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Deliverable D2.2

WORTECS Use Cases and Requirements

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Abstract

In this deliverable, WORTECS use cases and related key performances indicators / requirements are presented. Three main "Tbit/s" scenarios have been defined in order to drive theoretical studies and implementation of proofs of concepts: Virtual Reality, Enterprise communications / Virtual office and Stadium / Open-Air Festival / Themes Parks.

Keyword list

Use cases, requirements, key performance indicators (KPIs)

Executive Summary

The primary challenge addressed by WORTECS is the development of a system able to deliver ultra-high throughput (up to Tbps) based on the exploitation of spectrum beyond 90GHz.

This deliverable D2.2, entitled "WORTECS Use Cases and Requirements", defines the use cases prioritized by the project in order to drive theoretical studies and implementation work.

The use cases selected (and related key performance indicators and requirements) are based on state of the art use cases targeting Tbps capability (assumed to be here Tbps/area covered), adapted to the core objectives of WORTECS project. WORTECS use cases have been decided as follows:

- *Virtual Reality, which will be the main use case, driving the implementation work, requiring both huge data rates and short latency; a focus on virtual reality will be proposed in D2.3.*
- *Enterprise communications / Virtual office*
- *Stadium / Open-Air Festival / Themes Parks, in order to address as well outdoor environment.*

Impact on the other Work-packages

WP3: the use cases, key performance indicators and requirements defined in this deliverable will drive theoretical studies and simulation work.

WP4: the use cases, key performance indicators and requirements defined in this deliverable will drive implementation work.

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List of Acronyms

Acronym	Meaning
3GPP	3rd Generation Partnership Project
5G PPP	5G Infrastructure Public Private Partnership
AP	Access Point
DL	DownLink
eMBB	extreme Mobile BroadBand
HMD	Head Mounted Displays
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LC	Light Communications
mmMAGIC	mm-Wave based Mobile Radio Access Network for 5G Integrated Communications
NGMN	Next Generation Mobile Network
OCC	Optical Camera Communications
OWC	Optical Wireless Communications
RAN	Radio Access Network
RF	Radio Frequency
Tbps	Terabit per second
THz	TeraHertz
UL	UpLink
VR	Virtual Reality
WORTECS	Wireless Optical/Radio TErabit CommunicationS

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1 Overview of state-of-the-art high throughput use cases

One of the objectives of the ICT-09-2017 call "Networking research beyond 5G" is to pave the way for "*the full exploitation of the spectrum potential, notably above 90 GHz, with new waves of technologies and knowledge, bringing wireless systems to the speed of optical technologies, and for new applications.*", the primary target being the Tbps.

In this section a quick overview of "high throughout" use cases identified so far is proposed. The objective of WORTECS project is not to propose use cases "from scratch" but rather build on existing use cases that could be further enhanced, based on the exploitation of THz spectrum by wireless technologies.5G will be the next "big thing"! Standardisation activities have started on 3GPP side (early drop of 5G specifications is expected by end of 2017), partly fed by former and current research projects funded by European Commission. Use cases and requirements, including the delivery of high throughput services, are the drivers of the specification process. In section 1.1, 5G use cases (relevant for WORTECS context) will be presented.

IEEE standardization activities related to optical wireless communications are also flourishing; two working groups inside 802.15 and 802.11 should provide specifications exploiting visible / non visible spectrum bands. Interesting use cases are also proposed there, in relationship with WORTECS key objectives. Section 1.2 will present them in a synthetic way.

In the meanwhile a couple of THz initiatives (meaning "exploitation of THz bands with wireless solutions") have started here and there (IEEE, research projects…), providing as well food for thoughts (section 1.3).

1.1 5G initiatives

The European Commission created in 2013 a Public-Private Partnership in the area of 5G known as 5G PPP. The objective is to create "an open platform that helps us reach our common goal more coherently, directly, and quickly". Nineteen research projects have been selected following a first call (projects started mid-2015 and ended mid-2017). This first phase laid the foundation for the 5G design, including physical layer, RAN design, backhaul/fronthaul and network management. Table 1 below gives an overview of key use cases identified for 5G in the framework of some of these projects. Coming back to WORTECS focus, the main families requiring high throughputs are "*Dense Urban*" and "*Future Smart Offices*".

Group	Comments	METIS-II	FANTASTIC-5G	mmMAGIC	SPEED-5G	5G-NORMA	Flex5GWare	VirtuWind
Dense urban	Both indoor and outdoor in dense urban environment	Dense urban information society	Dense urban information society below 6 GHz	Dense urban society with distributed crowds Cloud services Immersive 5G early experience	Dense urban information society Future home environment	V2X + massive MTC communications in urban environ-ments	Crowded venues Dynamic hotspots	Smart meters and secondary substations in dense urban areas
Broadband (50+Mbps) everywhere	Focus on suburban, rural and high speed trains	Broadband access everywhere	50 Mbps everywhere High speed train	50+ Mbps everywhere Media on demand	Realistic extended suburban HetNet		50+ Mbps everywhere	Grid backhaul
Connected vehicles	uMTC and/or xMBB on cars. V2V and/or V2X	Connected cars	Automatic traffic control/ driving High speed train	Moving hot spots		Traffic jam Vehicular communication	Mobile broadband in vehicles V2X communications for enhanced driving	
Future smart offices	Very high data rates indoors and low latency	Virtual reality office		Smart offices	Future connected office			
Low bandwidth IoT	A very large number of connected objects	Massive deployment of sensors and actuators	Sensors networks				Smart Cities	Smart metering in grid access
Tactile internet / automation	Ultra-reliable communication with xMBB flavour		Tactile internet	Tactile internet/ video augmented robotic control and remote-robot manipulation surgery				Grid backhaul and grid backbone have reliable, ultra-low latency requirements

Table 1 – 5G PPP Use Cases families [1]

Table 2 below, extracted from 5G PPP mmMAGIC deliverable on use cases [2], gives, as an illustration, some KPIs and related requirements for three scenarios of interest for WORTECS:

KPI	Requirement		
	"Dense urban society with distributed crowds"	*"Smart offices"*	*"Immersive early 5G experience in targeted coverage"*
User data rate in DL	25 Mbps (up to 50Mbps)	1 Gbps Average load: 0.2 Gbps/user	>100 Mbps
User data rate in UL	50Mbps	500Mbps Average load: 0.027 Gbps/user	>50 Mbps
Connection density	Peaks of 150000 users/km² Average active users in stadium: 30000 users/stadium	75000/km²	~10000/km2
Traffic Density	Peaks DL: 3.75 Tbps/km² (DL stadium: 0.75 Tbps/km²) UL: 7.5Tbps/km² (UL stadium: 1.5 Tbps/km²)	15 Tbps/km² (DL) 2 Tbps/km² (UL)	1.7/0.85 Tbps per hotspot area (0.1km2) 17/8.5Tbps per km2
Mobility	Stationary/pedestrian	Pedestrian	0-5 km/h

Table 2 – 5G PPP mmMAGIC KPIs and requirements

In parallel, 3GPP started the standardisation of 5G with the identification of use cases [3], summarized in the figure below:

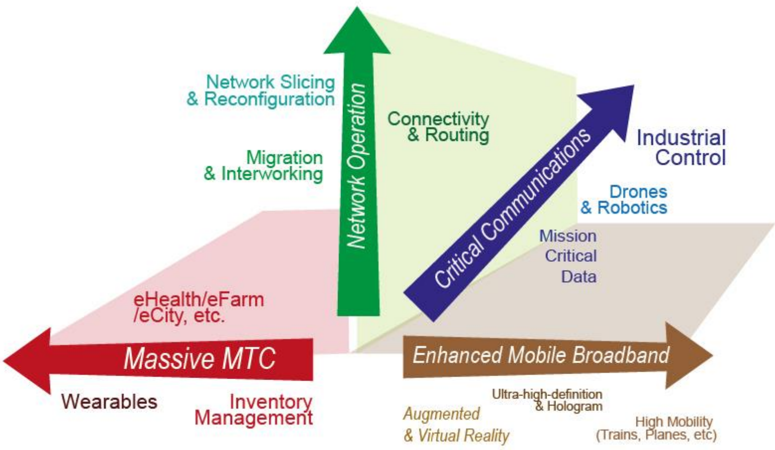


Figure 1 – 3GPP services for 5G ([4])

The services requirements for high data rate and traffic density scenarios are given in Table 3 below:

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

NOTE 1: For users in vehicles, the UE can be connected to the network directly, or via an on-board moving base station.

NOTE 2: A certain traffic mix is assumed; only some users use services that require the highest data rates [2].

NOTE 3: For interactive audio and video services, for example, virtual meetings, the required two-way end-to-end latency (UL and DL) is 2-4 ms while the corresponding experienced data rate needs to be up to 8K 3D video [300 Mbps] in uplink and downlink.

NOTE 4: These values are derived based on overall user density. Detailed information can be found in [10].

NOTE 5: All the values in this table are targeted values and not strict requirements.

Table 3 – Performance requirements for high data rate and traffic density scenarios [3]

ITU, International Telecommunications Union, has started to communicate on early key requirements (and the definition of the related Key Performance Indicators – KPI) related to the minimum technical performance of IMT-2020 candidate radio interface technologies in [5]. The work in ITU will be completed in Nov. 2017. As an example, the following KPIs have been proposed for eMBB (enhanced Mobile BroadBand) usage scenarios:

- Minimum peak data rate
  - Downlink: 20 Gbps
  - Uplink: 10 Gbps
- User experienced data rate (dense urban)
  - Downlink : 100 Mbps
  - Uplink : 50 Mbps
- Area traffic capacity (indoor hotspot)
  - Downlink: 10 Mbps/m^2

It has to be noted that the starting point of these diverse inputs is NGMN Alliance (Next Generation Mobile Networks) 5G white paper [6], whose a major part of the work was dedicated to use cases and related requirements identification.

1.2 Light communications

The light spectrum, for the most part, has been underutilised. The visible light spectrum alone stretches from approximately 430 THz to 770 THz, which means that there is potentially more than 1000x the bandwidth of the entire RF spectrum of approx. 300 GHz. Both the visible light spectrum and the infrared spectrum are unlicensed with most international radio frequency regulators limiting their remit to 3 THz. [7]

There are multiple standardization efforts on-going related to light communications (LC).

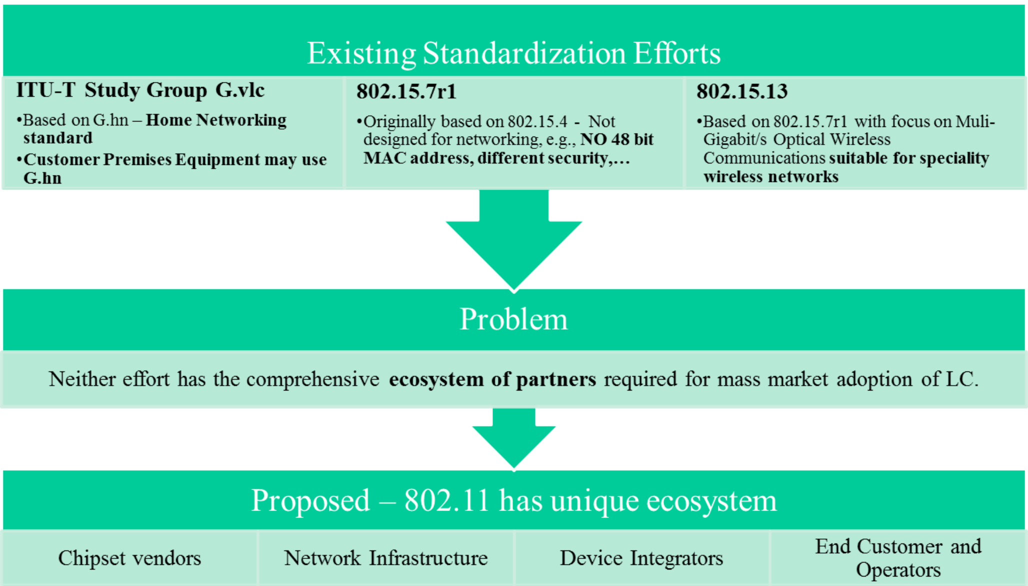


Figure 2 – Light Communications standardization effort

IEEE Standardisation has two different 802.15 efforts for Optical Wireless Communications (OWC):
a) the existing Visible Light Communications 802.15.7r1 looks to include Optical Camera Communications (OCC) and low rate photo diode communications. Low rate communications is targeted to enable smartphones to receive information for advertising or indoor positioning;
b) the 802.15.13 looks to deploy high speed OWC networks in industrial scenarios.

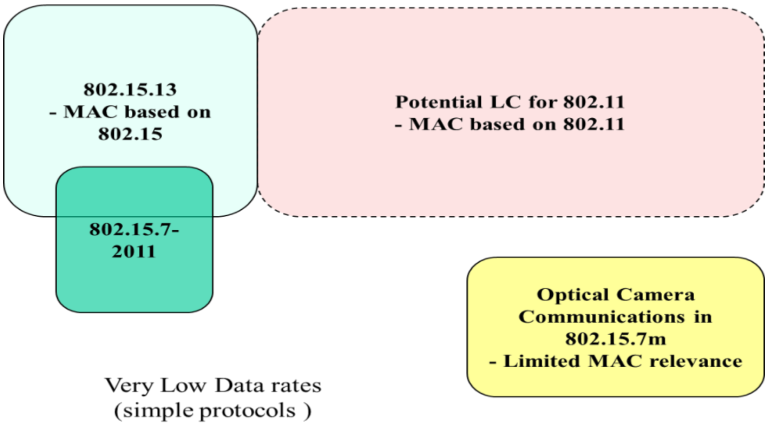


Figure 3 – IEEE 802.15 Optical Wireless Communications standardisation effort

In addition, LC technology is currently defining the scope for a potential IEEE 802.11 amendment to enable efficient access the light spectrum and satisfy various use-cases that can complement existing Wi-Fi use-cases and open new ones. It is important to note that according to the Cisco Mobile Virtual Index in 2016, over 53% of all wireless traffic went through a Wi-Fi access point. Therefore, incorporating LC as part of this extremely successful ecosystem will facilitate the mass market deployment of the technology and easy integration of LC as part of 5G and beyond wireless networks.

These use cases are as follows:

1. Enterprise
    a. Data access: where network connections are based on LC for daily work, conference, etc. streaming remote desktops along with potential video. Enhanced data security can be achieved for organizations that require high level of confidentiality. The directionality of light propagation can effectively reduce interferences in heavily populated offices. Wireless off-loading to light releases spectrum for connecting other devices.
    b. Use cases for RF (Radio Frequency) sensitive facilities: for RF sensitive facilities such as hospital and mining, LC can provide safe data access where RF may not be allowed
2. Home
    a. Data access: where mobile devices use LC for high data rate network access. Especially for heavily populated apartments so that reduced interference and enhanced privacy can be achieved.
    b. Home theater: Indoor use cases where high definition video and audio equipment connect to a LC Access Point (AP)
    c. Virtual reality (VR): use cases where VR goggles are connected to a LC AP

3. Retail
    a. Delivery of high-bandwidth data at particular points in store requires cabled connection. Makes these spots immobile. Alteration of retail space to enable new customer experiences is a key part of retailer strategy. High-bandwidth flexible retail space through LC enables cost reductions for retailers when modifying or refitting the space.
    b. Data density of LC enables very-high bandwidth content without fear of interference with other wireless resources.
    c. Density of light fixtures and LC APs allows highly precise localisation of users and paths. This enables the provision of navigational directions for users within a store or mall.
    d. The fact that light is non-penetrative and highly containable enables the establishment of very secure wireless signals.
4. IoT (Internet of Things)
    a. Home: smart home
        i. Connecting devices that convey sensitive information like CCTV (Closed-Circuit TV) cameras, baby monitors, etc. to a more private and secure LC network.
    b. Smart cities: provide high accuracy positioning
        i. LC AP can be installed on street furniture and ease congestion on spectrum resources by off-loading and releasing RF spectrum for increased connectivity of moving vehicles to the backbone.
    c. Factories of the future - Industrial and manufacturing
        i. In industrial and manufacturing scenarios, nowadays wired solutions are mainly used, because of high requirements with respect to robustness, security and low latency. Industrial protocols (i.e. Profinet) assign regular network access to the clients and ensure the transmission of data within a specific period and low latency.
        ii. Industrial wireless is also attractive due to easy deployment and flexibility. LC based solutions may provide benefits over RF based solutions with respect to,
            1. <u>Suitable for dense deployment:</u> Manufacturing belongs to the so-called dense wireless scenarios with multiple links maintained simultaneously all offering the above mentioned high service quality. LC can deliver safe wireless communications with low latency because it has well-confined propagation conditions in very small cells. Moreover, LC can be used complementary to RF systems for data off-loading.
            2. <u>Coexistence with other RF services:</u> One big issue for industrial wireless networks is coexistence with other services. Using other RF links in the same spectrum requires protocols like “listen before talk” which implies unpredictable delays and contradicts low latency requirements. Getting dedicated spectrum for industrial wireless is one way. LC operates in unused spectrum and could be another way to alleviate the current situation. Note that ambient light impose little interference on LC as discussed below in “LC Technical Feasibility”.
            3. <u>Robustness against jamming:</u> it is possible for actors to easily jam the used RF spectrum from great distances outside the plant with simple RF devices. The use of RF-based wireless links instead of cables has obviously a potentially harmful impact on the safe operation of the connected manufacturing facilities in general. In addition, the presence of strong electromagnetic interference may not be suitable for RF communication like in a steel mill, in nuclear power plants or in a

power station. On the other hand, LC is inert against RF jamming and electro-magnetic interference, the propagation is confined inside the plant.

d. Healthcare

i. Providing the same reliability and security as a wired connection with the flexibility of a wireless solution for indoor communications, including reliable and precise indoor positioning for patient/doctor/asset tracking as well as wireless connectivity in electro-magnetic interference sensitive environments like operating theaters or MRI rooms (Magnetic Resonance Imaging).

Since 2016 several projects under H2020 and individual programs continue to develop use cases which support the above to drive forward LC technology and standardization.

LC technology is projected as economically viable [7], as it sits on firm ground within the lighting sector. With the Increase in LED lights across the globe, it means that the base infrastructure for LC technology is already in place.

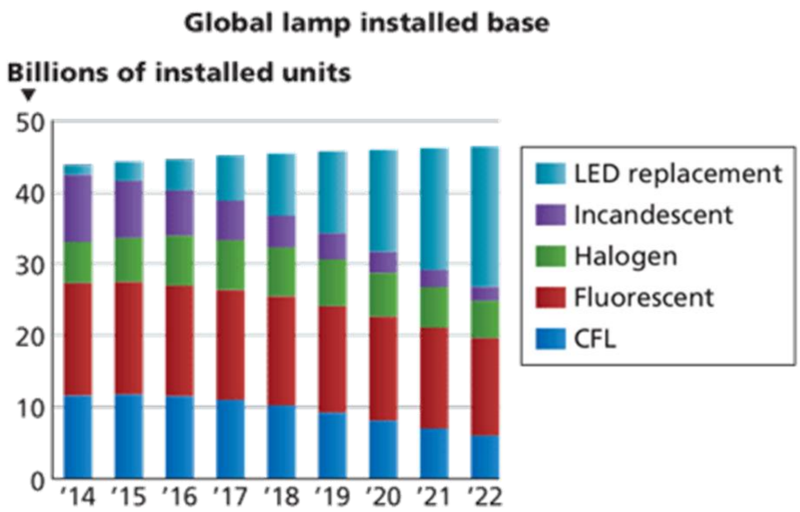


Figure 4 – Global lamp installed base [8]

Coupled with the advance of Power over Ethernet (PoE) and its increasing use to provide a backbone for lighting in new office buildings, offers reduced deployment cost and time.

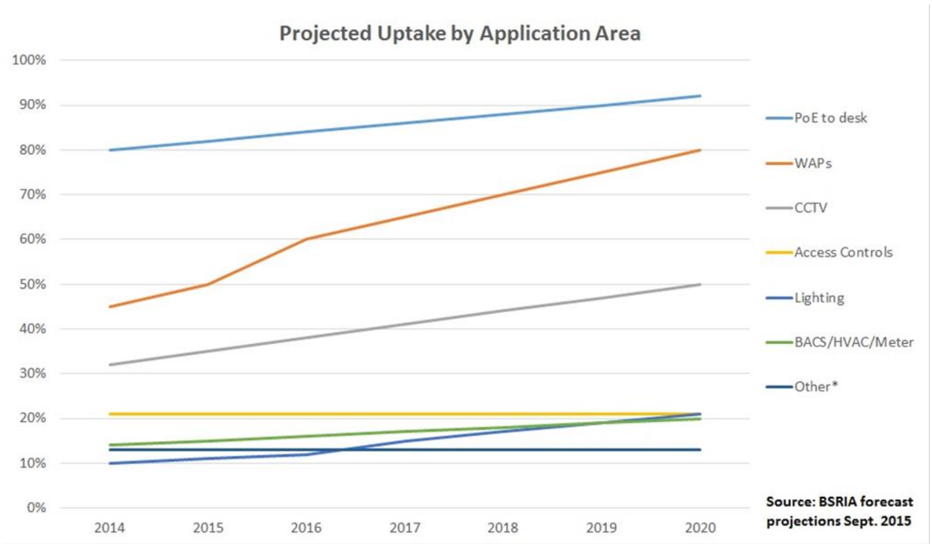


Figure 5 – Power over Ethernet usages [9]

The emergence of Light as a Service business model is the next step in the evolution of the lighting industry.

With the introduction of smart lighting control and increasingly the Internet of Things connectivity modules, the lighting industry is relying more on creating value for the end customer based on the available data about the building and behaviour of the users.

This shifting business model in lighting can leverage light communications and other wireless communications to improve the utility of lights.

The 5 – 10 year product replacement cycle is similar to the evolution of various 802.11 standards, ensuring that the future lighting sockets can all have 802.11 technologies embedded in the next generation of devices.

1.3 THz communications

On IEEE (Institute of Electrical and Electronics Engineers) side, an Interest Group on THz spectrum was launched in 2008 in the framework of 802.15 ([10]). It "has been chartered to explore the feasibility of Terahertz for wireless communications. […] There are no immediate plans to transition the group to a study group or a task group; rather, we want to fully understand the technology status."

Early scenarios considered in this group are depicted below [11]:

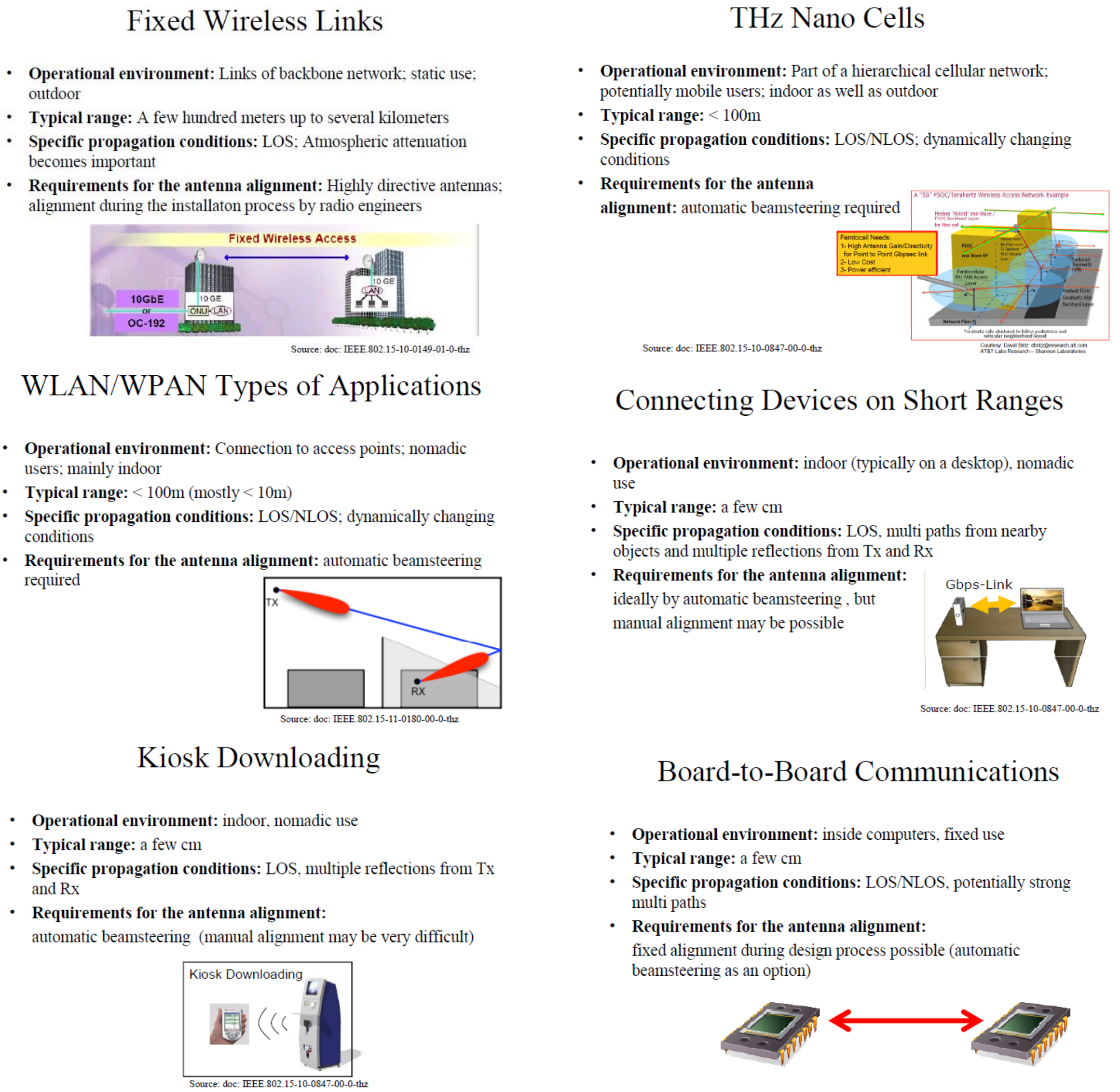


Figure 6 – Early applications of THz communications

In a more recent input to IEEE 802.15 THz IG [12], a focus was done on interconnections in data centres, chip-to-chip communications on motherboard, wearable devices communications.

In parallel to this IEEE activity, early research projects have started to explore the potential of THz spectrum:

- iBROW [13]
    - main focus is the development of "a novel, energy-efficient and compact ultra-broadband short-range wireless communication transceiver technology"
    - the use case is mm-wave/THz femtocell base stations connected to high-speed 40/100 Gbit/s fibre-optic networks
- TERAPAN [14]
    - "The objectives of the TERAPAN project" were ", firstly, to demonstrate an adaptive wireless point-to-point terahertz communication system for indoor environments, and secondly to validate its performance for distances of up to 10 m at data rates of up to 100 Gbps."
    - Applications considered were:
        - Smart office (high speed wireless point-to-point links between different work stations)
        - Wireless links in data centers
        - Intra device, kiosk download…

2 Use cases selection / definition methodology

As mentioned in WORTECS description of work, the identification and selection of WORTECS use cases is based on the three following steps:

- Step 1: State of the art overview of existing use cases exploiting higher part of the spectrum (see Section 1)
- Step 2: Sub-selection of three to five use cases more relevant for bands above 90 GHz and in terms of expected business
- Step 3: A single use case (and requirements) prioritized for implementation

During step 2, the following parameters have been taken into account:

- Relevance of the use case versus the contents of the ICT-09-2017 call: one of the objectives of the call (and of course of WORTECS) is to support Tbps communications; then, the primary focus of WORTECS use cases is high throughput/high capacity; the Tbps has to be understood here as a capacity per area (and not per user – current limitations of hardware capability on device side make the challenge of Tbps/user far too ambitious yet).
- Interest in terms of business: very first studies on expected impact of 5G on economy and on 5G markets are available today; for instance IHS ([15]) shows the expected significant impact of 5G/eMBB on industries such as *arts & entertainment*, *education*, *information & communications*, *manufacturing*, *professional services* (Figure 7). In addition, JUNIPER in [16] shows that eMBB will still remain a key driver for 5G (Figure 9) even if average revenue per user will decrease, while AR/VR should greatly be accelerated by 5G (Figure 8). These inputs have been taken into consideration for WORTECS use cases prioritization.

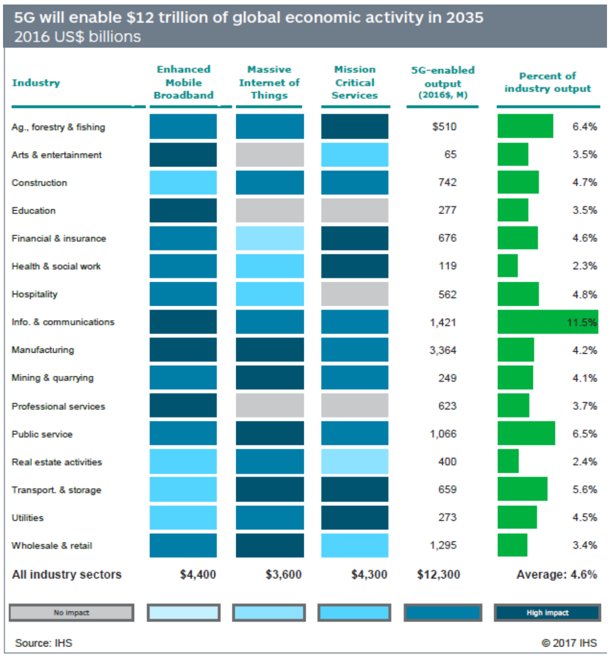


Figure 7 – 5G-enabled economic activity in 2035

Figure 8 – 5G AR & VR Market Snapshot: 2025

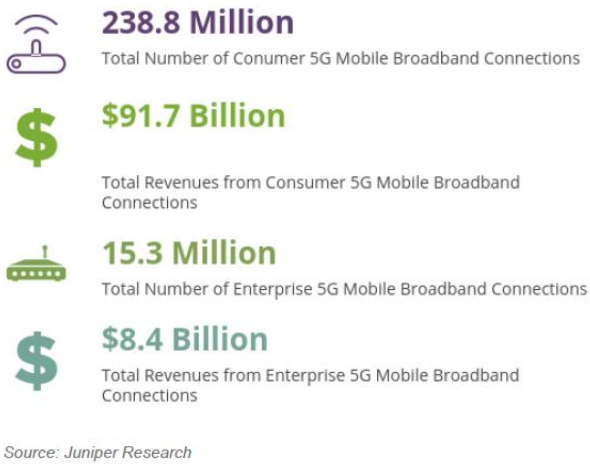


Figure 9 – 5G MBB Market Snapshot: 2022

- Diversity of use cases: even if it seems more straightforward to exploit higher spectrum for indoor scenarios, it has been agreed to also look at the applicability of such frequency bands for outdoor use cases as well.
- Feasibility: the objective of the use cases definition is to propose scenarios of interest for theoretical studies and implementation purpose; it has to be taken into account as well the related constraints for

both activities (e.g. channel model availability for simulation purpose, “implementability” of use cases for proofs of concept, inc. avoid unrealistic/unreachable requirements, too expensive developments…)

3 WORTECS use cases and requirements

3.1 Virtual Reality

Virtual Reality (VR) has hit the consumer market since the launch of the Oculus Rift Kickstarter in 2013. Ever since, the technology has been quickly evolving and the market growing fast. New VR oriented businesses have emerged, such as Location Based Entertainment (LBE), also known as VR arcades. These businesses propose multiuser VR experiences and untethered VR. Large businesses also use VR environments for prototyping, design, specifications, validation and decision making through digital mock-ups. But they are also limited by current VR technologies which do not readily allow multi-user cooperation. CAVE-like systems allow one user to interact in VR while others watch from the outside, whereas Head Mounted Displays (HMD) are usually tethered to high end computers and can lead to complicated wire tangling when multiple users are working in a shared physical space.

But the untethered VR solutions are not as straightforward as it seems with current VR technologies. A lot of HMDs need to be physically tethered to a computer running the VR simulation because they need extremely high computing power to deliver the best possible VR simulation. To that end, there currently are two solutions for untethered VR:

1. Use high end laptops carried in backpacks by the user, and tether the HMD to the backpack. This solution is bulky, heavy and is greatly dependent on battery life which can be pretty low considering the heavy power requirements of high end 3D simulations for VR.
2. Use external plugin modules that connect to the PC and HMD and transmit data wirelessly over proprietary protocols. Solutions like TPCast already exist commercially and answer the current needs of the market but are not future proof.

The bandwidth needed for transmitting high quality video content to a VR HMD is quickly reaching its limits. The current resolution of HMDs is 1080x1200 pixels per eye for the Oculus Rift and HTC Vive. Both headsets suffer from what is known as the screen door effect: at such low resolutions, the human eye can see the individual physical pixels in the image as if looking at it through a screen mesh door. Higher resolution HMDs are currently announced such as StarVR which boasts 2560x1440 pixel resolution per eye or even the Pimax 8K with 3840x2160 pixel resolution per eye.

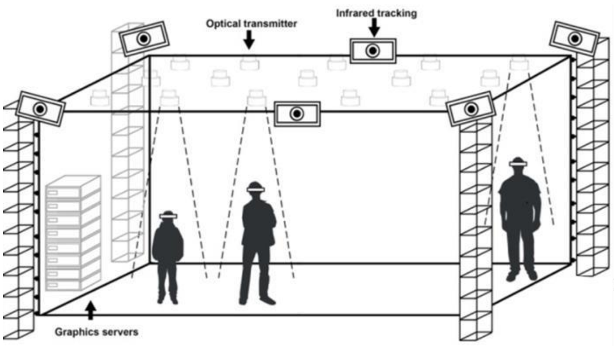
Resolution	Raw Bandwidth	Low-latency compression bandwidth(4:1)	Wireless technology
2x640x480 @60Hz	842 Mbps	210 Mbps	802.11ac
2x960x1080 @90Hz	4.16 Gbps	1004 Mbps	802.11ad
2x1080x1200 @90Hz	5.2 Gbps	1.27 Gbps	802.11ad
2x1440x1600 @90Hz	9.26 Gbps	2.23 Gbps	802.11ad
2x2560x1440 @90Hz	14.82 Gbps	3.7 Gbps	802.11ad?
2x3840x2160 @120Hz	55.6 Gbps	13.9 Gbps	???
2x9000x7800 @120Hz	470 Gbps	120 Gbps	???

Table 4 - Bandwidth requirements for wireless HMDs

But even these high resolutions are not sufficient to avoid the screen door effect. The human visual acuity is one sixtieth of a degree, meaning that any detail larger than one arc minute will be individually seen and recognized by the eye. Furthermore, the full field of view of human perception, taking into account peripheral vision, is 150 degrees per eye. Taking these physiological parameters into account, it will be necessary to have a resolution of 9000x7800 pixels per eye. This would need a bandwidth of 470Gbps per user to transmit wirelessly.

The video flow can be compressed before transmission, but the compression algorithms need to have near zero latency to avoid motion sickness. The overall accepted latency between user head movement and the display of the image is 17ms. That is 17ms between detecting user motion, computing the new position, sending the data to the computer, computing the new image, compressing the new image, sending it to the HMD and displaying it on the screen. Most of this time is already taken up by the computing and rendering of the image and little time is left for compression. Current lossless, near zero latency algorithms can provide approximately a 1 to 4 ratio compression which means we can reduce the bandwidth needed to approximately 120Gbps per user.

In order to test and validate the high bandwidth needs of multiuser VR, the WORTECS project will produce a prototype presented in Figure 10.



- Room size: 10x10m
- Nb Users: 10
- Wireless link with Optical Wireless Communication (OWC)
- Video Streaming: 200Gbps per user (8K per eye with 30 bits per pixel at 120fps)
- Latency: <3ms for video stream transport
- Multi-user
- Multi VR environment
- Interoperability: Staion X & Device Y
- Tracking:
  - Position: < 1mm
  - Orientation: < 1/10°
- Energy feed (from OWC Access Point to HMD)

Figure 10 - WORTECS Wireless Multiuser VR Prototype

Seeing how multiuser VR experiences are quickly becoming popular, the need for powerful untethered VR will soon be very high. When also factoring in the extremely high resolution needed for realistic and believable content, current wireless technologies will not be enough to respond to the bandwidth needs of high quality low latency video. To that end, extremely high bandwidth solutions and Tbps will most certainly be essential for the future evolution of VR.

KPI	**Requirement**		
	Mass Market VR	*High End VR*	*Prototype VR*
Potential HMD	Star VR	Pimax 8K	N/A
Resolution	5120x1440 (5K)	2x3840x2160 (2x4K)	2x7280x4320 (2x8K)
Bits per pixel	24	30 (HDR)	30 (HDR)
Frequency	90Hz	120Hz	120Hz
Connection density	10 users / 100m²		
DL Data Rate per user	14.8Gbps	55.62Gbps	210.88Gbps
DL Traffic Density	148.3Gbps / 100m² (1.48Tbps / km²)	556.2Gbps / 100m² (5.56Tbps/km²)	2.06Tbps / 100m² (20.6Tbps/km²)
Low latency video compression bandwidth for 10 users (4:1)	37Gbps	139Gbps	527.2Gbps
Video Stream Latency	<2ms	<2ms	<2ms

Table 5 - KPI and estimated requirements for wireless multiuser VR in 2020

3.2 Enterprise communications / Virtual office

This use case is based on the evolution of connectivity within the commercial world.

Communication, clear and secure, is paramount to the success of a business and the office environment is more connected than ever before with conferencing, emails and ever-increasing sharing of information.

As cybersecurity becomes more prevalent, there is a constant need to minimise that risk with innovative solutions. LC can provide the same level of security and reliability as traditional wired connection with the

flexibility of a wireless solution where reliable network connections are required for daily work, conference, and more eventually leading to streaming remote desktops from the cloud.
The directionality of light propagation can effectively reduce interferences in heavily populated offices allowing for much more dense deployments, providing a step change in ease of deployment and intuitive understanding of the technology for end customers. Wireless off-loading to LC releases spectrum for connecting other devices.

In summary the adoption of LC into the Enterprise Communication/Virtual office would not only complement existing systems but has the potential to increase mobility, connectivity and security.

KPI	**Requirement**	**Comments**
DL Data Rate per user	25Mbps (up to 1Gbps)	Compressed UHD/4k video requires less than 25 Mbps today looking at the 5G PPP
UL Data Rate per user	25Mbps (up to 1Gbps)	Aim is to provide complete virtual desktop/collaborative working environment requiring constant connectivity. Therefore the uplink should be symmetric to the downlink.
Connection density	10 device / 10 m^2	EU regulation requires for office space recommends 1 person per 10m^2. However, each person can be expected to have up to 10 devices.
DL Traffic Density	10 Mbps/m^2 - 10 Tbps/km^2	Connection density of 1 user per 10m^2. DL/UL office: 20 Tbps/km^2
UL Traffic Density	10 Mbps/m^2 - 10 Tbps/km^2	
Mobility	Stationary / Pedestrian	Users are either stationary or slowly moving
Latency	10ms	The most critical issue is the sharing of real-time HD videos ensuring high quality user experience

Table 6 – KPIs and requirements for Enterprise Communication/Virtual office use case

3.3 Stadium / Open-Air Festival / Themes Parks

This use case is inspired from mmMAGIC use case “Dense urban society with distributed crowds”. The objective here is to address an outdoor case where massive crowds are concentrated, temporarily or not, users being stationary or slowly moving, watching HD videos, sharing contents on social networks, accessing / receiving information from the cloud…

Figure 11 – Stadium use case [17]

The following examples illustrate the scenario in more details:

- Stadium: a dedicated wireless technology is deployed in a stadium in order:
    - for fans:

    - to view replays available on the club website, with different viewing angles…
    - to view videos of other games happening in parallel in other stadiums (e.g. on Saturday evening football game day in France)
    - to share, with friends, on social networks, live videos/pictures taken in the stadium
    - to bet on the result of the current game
    - …
  - for professionals of media to share videos/contents (with high quality level) with their editorial team
- Open air festival: this scenario is rather similar to the previous one except that the technology may be deployed temporarily for the specific event (e.g. summer festivals in areas not usually dedicated to such events).
- Theme Parks: in such areas, Augmented Reality experiences are already available but in dedicated rooms/areas only; as imagined by Disney in [18], “rather than locking visitors in one place for one experience, it [Augmented Reality] could be used to enhance the park as a whole and allow them to wander freely and actually interact. Imagine, for example, wearing augmented reality glasses and being able to engage in a Tinkerbell hunt around the park – a kind of ride outside of the main rides.”

Figure 12 – Themes Parks use case [19]

For this use case, the specific KPIs and requirements are basically inherited from NGMN [6]. The Tbps capability has to be reached for traffic density KPI.

KPI	Requirement
DL Data Rate per user [Mbps]	25 – 50
UL Data Rate per user [Mbps]	50
Connection density	30000 users/stadium (150000 users/km²)
DL Traffic Density [Tbps/km²] – peak value	3,75
UL Traffic Density [Tbps/km²] – peak value	7,5
Mobility	Stationary / Pedestrian

Table 7 – KPIs and requirements for Stadium/Open-Air Festival/Themes Parks WORTECS use case

4 Conclusion

In this deliverable, three main use cases have been identified in order for WORTECS members to have guidance for simulation and implementation work. These use cases, based on a state-of-the-art analysis are:

- *"Virtual Reality"*, which will be the core use case for WORTECS, with severe constraints on both the data rate to be delivered (downlink traffic density of more than 20Tbps/km²) and the latency to be guaranteed (lower than 2ms);
- *"Enterprise Communications / Virtual office"*, which could efficiently benefit from the take-off od light communications to deliver up to 10Tbps/km² in a symmetric way;
- *"Stadium / Open-Air Festival / Themes Parks*", whose one of the objective is to complement the two other use cases by adding the "outdoor" dimension, and requiring as well a couple of Tbps/km² in both uplink and downlink;

WORTECS USE CASES	**VIRTUAL REALITY**	**ENTERPRISE COMMUNICATION / VIRTUAL OFFICE**	**STADIUM / OPEN-AIR FESTIVAL / THEMES PARKS**
KPI	**Requirement**		
DL Data Rate per user	210.88Gbps	25Mbps (up to 1Gbps)	25 – 50Mbps
UL Data Rate per user	-	25Mbps (up to 1Gbps)	50Mbps
Connection density	10 users / 100m²	10 device / 10 m²	e.g. 30000 users/stadium (150000 users/km²)
DL Traffic Density [Tbps/km²]	20.6	10	3,75
UL Traffic Density [Tbps/km²]	-	10	7,5
Mobility	Stationary/pedestrian		
Latency [ms]	<2	10	-

Table 8 – KPIs and requirements of WORTECS use case: synthetic view

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