end-user perspective. They will be used by the METIS project as a basis for designing and evaluating technical solutions. For brevity, only the main challenges and descriptions of each test case are provided in the D1.1 main sections. Underlying assumptions and more detailed requirement descriptions are presented in the Annex.

Although the test cases described in this document are rather specific, the solutions derived from them are expected to address a much wider class of problems relevant for the same fundamental challenges that the test cases are based on. The concrete test case KPIs provide a direction for research and a measure of success for METIS.

Finally, D1.1 will be used to identify research items for the other work packages (WPs) and for the horizontal topics (HTs) within METIS. Based on the test cases, METIS will propose candidate solutions and map the end-user KPIs to solution-specific KPIs. METIS will then develop and evaluate technical components addressing the end-user and solution-specific KPIs. The various technical components and solutions will be integrated into a unified METIS concept that addresses the fundamental challenges of the beyond 2020 information society.

Contents

List of Abbreviations, Acronyms, and Definitions

2G	2nd Generation
3D	3 Dimensions
3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
ACK	Acknowledgement
BER	Bit Error Rate
CAPEX	CAPital EXpenditure
CDF	Cumulative Distribution Function
CDN	Content Delivery Network
C-ITS	Cooperative-Intelligent Traffic Systems
CENELEC	Comité Européen de Normalisation Électrotechnique
CPE	Customer Premise Equipment
C-RAN	Centralized Radio Access Network
CS	Circuit Switching
D	Deliverables
D2D	Device-to-Device
DL	DownLink
DRX	Discontinuous Reception
DTX	Discontinuous Transmission
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
E2E	End-to-End
E3F	Energy Efficiency Evaluation Framework
EARTH	Energy Aware Radio and network tecHnologies
ECU	Electronic Control Units
EMF	Electro Magnetic Field
eNB	Evolved NodeB
ETSI	European Telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplex
FP	Framework programme
Gbps	Gigabit per second
Gbyte	Gigabyte
GOOSE	Generic Object Oriented Substation Events
GSM	Global System for Mobile communications
HARQ	Hybrid Automatic Repeat reQuest
HT	Horizontal Topic
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMAX	Image Maximum
IMT	International Mobile Communications
ITS	Intelligent traffic systems

IP	Internet Protocol
ITU-R	International Telecommunication Union-Radio
KPI	Key Performance Indicator
LE	Low Energy
LTE	Long Term Evolution
M2M	Machine-to-Machine
MAC	Medium-Access Control
MBB	Mobile BroadBand
Mbps	Megabit per second
Mbyte	Megabyte
MMC	Massive Machine Communication
MNO	Mobile Network Operator
NA	Not Applicable
NGMN	Next Generation Mobile Network
OPEX	OPerational EXpenditure
OTT	One Trip Time
PC	Personal Computer
PDCP	Packet Data Convergence Protocol
PDF	Probability Density Function
PDR	Packet Delivery Rate
PER	Packet Error Rate
PHY	Physical
PR	Protective Relay
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RLC	Radio Link Control
RTT	Round Trip Time
RX	Receiver
SARTRE	SAfe Road TRains for the Environment
SER	Symbol Error Rate
SINR	Signal to Interference plus Noise Ratio
SMS	Short Message Service
Tbps	Terabit per second
Tbyte	Terabyte
TC	Test Case
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TTI	Transmission Time Interval
TV	Television
TX	Transmitter
UE	User Equipment
UL	UpLink
UMTS	Universal Mobile Telecommunications System
USD	United States dollar
V2D	Vehicle-to-Driver
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-anything
VoIP	Voice over Internet Protocol
VRU	Vulnerable Road Users

WiFi	Wireless Fidelity	**WP**	Work Package

1 Introduction

Societal development will lead to changes in the way mobile and wireless communication systems are used. In METIS' vision about the future information society private and professional users will be provided with a wide variety of applications and services, ranging from infotainment services, through increased safety and efficient usage of transportation, to completely new industrial and professional applications. This vision results in challenges such as the very high data rates, and the very dense crowds of users, with higher requirements on the end-to-end performance and user-experience. New types of challenges that arise from new application areas are the very low latency, and the very low energy, cost, and massive number of devices. In many cases one key challenge regards support of efficient mobility. To address these challenges, METIS will provide the technical enablers that will essentially lay the foundation of the future 5G communications systems.

This document identifies the fundamental future challenges and defines a system concept. Each challenge is reflected by a scenario description. Real-world applications might often entail more than one of the fundamental challenges. In order to ensure that the developed technical enablers meet the requirements of the identified challenges and future 5G communication systems twelve concrete test cases are defined to reflect these fundamental challenges. The selected test cases essentially sample the space of future applications, both human-centric and machine-type. Once the tested technical enablers fulfil the requirements for these test cases it is expected that many other applications, with the same fundamental challenges, will successfully be supported.

1.1 Future radio access

The main objective of METIS is to respond to societal challenges beyond 2020 by providing the basis for the all-communicating world and lay the foundation for a future radio access mobile and wireless communications system. This will realize the METIS vision of a future where access to information and sharing of data is available *anywhere* and *anytime* to *anyone* and *anything*. METIS will develop a concept for the future 5G mobile wireless communications system and will identify the research key building blocks of such a future system. The METIS overall technical goal provides a system concept that, relative to today, supports:

- 1000 times higher mobile data volume per area,
- 10 times to 100 times higher number of connected devices,
- 10 times to 100 times higher typical user data rate,
- 10 times longer battery life for low power Massive Machine Communication (MMC) devices,
- 5 times reduced End-to-End (E2E) latency.

The key challenge is to achieve these objectives at a similar cost and energy consumption as today's networks [1].

The main goal of this deliverable is to describe specific scenarios that capture the METIS objectives as described above. The identified scenarios and test cases aim at capturing the needs from an end-user perspective. Specific characteristics of each scenario and each test case will be derived including elaboration of the key assumptions regarding requirements and Key Performance Indicators (KPIs).

This document aims to guide and support the technical work within the project. The identified scenarios and test cases define a problem space, with focus on its requirements. They are mostly end-user centric, but aspects relevant for other important actors e.g. society and mobile network operators, such as energy consumption or costs are also included. However, they do not describe the possible solutions for any of the described problems, nor do they describe solution-specific requirements and KPIs. For the reference, in METIS, the description on solution-specific requirements and KPIs will be delivered from the technical WPs, e.g. requirements relevant for new air interface will be delivered as D2.1 and the future spectrum needs and usage principles will be published as D5.1.

1.2 Structure of the document

The rest of the document is organised as follows:

- Section 2 captures the methodology used to describe the identified scenarios and provides definitions of the terms included in the document.
- Section 3 provides a description of the scenarios, namely “Amazingly fast”, “Great service in a crowd”, “Ubiquitous things communicating”, “Best experience follows you”, and “Super real-time and reliable connections”. Then the separate test cases, comprising the aforementioned scenarios, are briefly described.
- Section 4 describes the identified KPIs that will be used to evaluate the performance of the METIS solutions.
- Section 5 contains conclusions of the findings.

In addition, this document has an Annex. Here, a more detailed description of each test case is provided, Section 7 to Section 18, including background and motivation as well as requirement and KPI details. Furthermore, the scenario and test case mapping table is given in Section 19 and additional information regarding the energy consumption and cost KPIs are presented in Section 20.

2 Methodology

According to METIS vision, the use of future wireless communication systems will expand into new areas of applications. Due to the uncertainty about the future, one can consider many possible futures. METIS will provide technical components that can address the challenges of the unknown future. The underlying idea of the applied methodology is that the technical components will be able to address the unknown future, if they can handle a relatively small number of suitably selected test cases.

The test case selection is done as follows. Firstly, the possible futures are treated as a problem space. Each problem is seen from an end-user perspective and obviously has some underlying technical challenges. Secondly, the space is spanned by a handful of fundamental challenges. Each challenge is illustrated by a scenario, which is described in general terms, from an end-user perspective. By describing the challenge-scenario pairs as the two faces of a coin, Section 3 in this document makes the connections between the technical issues that METIS will address and what the end-user in the information society will be provided with. Thirdly, the problem space is sampled by a dozen concrete test cases. The requirements of a test case are primarily defined from an end-user perspective, but also other aspects are taken into consideration whenever relevant, such as energy consumption or cost. Each test case may have several challenges and therefore typically belongs to several scenarios. A suitable selection of test cases means that the tested technical component, and the METIS concept that builds upon them, will be able to handle the space of possible future problems.

2.1 Terminology

In this subsection, definitions are provided for the methodology concepts and terms; moreover, the interrelations between such concepts are provided. The terms composing the METIS methodology, together with their definitions, are listed below:

- **Challenge**: The fundamental technical difficulty of posed by possible futures. It is illustrated by scenario, for which it highlights the most demanding aspect of the underlying technical problem.
- **Scenario**: “An internally consistent view of what the future might turn out to be”, Michael Porter [2]. In the following, this view is given as a *general* account of a situation or course of actions that may occur in the future [3]. It is described from end-user perspective and it illustrates a fundamental challenge.
- **Test case**: A practical aspect formulated from end-users’ perspective. Each test case also contains a set of assumptions, constraints, and requirements. A scenario may cover several concrete test cases; a test case may have several challenges and therefore belong to several scenarios.
- **Requirement**: Captures the technical needs derived from the user needs so as to drive research towards this direction. It may be related to e.g. traffic needs, energy, and spectrum.
- **Key Performance Indicator (KPI)**: A quantifiable measurement, agreed to beforehand, that reflect the critical success factors of a proposed solution; it reflects the goals captured by each test case. The KPIs are linked to the test case so as to link the proposed solutions with the usage driven test cases.

- **Legacy solution**: A solution that used to deal with the proposed user oriented test case before a METIS solution is implemented. A new METIS solution might complement the legacy solution or to be competitive to it.
- **Assumption**: The preconditions and conjunctures. The assumptions are related to e.g. data traffics, roles of actors, and traffic models.
- **Model**: A probabilistic description of the test case environment and context. The models are containing e.g. description of the environment, users and devices distribution, data traffic, spectrum to be used, and energy consumption.

The terms composing the METIS methodology are depicted in Figure 2.1 together with the identified relations between the terms.

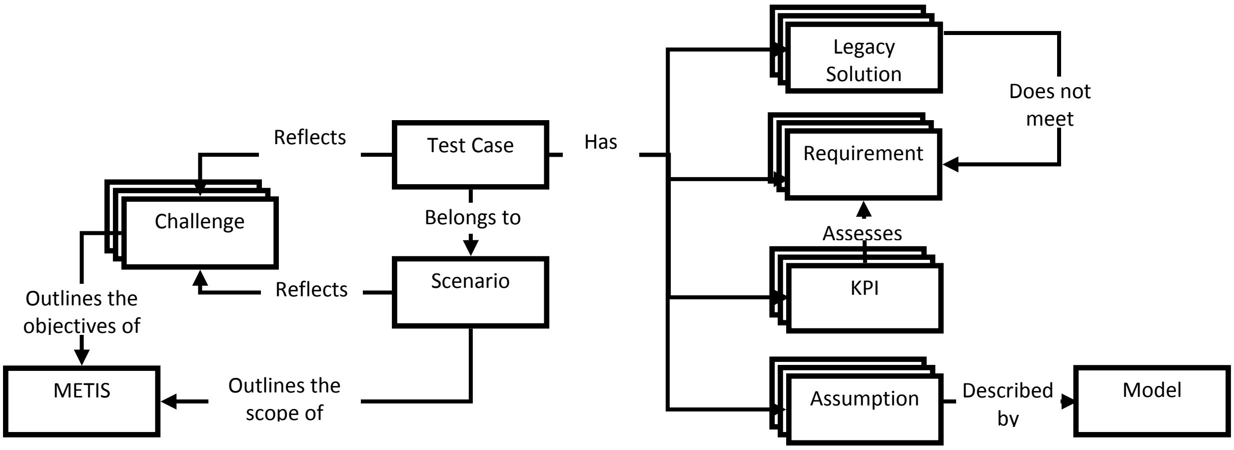


Figure 2.1: Relation between methodology terms.

The relation between the methodology terms in Figure 2.1 can be traced as follows:

- Challenge. The set of Challenges outline the objectives of METIS.
- Scenario. The Scenarios outline the scope of METIS. Each scenario reflects one specific Challenge.
- Test Case. A test case reflects one or more Challenges and belongs to one or more Scenarios. Each test case has a set of:
  - Legacy Solutions.
    - A legacy solution does not meet all requirements posed by the test case, but may complement the METIS solutions.
  - Requirements.
    - A requirement is defined from the end-user perspective.
  - KPIs.
    - A KPI assesses a (set of) requirement(s).
  - Assumptions.
    - An assumption is being described by a Model.

2.2 Approach

METIS covers a wide range of technologies which address different protocol layers, different end-user and technical challenges. This diversity represents a real difficulty when defining scenarios and requirements. The following guidelines have been used:

- Avoid tailoring scenarios and requirements for specific technology components. The scenarios and requirements are primarily defined from the end-user perspective and are solution-agnostic. This allows for solutions and network architectures to be compared, that includes, but not limit to, traditional cellular networks. The requirements capture also other aspects, such as the energy consumption and cost which are relevant for a mobile operator's perspective.
- Provide concrete and general scenarios.

Initially a set of fundamental future challenges, where each challenge belongs to a scenario, were identified. The scenario focuses on its specific challenge, although other challenges may also be relevant in parts of the described scenario.

The realistic test cases focus on user related problems that may contain several of the challenges. The test case belongs to a group of scenarios that is identified by the challenges. The grouping of the test cases to scenarios enables dealing with specific problems and identifying specific similarities among the test cases. In addition, the test case descriptions are full descriptions of user storylines.

As depicted in Figure 2.2, each test case belongs to a number of scenarios, has a set of requirements from an end-user perspective. The Problem space is within the scope of this document, and contains End-user KPIs that are mathematically defined through traffic models. The Solution space, on the other hand, is out of the scope for this document. After having derived Solution-specific KPIs in the Solution space, through deployment and propagation models, the end-user KPIs derived within this document will be mapped to the solution-specific KPIs via candidate solutions. The end-user and solution-specific KPIs will then be addressed during the development and evaluation of the technical components. The solutions and technical components will then be integrated into a unified system concept that addresses the challenges and overall METIS goal.

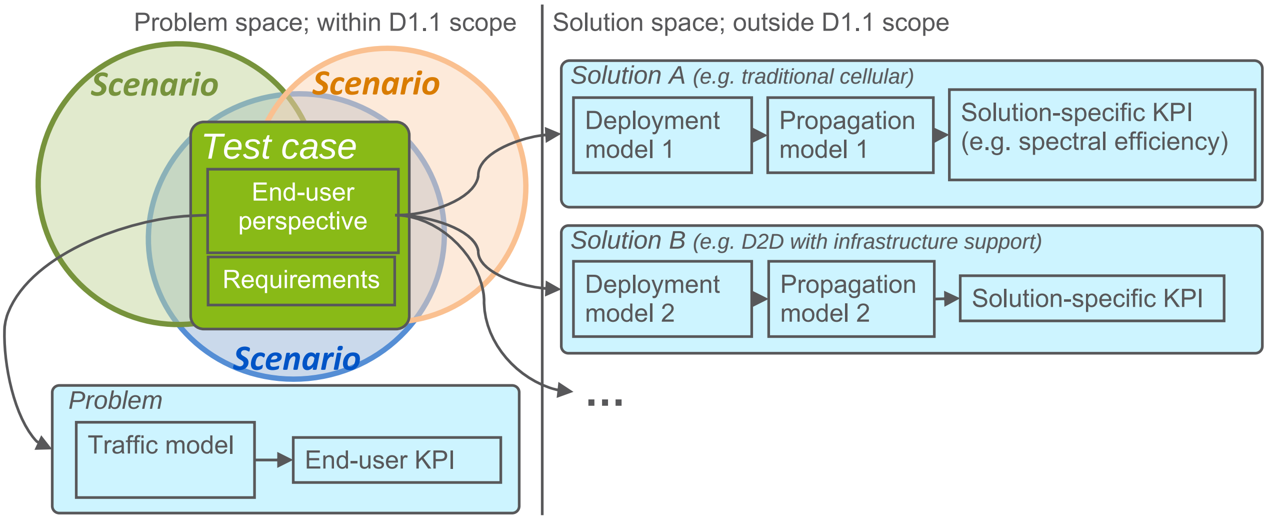


Figure 2.2: Illustration of the end-user KPIs and solution-specific KPIs. The end-user KPIs are within the scope of this document.

3 Scenario overview

A scenario focuses on one challenge, while a test case may address several scenarios and their corresponding challenges. In this section the challenges, scenarios and test cases are presented. Further, some common assumptions are introduced.

3.1 Challenges

The challenges are identified fundamental technical difficulties that should be addressed within the future radio access mobile and wireless communications systems. The definition of a challenge is presented in the terminology Section 2.1.

In order to locate what solutions will be successful in 2020 and beyond the possible future requirements need to be investigated. Within the scope of METIS five different challenges, that cannot easily be addressed by an evolutionary approach of today's networks, have been defined.

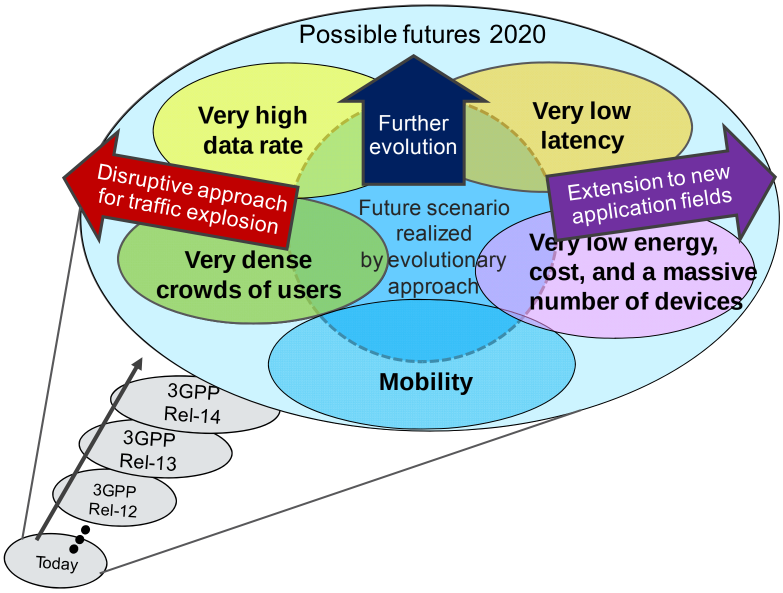


Figure 3.1: The five identified fundamental challenges span a larger space of possible future outcomes than the evolutionary approach.

In Figure 3.1 the possible futures of today are illustrated, where the evolutionary approach merely would capture the inner circle. In order to further stretch the space of possible future by addressing visions of METIS, see Section 1.1 and Section 2, describing the important trends and foreseeable future needs of mobile and wireless communications in 2020 and beyond, the disruptive approach as well as further evolutional approach should be investigated to prepare for the expected traffic volume explosion as well as extending into new application areas. The former concerns the enhancement of the user experience and sustainment of the increased traffic volumes, addressed by the two challenges: Very high data rate, and Very dense crowds of users. The later direction concerns applications into new areas that will pose the two new types of challenges: Very low latency, and Very low energy, cost, and a massive number of devices. The final challenge is Mobility, and it belongs to both directions as the efficient mobility support is a key challenge in many cases.

3.2 Scenarios

The scenarios outline the scope of METIS and reflect one specific challenge each, as described in the terminology Section 2.1. The challenges are e.g. given in Figure 3.1. Each scenario addresses at least one METIS overall technical goal, defined in the Future radio access Section 1.1, while each technical goal is addressed by at least one of the scenarios. The mapping between scenarios, their challenges, and the METIS overall goals are given in Table 3.1, where a slogan describes each scenario.

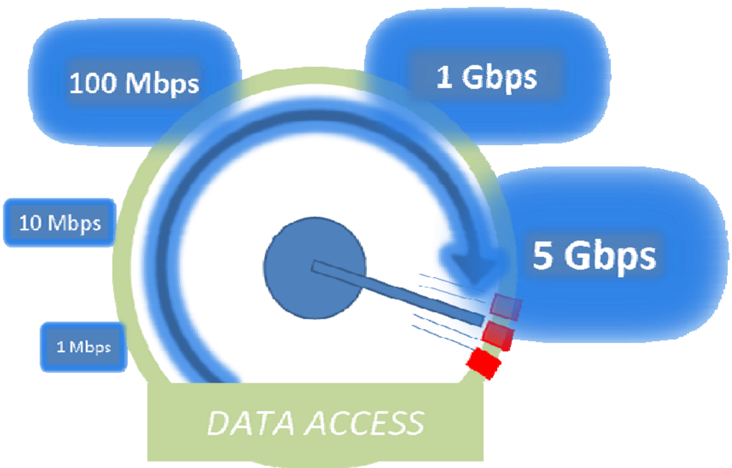
Table 3.1: Mapping between scenario, its challenge, and METIS overall goals.

Scenario		Amazingly fast	Great service in a crowd	Ubiquitous things communi-cating	Best experience follows you	Super real-time and reliable connections
Challenge		Very high data rate	Very dense crowds of users	Very low energy, cost, and a massive number of devices	Mobility	Very low latency
METIS overall goals	1000x data volume	x	x			
	10-100x data-rate	x	x		x	
	10-100x number of devices		x	x		
	10x longer battery life			x		
	5x reduced E2E latency					x

In the following sub-sections, each scenario is being described and analysed briefly.

3.2.1 Amazingly fast

In this scenario, users can enjoy the great experience of instantaneous connectivity without waiting times caused by the common network. This enable the user to enjoy the work or infotainment, as the used applications have a "flash" behaviour: a single click and the response is perceived as instantaneous. The amazingly fast feeling could be experienced by the user e.g. at work, in public spaces, or when travelling. The users will experience that they get all they need, when they need, wherever they will have the need.

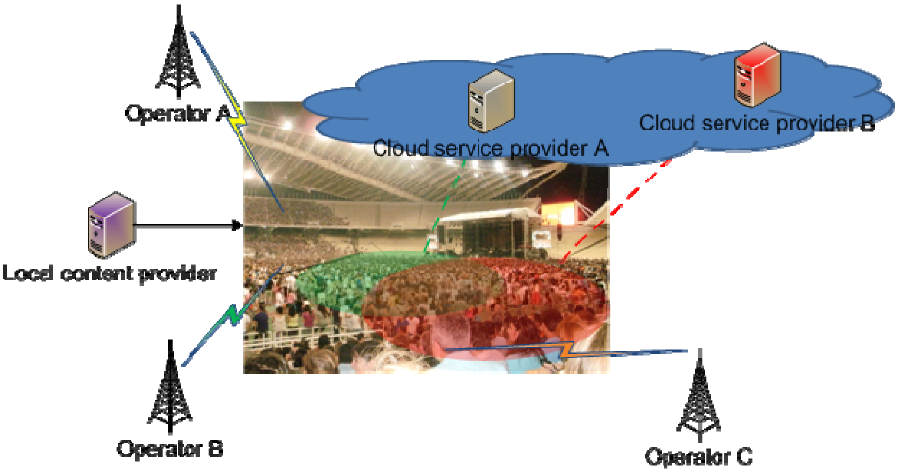


The flash behaviour will be a key factor for the success of cloud services and applications, such as the network-based file storage. It will also be a key for professional applications in which large data volumes will be exchanged between many users interactively, that is, without any perceived waiting time. The wireless system that supports this behaviour will be an enabler for the future development of new applications, e.g. within the health, office, and entertainment sectors.

The technical challenge is to provide high data-rates at the application layer. In order to realize this, wider carriers in new spectrum bands might be needed along with the technology that can handle these new bands.

3.2.2 Great service in a crowd

Today's mobile communication systems are designed so that a user is provided with reasonable mobile broadband experience when being alone in public spaces such as bus-stops, parks, or stadiums. However, today many users do not expect to have a good user experience of mobile and wireless internet access service when being surrounded by crowds of people. Furthermore, the network load will increase due to increased penetration of high-end devices and challenging services such as mobile computing, this might further degrade the user experience provided by the legacy network. In the future, users will expect good service even in very crowded places, despite the increase in traffic volume.

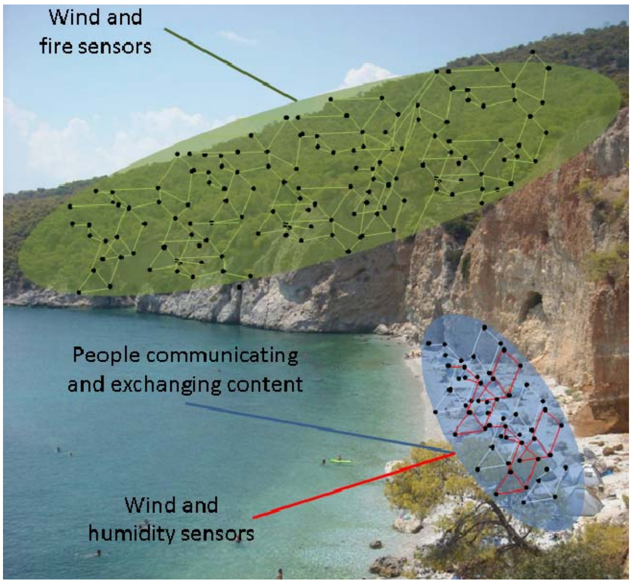


Fast connections and services all around will enable the end-users to always have the communication experiences satisfied. This will allow end-users to enjoy infotainment applications in shopping malls, stadiums, open air festivals, or other public events that attract a lot of people. It will allow people to work while getting stuck in unexpected traffic jams, or when travelling in crowded public transportation systems. It might also allow professionals such as police, fire brigades, and ambulances to exploit the public communication networks in these crowded environments[1]. New societal services can also be provided if good Machine-to-Machine (M2M) communication and Device-to-Device (D2D) communication are enabled in these crowded environments.

This scenario addresses the end-user demands for future communication solutions to work well in a crowd, enabling reasonable end-user experience also in such situations. The technical challenge is to provide such service at high traffic density per area despite a large number of UEs, such as handsets and machines/devices per area in combination with deployment cost constraints.

[1] Nowadays, this communication is handled by expensive dedicated networks. Should the future public communication networks be able to handle this type of traffic too, then one may expect that the synergies would lead to better usage of resources and lower service costs.

3.2.3 Ubiquitous things communicating

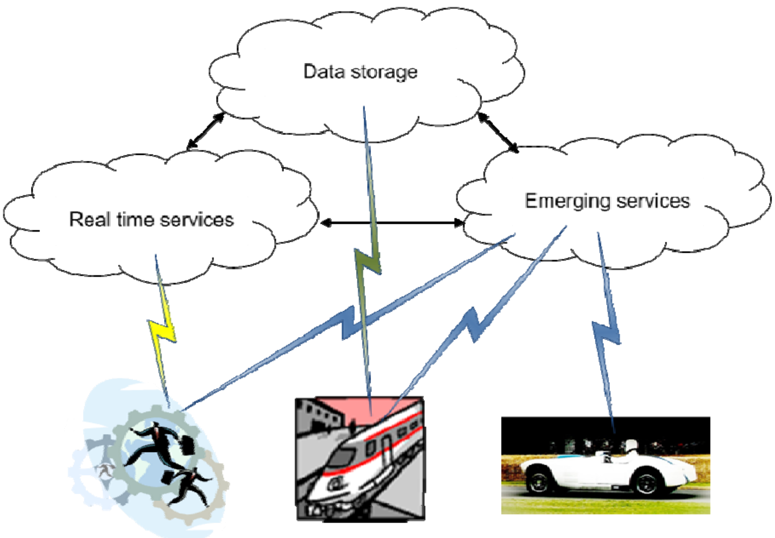


In a fully connected society, where today's human centric communication is complemented with machine-type communication, basically anything that profits from being connected will be connected. A majority of the connected machine-type devices will most likely be simple, such as sensors and actuators, for which the main requirements are low energy consumption and low cost. However, also more advanced and service critical devices will become connected, e.g. components of a smart electrical grid, industrial devices, and medical devices.

This scenario addresses the communication needs of a massive deployment of ubiquitous machine-type devices, ranging from low complexity devices to more advanced devices. The resulting, widely varying, requirements in several domains e.g. in terms of energy consumption, cost (complexity), transmission power, latency, cannot always be best met by today's cellular networks. Ubiquitous devices will sometimes communicate in a local context, which means that the traffic pattern and routes may be different than in cloud or traditional human-centric communication. To integrate the ubiquitous things communication in a unified communications network is an important issue e.g. for applications combining information from different types of sources. Another difficulty lies in how to manage the created overhead by the high number of devices.

3.2.4 Best experience follows you

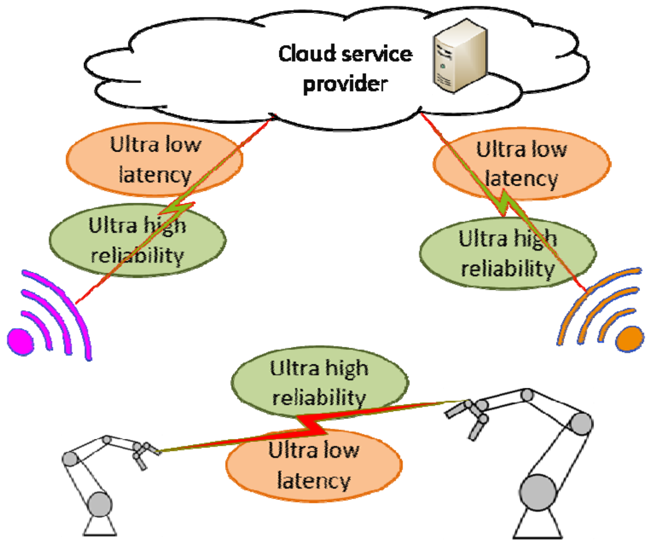
A fully connected beyond 2020 society requires reliable connectivity and high user experience not only for static users. This scenario strives at bringing a similar user



experience for end-users on the move as for static users e.g. human users at home or in the office. No matter where or how one is moving e.g. walking in a city, travelling on a train or subway or in a car on the highway, the beyond 2020 end-user is provided a communication that works reliably and provides a high user experience as if the best experience were following the user. This is of course equally true for communicating machines as for human end-users. Highly mobile devices, e.g. cars or trains, are obvious examples of relevant communicating machines for this scenario, but also sensors or actuators related to widely varying applications, e.g. monitoring of transported goods or monitoring of moving components in industries, plants (e.g. wind mills), or vehicles are relevant.

To provide the "best experience" to highly mobile UEs and communicating machine devices, robust and reliable connectivity solutions are needed as well as the ability to efficiently manage the mobility.

3.2.5 Super real-time and reliable connections



The reliability and latency in today's communication systems have been designed with the human user in mind. For future wireless systems we envisage the design of new applications based on M2M communication with real-time constraints, enabling new functionalities for traffic safety, traffic efficiency, smart grid, e-health or efficient industrial communications. Such new applications may require much higher reliability and lower latency than today's communication systems: for certain use cases, a maximum E2E latency must be guaranteed with very high reliability, e.g. 99.999%.

In this scenario the challenge lie in reducing the E2E latency while providing high accessibility and reliability of the communication services. The economic benefits of the potential solutions cannot easily be evaluated in terms of cost savings for the MNOs. Hence an evaluation measure can be totally different from the conventional ones, e.g. throughput or capacity. For example, it could be the reduction of the probability for an undesired event or issue to occur, e.g. the avoidance of a traffic accident.

3.3 Test cases

A test case entails one or more challenges for a future practical application with requirements, according to the terminology Section 2.1. Each challenge is reflected by its scenario, and those address the relevant METIS overall technical goals according to the mapping in Table 3.1.

Twelve different test cases have been selected to represent the problem space that was illustrated in Figure 2.2. These test cases have been selected such that they essentially sample the space of future applications, implying that some of them have applications that traditionally have not been considered within studies of telecommunication systems. Hence, as a studied technical enabler fulfils the requirements of the specific test case, it is expected to successfully support the similar applications.

The test cases and the scenarios to where each test case belongs are illustrated in Figure 3.2. Within the figure, a test case (TC) that belongs to several scenarios is located in the overlapping area of those scenarios. Note that the number of test cases within a scenario does not reflect the importance of it. In the Annex, Section 19, the same information as in Figure 3.2 is presented in a table.

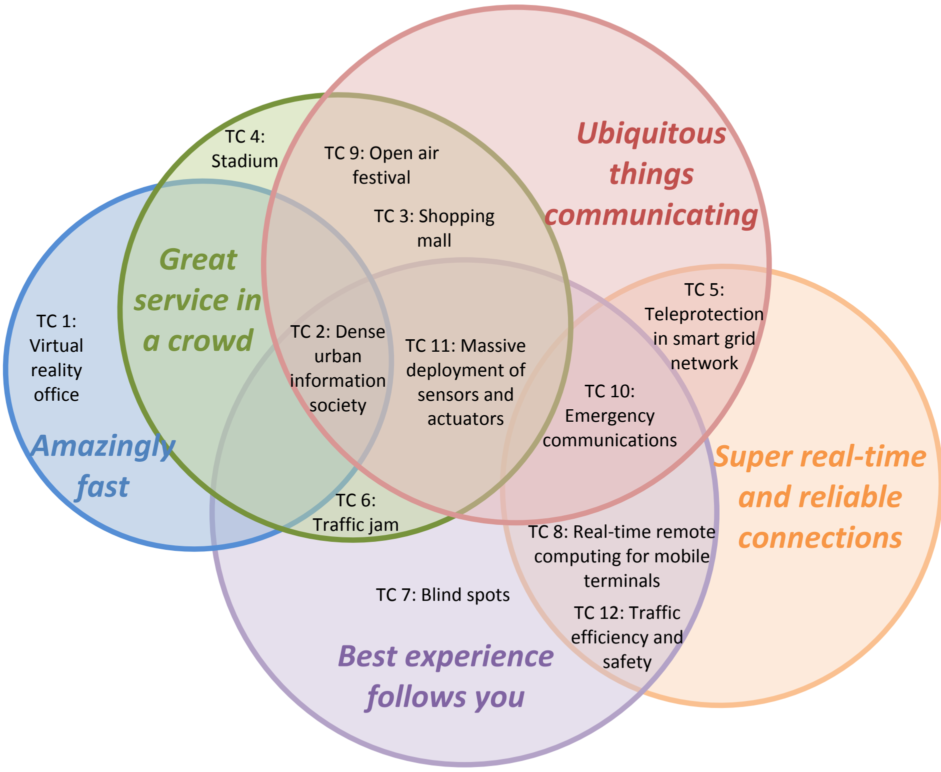
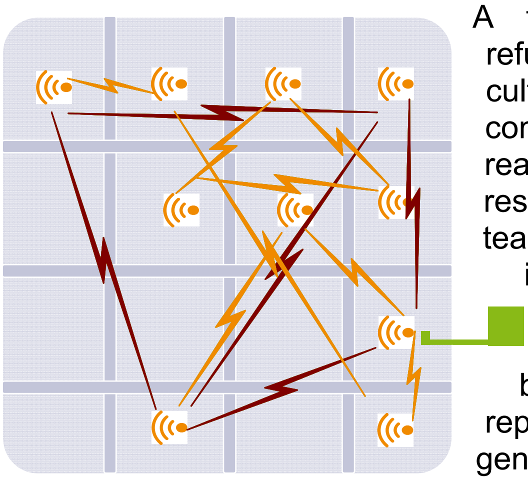


Figure 3.2: Mapping of the five scenarios and the twelve test cases.

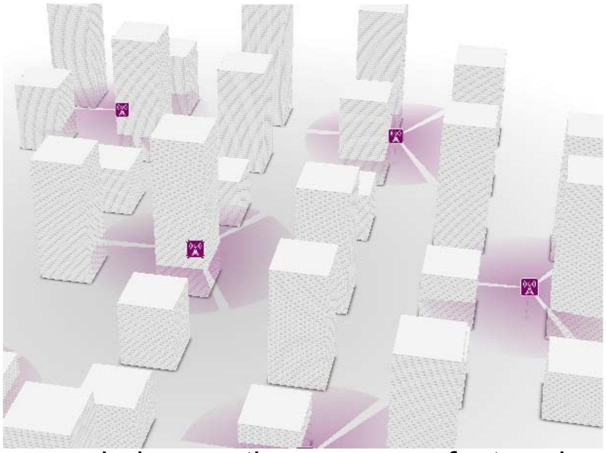
A narrative description of each test case is provided in the following sub-sections. A more detailed background and motivation of each test case is presented in the Annex, Section 7.1 to Section 18.1.

3.3.1 TC1: Virtual reality office



A top-modern office space is located in a refurbished 19th century building classified as cultural heritage. The building is rented by a company working with 3D tele-presence and virtual reality. The work involves interaction with high resolution 3D scenes and is typically performed in teams of some 5 to 10 individuals simultaneously interacting with a scene. Some of the team members are sited within the building; others are working remotely from other office buildings. Each scene may include the virtual representation of the team members or computer generated characters and items. The high-resolution quality of the scene provides an as-if-you-were here feeling. Since each team member may affect the scene, all must continuously update the scene by streaming data to the others. In order to provide the real-time interaction, the work is supported by bi-directional streams with very high data-rates and low latencies.

3.3.2 TC2: Dense urban information society



The “Dense urban information society” test case is concerned with the connectivity required at any place and at any time by humans in dense urban environments. We here consider both the traffic between humans and the cloud, and also direct information exchange between humans or with their environment. The particular challenge lies in the fact that users expect the same quality of experience no matter whether they are at their workplace, enjoying leisure activities such as shopping, or being on the move on foot or in a vehicle. Further, a particular aspect arising in urban environments is that users tend to gather and move in “dynamic crowds”, for instance because people are waiting at a traffic light or bus stop, which leads to sudden high peaks of local mobile broadband demand. Similar cases might arise as well in indoor environments with a spontaneous crowd concentration in a common part of the building.

3.3.3 TC3: Shopping mall

A typical setting for a future extended rich communication environment, that involves both “traditional” radio networks (both wide, small and local area) as well as a wireless sensor networks, is a large shopping mall with its high density of customers and service staff of shops and the real estate owner.

Customers are strongly interested to get access to mobile broadband communication services also in the heterogeneous indoor environment of the mall, e.g. shops, catering areas, galleries. In addition they will be directly addressed by generalized and/or personalized location-based services of the shopping environment for guiding, advertisement or product information purposes realized, e.g. via augmented reality, multimedia objects, or holographic applications.

Besides customer-related services the mall will provide a fixed/wireless communication infrastructure to support general commercial, e.g. cash desks, vending machines, electronic payment, as well as operational services, e.g. automatic doors, surveillance, fire protection. The final network deployment should be realized in an energy- and cost-efficient way to allow seamless handling of services across different domains, e.g. mobile/fixed network operators, real estate/shop owners, application providers.

3.3.4 TC4: Stadium

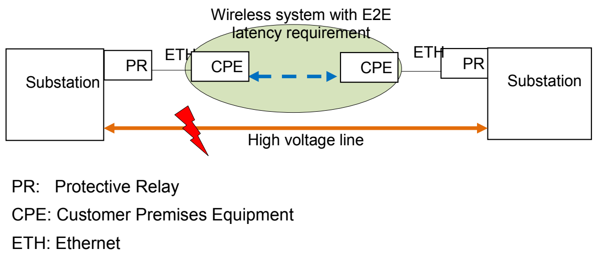
The situation is an event in a stadium that gather a lot of people interested in watching and exchanging high quality video contents, e.g. a football match, other sport events like the Olympic games or Formula1 races. During such events there are very likely peaks of traffic due to the big amount of people gathered in the same place for the period of time of the event. People can exchange multimedia content inside the stadium or transmit them outside, particularly during the intervals of the main event in the stadium.

The service is either belongs to the “pull” category, meaning that the traffic is from outside into the stadium, or belongs to the “push” category, in which the traffic is generated within the stadium and transmitted elsewhere. In general, these networks could potentially be used as a mean to start new services and functionalities. A very relevant feature of this test case is the huge amount of traffic that is generated during a quite short time period, i.e. the duration of the event, while the traffic in the area is normal or very low for the rest of the time.

3.3.5 TC5: Teleprotection in smart grid network

A smart energy distribution grid system aims at improving the efficiency of energy distribution and requires prompt reaction in terms of a reconfiguration of the network and routing lines in response to unforeseen events, e.g. blackout if a tree falling in a thunderstorm damages a power supply line. In the case of teleprotection where messages must be sent between substations to prevent the power system from cascading failures and damage, timely information is critical. If the network is not able to react to the altered system conditions fast enough the energy distribution network is in danger to collapse. The time constraints to be fulfilled here lie in the range of a few milliseconds.

Substation automation is a term used to collectively describe automation within and between power grid substations. IEC 61850 is one particular standard that governs substation automation and sets out the communication requirements for scenarios such as teleprotection.



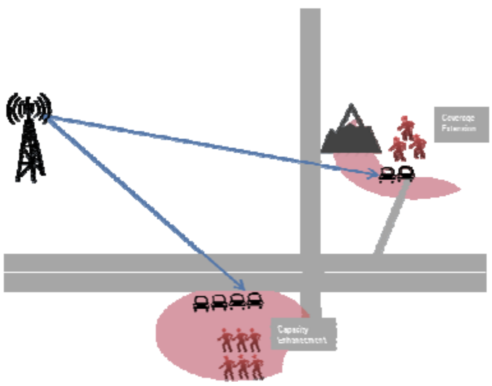
For example, if a fault happens at one particular substation, this message must be relayed to other affected substations within milliseconds in order for protection mechanisms to react in time. If failing to do so, it is likely to cause damage to the grid and to be costly for the energy distribution company. Given the critical nature of these events, low latency, high reliability and quality of service prioritization are essential for the communication link.

3.3.6 TC6: Traffic jam

The high popularity of Smartphones and Tablet PCs, like the iPad, is expected to increase the consumption of public cloud services on the move. As a result, users travelling inside cars or buses will be used to enjoy services such as web browsing or file download with their personal devices as well as with the vehicle’s infotainment systems. Together with those traditional services, a significant increase in the consumption of high-definition video is expected as a result of larger and better quality screens. In the future, the provision of public cloud services inside vehicles will be challenged during the occurrence of traffic jams due to the sudden increase in the capacity demand. In this case, it is important that the QoE of public cloud services is maintained regardless of the number of vehicles that might become trapped in the traffic jam. This is especially challenging in motorways and rural areas, in which the deployment of network infrastructure might not be dense enough to satisfy the capacity needs of a large number of users.

3.3.7 TC7: Blind spots

The demand for very high data rate Internet access at any time and at any place is constantly increasing. The ubiquitous capacity demands of future users will be challenging to satisfy in blind spots, such as rural areas with sparse network infrastructure or in deeply shadowed urban areas. In these scenarios, the amount of data traffic that must be delivered by the network is highly correlated with the distribution of vehicles in the space domain, i.e. the more vehicles located in the proximities, the higher the data traffic. Furthermore, the battery consumption of smart phones and tablet terminals in areas with low coverage increases significantly due to higher propagation losses. While cell densification is promising for solving the boosting capacity in future urban environment, flexible and energy and cost efficient solutions must be developed in future wireless communication systems to provide ubiquitous coverage in rural and heavily shadowed areas.



3.3.8 TC8: Real-time remote computing for mobile terminals

The evolution of remote services allows not only the storage of data on a common entity, e.g. a server in the Internet, but also the remote execution of applications, e.g. office applications. This means that a terminal, e.g. a netbook, can shift certain complex processing tasks to a remote server, whereas the terminal itself only serves as a user interface and therefore can relieve its own local processor units. The advantage of these systems lies in the fact that remote applications and services can easily and centrally be maintained and updated without user interaction. Moreover, the data and

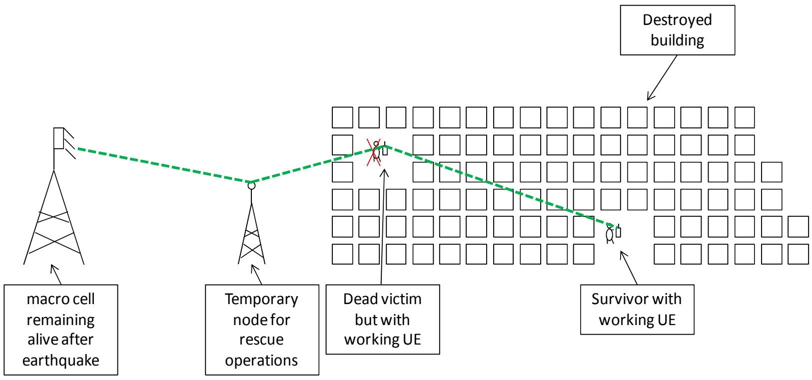
applications – such as augmented reality services – are accessible to all users regardless of the terminal processing capabilities. Beyond 2020, people will not only use remote services in stationary or slow-mobility scenarios, e.g. in the office, but also on-the-go at higher speeds, e.g. on their way to work either while using public transport or while driving their cars. Moreover, the automotive and transportation industry will rely on remote processing to ease vehicle maintenance and to offer novel services to customers with very short time-to-market. This requires robust communication links with very low latencies together with an availability that is close to 100%, while moving at velocities up to 350 [km/h].

3.3.9 TC9: Open air festival

A small rural area, less than 1 [km^2] is visited by at least 100 000 visitors during a 4-day long multi-stage open air music festival. For example, the visitors want to be able to locate interactively, share real-time or recorded high definition video clips from the simultaneous ten stages, and to access the Internet at a high-speed that is greater than 30 [Mbps], especially during the breaks between the performances. The high density of active users leads to a huge amount of aggregated data traffic about up to 900 [$Gbps/km^2$]. On the festival there are also thousands of trash bins, portable toilets, hundreds of vending machines, food stalls, and other service devices which rely on wireless communication to support their reliable and timely operation and maintenance. The security is ensured by good and reliable communication between headquarters, guards, medics, surveillance cameras, and a wide range of sensors. But normally in such remote area, only a small number of people exist, thus the mobile access network nodes are very sparsely deployed, i.e. the normal network is highly under-dimensioned.

3.3.10 TC10: Emergency communications

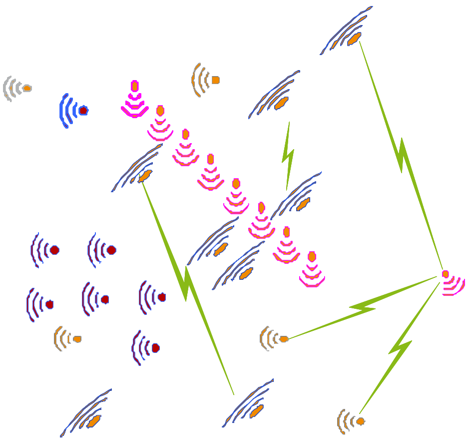
You are in a place where little mobile or wireless network infrastructure exists, e.g. due to a natural disaster. Basic communications must be maintained using regular devices. For instance in case of an earthquake in dense urban environment, survivors below rubble should be able be found quickly and a communication life-line should be provided until they are rescued. As the natural disaster may have affected the power grid, the energy consumption of both terminals and network infrastructure must be low to provide functionality and discovery of victims for at least one week without external power supply. When such an event occurs, devices and network must be able to switch to an “emergency mode”, in which the network in operation is focused on maintaining



connectivity and surviving on batteries for a long time. In order to ensure connectivity, a network might be dynamically (re-)composed out of all surviving base stations, mobile user equipment and/or special temporary nodes especially deployed for emergency management. The time needed to set up the “emergency mode“ and make the service available shall not exceed ten seconds. While in emergency mode, the devices may have special functionality, e.g. such as allowing the user equipment to act as relays, using other access protocols. This functionality must consume very little energy, both at the network and for the devices.

3.3.11 TC11: Massive deployment of sensors and actuators

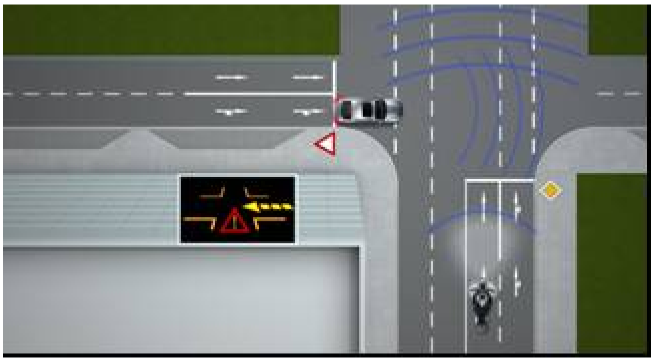
In this test case, we consider small sensors and actuators that are mounted to stationary or movable objects and enable a wide range of applications connected to monitoring, alerting or actuating. Possible applications are monitoring of materials, structures and critical components, such as buildings, wind mills, high-speed trains and applications connected to agriculture. Furthermore, portable objects may be equipped with tiny tags for the purpose of tracking the location of the objects or monitoring the usage or environment of these objects.



The devices typically need only transmit data occasionally, e.g. in the order of every minute, hour, week. However, the devices may need to be able to issue an alert. The devices may further be used to enable remote actuating, e.g. in the context of smart cities to dynamically adapt traffic flows, access or lighting, or in the context of connected buildings to control access, temperature, lighting. The net payload for such applications is typically small, in the order of 20 to 125 [byte] per message, and the latency requirements are often moderate, in the range of a few seconds. These devices need to be energy efficient, low cost and they can be used in quantities of billions. In terms of energy, at least for the object tracking devices, they either may rely on tiny batteries or on no power at all, possibly with solar energy or acceleration as an energy source. Hence the overall power dissipation has to be extremely minimized.

3.3.12 TC12: Traffic efficiency and safety

In Europe alone, some 40 000 people die and 1.7 million are injured annually in traffic accidents. At the same time, traffic increases on our roads leading to traffic jams, increased travel time, fuel consumption and increased pollution. Cooperative intelligent traffic systems (C-ITS) can address these problems. Cooperative active safety systems can warn drivers of dangerous situations and intervene through automatic braking or steering if the driver is unable to avoid an accident. Cooperative driving applications, such as platooning (road-trains) and highly automated driving can reduce travel time, fuel consumption, and CO_2 emissions and also increase road safety and traffic efficiency. Moreover, not only cooperation



between vehicles or between vehicles and infrastructure is required, but also the cooperation between vehicles and vulnerable road users, e.g. pedestrians and cyclists, through their mobile devices, such as smartphone and tablets, will be an important key element to improve traffic safety. C-ITS systems rely on timely and reliable exchange of information. Common to most applications are real-time requirements, and strict requirements on reliability and availability, especially when considering high mobility and large message sizes. End-to-end latency requirements of less than 5 [ms] for message sizes of about 1600 [byte] need to be guaranteed for all V2X transmissions. Data is sent either event-driven or periodically with a rate of about 10 [Hz]. Relative speeds of up to 500 [km/h] are possible on high-speed highways.

3.4 Common assumptions

The role of the operator

In the considered test cases, either the legacy cellular network of at least one traditional mobile network operator (MNO) is available, or no infrastructure is available at all, e.g. in case of a natural disaster and totally new application area. Moreover, one or more MNOs may be among the stakeholders of some test case. The METIS solutions will build on top of the legacy infrastructure, most likely complementing it with new deployments. Compared to the legacy technology the METIS solutions will provide enhanced merit, will complement them, or may even in some cases replace them. The METIS solutions will enhance the business competitiveness of the legacy operators. However, in some challenging scenarios the operators may have to collaborate. Moreover, the METIS solutions may also allow for new business models or for new actors to enter the mobile and wireless communications market. Both for traditional MBB and for the emerging services, the scenarios defined in the remainder of this document will concentrate on the emerging, novel aspects of wireless and mobile communications. Whenever the comparison to existing mobile and wireless communications systems is possible, the provisioning of services needs to be achieved with enhanced efficiency in terms of energy, cost, spectrum utilization, increased versatility and improved scalability.

User data traffic

In the following descriptions, the traffic demand is assumed to be an external and independent parameter, i.e. the use behaviour and expectations are assumed to be independent in the short term on the performance of the underlying network. Even if some test cases are focused on particular situations or places, the traffic of interest is typically covered by other data traffic. Depending on the selected solution e.g. which radio resources are used, the surrounding traffic may compete for the same radio resources with the traffic of interest. The surrounding traffic could amount to some “external” interference, for the “external” load in common resources such as e.g. backhaul, common servers, and shared sensors. Hence the surrounding traffic can be seen as boundary conditions or constraints for the problem to be solved. It is pointed out that in some extreme cases, if no further adjustments are possible, some further flexibility may need to be introduced in the other traffic, e.g. some of its resources might be trimmed instead of treating them as an unchangeable entity.

4 Key Performance Indicator overview

This section provides an overview of the Key Performance Indicators (KPIs) identified to assess the performance of the technical solutions derived within METIS. After some general considerations a detailed description of the KPIs defined from end-user perspective is given, followed by a summary of the challenging targets set in the different test cases. Due to the wide variation of the environmental conditions in the different test cases there is also a corresponding spread of the KPI values which has to be taken into account, i.e. a single KPI value does not usually fit all METIS scenarios.

4.1 General considerations

The scenarios and test cases described in D1.1 are presented from an end-user perspective. The end-user of a METIS solution can be a human being, but also a machine or sensor device communicating with other machines and/or humans (via their devices). Therefore, the requirements and KPIs are primarily related to the end-user taking into account the goals defined for the METIS system concept, see Section 1.1.

The KPIs are defined to be solution-agnostic. The mapping to the solution-specific KPIs is outside the scope of this document and will be handled in the technical WPs of the METIS project. Due to different conditions and requirements the given KPIs cannot be directly mapped to those applied, e.g. by ITU-R or 3GPP for performance evaluation and comparison of IMT-Advanced and LTE-Advanced system features, see [4]-[7]. Also KPIs defined by 3GPP for E-UTRAN operation, [8]-[9], do not fully fit due to their strong relation to LTE-specific features.

The KPIs taken as basis for assessment of the radio link related requirements set from end-user perspective are as follows:

- Traffic volume density;
- Experienced end-user throughput;
- Latency;
- Reliability;
- Availability and retainability.

Nevertheless some KPIs are also needed to assess the final METIS system solution, e.g. reflecting an energy or economic perspective:

- Energy consumption (efficiency);
- Cost (CAPEX, OPEX).

Despite of improvements in traffic density and throughput by the METIS solution both KPIs should not be increased compared to today's solutions. Especially the energy consumption of low power MMC devices is targeted to provide a 10 times longer battery life compared with today's devices and sensors with similar characteristics. Both KPIs can be separated in radio network infrastructure and end-user equipment. In the METIS evaluations on cost and energy consumption, the absolute values are not in the focus, but rather the relative values compared to the legacy network solutions.

All radio solutions to be derived within the METIS project will be finally assessed with respect to their electromagnetic field (EMF) exposure to be compliant with relevant recommendations, standards and regulations. Products and solutions emitting radio-frequency EMF need to be designed and tested to comply with relevant recommendations, standards and regulations on human exposure to EMF [10]-[16]. The possibility to comply with relevant EMF exposure requirements shall be considered for solutions developed within the framework of this project. The corresponding assessment will take place if there are reasons to assume that said solutions introduce new prerequisites for compliance compared to regular EMF exposure assessments of existing products and solutions.

4.2 KPI definitions

The KPI definitions are given within this section. Each KPI has a qualitative definition, motivation, mathematical definition and a legacy networks description.

4.2.1 Traffic volume density

Qualitative definition: The traffic volume density describes the total user data volume transferred to/from end-user devices during a predefined time span divided by the area size covered by the radio nodes belonging to the RAN(s). For multi-hop solutions each user data is only counted once.

Motivation: This KPI is directly related to the METIS goal to support a 1000 times higher traffic volume density than today's networks. This target figure is expected due to strongly increasing number of mobile devices with high data rate capabilities and traffic demand of multimedia-based services with rising share of high-resolution video during next decade, [17]-[20]. Figure 4.1 schematically shows the expected exponential growth of the mobile traffic volume over time for a given area.

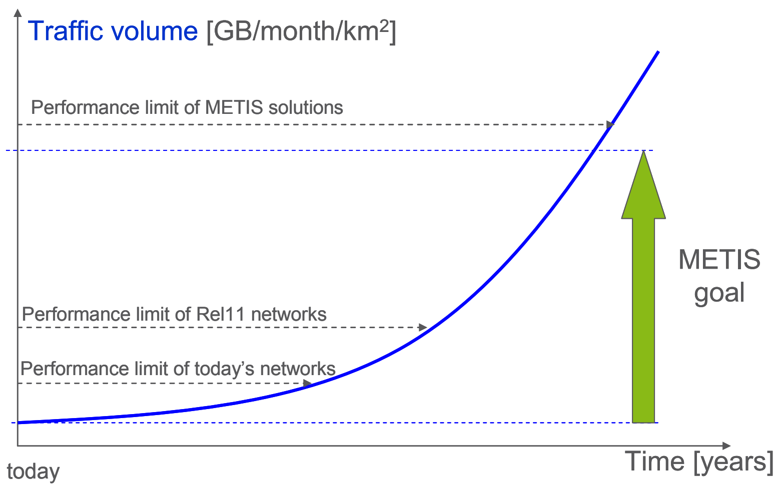


Figure 4.1: Exemplary expected increase in traffic volume.

Today's legacy radio networks in Europe, based on a mixture of GSM, UMTS and LTE Rel-8 as well as of WiFi for hotspot scenarios, will not be able to cope with the expected traffic volume increase. Even further radio technology improvements coming with already approved releases of 3GPP up to Rel-11 will not be able to keep pace with the demand.

The traffic volume density is mostly interesting for future scenarios “Amazingly fast” and “Great service in a crowd” evaluated in METIS taken into account high user densities as well as locations with high user data on demands.

Mathematical definition: The traffic volume density in a network can be generally computed by the sum of traffic volumes each produced by an end-user device, possibly differentiated between downlink and uplink direction, divided by the overall service area covered by the corresponding radio nodes.

It has to be noted that the traffic volume density is usually strongly correlated with the environment and corresponding user densities. E.g. in dense urban areas with many large buildings and high user penetration the density will be much higher than in rural areas, see graphical illustration in Figure 4.2 (left diagram). In addition, the instantaneous density will vary over the day with the traffic busy period being most important time slot for statistical evaluation, illustrated in Figure 4.2 (right diagram). Therefore the variation in time and space has been taken into account at the definition of the KPI value for the different test cases.

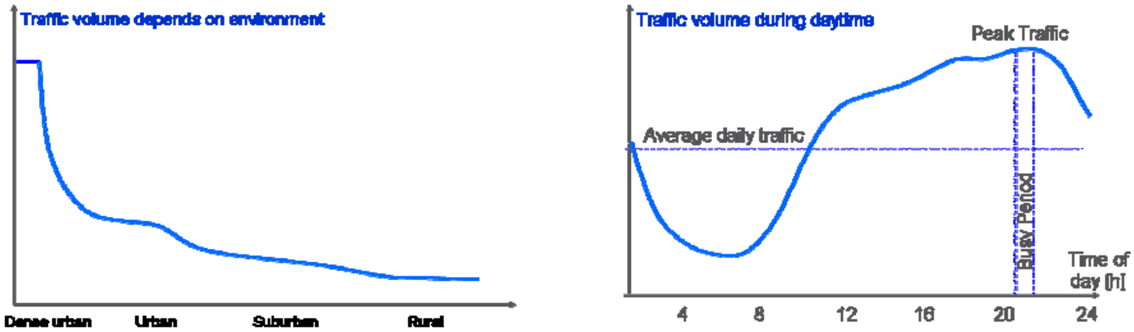


Figure 4.2: Exemplary dependency of traffic volume on environment (left) and day time (right).

Legacy networks: According to Cisco’s estimates for 2012 [17], the monthly amount of generated data are 342 [Mbyte], 820 [Mbyte], 2.5 [Gbyte] for a typical user of a smart phone, tablet, and laptop, respectively. Based on these numbers we take 500 [Mbyte] as a typical amount of generated data per month for a device. This corresponds to global total data traffic of 885 [petabyte] per month with about 28% of that traffic in Europe, 247.5 [petabyte]. Ericsson’s estimate [18] for the end of 2012 is 450 [Mbyte] and 3 [Gbyte] per month for smart phones and laptops, respectively.

In order to further detail what the above traffic volume may correspond to, assume that (a) the average traffic volume is 0.82 [Gbyte] per month and subscriber (i.e. Cisco’s estimate of the tablet traffic volume), (b) the traffic during a busy period (hour) is 6% of the daily traffic, and (c) there are 5000 subscribers per [km^2] (urban area environment). Under these assumptions, the average traffic volume density is about 18.4 [$Mbps/km^2$] during busy periods (hours)[2].

Further forecasts on the evolution of the traffic volume during next years can be found, e.g. in publications of the UMTS Forum [19] and in ITU-R Report M.2243 [20]

[2] For a macro deployment with average inter-site distance of 500 [m] and 3 sectors per site (sector area about 0.07 [km^2]), this corresponds to an average cell (sector) throughput of 1.3 [Mbps] assuming a uniform traffic distribution across the cells and a uniform user distribution inside the cell area.

Additional examples for target KPIs related to traffic volumes and experienced data rates are also given in the EARTH project deliverable D2.3 [21].

4.2.2 Experienced user throughput

Qualitative definition: The experienced user throughput is the data throughput an end-user device achieves on the MAC layer (user plane only) averaged during a predefined time span. This metric is one possible measure for the quality of experience (QoE) level a user experiences for the service applied. However, the data rate of the service application itself is lower than the experienced user throughput as additional protocol overhead and/or traffic control on higher layers, e.g. PDCP and RLC at LTE, IP, TCP/UDP/SCTP). The experienced user throughput depends on the test case environment, but also on the number of users and the amount of data they generate, because they affect the cell load and interference from surrounding cells in a radio network.

Motivation: The KPI is directly related to the METIS goal to achieve a 10 to 100 times higher typical user data rate. In principle it is relevant for all scenarios considered in METIS, but it is particularly challenging for “Amazingly fast” and “Great service in a crowd”, but also “Best experience follows you”.

Mathematical definition: Let the k-th packet (at the MAC layer) of the i-th user have a size $L_{i,k}$ [bits]. Its distribution depends on the application. Let $T_{i,k}$ be the end to end delay for delivering the packets to the destination. It depends on e.g. the RAN solution, user position (radio conditions), scheduler load. The throughput for this packet is $R_{i,k} = L_{i,k} / T_{i,k}$. For instance, if a packet of 1.25 [Mbyte] is delivered in 1 [s], then the packet throughput is 10 [Mbps]. The experienced user throughput is computed as the expected packet throughput:

$$Th_i = E_k\left[R_{i,k}\right],$$

where the expectation is taken over a time span which is specific to the application or test case. For instance, it could refer to all packets belonging to a session or when the user is in a predefined location. An approximation of the throughput can be computed as $E_k[L_{i,k}] / E_k[T_{i,k}]$. Since $T_{i,k}$ is defined at the MAC layer, $\sum_k T_{i,k}$ does not include the waiting time at the application layer, e.g. reading time for web-browsing, back-off time introduced by TCP/IP’s traffic control, and therefore it is different than the session length. A distribution of the experienced user throughput can be derived for each test case, based on assumed traffic volume and evaluated RAN solution a distribution of the experienced user throughput can be derived for each test case (probably differentiated between DL and UL). Depending on final service availability (or coverage) defined in the test cases, the KPI value may be defined, e.g. as the 5th-percentile of this distribution, i.e. 95% coverage for a certain data rate, or as the 1th-percentile, i.e. 99% coverage.

The experienced user throughput defined here is different to values known, e.g. from 3GPP and ITU-R evaluations on LTE-Advanced and IMT-Advanced systems where user throughput curves are usually derived for homogeneous hexagonal macro cell structures with fixed numbers of equally-distributed users in each cell based on a full buffer approach for each user queue, i.e. 100% network load.

In real mobile radio network scenarios the experienced user throughput is different due to typically lower network load taken into account the user’s randomized access to shared radio resources according to their service applications. NGMN proposed in [22] to apply file transfers as a basis for simulator evaluations. 3GPP proposed in [23] similar model to enable user throughput assessment at various network loads. Similar approaches were also used in the performance evaluations within the EARTH project, [21].

In contrast to those methods the more general approach applied in METIS can also be used in heterogeneous networks with unequal distribution of sites, users and traffic.

Legacy networks: In measurement campaigns to evaluate the achievable data rates in deployed mobile radio networks file transfers are also often applied:

- Ericsson's global median value for smart phones during 2012 was 1.3 [Mbps] in DL, based on statistics collected from SpeedTest.net.
- An extensive measurement campaign was performed by the French regulator in 2G-3G networks in France in 2012 [24]. The median DL data rates are between 2.4 and 3.9 [Mbps] for 3G single carrier transmission and between 4 and 7.5 [Mbps] for dual carrier aggregation dependent on the network operator.
- Similar measurements were also performed in Germany in 2012 published in [25]. The average data rate varies between 1.1 and 8.2 [Mbps] for file download and between 0.6 and 1.8 [Mbps] for file upload (results dependent on UE type, file size and network operator). For 4G, LTE Rel-8, networks static measurements show data rates of up to 32.5 [Mbps] for download and 17 [Mbps] for upload, but it has to be noted that LTE networks had only a very low load at the time of the measurement.

4.2.3 Latency

Qualitative definition: Different types of latency are relevant for different applications. E.g. the end-to-end latency, or one-trip time (OTT) latency, refers to the time it takes from when a data packet is sent from the transmitting end to when it is received or the receiving end. Another latency measure is the round trip time (RTT) latency which refers to the time from when a data packet is sent from the transmitting until acknowledgements are received from the receiving entity, e.g. internet server or other device. The measurement reference in both cases is the MAC layer. Any processing time on higher layers, e.g. for audio and video encoding and decoding, on the application layer, is not considered here. The entire network (radio, core, and backhaul/aggregation) typically affects the latency, although this is test case dependent. Only the user data plane is considered in the evaluation.

Motivation: The KPI is directly related to the METIS goal to provide a 5 times reduced E2E latency. In principle all scenarios considered in METIS would benefit from a latency reduction, but main challenges are with respect to safety-relevant services (e.g. for V2V communications) that require fast reactions of the involved parties as considered especially in the scenario of "Super real-time and reliable connections".

With respect to the METIS goal it has to be noted that network entities like the mobile core, backhaul/aggregation links as well as internet connections might be included in the E2E transmission chain which are not in the main METIS focus. Latency improvements are to be expected mainly in the RAN area up to the core elements considering new features like D2D communication, local break-outs or content delivery network (CDN) functionalities.

Mathematical definition: The RTT latency T_{RTT} is the time span measured between the start time T_{S1} of the transmission of a data packet from an end-user device (peer 1) to a remote station or device (peer 2) and the time instant T_{A1} when the acknowledgement, sent by peer 2, arrives at peer 1:

$$T_{RTT} = T_{A1} - T_{S1}.$$

The OTT latency is the time span measured between the start time T_{S1} of the transmission of a data packet from an end-user device (peer 1) to a remote station or device (peer 2) and the time instant T_{A2} when peer 2 receives the message:

$$T_{OTT} = T_{A2} - T_{S1}.$$

In the test cases a differentiation is required for latency KPI values depending on the availability of an already established radio communication data link. For example, for MMC with only low data amounts and energy-efficiency requirements the change between a non-active to an active state has to be as short as possible, e.g. change from idle to connected mode in LTE, which requires a minimized signalling overhead.

Legacy networks: In presently deployed LTE Rel-8 networks typical RTT latencies in case of internet access, between end-user device and server, are in the range of 30 to 60 [ms], in a laboratory environment without long interconnections the values are between 10 to 20 [ms]. For LTE Rel-10/11 the pure RAN user plane OTT latency will be about 4 [ms] (FDD; 4.9 [ms] for TDD) according to ITU-R evaluations [26]. The transition time between idle mode (with IP address allocated) to connected mode is 50 [ms].

4.2.4 Reliability

Qualitative definition: The reliability is an assessment criterion to describe the quality of a radio link connection for fulfilling a certain service level.

Motivation: The KPI is important for all considered scenarios, but main challenge is seen in “Super real-time and reliable connections”, where very high reliability values are requested for safety-relevant services.

Mathematical definition: Reliability can be defined diversely, if different layers of the network or different applications are considered. While some of the metrics characterize reliability at the PHY/MAC layer including signal to interference plus noise ratio (SINR), bit error rate (BER), symbol error rate (SER), packet error rate (PER) and outage probability [27], there are metrics like packet delivery rate (PDR), channel collision rate in the context of ad-hoc network.

Generally, reliability is defined as the probability that a certain amount of data to or from an end user device is successfully transmitted to another peer (e.g. Internet server, mobile device, sensor) within a predefined time frame, i.e. before a certain deadline expires. The amount of data to be transmitted and the deadline are dependent on the service characteristics in the underlying test case. Typically, the deadline corresponds to the E2E latency requirement of the test case, as defined in Section 4.2.3. Mathematically, the reliability (R) can be expressed as follows:

$$R = \Pr(L \le D),$$

where L is the measured E2E latency and D is the deadline, which characterizes the degree of real-time of the communication link. Specifically, if no retransmission is allowed to meet the deadline D, the reliability, R, is equivalent to probabilistic complement of packet loss rate.

Similar to the latency KPI, a differentiation for a second use case has to be required during evaluation dependent on the test case background. If a low data rate radio node, e.g. a sensor, is usually switching to inactive state after transmission of a small packet on the user plane due to energy saving reasons, it has to attach first to the network on the control plane before the next data transmission. The time needed for attachment and the corresponding success rate should be considered in the final reliability. Ideally the final METIS concept will provide a solution to minimize the attachment time and maximize the success rate.

Legacy networks: The reliability in today's wireless networks is finally dependent on the service levels agreed with customers. Apart from enterprise business customers, in most cases only best effort is guaranteed.

4.2.5 Availability and retainability

Qualitative definition: When the reliability decreases below an acceptable level QoE, $QoE \in [0,1]$, then the user may be so dissatisfied that it may regard the service as unavailable. The availability is an assessment criterion to describe inside a coverage area the percentage of places where a service is provided to the end user with the user's requested QoE level**.** Alternatively, availability is defined as the percentage of users or communication links for which the QoE requirements are fulfilled within a certain geographical area, e.g. in terms of reliability as defined in Section 4.2.4. The latter definition is better suited to the case of D2D communications. Retainability is a special aspect of the above, by which a service has been made available as long as the user needs the service.

There is a strong correlation of availability and retainability to reliability in Section 4.2.4. During final evaluation of both KPIs possible degradations have to be taken into account which might occur during handover processes between neighbouring cells when the end-user is moving and between different radio access layers (different technologies and/or frequency layers) if the end-user data bearer is shifted to a different layer.

Motivation: The KPI is important for all considered scenarios as it will provide a measure to identify the service availability for the end-users in the intended coverage area. Moreover, the KPI will contribute to the optimization of the network layout. It finally depends on the service criteria underlying the different test cases.

Mathematical definition: The availability in percentage is defined as the number of places (related to a predefined area unit or pixel size) where the QoE level requested by the end-user is achieved divided by the total coverage area of a single radio cell or multi-cell area (equal to the total number of pixels) times 100.

Alternatively, availability can be defined as the probability that the QoE requirements are fulfilled for a user or communication link within the service area. For the case when the QoE is expressed in reliability terms, the availability (*A*) is expressed as follows:

$$A = \Pr(R \geq QoE),$$

where *R* is the measured reliability and QoE is the QoE requirements in terms of reliability of the underlying test case. Retainability can be defined as the probability for *R* to remain larger than the QoE-target, QoE, given that the service has already been made available. With other words, it is the probability for a user to satisfactory completes a session or a call, once it has been made available. It is the complement of drop-rate for a session, call or any other service.

Legacy networks: The availability in today's commercial mobile radio networks is primarily adapted to the coverage probability of a network (mostly related to 95%).

4.2.6 Energy consumption

Qualitative definition: Introduce an indicator to highlight the energy efficiency of any innovation introduced in METIS, including the whole METIS system architecture.

Motivation: The explosion of traffic demand foreseen beyond the 2020 horizon future and the intrinsic increase of resources to be deployed to tackle the METIS challenges casts severe requirements in terms of energy consumption of the corresponding system. It is quite straightforward and currently widely accepted that these demands have to be monitored not by metrics referring to energy consumption only, but rather to energy efficiency, i.e. including the increased provisioning of capacity that the new system will ensure.

Mathematical definition: An elaborate description of the metrics to be adopted for energy efficiency has been provided in the European FP7 project EARTH and it is taken as a reference also within METIS. In particular a close reference is made to the deliverable D2.4 from EARTH [28].

The definition should be applied to three different environments: component level (for hardware innovative solutions), node level (for innovative solution in the transmitting nodes) and network level (for efficiency of the whole network). More insight is given here on the latter metric (the network one) due to the specific METIS goals, but all the details about component and node level metrics can be found in [28].

Regarding network energy efficiency three metrics are worth mentioning:

- Energy per information bit, expressed as follows

  $$\lambda_I = \frac{E}{I} = \frac{P}{R}\; in\; [J/bit]\; or\; [W/bps]$$

  that is the most widely accepted metric for energy efficiency, especially in urban environments (*E* stands for consumed energy in a given observation period *T* with consumed power *P*, *I* is the information volume with rate *R,* measured at MAC layer.

- Power per area unit

  $$\lambda_A = \frac{P}{A}\; in\; [W/m^2]$$

  typically applicable in suburban or rural environments (*P* is the power consumed and *A* the area coverage).

Legacy networks: In terms of energy efficiency it is advisable to consider LTE Rel-11 as baseline to compare results of the innovations performed in METIS, whenever possible.

In order to evaluate the METIS goal, the energy consumption must be modelled and analyzed both for the infrastructure and for the terminals. On the infrastructure side, models for analyzing and improving the energy efficiency of nowadays technologies have been proposed in the EARTH project [21]. On the terminal side, the energy consumption has been discussed for instance in [29]. More details about the energy consumption models, particular for legacy networks and technologies, are given in the Annex, Section 20.1 and Section 20.2.

It is possible that for many innovations in METIS no legacy reference will be available. As an example, consider the energy consumption of a car that could become a radio node in a future METIS network: of course there is no legacy reference for this case and it is also quite questionable if a reference to a car without any “mobile network related” facility could be reasonable. Whenever new network elements are introduced in the METIS network, the only reasonable reference is to the overall network energy efficiency, considering these new elements as further nodes in the network providing more capacity to the whole system.

So far no particular investigations have been considered with the due attention regarding energy efficiency of “devices”, i.e. for D2D, and “machines”, i.e. for M2M, at least within the framework of a mobile network perspective. It has to be analysed case by case the efficiency of these solutions, making comparisons to the previous conditions, where the innovative METIS functionalities were not applied to these devices or machines.

4.2.7 Cost

Qualitative definition: Unless otherwise stated in the test cases, the cost refers to all the additional investments and expenses required by the new METIS solution. Hence, if the METIS solution reuses part of the legacy infrastructure or it is a complement for it, then the cost of the legacy network is not included into the cost of the METIS solution.

For a cellular network solution, the cost typically includes a part related to infrastructure, a part related to the end-user equipment, and a part related to spectrum licenses. Costs that are not related to the technical solution, such as customer care and marketing, are not considered. The infrastructure part is typically divided into the capital investment to acquire and deploy the network, called *capital expenditure* (CAPEX), and the costs to operate the network, called *operational expenditure* (OPEX). For instance, the CAPEX of a macro site covers the site acquisition and preparation; the equipment acquisition, installation, and configuration; the backhaul installation; the antenna systems; the power cables. Typically, CAPEX consists of one-time expenditures. However, for practical reasons these expenditures are spread over several years, i.e. *annualized*. The OPEX for such a site covers site rental; power consumption; maintenance, optimization, reparations, and replacements; backhaul transmission costs; software and operation services.

The METIS focus is on the radio access network and therefore the costs of the core network and service platforms are typically not included, unless otherwise stated in the test cases.

The costs with the end-user equipment may be significant too. Some new technical solutions may require changes both in the infrastructure and the end-user equipment. Thus an investment in the infrastructure might not bring the expected benefits unless a significant part of the user equipment has been replaced. Therefore the operator(s) may have an incentive to invest in speeding up the natural process of renewing the end-user equipment.

For new types of services, applications, and technical solutions, it might be harder to draw the line between the infrastructure and the end-user equipment, as is the case with small mobile base stations, or relays, mounted on vehicles. But similar principles may as well be applicable for most of the test cases.

Motivation: METIS has an explicit goal of providing solutions whose costs do not exceed the cost of today's networks, although their performance is substantially better.

Mathematical definition: The mathematical definition is tightly connected to the model one chooses to use. A simple model can be based on the assumption that the total cost of ownership for an operator is proportional to the number of infrastructure nodes, to the number of end-user devices, and the spectrum. For more details, see Annex, Section 20.3.

Legacy networks: Examples of cost of ownership for radio access networks can be found for instance in [30]-[33]. In practice, the actual cost for different site types may vary between market and/or countries. Since the METIS goal related to cost Is expressed in relative terms with respect to the cost of the legacy network, it might be enough for some solutions to analyse the relative cost as exemplified in the Annex, Section 20.3, without the need to specify the node, or site, costs in absolute terms.

4.3 Requirements and KPIs

The main requirements and KPIs for each test case are given in Table 4.1.

Table 4.1: Summary of main requirements and KPIs for the different test cases.

Test case	KPI	Requirement
TC1 Virtual reality office	Traffic volume per subscriber	36 [Tbyte/month/subscriber] in DL and UL, respectively
	Average user data rate during busy period	0.5 [Gbps] DL and UL, respectively
	Traffic volume per area	100 [Mbps/m^2] DL and UL, respectively
	Experienced user data rate	1 [Gbps], UL and DL, with 95% availability (5 [Gbps] with 20% availability)
TC2 Dense urban information society	Traffic volume per subscriber	500 [Gbyte/month/subscriber] (DL+UL)
	Average user data rate during busy period	5 (1) [Mbps] DL (UL)
	Traffic volume per area	700 [Gbps/km^2] (DL+UL)
	Experienced user data rate	300 (60) [Mbps] DL (UL) with 95% availability Together with the mentioned traffic volume, this would (as an example, and assuming only DL traffic) correspond roughly to: One downlink packet of size 30 [Mbyte] generated once per minute and user throughout 9 [hours/day], and expected to be downloaded within 1 [s] in 95% of area and time.
TC3 Shopping mall	Traffic volume per subscriber	1.07 [Gbyte/subscriber] (DL+UL) during busy period (peak sales hour in the mall)
	Average user data rate during busy period (peak sales hour in the mall)	1.7 (0.7) [Mbps] DL (UL)
	Traffic volume per area	170 (67) [Gbps/km^2] DL (UL)
	Experienced user data rate	300 (60) [Mbps] DL (UL) under below availability, continuous traffic up to 20 [Mbps] (both DL and UL)
	Availability	95% of indoor environment space of shopping mall area for commercial data traffic 99% for safety-related sensor applications

Test case	KPI	Requirement
	Reliability	95% of time for commercial data traffic 99.9% for safety-related sensor applications
TC4 Stadium	Traffic volume per subscriber Average user data rate during busy period Traffic volume per area	9 [Gbyte/h] per subscriber DL+UL in busy period (peak of traffic during the sport event) 0.3-3 [Mbps] (for UL+DL considering the traffic profile reported in TC4 description) 0.1-10 Mbps/[m^2] / (stadium area 50,000 [m^2])
	Experienced user data rate	0.3-20 [Mbps] DL+UL
TC5 Teleprotection in smart grid network	Latency, end-to-end	8 [ms] for 1521 [byte] payload with reliability 99.999%
TC6 Traffic jam	Traffic volume per subscriber	480 [Gbps/km^2] DL+UL
	Experienced user data rate	100 (20) [Mbps] DL (UL) with 95% availability
TC7 Blind spots	Experienced user data rate	100 (20) [Mbps] DL (UL) with 95% availability in blind spots
	Energy efficiency	50% (30%) reduction for UE (infrastructure) should be achieved compared with legacy network
TC8 Real-time remote computing for mobile terminals	Latency, end-to-end	Less than 10 [ms] with reliability 95%
	Experienced user data rate	100 (20) [Mbps] DL (UL) with 99% availability
	Mobility	Up to 350 [km/h] for trains Up to 250 [km/h] for cars
TC9 Open air festival	Number of users and devices per area	100 000 users and 10 000 machine devices within 1 [km^2] area
	Traffic volume per subscriber Average user data rate during busy period Traffic volume per area	3.6 [Gbyte/subscriber] DL+UL during busy period of the festival 9 [Mbps] (DL/UL) 900 [Gbps/km^2] (DL+UL)
	Experienced user data rate	30 [Mbps] (DL or UL) at 95% availability Downlink: One packet size of 30 [Mbyte] generated per minute and user throughout of totally about 2 hours during the busy period of the festival event. Expected to be downloaded less than 10 [s] in 95% probability. Uplink: In case of data sharing, same for downlink. In case of web-browsing and sensor, the required data rate can be much lower.
	Fixed permanent infrastructure	Not existing within the open area
TC10 Emergency communications	Infrastructure	Destroyed or unreliable
	Battery lifetime (infrastructure and UEs)	1 [week] (with today's battery technology)
	Availability	99,9% victim discovery rate

Test case	KPI	Requirement
TC11 Massive deployment of sensors and actuators	Energy efficiency	0.015 [µJ/bit] for a data rate in the order of 1 [kbps]
	Protocol scalability	80% protocol efficiency at 300 000 devices per access node
	Coverage	99.9%
TC12 Traffic efficiency and safety	Latency, end-to-end (including detection delay) for receivers within the target range	Less than 5 [ms] for 99.999% of the transmissions
	Relative velocity	Up to 500 [km/h]
	Detection range	Up to 1 [km]

More detailed requirements and KPIs of each test case are presented in the Annex, Section 7.2 to Section 18.2.

5 Summary

To achieve the overall goal of the METIS project, the deliverable D1.1 described the representative challenging scenarios, test cases and their requirements and KPIs foreseen for this time frame.

More specifically, in the document, a wise strategy for designing long-term solutions for mobile communications was taken to expect the unexpected and to be prepared for radical changes in user behaviour and device ecosystem. To this end the document described five generic scenarios based on five fundamental challenges that are relevant for the considered time frame and which are wide in scope: “Amazingly fast” focused on providing *high data-rates* for future mobile broadband users. “Great service in a crowd” focused on providing mobile broadband experience even where very high user densities require *extreme area capacity*. “Ubiquitous things communicating” focused on efficient handling (cost, energy, scalability) of a *very large number* of devices with *widely varying requirements*. “Best experience follows you” focused on proving *end-users on the move* with high-level of experience. “Super real-time and reliable connections” focused on new applications and use cases with significantly stricter requirements on *latency and reliability* than what today’s mobile broadband networks capability.

To facilitate the development work of technical solutions with more specific research questions, the document defined totally twelve concrete test cases based on the scenarios. Each such test case typically contains one or multiple fundamental challenges from several scenarios. The aim of the test cases was to provide distinct problem descriptions, requirements and KPIs, defined from the end-user perspective. These will be used by the METIS project as a basis for designing and evaluating technical solutions. Hence, the technical solutions addressing the test cases were not within the scope of this document.

Although the test cases described in this document were rather specific, the ambition is that the solutions derived from them are expected to address a much wider class of problems relevant for the same fundamental challenges that the test cases are based on. The concrete test case KPIs provided a direction for the research and a measure of success of METIS. However, it was understood that a sensitivity analysis of the solutions around these KPIs would be essential for assessing the generality and providing a deeper understanding of the solutions.

While a significant effort was made to design the test cases to span challenging requirements for future applications, additional applications with even stricter requirements may still appear during the course of the project, along the lines of “expect the unexpected”. Such applications, when/if appearing, will be handled on a case-by-case basis and may lead to new, or modified, test cases.

This document will be used to motivate research items for the other work packages within METIS. Based on the test cases METIS will propose candidate solutions and map the end-user KPIs to solution-specific KPIs. METIS will then develop and evaluate technical components addressing the end-user and solution-specific KPIs. Often, a test case KPI can likely be addressed by more than one solution. However, it is not expected that a single solution can efficiently address all test cases. Rather, the various technical components and solutions will be combined into a unified METIS concept that addresses the fundamental challenges of the beyond 2020 information society.

6 References

[1] https://www.metis2020.com/

[2] M. Porter, “Competitive Advantage”, New York Free Press, 1985.

[3] IEEE 100 The Authoritive Dictionary of IEEE Terms, 7th edition, IEEE Press, December 2000. ISBN 0-7381-2601-2.

[4] “Requirements, evaluation criteria and submission templates for the development of IMT-Advanced”, ITU-R Report M.2133, 2008.

[5] “Requirements related to technical performance for IMT-Advanced radio interface(s)”, ITU-R Report M.2134, 2008.

[6] “Guidelines for evaluation of radio interface technologies for IMT-Advanced”, ITU-R Report M.2135-1, 2009.

[7] “Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced)”, 3GPP TR 36.913 V11.0.0, September 2012.

[8] “Key Performance Indicators (KPI) for Evolved Universal Terrestrial Radio Access Network (E-UTRAN): Definitions”, 3GPP TS 32.450 V11.0.0, September 2012.

[9] “Key Performance Indicators (KPI) for Evolved Universal Terrestrial Radio Access Network (E-UTRAN): Requirements”, 3GPP TS 32.451 V11.0.0, September 2012.

[10] Council Recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 HZ to 300 GHz) (Official Journal L 197 of 30 July 1999).

[11] FCC, Code of Federal Regulations CFR title 47, part 2.1093 “Radiofrequency radiation exposure evaluation: portable devices.”, Federal Communications Commission (FCC), October 2008.

[12] IEC 62209-2, “Procedure to determine the specific absorption rate (SAR) for mobile wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)”, March 2010.

[13] EN 62311, “Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz – 300 GHz), European standard, January 2008.

[14] CENELEC EN 50385, “Product standard to demonstrate the compliance of radio base stations and fixed terminal stations for wireless telecommunication systems with the basic restrictions or the reference levels related to human exposure to radio frequency electromagnetic fields (110 MHz – 40 GHz) – General public”, European Committee for Electrotechnical Standardization (CENELEC), August 2002.

[15] CENELEC EN 50383, “Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz – 40 MHz)”, European Committee for Electrotechnical Standardization (CENELEC), August 2010.

[16] FCC, "Evaluating Compliance with FCC Guidelines from Human Exposure To Radiofrequency Electromagnetic Fields", Supplement C Edition 01-01 to OET Bulletin 65 Edition 97-01, June 2001.

[17] "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017", Cisco, http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

[18] "Ericsson Mobility Report", Ericsson, November 2012, http://www.ericsson.com/res/docs/2012/ericsson-mobility-report-november-2012.pdf

[19] "Mobile traffic forecasts 2010-2020", UMTS-Forum Report 44, January 2011, http://www.umts-forum.org/component/option,com_docman/task,cat_view/gid,485/Itemid,213/

[20] "Assessment of the global mobile broadband deployments and forecasts for International Mobile Telecommunications", ITU-R report M.2243, 2011.

[21] "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown", EARTH project deliverable D2.3, November 2010, https://bscw.ict-earth.eu/pub/bscw.cgi/d71252/EARTH_WP2_D2.3_v2.pdf

[22] "User data rates in mobile data networks", NGMN Alliance, May 2010.

[23] 3GPP TR36.814, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects", 2010.

[24] Autorité de Régulation des Communications et Postes, République Française, "La qualité des services de voix et de données des opérateurs mobiles (2G et 3G) en France métropolitaine", Les actes de l'ARCEP, November 2012, http://www.arcep.fr/uploads/tx_gspublication/cr-enquete-QoS-2g-3g-nov2012.pdf

[25] http://www.connect.de/netztest/

[26] "The outcome of the evaluation, consensus building and decision of the IMT-Advanced process (Steps 4 to 7), including characteristics of IMT-Advanced radio interfaces", ITU-R Report M.2198, November 2011.

[27] I. Guvenc, S. Gezici, Z. Sahinoglu, and U. C. Kozat, Reliable Communications for Short-Range Wireless Systems. Cambridge University Press, 2011.

[28] "Most suitable efficiency metrics and utility functions", EARTH project deliverable D2.4, January 2012, https://bscw.ict-earth.eu/pub/bscw.cgi/d70454/EARTH_WP2_D2.4.pdf

[29] 3GPP R2-071284, Evaluating DRX concepts for E-UTRAN, Nokia.

[30] K. Johansson, A. Furuskär, and C. Bergljung. "A methodology for estimating cost and performance of heterogeneous wireless access networks", In IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, September 2007.

[31] K. Johansson, A. Furuskär, P. Karlsson, and J. Zander. "Relation between base station characteristics and cost structure in cellular systems", Personal, Indoor and Mobile Radio Communications, 2004. PIMRC 2004. 15th IEEE International Symposium on, 4(15):2627-2631, 2004.

[32] M. Werner, P. Moberg, and P. Skillermark. “Cost assessment of radio access network deployments with relay nodes”, In ICT-MobileSummit, 10-12 June, Stockholm, Sweden, 2008.

[33] M. Werner, P. Moberg, P. Skillermark, M. Naden, W. Warzanskyj, and I. Berberana. ”Optimization of cellular network deployments with multiple access point types, In WWRF Meeting 20, Ottawa, Canada, 22-24 April, 2008.

[34] IEC 61805-5, “Communication networks and systems in substations, Part 5: Communication requirements for functions and device models,” 1st edition, July 2003.

[35] M. Blesinger, E. Biebl, T. Gehrsitz, J. Eberspacher, P. Fertl, O. Klemp, H. Kellermann, "Angle-Dependent Path Loss Measurements Impacted by Car Body Attenuation in 2.45 GHz ISM Band," Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th , pp.1-5, 6-9 May 2012.

[36] 3GPP, TR36.888, “Study on provision of low-cost MTC UEs based on LTE”.

[37] European Commission, General for Mobility and Transport 20/07/2010: EU road fatalities.

[38] European Commission, Road Safety: Commission outlines measures to halve road deaths by 2020 (IP/10/970), press release, July 2010.

[39] CARE – EU road accidents data base: http://ec.europa.eu/idabc/en/document/2281/5926.html, Nov. 2010.

[40] C. Lottermann, M. Botsov, P. Fertl, R. Mullner, "Performance evaluation of automotive off-board applications in LTE deployments,"Vehicular Networking Conference (VNC), 2012 IEEE, pp.211,218, 14-16 Nov. 2012.

[41] C. F. Mecklenbräuker, A. F. Molisch, J. Karedal, F. Tufvesson, A. Paier, L. Bernado, T. Zemen, O. Klemp, and N. Czink., “Vehicular Channel Characterization and Its Implications for Wireless System Design and Performance”, Proceedings of the IEEE, vol. 99, no. 7, pp. 1189-1212, July 2011.

[42] E. G. Ström, “On medium access and physical layer standards for cooperative intelligent transport systems in Europe.”, Proceedings of the IEEE, vol. 99, no. 7, pp. 1183–1188, July 2011.

Annex

7 Annex - TC1: Virtual reality office

7.1 Background and motivation

The importance of interactive video communication will increase in the future, both for personal as well as professional use. Today's tele-presence services will evolve into high-resolution 3D versions, which will allow friends and relatives to have the amazing experience "as if you were there". On the professional side, the movie industry is expected to expand the success of 3D panorama screening, of IMAX type. An inexpensive and flexible wireless communication system, able to exchange the huge amount of data generated during the process, will be an essential part of the technical solution. It is likely that the technology developed to support this kind of complex interactive work, by means of virtual reality imaging, will find use also in other areas.

Today's wireless technologies are not capable to provide, at reasonable costs, the high data-rate and capacity requirements posed by this type of applications on the access and the in-building backhaul to the wireless access points. For this reason, METIS will contribute solutions aimed at addressing the ultra-high data rate requirements envisioned in future applications and illustrated by this test case.

7.2 Requirements and KPI

The requirements which must be satisfied for this test case are described below and the key performance indicators are summarized in Table 7.1.

End-users should be able to experience sustainable data-rates of at least 1 [Gbps] to other team members and to the office cloud servers. The end-users may be located in different rooms or at different floors or even in other buildings. For purposes of synching large amounts of data (e.g. downloading large files from the office cloud to a local storage) even higher data rates, 5 [Gbps], should be experienced, although a lower availability can be accepted for this use case.

End-users should be able to experience data rates of at least 1 [Gbps] in 95% of office locations and at 99% of the busy period. Additionally, end-users should be able to experience data rates of at least 5 [Gbps] in 20% of the office locations, e.g. at the actual desks, at 99% of the busy period.

The round-trip time latency should be no more than 10 [ms]; i.e. the time from a packet is sent until an ACK is received should not exceed 10 [ms].

Each end-user will generate an average traffic of at least 36 [Tbyte] per month in DL and UL. This corresponds to each user being active for 4 hours per day for 20 days a month and transferring data at a rate of 1 [Gbps]. This comes from a user on average active four hours per day with 1 [Gbps] rate for 20 days a month. Due to this test case relying on streaming the average (during busy period) and the peak traffic is similar.

Provide enough capacity to support the generation and consumption of at least 0.1 [Gbps/m^2]. This comes from the rate per user and the average user density (one per 10 [m^2]).

The installation of the building's communication network should be quick and smooth without troublesome configurations and with small impact on the building. A high speed connection (e.g. optical fiber) is available on each floor but it is desired, for reasons of flexibility and installation simplicity and cost, to reduce the amount of cabling, for instance for the transport backhaul.

The technologies should also be low cost, scalable and relatively easy to roll-out, configure and maintain.

Table 7.1: Requirements and KPIs for TC1

Variable/parameter	**Value**
Performance targets	
Experienced user throughput	At least 1 (5) [Gbps] with 95% (20%) location reliability in DL as well as UL; see availability and reliability below
Traffic volume density	Average 0.1 [Gbps/m^2] in both DL and UL; peaks can be 5 times higher
Latency	10 [ms] RTT
Availability	1 [Gbps] at 95% , 5 [Gbps] at 20% office space
Reliability	99% working hours
Constraints	
Energy consumption (infrastructure)	Low-energy operations are preferred mainly for cost and sustainability reasons. When not transmitting user data the consumed energy should be very low
Energy consumption (UE or other devices)	UE should be able to operate on battery for several hours
Cost (infrastructure)	Network infrastructure should be cheap both in terms of hardware cost as well as installation and maintenance costs
Cost (UE or other devices)	UE cost should be similar to today's smartphones or 3G/4G modems
Test case definition	
User/device average density	1/10 [m^2] per floor
Traffic volume/type	36 [Tbyte/user/month], DL as well as UL; video dominates
User type	Mainly human
User mobility	Static or low mobility nomadic (less than 6 [km/h])

8 Annex - TC2: Dense urban information society

8.1 Background and motivation

The "Dense urban information society" test case is concerned with the connectivity required at any place and at any time by humans in dense urban environments. We consider here both the traffic between humans and between human and the cloud, and also direct information exchange between humans or with their environment.

Public cloud services

Besides classical services such as web browsing, file download, email, social networks, we will see a strong increase in high definition video streaming and video sharing, possibly also with higher requirements for image resolution, e.g. 4K standard. This trend will, for instance, be fostered through the availability of new user interface improvements like resizable portable screens, or screens embedded into watches or glasses. Besides a massive increase in the data volumes connected to the usage of public cloud services, a key challenge in communication systems beyond 2020 will lie in the fact that humans will expect the same reliable connectivity to the cloud anytime and anywhere.

Device-centric services

Also, augmented reality services will be essential in our daily life. For a full experience of the augmented reality, information could be fetched from various sources, such as sensors, smart phones, wirelessly connected cameras, databases, servers, and used locally in the device or sent to be processed in the cloud. Hence, the future mobile and wireless communication system should integrate both highly capable devices and other wireless devices in an efficient way. In an urban area, some of these devices may provide information about the surrounding of the users by measuring a certain phenomenon or by providing information about the presence of certain objects of interest. Based on the information harvested from surrounding devices and other sources, the UE could provide the user with contextual information so as to help the users to better understand and enjoy their environment. Also the information collected in or by the device can be uploaded to the cloud servers and shared with others through the cloud connectivity – a tight latency requirement will here be as important as a high data rate.

The challenge for mobile communication systems beyond 2020

The mobile technology, completely transparent for users, will allow network access at any location and any time with service quality comparable to current wired broadband access with optical fibre.

8.2 Requirements and KPIs

In this test case, we consider both UEs exchanging information with cloud servers (i.e. for public cloud services) and also with other UEs, devices or sensors located in close vicinity (i.e. for device-centric services). The key requirements are described below and the KPIs are summarized in Table 8.1.

- For public cloud services, the requirement is to enable in **95% of locations and time an experienced data rate of 300 [Mbps] and 60 [Mbps] in downlink and uplink, respectively.**

- For device-centric services, the experienced data rate between UEs or sensors is required to be **10 [Mbps] or more**.
- The network is required to provide the above QoS levels while sustaining an average traffic volume of **500 [Gbyte] per device and per month**. This corresponds to 1000 times today's average monthly traffic volume per subscriber. Note that averaging is done over various types of users and devices.

Note that the above stated requirements will be connected to a mix of different traffic forms, e.g. bursty traffic and video streaming. If, as an example, only highly bursty downlink traffic is considered, the above experienced data rate requirements and the traffic volume per subscriber could be translated into a traffic model foreseeing "1 downlink packet of size 30 [Mbyte] per user and minute, throughout 9 hours per day, to be delivered within 1s in 95% of time and area". The exact split of the monthly user traffic volume among uplink and downlink, different times of the day, different areas (e.g. office, pedestrian sidewalks, residential areas, parks) and different forms of traffic (e.g. bursty and streaming) will be specified later by the METIS partners.

For the limited areas that will cover enterprises locations (e.g. complex of office buildings), universities (e.g. campus buildings) or any other managed public space, operators may provide cloud services at the quality level beyond the values stated above, i.e. **achieving data rates up to 1 [Gbps]**.

The latency requirement from an end-user's perspective depends on the service type:

- web browsing: less than 0.5 [s] for download of an average size web page. A latency of 0.5 [s] may not appear very challenging, but is has to be taken into account that typical web page sizes beyond 2020 will be much larger than today (In conjunction with the requirement of an experienced data rate of 300 [Mbps], web page sizes will be on the order of 20 [Mbyte]), and that from the human user perspective it will not make a difference if latency requirements are further tightened.
- video streaming: less than 0.5 [s] for video starting
- augmented reality processed in the cloud and locally: less than 2 to 5 [ms]

In order for this service to be acceptable, the additional energy consumption of providing this service is less than 10% as compared to the energy consumption when this service is not used (This refers to the power consumption of the user device and of the access network, normalized to the number of users). Additional constraints on the energy consumptions must be formulated for the new types of devices.

D2D related KPIs include D2D discovery time (synchronization scheme dependent), D2D link coverage (mininum 250 [m]), D2D setup latency (solution dependent, e.g. the level of network assistance), feedback latency, e.g. HARQ feedback latency (less than 1 [ms]), D2D link throughput and device battery consumption (total D2D radio power consumption should be lower than the cellular radio power consumption).

Table 8.1: Requirements and KPIs for TC2

Variable/parameter	**Value**
Performance targets	
Experienced user throughput	300 [Mbps] in DL 60 [Mbps] in UL
Traffic volume density	About 700 [Gbps/km^2]

Latency	web browsing: less than 0.5 [s] for download of an average size web page video streaming: less than 0.5 [s] for video starting augmented reality processed in the cloud and locally: less than 2 to 5 [ms] D2D HARQ feedback latency less than 1 [ms]
Availability and reliability	95% in space and time
Constraints	
Energy consumption (infrastructure)	Low-energy consumption is preferred for cost and sustainability reasons. The consumed energy should be very low when not transmitting user data. Generally the network energy consumption should be comparable to the energy consumption of today's metropolitan deployments, despite the drastically increased amount of traffic.
Energy consumption (UE or other devices)	Energy consumption should be similar to that of today's devices
Cost (infrastructure)	Infrastructure cost should be kept on the same level per area as today.
Cost (UE or other devices)	Future mobile broadband UE cost should be similar to today's smartphones or 3G/4G modems (transceiver part). A sensor device must have a significantly lower cost than a regular handset devices, i.e. not more than a few euros for the radio part of the sensor
Test case definition	
User/device density	up to 200 000 users per [km^2]
Traffic volume/type	500 [Gbyte/month/subscriber] (DL and UL share not defined yet)
User type	Primarily human generated and consumed traffic
User mobility	Most of the users ,devices, have velocities up to 3 [km/h], in some cases up to 50 [km/h]

9 Annex - TC3: Shopping mall

9.1 Background and motivation

The main characteristic of the present test case is the challenging mixture of different future service types to be realized for shopping purposes (e.g. customer interaction, shopping mall operation and maintenance) as well as for usual communication in an indoor environment with high density of human users and sensors/machines inside a rather small area.

Within the indoor environment of a shopping mall mobile network operators are requested to provide sufficient radio coverage for their customers to allow them continuing their usual communication via their personal devices. Broadband service offerings inside the mall require additionally a densification of radio nodes to keep pace with the increasing capacity demand of user crowds. Especially catering areas will function as communication hotspots as there will be also a high demand in entertainment applications during shopping breaks.

The mobile radio infrastructure is supplemented by a local radio/fixed infrastructure with inclusion of large machine communication/sensor network, potentially operated on behalf of the real estate owner. Main focus of that network is to support general commercial services (cash desks, vending machines, electronic payment, couponing, advertisement), but also to address the customers via direct interactions. One example is the (indoor) navigation of customers via their devices to the shops of their preference and the provisioning of personalized information (e.g. detailed product information, real-time price comparisons) dependent on their location before or inside the shops, may be directly on the screen of their own device based e.g. on augmented reality services or after interaction between device and network infrastructure via multimedia objects mounted at shops. Due to customer mobility inside the mall session/service handovers between radio/sensor nodes in the proximity of the customer have to be handled in an efficient way. For elderly and handicapped people small electrical vehicles (similar to wheel chairs) are available which bring the people to places of their interest via autonomous routing without driver involvement (interaction between the vehicle and the surrounding sensor network). Dependent on the services that eventually will be offered, the data rates will cover a large range from few packets up to real-time video for product presentations.

The radio link handling incl. change between shopping mall and mobile radio infrastructure or creation of parallel links has to be performed automatically without user interaction based on pre-selected cost/link efficiency policies. For social networking purposes customers may be also informed about friends/buddies being on-site in the shopping mall at the same time. Dependent on radio link availability a connection between the parties can be realized via the local or mobile radio network infrastructure or via direct D2D communication. D2D may be also a communication feasibility for service assistants e.g. inside the catering areas (human-to-human as well as human-to-machine).

The local infrastructure may also support safety/security-related applications. For emergency cases a very reliable overlay network might be provided which supports also interactions with external staff like fire workers or medical rescue teams as their usual connection links may be disturbed by propagation loss inside the building.

9.2 Requirements and KPIs

A high network/service capacity has to be provided by the METIS solution for a shopping mall area to cover a high density of people (varying during day time, also dependent on special events, e.g. Sunday or late-evening shopping) and sensors/machines.

Main KPIs to be achieved:

- Provisioning of network capacity per area to solve the minimum required throughput values (see following table):
    - Measurement of PDF/CDF of spectral efficiency as well as user throughput. Target is to achieve the minimum throughput with probability of 95%.
- Network feasible to handle expected user/device numbers without significant degradation in data rate transmission and latency.
    - Statistics on random access procedures and initial attachments.

Table 9.1: Requirements and KPIs for TC3

Variable/parameter	Value
Performance targets	
Experienced user throughput	Intermediate data rates for bursty traffic pattern of at least 300 (60) [Mbps] in DL (UL)
Traffic volume density (during shopping busy period (hour); sensor traffic not considered as only minor part)	About 170 (67) [Gbps/km^2] in DL (UL)
Latency	RAN latency (user plane) less than 5 [ms] (RTT). For some sensor-types (e.g. sensor – user device communication during movement) short delay less than 5 [ms] for network attach (control plane)
Availability	95% of indoor environment space of shopping mall area for commercial data traffic 99% for safety-related sensor applications
Reliability	95% of time for commercial data traffic 99.9% for safety-related sensor applications (time for successful short message delivery finally dependent on application, max. less than 1 [s] including connection set-up)
QoS/QoE	Higher QoS level required for safety-related sensor application (e.g. fire protection) compared to other traffic (also related to network attach interval)
Constraints	
Energy consumption (infrastructure)	In principle no constraints due to indoor installation with power supply availability at least for common radio nodes; nevertheless low-energy operation of all radio nodes incl. sensors expected due to energy cost and EMF reasons; especially auto-configuration/operation

	including switch-on/off of radio nodes dependent on traffic load/day time as important implementation feature
Energy consumption (UE or other devices)	In principle no divergent constraints for UEs, but initial network access and data transport to be handled in energy-optimized way; this is especially true for sensors with battery power supply only
Cost (infrastructure)	Infrastructure ownership consolidation required between real estate owner, network operator(s) and ICT providers to allow optimized operation. Usage of available fixed network infrastructure for wireless traffic backhaul/aggregation should be incorporated as far as possible to keep cost low. Typically limited places for installation of larger radio equipment. Restrictions for wireless backhauling due to indoor installation. Better incorporation of wireless sensors possible, but dependent on type power supply and backhaul might be critical. Low cost sensor network appreciated with total cost scalable to the number of sensors. Operational rooms for server installation (possible use for local C-RAN and CDN functionalities).
Cost (UE or other devices)	Standard UE approach for customer devices; use of low-cost sensors should be feasible
Test case definition	
User/device density (average across indoor shopping mall area)	Human user density: 0.1 per [m^2] Sensors: 0.7 per [m^2]
Traffic volume/type (during shopping busy period (hour); sensor traffic not considered as only minor part)	About 5.6 [Tbyte/h] in total (4 [Tbyte] in DL, 1.6 [Tbyte] in UL), aggregated for all users in the mall
User type	Human, machine/sensor
User mobility	Human: Static - walking speed Sensors: Static
Indoor positioning accuracy	Less than 0.5 [m]
Position tracking	Fast tracking of UEs between neighbouring radio nodes/sensors required (tracking interval less than 250 [ms])

10 Annex - TC4: Stadium

10.1 Background and motivation

The stadium use case relies on an existing market, where anyway operators experience today a “difficulty” in providing a service with good quality of experience; providing then service with high level of quality of experience could be considered as a thorough new market. The mentioned “difficulty” is mainly related to the extreme crowdedness of the stadium (or the sport facility) that requires very peculiar deployments. On the other hand the service in this scenario has to be provided for very limited time intervals, putting some constraints also from a cost perspective of the deployment.

In this sense, this can be considered as mostly an operator-centric use case, also in the case of local data exchange performed as an example by network controlled direct D2D, where the operator provides the infrastructure and the service for the users, here intended as traditional users equipped by evolved phones, tablets, and so on. Relationships with the stadium owners or the national authorities have to be taken also into consideration. To identify the scenario from a technical point of view, the general challenge is to offer a reliable and extremely huge bandwidth service to a multitude of users temporarily located in a single cell already deployed area.

10.2 Requirements and KPIs

Any solution that will be applied in the case of the stadium deployments, as well as in terms of cost, shall be evaluated in terms of:

- User throughput (average, median, cell edge user). Consider increasing, in order to comply with the EU long-term goal of 30 [Mbps] for all EU citizens.
- Traffic volume density, achieved in the stadium or sport facility during the events; it is hence a very big amount of data offered by users temporarily located in a relatively small area

Energy efficiency shall be evaluated as well as costs, but exact constraints will be detailed in the next phases of the project.

Table 10.1: Requirements and KPIs for TC4

Variable/parameter	**Value**
Performance targets	
Traffic volume per subscriber Traffic volume per area	9 [Gbyte/h] per subscriber DL+UL in busy period (peak of traffic during the sport event) 0.1-10 [Mbps/m^2] / (stadium area 50,000 [m^2])
Experienced user data rate Average user data rate during busy period	0.3-20 [Mbps] DL+UL 0.3-3 [Mbps] (for DL+UL considering the traffic profile reported in TC4 description)
Latency	RAN latency (user plane) less than 5 [ms] (RTT)
Availability	95 % within stadium Only on a limited area where a high number of people usually gathers to follow

	events (e.g. football match, Olympic Games, Formula1 races)
Reliability	Throughput offered only during events in the stadium, for the remaining time network can be switched off
Constraints	
Energy efficiency (infrastructure)	Low-energy operation of all radio nodes expected due to energy cost and EMF reasons; especially auto-configuration/operation including switch-on/off of radio nodes dependent on traffic load/event time as important implementation feature.
Energy efficiency (UE or other devices)	Same constraints as the general METIS goal for UEs efficiency
Cost (infrastructure)	Infrastructure ownership consolidation required between owners and network operator(s). Usage of available fixed network infrastructure for wireless traffic backhaul/aggregation should be incorporated as far as possible to keep low cost. Typically limited places for installation of large radio equipment.
Cost (UE or other devices)	Standard approach for UEs cost management
Test case definition	
User/device density	20-50 thousands in roughly 50000 [m^2]
Traffic volume/type	9 [Gbyte/h] per subscriber DL+UL in busy period (peak of traffic during the sport event). Traffic variable according to sport events and in the range above mentioned; mostly unicast
User type	DL users, but UL to be considered as well
User mobility	Low

11 Annex - TC5: Teleprotection in smart grid network

11.1 Background and motivation

Real-time communications with guaranteed delays (e.g. a few milliseconds between two ends) and jitter can serve as an important enabler for diverse machine type applications in the future. The setting for these types of applications could be in industry automation, resource management and resource distribution, among other things. For instance, reliable transmission of real-time information can be used to control industrial facilities like systems for production of goods or for distribution of resources, e.g. energy management for fast teleprotection, telecontrol, telemetry. These kinds of systems may require real-time monitoring and alerting functionalities and an immediate response to altered system conditions that may occur at a remote distance from the site controlling the process. Providing such real-time communication, with guaranteed latency and jitter at a low cost is the main challenge raised by this test case. Naturally, a wireless communication system enabling reliable information delivery with low E2E latency may have further applications, e.g. in wireless factories (applications in factory automation, especially process automation) or mobile health.

Mobility issues such as support of quickly moving devices and seamless wide area coverage may be beneficial for the applications mentioned above. However, such aspects are considered in separate test cases, see, e.g. TC12.

11.2 Requirements and KPIs

When a shortcut happens on a high power line, e.g. fallen tree, then the Protective Relay (PR) of the closest substation can detect the damage within short time (few power cycles). In order to prevent further damage and a costly blackout, it is very important that the information is forwarded to neighboring substations, which will shut off power to the damaged line, and possibly activate other lines to compensate for the loss. Preferably, this information exchange happens over fiber lines but in most cases this solution is prohibitively expensive. Thus, there is a strong interest in wireless solutions communication between substations. The most critical is the latency requirement, which cannot be achieved by the current systems and standards and there is a clear need for new concepts and protocols are needed in order to reduce the wireless latency.

The requirements for this test case are described below and the key performance indicators are summarized in Table 11.1. The specific values are based on the IEC 61850 standard for communication between substations in a power grid [34].

- Up to 1521 [byte] of payload, GOOSE (generic object oriented substation event) message, should be reliably delivered within 8 [ms] between two communicating substations. This requires the network to provide a data-rate of up to 1.5 [Mbps] for one device. However, less data is transmitted in practice. A typical number is 150 [kbps] per device.
- The expected OTT latency between any two communicating points (CPE, the figure in Section 3.3.5) should be less than 8 [ms]. This includes processing delay, coding delay and decoding delay for an event-triggered message that may occur anytime.

- The level of reliability is set to be at least 99.999%. Higher reliability can be achieved by link redundancies.

Table 11.1: Requirements and KPIs for TC5

Variable/parameter	Value
Performance targets	
Experienced user throughput	Approximately about 200 [byte] up to 1521 [byte] of information reliably delivered within 8 [ms], corresponding to 150 [kbps] up to 1.5 [Mbps]
Traffic volume density	Not relevant requirement
Latency	8 [ms] OTT for an event-triggered message that may happen anytime
Availability	100% network availability at each substation (fallback solutions available, the channel allocated for teleprotection should be permanent and always active, or be mandatory occupied with the TOP priority.)
Reliability	99.999% service availability (Assuming equal failure rate for energy and ICT system, we can estimate 1.5 minutes failure duration for ICT network resulting in over 99.999 % reliability (CENELEC EN 50-160)
Constraints	
Energy consumption (infrastructure)	Network needs to be able to operate ca 24 hours on battery backup, otherwise not critical
Energy consumption (UE or other devices)	NA
Cost (infrastructure)	Cost should be rather low; separate infrastructure solution will likely be too expensive
Cost (UE or other devices)	Can be significantly larger than today's smartphones
Test case definition	
User/device density	Dense urban: around hundreds per km^2 Urban: up to around 15 substations per [km^2] Populated rural: up to around 1 substation per [km^2]
Traffic volume/type	GOOSE messages of 200 up to 1521 bytes payload in the IEC 61850 standard transmitted at unforeseen times
User type	Machine: electrical grid substation
User mobility	Static

12 Annex - TC6: Traffic jam

12.1 Background and motivation

The high occurrence and severity of traffic jams in countries such as China and Japan, has increased significantly the penetration ratio of in-car digital terrestrial TV receivers in these markets. The consumption of video-on-demand services delivered by mobile networks within vehicles is expected to play a significant role in the future, acting as a substitute for traditional broadcast TV services. Moreover, in addition to pure media services, more traditional public cloud services such as web browsing or file download (see TC2) will be enjoyed by users travelling inside their vehicles. The capacity required by this kind of services during traffic jams can easily swamp the capabilities of networks deployed in motorways and rural areas. In addition to high capacity demands, the network has to satisfy the QoE requirements in terms of end-to-end latency and reliability. This test case captures the challenge of providing good QoE for in-vehicle users that utilize bandwidth-demanding services during future traffic jam situations.

Figure 12.1: Rear seat infotainment system.

12.2 Requirements and KPIs

The requirements for this test case are described below, with the key performance indicators summarized in Table 12.1.

- High data rate connectivity is expected for the users inside the vehicles using their personal devices and/or the on-board interfaces. Each user should be able to experience a data rate of at least 100 [Mbps] in downlink and 20 [Mbps] in uplink.
- We assume a vehicle density of 1000 vehicles per [km^2] and a maximum of 4 active users per vehicle. Therefore the total traffic volume is 480 [$Gbps/km^2$] including downlink and uplink. Note: The vehicle density was computed by assuming an average vehicle length of 5 [m], a separation between vehicles of 1 [m] and a 6-lane highway of length 1 [km] suffering a traffic jam.
- Each user is expected to generate a total traffic volume of at least 53 [Gbyte] per hour (including downlink and uplink).
- The end-to-end latency has to be maintained below 100 [ms] in order to satisfy the QoE requirements of public cloud services.
- The availability must be as high as 95%.

- A reliability of 95% is necessary in order to satisfy the QoE requirements of public cloud services (seamless experience without perceived errors).

Table 12.1: Requirements and KPIs for TC6

Variable/parameter	Value
Performance targets	
Experienced user throughput	100 [Mbps/user] in downlink 20 [Mbps/user] in uplink
Traffic volume density	480 [Gbps/km^2]
Latency	Less than 100 [ms]
Availability	Greater than 95% of users
Reliability	Greater than 95%
Constraints	
Energy consumption (infrastructure)	In principle no particular constraints; nevertheless low-energy operation of all radio nodes expected due to energy cost and EMF reasons;
Energy consumption (UE or other devices)	In principle no divergent constraints for UEs, but initial network access and data transport should be handled in an energy-optimized way; this is especially true for devices with battery power supply only.
Cost (infrastructure)	Additional deployment of infrastructure should be avoided
Cost (UE or other devices)	No additional costs for UEs
Test case definition	
User/device density	4000 users per [km^2]
Traffic volume/type	53 [Gbyte/hour/device]
User type	Primarily human consumed traffic
User mobility	Less than 3 to 10 [km/h]

13 Annex - TC7: Blind spots

13.1 Background and motivation

Due to the introduction of smartphones and tables, users are getting used to the consumption of high data rate services no matter where they are. However, the Quality of Experience (QoE) of this kind of services might be significantly degraded in blind spots such as rural areas due to the lack of radio resources and/or low coverage caused by insufficient network deployment. Furthermore, in areas with low coverage, the transmission power generally increases to compensate for the higher propagation losses. This lowers the battery life of smartphones and tables, which is considered as a critical factor for user satisfaction. A very important aspect to consider in this test case is the high correlation between the distribution of vehicles and users user satisfaction. In other words, the higher the data traffic demands, the higher the number of vehicles in the proximities. This property can be exploited to cope with the presence of blind spots in the service area in a flexible and cost efficient manner.

13.2 Requirements and KPIs

The requirements and the key performance indicators are summarized in Table 13.1.

High data rate coverage is expected at every location of the service area, even in remote rural areas. Mostly, video streaming and file downloads are required, corresponding to a very high data rate per user. In particular, each user should be able to experience a data rate of at least 100 [Mbps] in downlink and 20 [Mbps] in uplink.

In rural areas we assume a user density of 100 per [km^2], which results in a total traffic volume of 12 [$Gbps/km^2$]. In urban scenarios, the user density, and therefore the total traffic volume, can be 10 times higher.

The end-to-end latency has to be maintained below 100 [ms].

The availability must be as high as 95% in blind spots, i.e. locations with bad coverage.

Reliability is not in the focus of this test case. Nevertheless, some level of reliability is required in order to ensure a seamless consumption of video services together with timely file delivery. For example, low reliability levels can lower the QoE of video services due to the presence of visual errors and can also delay the download time of file delivery services. As a result, a reliability value of 95% is assumed.

Both infrastructural and end user energy consumption should be minimized. In this regarding, operators associated infrastructure should reduce 30% energy by joining some flexible small cells, whereas the users need to spent just half as much as energy compared with legacy network.

Network cost including infrastructural equipment, site rental, energy consumption etc, is expected to be reduced by 50%.

An assumption on vehicle density and user density in rural areas can be e.g. 100 per [km^2] and 100 per [km^2], respectively. In urban scenarios, the density can be 10 times higher. It is worth noting that the distribution of users and vehicles is correlated.

Human users are generally the main target of this test case, while a large diversity of services should be supported, such as file downloading and video streaming.

Table 13.1: Requirements and KPIs for TC7

Variable/parameter	Value
Performance targets	
Experienced user throughput	High throughput/QoS must be achieved for 100 [Mbps] (DL) and 20 [Mbps] (UL)
Traffic volume density	Rural ≈ 12 [Gbps/km^2] Urban ≈ 120 [Gbps/km^2]
Latency	Less than 100 [ms]
Availability	Greater than 95% of users in blind spots
Reliability	Greater than 95%
Constraints	
Energy efficiency (infrastructure)	To be minimized, 30% reduction should be achieved compared with legacy network
Energy efficiency (UE or other devices)	To be minimized, 50% reduction should be achieved compared with legacy network
Cost (infrastructure)	To be minimized, 50% reduction should be achieved compared with legacy network
Cost (UE or other devices)	NA
Test case definition	
User/device density	Rural: 100 vehicles per [km^2], 100 user per [km^2] Urban: 10 times more than in rural Correlation between the distribution of vehicles and users
Traffic volume/type	53 [Gbyte/hour/device]
User type	Human
User mobility	Low, typically less than 30 [km/h]
Other test case specific performance targets	
-	-
Other test case specific constraints	
Vehicle mobility	Low/stationary, typically less than 10 [km/h]

14 Annex - TC8: Real-time remote computing for mobile terminals

14.1 Background and motivation

In-vehicle users currently experience a limited QoS due to the lack of mobility management, insufficient antenna capabilities and the penetration loss of the vehicle shell (especially for cars, trains, and buses with metal-film windows the body penetration loss can reach up to 20 [dB], [35]. The quality degradation becomes more severe especially in rural area and mountain area where the wireless infrastructure is sparsely populated and the path loss becomes large.

This makes it very difficult to deploy real-time remote services such as data storage and processing with an acceptable QoE in vehicles that move at high speeds. It becomes even more challenging when not only human users require such services, but also machine-to-machine type communication. Real-time remote processing will allow for shifting complex processing tasks from on-board devices in the vehicle to a server. This will ease the maintenance of electronic control units in vehicles and guarantee fast time-to-market for novel services in the future.

In order to meet the QoS and QoE demands of such services in such challenging circumstances (i.e. high speeds and sparsely deployed geographical areas), new technology solutions must be developed. Today, passenger internet on vehicles is often provided through personal dongles which connects to the 3G networks directly through the vehicle windows. However, this technique has some significant drawbacks: the user experience will be limited by the network provider's coverage and capacity along the route (which is even more degraded due to the additional vehicle body loss). With the help of advanced antenna systems at the roof of the vehicle and relay nodes, the problems of the penetration loss of the metallic vehicle shell will be overcome. This will also enable on-board devices and vehicle services that require a real-time connection to the remote server. Currently, car manufacturers need to update the electronic control units (ECUs) of their whole vehicle fleet in order to provide new services to all of their customers. With remote processing, car manufacturers could introduce novel applications remotely without having to modify the ECUs inside their vehicles. A representative example of such a case is the introduction of augmented reality applications being displayed in the vehicle's wind shield.

Beyond 2020 such services will request high data rates even while the terminal is moving at very high speeds, e.g. up to 350 [km/h] for trains. In addition, real-time remote services require robust communication links with very low latency and availability close to the 100% in order to achieve a seamless user experience and acceptable performance. This is especially challenging in rural and mountain areas where the wireless infrastructure is sparsely deployed.

14.2 Requirements and KPIs

The main KPIs of this test case are

- High availability of 99%
- Low E2E latencies of less than 10 [ms].

The requirements and key performance indicators for this test case are summarized in Table 14.1 and described in more detail as follows:

- High data rate connectivity is expected for vehicles (or specifically, the on-board devices) and also for user devices inside of vehicles. Real-time interactive services (such as augmented reality and virtual office applications), location based services, and any service that requires to shift certain complex processing tasks (usually performed locally) to a remote server correspond to high data rate demands with real-time requirements. As a result we assume that every active device in the vehicle requires a data rate of 100 [Mbps] in downlink and 20 [Mbps] in uplink. Assuming at most 5 simultaneously active devices per vehicle (including the on-board devices) and a vehicle density of 100 vehicles per [km^2] in motorways, this leads to a total traffic volume of 60 [Gbps/km^2].
- For cars on highways we can assume a vehicle density of 100 vehicles per [km^2]. Expecting every active device in the vehicle to require a data rate of 100 [Mbps] in downlink and 20 [Mbps] in uplink and assuming at most 5 simultaneously active devices per vehicle (including the on-board devices), leads to total traffic volume 5 [Gbps/km^2].
- Multi-operator solutions are required in order to serve users with different network operator contracts and thus make this KPIs available
- The considered applications have real-time requirements. Therefore, E2E latencies lower than 10 [ms] with high reliability (i.e. 95% of the packets should be successfully transmitted within this time) needs to be achieved.
- The energy efficiency for the devices used in the vehicles and for ECUs using remote processing services should be high. Power consumption should be minimized in order extend the battery time and allow for high productivity of the users inside the vehicles.
- Device densities depend mainly on the means of transportation system. By 2020 and beyond people are expected to carry more than one cellular device. Moreover, the vehicle itself (through in-vehicle ECUs) may shift complex processing tasks to a remote server in real-time. The number of active devices (passenger devices plus vehicle on-board devices) scales with the size of the vehicle:
    - Less than 5 simultaneously active devices per car
    - Up to 50 user devices simultaneously active per bus
    - Up to 300 user devices simultaneously active per train
- Assuming 10 [Mbps] per active device including the vehicle itself, results in a traffic volume of 4.4 [Gbyte/hour/device].
- The test case considers human-to-machine and machine-to-machine type communication with high mobility making use of real-time remote processing.

User mobility equals the vehicle speed which can reach up to 350 [km/h] or more for high speed trains.

Table 14.1: Requirements and KPIs for TC8

Variable/parameter	Value

Performance targets	
Experienced user throughput	100 [Mbps] in downlink 20 [Mbps] in uplink
Traffic volume density	60 [Gbps/km^2] (for cars on a highway)
Latency	Less than 10 [ms] E2E latency
Availability	99% in space and time; Multi-operator solutions are required in order to serve users with different network operator contracts
Reliability	High reliability for real-time processing services; 95% of the packets shall be transmitted successfully within a maximum E2E latency of 10 [ms]
Constraints	
Energy efficiency (infrastructure)	In principle no particular constraints; nevertheless low-energy operation of all radio nodes expected due to energy cost and EMF reasons; especially auto-configuration/operation incl. switch-on/off of radio nodes dependent on traffic load/day time as important implementation feature
Energy efficiency (UE or other devices)	Significantly reduced battery consumption; UE transmit power should be constraint to the minimum
Cost (infrastructure)	Infrastructure cost should be kept on the same level per area as today.
Cost (UE or other devices)	No additional costs for UEs; solutions should be transparent for the devices
Test case definition	
User/device density	Less than 5 simultaneously active devices/car; approximately 100 cars per [km^2] (on a highway) Up to 50 user devices simultaneously active per bus Up to 300 user devices simultaneously active per train
Traffic volume/type	53 [Gbyte/hour/device]
User type	Human or Machine
User mobility	up to 350 [km/h]

15 Annex - TC9: Open air festival

15.1 Background and motivation

A motivation for the present test case is to enhance the user experience of an extremely high density of active users/devices with a huge amount of aggregated traffic in terms of user throughput, availability, and reliability in an area where normally the mobile access network nodes are sparsely deployed, i.e. the normal network is highly under-dimensioned.

The test case includes the challenges shown below that fit to the METIS overall goals that may require revolutionary approach.

- Accommodating a high density of users and devices substantially far beyond 1000 times compared to usual situation (only a very small amount of people (or almost no people) are present there during the rest of the year except the festival events in such a remote area).
- Although there are some existing solutions available, e.g. mobile eNB, they are far below the customers' satisfaction in terms of end-user throughput and latency currently. The challenge of the test case indicates the improvement in enhancing the user throughput by more than 10 times relative to the typical situation of today even in the very dense scenario like the test case.
- The test case implicates the challenge to simultaneously accommodate the diverse QoE requirements of conventional smartphone / handset users and machines / devices

The potential solutions of the test case may provide the operators or festival organizers the possibility to offer rich wireless communication services at lower deployment cost and energy consumption than with today's solutions. Thus, new players, e.g. temporal local network providers, may play an important role by making a contract with the festival organizers who like to provide better festival experiences to users.

15.2 Requirements and KPIs

Measures

The proposed solutions of the test case will be measured in terms of

- Total achievable capacity (accommodated traffic volume) per area [bps/km^2].
- User throughput (in terms of MAC throughput) (average user throughput, cell edge (5% CDF user throughput)). In fact, the notion of the cell may not be applicable in all solution approaches, but the 5% CDF user throughput requirement is still applicable.
    - The mathematical definition of MAC throughput is same as the current 3GPP definition, see Section 4.2.2.
    - The alternative option is to measure in terms of the TCP throughput.
- E2E latency (in particular for the machine/devices)
- Deployment cost compared to legacy cellular + WiFi approach

- Energy efficiency of radio access network (base station and access node) of proposed solutions compared to legacy approach
- UE power consumption (D2D users, if applied, and users and devices accessing to radio access network node) compared to legacy approach

Key requirement/KPIs

The highlights of the requirements and KPIs for this test case are described below, with summary in Table 15.1.

- Accommodated traffic (capacity) per area: up to 900 [Gbps/km^2]
  - o 900 [Gbps/km^2] = 30 [Mbps] per user x 100,000 users x 0.3 (user activity factor)
- Average experienced user throughput of video data sharing / web browsing users
  - o 30 [Mbps] at MAC layer with 95% probability
- Maximum E2E latency
  - o Less than 1 [s] for 99% machine/devices
  - o Delivery delay for delay tolerant data should not exceed 10 minutes with 95% probability.
- Outage probability as experienced by users (a period during which neither delay sensitive nor delay tolerant data is delivered to/from the user) should be less than 1% irrespective of user density (up to the maximum);

Others

- Number of connected users and devices in the area: Over 100,000 smartphone subscribers (= active and idle users) and 10,000 machine or sensor devices
- Ratio of active smartphone users to total subscribers is 10-30%

Table 15.1: Requirements and KPIs for TC9

Variable/parameter	**Value**
Performance targets	
Experienced user throughput	Average: over 30 [Mbps] at MAC layer during busy period (DL/UL) with 95% probability
Average user data rate during busy period	9 [Mbps] (DL/UL) Downlink: One packet size of 30 [Mbyte] generated per minute and user throughout of totally about 2 hours during the busy period of the festival event. Expected to be downloaded less than 10 [s] in 95% of area and time. Uplink: In case of data sharing, same for downlink. In case of web-browsing and sensor, the required data rate can be much lower.
Traffic volume density Traffic volume per subscriber	900 [Gbps/km^2] (DL+UL) 3.6 [Gbyte] per subscriber during busy period

Latency	Machine/device traffic -OTT latency less than 1 [s] with 99% probability Smartphone user traffic -Same order as today's service (10-50 ms) -Delivery delay for delay tolerant data should not exceed 10 minutes with 95% probability
Availability	-95% of the small space of the festival event for data traffic of smartphone users -100% for sensor applications
Reliability	-Outage probability should be less than 1%. -Wireless access offered only during the festival events. For the remaining time the mobile / wireless access network is either switched off or removed
Constraints	
Energy efficiency (infrastructure)	Due to the outdoor installation in the rural area, the power supply availability is limited, so the low-energy operation is required
Energy efficiency (UE or other devices)	In principle no specific constraints for normal UE terminal. For sensors with battery power supply only, the energy-optimized operation is required.
Cost (infrastructure)	Typically limited availability of the backhaul link due to the installation of isolated space. The cost of (wireless) backhaul should be taken into account in calculating the equipment cost and instalment cost for CAPEX, and site, backhauling, and maintenance cost for OPEX.
Cost (UE or other devices)	Basically no test-case specific cost constraint for normal smartphone users, for sensor device, the significant cost reduction compared to normal handset is needed
Test case definition	
User/device density	Max. 4 subscribers per [m^2]
Traffic volume/type	Video clips sharing, internet access, and sensor device communication with total traffic volume per area: 900 [$Gbps/km^2$]
User type	Human, machine/sensor device
User mobility	Static or low mobility (3 [km/h])

16 Annex - TC10: Emergency communications

16.1 Background and motivation

You are in a place where little mobile or wireless network infrastructure exists, e.g. due to a natural disaster or because this is an inhabited area. Communications are needed instantaneously on demand using regular devices. For instance in case of an earthquake in dense urban environment, survivors below rubble should be able to signal their presence such that they can be found quickly. When such a demand is requested, devices and network can switch to a "recovery mode" during which the user can use its device to make calls, send messages and automatically signal its location with reliable connectivity towards other nearby devices.

16.2 Requirements and KPIs

Time to setup the emergency solution: less than 10 seconds for the network to be up and running. This means that all the needed interfaces are reconfigured and ready. The network should be able to dynamically reconfigure itself, as new (reliable) nodes are added to the network and/or nodes in the network are affected by additional failures.

Availability: The discovery rate should be 99.9% (less than 1 victim in 1000 should be missed).

Time to discover a victim (survivor): 80% of the victims should be discovered within 10 minutes after the incident. 99% should be discovered within an hour after the incident. 99.9% should be discovered within a day. Once a victim is discovered, a basic communication should be established within a minute from the request (dial-up or paging).

Energy consumption: As low as possible. 5 days of operations should be supported in "emergency mode" with the battery backup designed for 1 day of operations in normal mode. The solution should allow terminals to be discovered during one week. It is challenging for end user terminals to save battery life until survivors are rescued.

System capacity: A victim is considered satisfied if the communication can be established and automatically maintained. Minimum 10 phone calls (CS or VoIP) can be established, and 10 text messages per victim be sent during 1 week. The system is expected to support also those victims that are not trapped under rubble and hence are roaming around. The system is also expected to support the traffic of the professionals involved into the rescue operations. Since the energy consumption is proportional to the number of user that must be served, the system capacity is defined as the density of satisfied victims. The system capacity is expected to be 1/10 [m^2] (corresponding to a population density of 100,000 per [km^2]).

Table 16.1: Requirements and KPIs for TC10

Variable/parameter	Value
Performance targets	
Service provided	Successful mobile originating or terminating voice call (CS or VoIP) Successful SMS
Traffic volume density	10 voice calls and 10 SMS per UE per week per 10 [m^2]
Latency	No specific target on latency

Availability	99.9% discovery rate
Reliability	Infrastructure setup time less than 10 [s] Call establishment time less than 1 [s]
Constraints	
Energy efficiency (infrastructure)	1/5 of normal operation mode
Energy efficiency (UE or other devices)	10 Successful mobile originating or terminating voice call (CS or VoIP) and 10 SMS per UE for 1 week.
Cost (infrastructure)	NA
Cost (UE or other devices)	NA
Test case definition	
User/device density	1 UE per 10 [m^2]
Traffic volume/type	10 voice calls and 10 SMS per UE per week
User type	Human (earthquake survivor)
User mobility	None

17 Annex - TC11: Massive deployment of sensors and actuators

17.1 Background and motivation

The importance of this test case will grow together with the massive deployment of these low cost and of low energy consumption devices. In order to get the maximum of information from these devices, so as to increase environmental awareness and better user experience, there is a need for these devices to be able to communicate with other devices, the network, or with other mobile phones.

Within the METIS context, this test case is targeting the following METIS goals, [1],

- 100 times higher number of connected devices,
- 10 times longer battery life for low power MMC,
- At similar cost and energy consumption as today.

Examples of use cases for the tracking of portable objects are listed in the sequel:

- **Tools (e.g. drills)**, where the purpose of the communication node in each tool is to measure in which environment and how the tool is used (e.g. in order to notify the user that he should rather be using a different tool or to develop tools which are better suited to their usage) and detect early signs of product failure
- **Other products where the producer is interested in improving usability**. An example could be books (such as manuals), where sensors detect which pages are opened when and in which order. Another example could be related to a restaurant where it is measured which tables and chairs are occupied.
- **Products which require care (e.g. flower pots),** where the communication sensor/node would send a warning if watering or fertilization is needed.
- **Fragile products**, where the communication node could measure whether the product is handled with sufficient care (e.g. not too much acceleration, and right temperature), and send an alarm if this is not the case.
- **Potentially dangerous products**, such as knives, chemicals (or weapons), where the communication node could send an alarm if somebody unauthorized uses or moves these products.
- **Products that expire**, such as groceries and spices, where an alarm could be sent if product properties cross a certain threshold.
- **Products where statistics on the movement are to be collected**. For instance, a company may want to monitor a fleet of, e.g. bicycles. In an extreme case, one could imagine the European Central Bank tagging Euro notes in order to observe the flow of hard currency.
- **Products often subject to theft**, such as hand-bags or jewellery, where communication nodes could raise an alarm in case of unauthorized movement. Similarly if the customer places the products to a wrong location

(shelf), the communication node can warn the customer and probably customer service.

Example of use cases for the monitoring of, e.g. environment, materials, may include:

- **Agricultural application**: A large number of sensors spread out over large agricultural areas to measure, e.g. fertility and humidity, to help the farmer optimize the right time for harvesting and fertilizing (approximately 10 sensors per [km^2], it is acceptable if 50% of sensors manage to get a 20 [byte] uplink net payload through to the infrastructure once per day). It could also be imagined that such sensors are used indoors in, e.g. greenhouses.
- **Material monitoring (particular example: wind mill):** Sensors are placed every 5 [m] on the surface of the structure of a modern power-generating wind mill, reporting vibrations and other measures that may give an early indication of material damage or suboptimal usage (50 sensors per wind mill, all sensors should be able to get a 20 [byte] net uplink payload through to the infrastructure once per day). Note that in this particular case the sensors are moving, though this movement is highly predictable.
- **Material monitoring (particular example: high-speed train)**: Sensors are placed in each wheel of the train and are able to measure vibrations and early indications for track or wheel damage (4 sensors per carriage, all sensors should be able to get a 20 [byte] net payload through to the infrastructure per day). Such sensors – even at such a low duty cycle - would be able to prevent dangerous train accidents that have happened in the past due to unnoticed material faults.
- **Material monitoring (particular example: building)**: Sensors are placed in a building or on the surface of a building, again to monitor vibrations and other early indications for potential material failure. These sensors will also be useful to quickly assess the state of a building after a natural disaster, such as an earthquake or a hurricane (all sensors should be able to get a 20 [byte] net payload through to the Internet once per day).

17.2 Requirements and KPIs

17.2.1 Requirements

As mentioned in Section 17.1 this test case targets the METIS goals related to the number of connected devices, energy consumption per device by maintaining the same energy consumption and cost at the network side.

In this respect, requirements are:

- Number of devices supported in the system is 10-100 times higher compared to a basis system of today, e.g. 3GPP LTE Rel-11. In [36], i.e. 3GPP Rel-11 assumptions for 30.000 devices per cell were described and studies within 3GPP have shown that 3GPP LTE Rel-11 can support this number of devices within a cell. Consequently, the goal for METIS is to be able to provide connectivity for 300.000 devices within one cell.
- Long battery life (on the order of 5+ years) of the wireless device, implying the need for high energy efficiency. Battery life is directly related to energy efficiency. Considering that among the candidate systems, Low Energy (LE) Bluetooth is the most efficient ones, considering that the energy consumption in

LE Bluetooth is 0.153 [μJ/bit], it is sensible to assume a target for 0.0153 [μJ/bit] for METIS.

- Minimum possible signalling overhead
- Low cost for the wireless device
- 99.99 % Coverage

Similar energy consumption and cost for the infrastructure as for the base systems of today, e.g. 3GPP LTE Rel-11 or ZigBee, or Low energy (LE) Bluetooth.

17.2.2 Key Performance Indicators (KPIs)

In order to be able to assess the performance of the studied algorithms/mechanisms towards METIS goals and the requirements described above, there is a need to define relevant KPIs. Based on the requirements of Section 17.2, the following KPIs are proposed for this test case.

Number of Devices Supported

This KPI, *N*, is defined as

N = Number of Devices Supported per network access point with the minimum required Quality of Service (1)

As an example, a partner working with an algorithm on scheduling and the required Quality of Service (QoS) is e.g. that at least one packet of size equal to 40 [byte] is correctly decoded within 20 seconds, or equivalently 16 [bps], the number of users supported within an area and getting this data rate are the ones which counted.

In terms of QoS, other requirements might be set, e.g. Packet Error Rate (PER), or latency to access the channel (for MAC schemes), or latency for establishing a connection (e.g. for D2D).

This number of connected users is compared to the number within the base scenario. As a base scenario, the one described in [36] is used in which 30 000 devices are located within one 3GPP Case 1 cell.

Battery Life / Energy Efficiency

A performance indicator of paramount importance for this test case is the battery consumption. In order for this massive deployment to take place, there is a need to guarantee that wireless devices can operate autonomously for longer periods of time. Moreover, frequent battery replacement for these devices should not be considered as an option. Typically, existing wireless devices operate with the help of a battery which has a given “battery capacity”, or “battery energy” as this is termed. Typically the stored battery energy is measured in Watts-seconds, or Joule. In order to estimate the battery life time, *B*, of a sensor, there is a need to know the total amount of energy, *C*, that is stored in the battery and the amount of average power consumption, *P*, of the device at each second of activity (power consumption measured in Watts). In addition, there is a need to have knowledge on the average amount of activity, *A*. Hence, a fair indicator of battery life, *B*, is:

$$B = \frac{C}{P \cdot A}. \qquad (2)$$

From formula (2) it can be readily deduced that there is a need for a value for the total amount of energy saved in the battery. There is a need for consensus on the baseline battery energy level.

In case the total amount of energy saved in the battery is not available, the relevant KPI is the average amount of energy consumption, *E*, in Joule (or [Ws]), which can be given by the average power consumed (in Watts) multiplied with the time (in seconds) of activity so as to perform a given operation, e.g. device detection.

A further relevant KPI in this respect is the energy dissipation at the device side per successfully transmitted and received data bit. This KPI can be used to determine the efficiency of any solution proposed for this test case w.r.t.

- The energy that is used for the actual transmission over the channel, i.e. transmit power related.
- The energy dissipated for, e.g. signal processing and RF circuitry, both in active and idle state.
- The energy dissipated for signalling overhead.

Signalling Overhead

In order to meet the METIS targets for high number of connected devices and low energy consumption, a method widely seen as a valid approach towards these targets is the reduction of signalling overhead; namely, minimizing the amount of radio resources consumed by signalling will implicitly result in a higher number of served devices within an area. In addition, lower signalling overhead will reduce the activity time and energy consumption within devices.

Let N_D denote the number of data bits and let N_S denote the number of signalling bits. Thus, a sensible measure of protocol efficiency, PE, is given by

$$PE = \frac{N_D}{N_D + N_S}, \qquad (3)$$

where the nominator stands for the number of data bits, i.e. payload, and the denominator is the sum of bits exchanged for signalling plus the number of data bits exchanged. The signalling overhead is given by $S = 1 - PE$.

The number of signalling bits may be the number of bits used within the MAC protocol header, as well as the number of bits exchanged during a signalling mechanism. As an example, in case of D2D, the number of bits exchanged during two devices prior to connection establishment should be considered in the number of signalling bits of formula (3).

This signalling overhead should be compared with the signalling overhead of baseline systems.

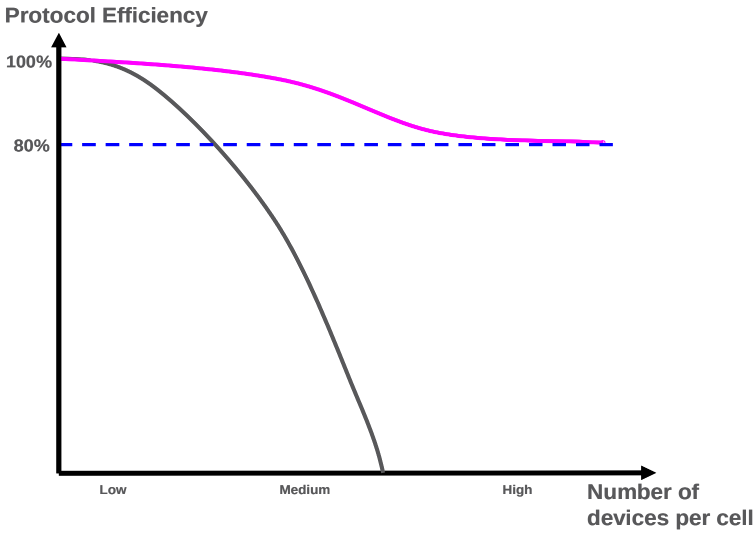


Figure 17.1: The black curve depicts today's limit, while the pink curve illustrates what is aimed to be achieved with this test case, the massive deployment of sensors and actuators.

It is noted, that in some cases, probably, the absolute number of signalling bits should also be considered, in combination with the ratio of formula (3).

Considering that low energy Bluetooth was considered for the energy consumption, LE Bluetooth is used as basis for the signalling overhead/protocol efficiency requirement. Protocol Efficiency, PE for LE Bluetooth is 66% and therefore a sensible requirement for METIS would be to have PE in the order of 80% or above.

Device Cost

As mentioned, the major challenge for the massive deployment of devices is that devices should be of very low, competitive cost. The device cost of METIS solutions could be measured either in absolute cost numbers or in relative numbers when compared to LTE Rel-11 modems or ZigBee modems. Considering that LTE modem cost is a competition feature, absolute numbers might not be straightforward to obtain. However, cost reduction techniques are discussed [36] and numbers from there can be taken. In this case, the device cost of the METIS solutions could be measured as percentage (%) to the LTE Rel-11 modem cost. Probably, similar to 3GPP LTE cost models exist for other systems. Typically for low cost and energy systems, the cost for the radio part lies in the order of few USD.

Coverage

In order for this massive deployment of sensors to take off, there is a need also that this happens without significant investments from network operators. Therefore, solutions involving massive deployment of base stations and relay nodes should be out of scope within this test case. Relaying functionality could be provided, but only from other devices, mobile phones and other end user terminals. As such, it is required that almost 100% coverage is provided to these devices with the existing network infrastructure. Considering hence, that a high number of these wireless sensors/meters are located within areas of sparse coverage, e.g. forests, mountains, or within challenging propagation environments, e.g. in the basement of large buildings, it is required that link budget improvement of 20 [dB], as compared to 3GPP LTE Rel-11, or as compared to ZigBee is provided.

Infrastructure Energy Consumption and cost

As also mentioned in the paragraphs above, the goal with the solutions proposed within this test case and in METIS in general should not result into higher cost than today's infrastructure. As such, solutions assuming massive deployments of network nodes and access points are out of the scope in this test case.

Table 17.1: Requirements and KPIs for TC11

Variable/parameter	**Value**
Performance targets	
Energy efficiency	0.015 [μJ/bit] for a data rate in the order of 1 [kbps]
Protocol scalability	80% protocol efficiency at 300 000 devices per access node
Coverage	99.9%
Constraints	
Energy efficiency (infrastructure)	In principle no specific constraints for the infrastructure.
Energy efficiency (UE or other devices)	The power supply availability is limited, so low-energy operation is required. For sensor type devices with battery power supply only, the energy-optimized operation is required.
Cost (infrastructure)	Infrastructure cost should be kept on the same level per area as today.
Cost (UE or other devices)	For sensor type devices a significant cost reduction compared to normal handset devices is needed.

18 Annex - TC12: Traffic safety and efficiency

18.1 Background and motivation

Information exchange among vehicles will enable the provision of safety hints to the driver or warnings about the road status, e.g. constructions, weather conditions, road hazards. Consider a vehicle arriving into an intersection with low visibility; in order to aid the driver and avoid the occurrence of an accident, the vehicle could signal to the driver the direction and velocity of any moving vehicle that approaches the intersection. Additionally, the vehicle could communicate with other vehicles and actively intervene in order to avoid accidents. An example could be the autonomous intervention of the vehicle (e.g. emergency braking), based on the notification of the presence of another vehicle, to avoid an accident. Figure 18.1 illustrates an example of a dangerous traffic situation which can be avoided with proper information exchange between vehicles and infrastructure.

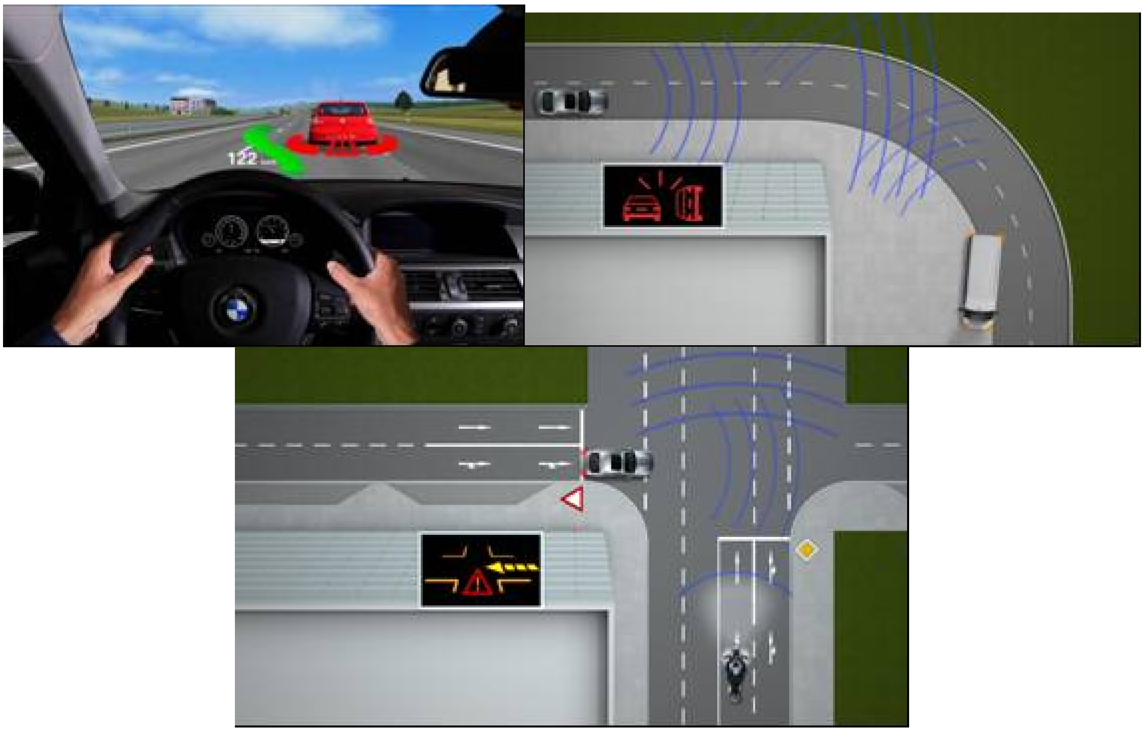


Figure 18.1: Illustration of a dangerous situation that can be avoided by means of V2V communications. Note that "V" can denote many types of vehicles. The examples show local danger and hazard warning as well as intersection assistance.

In 2009, 34 500 people lost their lives on European roads [37]. The European Commission has set a goal to cut this number in half by 2020, focusing on making improvements to vehicles, infrastructure and road users' behaviour [38]. One casualty group of special interest are vulnerable road users (VRUs). In 2008 46% of all deaths on the road were comprised of this group, with pedestrians representing 21%, motorized-two-wheelers 18% and cyclists 7% [39]. A typical scenario is that a car is moving at the speed of 60 [km/h] and the driver overlooks a pedestrian that is running across the street because of reasons like poor visibility or sleep deprivation of the driver.

With the help of advanced radio interfaces in 2020, the accident rate is expected to be reduced by 50% and the fatal accident rate is expected to be limited to 1000 pedestrian and 500 cyclist accidents.

The idea is therefore to collect safety-relevant information directly from the vulnerable road users (VRU). This can be achieved by exploiting the information from an existing and very powerful sensor that almost everyone carries in their pocket today: a mobile phone. Information is exchanged between the VRU device and the vehicles in order to warn the driver and the VRU about the presence of each other in order to actively initiate the necessary actions to avoid an accident

Figure 18.2: Illustration of a dangerous situation with vulnerable road users (i.e. pedestrians, cyclists,...) that can be avoided by means of V2D communications. Note that "D" can denote any cellular device that the vulnerable road user may carry (e.g. smartphone, tablet, sensor tag).

Figure 18.3: Illustration of assistance services that can improve traffic efficiency by means of V2X communications. The examples show traffic sign recognition and green light assistance.

Besides providing a safer driving environment, information exchange between vehicles can also enhance traffic efficiency. This refers to increasing traffic flows and reducing fuel consumption and emissions. So-called platooning (or road trains) is a promising traffic efficiency application, see, Figure 18.4. Vehicles drive close to each other, with an inter-vehicle distance of 3 to 5 meters, in an autonomous manner. The lateral and longitudinal position of a vehicle in a platoon is controlled by collecting information about the state of other vehicles (e.g. position, velocity and acceleration) through communications. Such a cooperative automation system requires high reliable communication and the capability for vehicles to receive and process co-operative awareness messages with other involved vehicles within very short delays (less than 100 [ms]).

Figure 18.4: A platoon in practice. Note the large antennas on the vehicles, illustrating the need for efficient communications. Source: FP7 project SARTRE http://www.sartre-project.eu.

Moreover, highly automated vehicles, see Figure 18.5, will benefit significantly from additional information delivered via V2X communication, since the vehicle environment model can extends its prediction horizon. This will bring additional comfort benefits for such services.

Figure 18.5: Highly automated vehicles, note that the driver is not steering.

18.2 Requirements and KPIs

The main challenges of this test case lie in the required reliability, availability, and latency of automotive safety services. The requirements are described below and the key performance indicators and constraints are summarized in Table 18.1. A maximum network end-to-end delay (including device detection, connection setup and radio transmission) of 5 [ms], with transmission reliability of 99.999% should be guaranteed to deliver the drive safety service. This is a major challenge, as shown in [40].

- V2X communication needs to be established across different network operators with the same requirements in terms of latency and service guarantee as within a single network operator.
- 100% availability required such that the services are present at every point on the road.

Additional KPIs and constraints are the following:

- Relative positioning accuracy below 0.5m is needed. GPS may not always be available and sufficient, and hence cellular based positioning techniques could be useful.
- Data traffic (inspired by current ETSI Technical Committee ITS and IEEE standardization work [41]-[42], though, the parameter values are more challenging than what is discussed for today's systems):
    - Periodic broadcast traffic consisting of at least 1600 payload [byte] (for transmission of information related to 10 detected objects resulting from local environment perception and the information related to the actual vehicle) with repetition rate of at least 5-10 [Hz]. The update rate is chosen high enough such that the vehicle velocity vector does not change too much between updates. The traffic generated by each vehicle has to be delivered to all the neighbouring vehicles within the specified range.
    - Event-driven broadcast traffic consisting of at least 1600 payload [byte] with repetition rate of at least 5-10 [Hz] (for transmission of information related to 10 detected objects resulting from local environment perception and the information related to the actual vehicle).
    - Both traffic types (periodic and event driven) can exist at the same time. Note that the repetition rate of both traffic types is determined by the need to track changes in the environment.
    - For communication between vehicles and other devices (e.g. smartphones) a payload of 500 [byte] may be sufficient (for transmission of the information from the actual consumer electronics device, such as current position and additional data from the device sensors).
- Three different mobility environments need to be distinguished: Urban, rural, and highway.
    - Urban: maximum absolute velocity of 60 [km/h] and 120 [km/h] relative velocity between vehicles.
    - Rural: maximum absolute velocity of 120 [km/h] and 240 [km/h] relative velocity between vehicles.
    - Highway: maximum absolute velocity of 250 [km/h] and 500 [km/h] relative velocity between vehicles.
    - Vulnerable road user velocities ranging from 3 [km/h] (pedestrian) up to 30 [km/h] (bicycle).
- User and device densities depend on the environment and scenario:
    - Vehicular devices:
        - In urban environments the user density can be up to 1000 users per [km^2]
        - In rural and highway environments the user density can be up to 100 users per [km^2]
    - Vulnerable road user devices:

    - In rural and highway environments the user density can be up to 150 relevant users per [km^2].
    - In urban environments the user density can be up to 5000 relevant users per [km^2].
- The required communication range is different for the various environments:
    - Up to 1 [km] in highway scenarios.
    - Up to 500 [m] in rural scenarios.
    - Up to 300 [m] in urban scenarios.
- Additional spectrum constraints are:
    - Use of dedicated spectrum if available
    - preferable frequencies below 5 [GHz]

Table 18.1: Requirements and KPIs for TC12

Variable/parameter	**Value (urban/rural/highway)**
Performance targets	
Experienced user throughput	1600 [byte] x 10 [Hz], i.e. approximately 100 [kbps]
Traffic volume density	0.1 / 0.01 / 0.01 [Gbps/km^2]
End-to-end latency (including connection setup &detection delay) for receivers within the target range	5 [ms] with transmission reliability of 99.999% of the transmissions
Availability: percentage of transmitters whose transmissions meet the latency requirement	≈ 100%
Reliability	99.999%
Constraints	
Energy consumption (infrastructure)	In principle, no particular constraints are required. Nevertheless low-energy operation of all radio nodes including sensors is expected due to energy cost and EMF considerations, especially auto-configuration/operation including switch-on/off of radio nodes dependent on traffic load/day time is considered as an important implementation feature.
Energy consumption (UE or other devices)	Energy consumption should be minimized and should not exceed the energy consumption of conventional terminals (without V2X technology). Main reason is that V2X terminals will mainly depend on battery power supply.
Cost (infrastructure)	V2X communication needs to be established across different network operators with the same requirements in terms of latency and service guarantee as within a single network operator. Therefore agreements and consolidation between operators is required. The cost of deploying V2X in additional infrastructure

	(such as traffic lights) should not exceed the costs of traditional cellular modems in order to guarantee a high market penetration.
Cost (UE or other devices)	V2X terminals/chips should come at the cost of traditional terminals/chips in order to guarantee a high market penetration and thus ensure 100% availability of safety services.
Test case definition	
User/device density	More than 1000 per [km^2] / 100 per [km^2] / 100 per [km^2]
Traffic volume/type	1600 (500) [byte] periodic broadcast with 10 [Hz] per user V2V (V2D) 1600 (500) [byte] event-driven broadcast
User type	Machine or Human, V2V or V2D
User mobility	60 [km/h] /120 [km/h] / 250 [km/h] vehicle speed; slow speed for VRUs: 3-30 [km/h] X2 for relative speed
Other test case specific performance targets	
Number of delivered message	To be maximized
Packet/message delivered rate	≈100%
V2X Range	300 [m] / 500 [m] / 1 [km]
Positioning accuracy	Relative accuracy less than 0.5 [m]

19 Annex - Mapping the test cases and the scenarios

A mapping between the test cases and the scenarios are given in Table 19.1. This information is also illustrated in Figure 3.2, Section 3.3.

Table 19.1: Mapping between test cases and scenarios

Scenario	Amazingly fast	Great service in a crowd	Ubiquitous things communicating	Best experience follows you	Super real-time and reliable connections
Test case					
TC1:Virtual reality office	x				
TC2:Dense urban information society	x	x	x	x	
TC3:Shopping mall		x	x		
TC4:Stadium		x			
TC5:Teleprotection in smart grid network			x		x
TC6:Traffic jam		x		x	
TC7:Blind spots				x	
TC8: Real-time remote computing for mobile terminals				x	x
TC9:Open air festival		x	x		
TC10:Emergency communications			x	x	x
TC11:Massive deployment of sensors and actuators		x	x	x	
TC12:Traffic efficiency and safety				x	x

20 Annex - Energy consumption and cost aspects

Energy consumption and cost are key aspects when evaluating the METIS the technical components proposed by METIS. This section summarizes several models which are based on state of the art references.

20.1 Network infrastructure power consumption model

The power can be estimated from direct measurements, where applicable, or from a suitable power model, where measurements are not available. Power model of network infrastructure is a theoretical derivation of the consumed power in a node, taking in consideration all the consumption sources in it and generally starting from the knowledge of the RF power. Some examples of network infrastructure power models can be found in EARTH deliverable D2.3, [21].

The network metrics mentioned above are directly applicable to small base stations. In order to have an estimate on wide scale scenarios, the so-called E3F model, [21], has to be applied. This framework indicates how to extrapolate the information achieved in the small networks towards global networks, e.g. the entire network in a country or the network of an operator, by means of sociological figures that allows to combine together the estimations made in properly selected small networks, e.g. a small network in suburban environment or a small network in urban.

20.2 UE power consumption model

To model UE power consumption we extend the model given in [29] and further list the parameter values can be used for the initial simulations. We note that the model shown in Figure 20.1 is an exemplary model (e.g. deep sleep and light sleep modes) to be improved during the project. The values given in Table 20.1 may also be modified depending on changes in the model and the assumptions on RF modem. Here, we only consider the RF modem power consumption in downlink; e.g. DSP, micro-processor, display and other power consumption sources are not considered. Primarily, we identify three states of the UE: Active (where UE reads allocation information every transmission time interval (TTI) and is ready to transmit/receive upon scheduling), light sleep, and deep sleep. We have used two different types of "sleep" states since when DRX/DTX is longer the UE may be able to power down more hardware than if the DRX/DTX period is shorter. For each of the three states, we have chosen arbitrary average power consumption when being in that state, which can be used as reference numbers if needed. For deep and light sleep, we denote this power consumption as P_D and P_L respectively. The active state has been divided into two different modes depending on whether the UE is receiving downlink data during that TTI (and thus needs to read the complete TTI information) or not. Those two modes are denoted as P_{A+D} and P_{A-D} respectively. Further, as the transition between some of the states cannot happen momentarily we have selected some transition times (and associated power consumption) among the different states of importance. This is considered by using separate parameters. For instance, the transition from deep sleep to light sleep is denoted by transition time D_{D2L} and associated average power consumption during transition time being P_{D2L}. The same is valid for other state transitions.

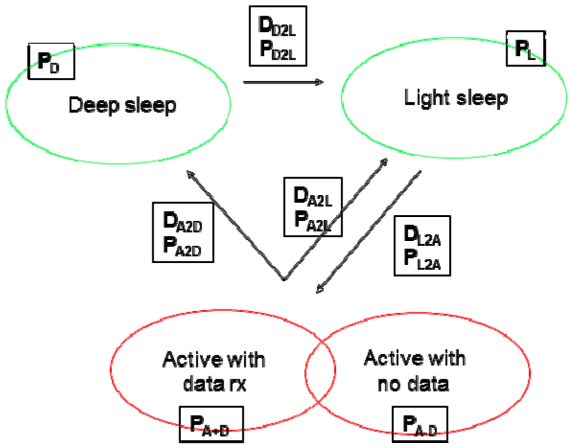


Figure 20.1: Illustration of the used state model for UE power consumption pattern.

In setting default parameters, anticipated delays are converted (which may be very short for some transitions) to a TTI resolution for the sake of simplicity. As getting accurate absolute numbers for typical parameter values is virtually impossible at this stage, we have given some reference numbers based on best guesses and given them relative to the "Active with data Rx" state in Figure 20.1. The parameters are given in Table 20.1.

Table 20.1: Default simulation parameters for MBB UE power consumption model

Parameter	Label/value	Default value
Absolute power consumption in "Active with data rx" state.	P_{A+D}	500 [mW]
Relative power consumption in "Active with no data rx" state.	P_{A-D}/P_{A+D}	0.50
Relative power consumption in "Deep sleep" state.	P_D/P_{A+D}	0.00
Relative power consumption in "Light sleep" state.	P_L/P_{A+D}	0.02
Relative power consumption while changing from "Deep sleep" to "Light sleep" state.	P_{D2L}/P_{A+D}	0.12
Duration of transition from "Deep sleep" to "Light sleep" state.	D_{D2L}	1 TTI
Relative power consumption while changing from "Light sleep" to "Active" states.	P_{L2A}/P_{A+D}	0.08
Duration of transition from "Light sleep" to "Active" states.	D_{L2A}	1 TTI
Duration of transition when going to sleep modes.	D_{A2L} ,D_{A2D}	0 TTI

20.3 Operator cost model

The following mathematical definition applies to a network with a cellular architecture. Similar expressions could be derived for other solutions. However, since it is out of the scope of this document to describe METIS solutions, the following definition can be used as reference if revolutionary different solutions are proposed for some test cases.

Let C_M^{CAPEX} be the annualized capital expenditure and C_M^{OPEX} be the annual operation costs associated with a macro site. Let C_S^{CAPEX} and C_S^{OPEX} be the corresponding annual costs for a small base station site. Let C_{UE} be the average customer retention cost, associated for instance with the costs of subsidizing the replacement of the UE fleet. Let $C_{spectrum}$ be the annualized cost for spectrum licenses and A_{syst} the coverage area of the entire operator's network. Let N_M be the average number of macro sites per unit of area, N_S be the average number of small base station sites, and N_{UE} the UE density per area. The total cost of a radio access network comprising macro sites and small sites normalized per unit of area, can be approximated by:

$$C_{tot} = \left(C_M^{CAPEX} + C_M^{OPEX}\right)\cdot N_M + \left(C_S^{CAPEX} + C_S^{OPEX}\right)\cdot N_S + C_{UE}\cdot N_{UE} + \frac{C_{spectrum}}{A_{syst}} \quad [\text{cost / area}].$$

Since the METIS goals are expressed in relative terms, a convenient approach is to normalize the cost of a solution to the cost of the legacy network. For instance, if the legacy network consists only of macro sites with density N_M^{legacy}, then the additional cost for the new solution can be expressed as[3]:

$$\frac{\Delta C_{tot}}{\left(C_M^{CAPEX} + C_M^{OPEX}\right)N_M^{legacy}} = \frac{N_M - N_M^{legacy}}{N_M^{legacy}} + \frac{\left(C_S^{CAPEX} + C_S^{OPEX}\right)}{\left(C_M^{CAPEX} + C_M^{OPEX}\right)}\cdot\frac{N_S}{N_M^{legacy}} + \frac{C_{UE}}{\left(C_M^{CAPEX} + C_M^{OPEX}\right)}\cdot\frac{N_{UE}}{N_M^{legacy}} + \frac{C_{spectrum}}{\left(C_M^{CAPEX} + C_M^{OPEX}\right)\cdot A_{syst}\cdot N_M^{legacy}}$$

Hence, the metrics to check the METIS goal fulfilment could be expressed in relative terms, primarily based on the additional number of sites required to fulfil the other KPI targets.

[3] In this expression, the spectrum cost of the legacy network is ignored for sake of simplicity. The underlying assumption is that the expenditures with the legacy spectrum have been amortized. For the sake of consistency, the same assumption could be made for all the capital expenditures with the legacy network, which would lead to a more complex model. An even more accurate model could be obtained by using *present values* instead of annualizing the CAPEX.