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| **Radiocommunication Study Groups** |  |
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| **5 June 2017** |
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| Annex 36 to Working Party 5A Chairman’s Report | |
| Working Document towards a Preliminary Draft New Report ITU-R M.[IOT/m2M\_usage] | |
| Technical and operational aspects of Internet of Things and Machine-to-Machine applications by systems in the Mobile Service (excluding IMT) | |

# [*Editor’s note: WP 5D is also developing an IMT report on MTC/IoT. WP 5A should coordinate this effort with WP 5D in order to avoid any duplication*.]

# 1 Introduction

*[TBD]*

# 2 Scope

This report provides information on the technical and operational aspects of Machine Type Communications (MTC) including Internet of Things (IoT)/Machine to Machine (M2M) applications by systems in the Mobile Service (excluding IMT). This report also provides information on the existing and planned/future usage of Mobile Service frequency bands by IoT/M2M applications.

*[Editor’s note: The scope can be extended later based on input contributions.]*

# 3 Related documents

Resolution ITU-R 54 “Studies to achieve harmonization for short-range devices”

Resolution ITU-R 66 “Studies related to wireless systems and applications for the development of the Internet of Things”

Working document towards a draft new Report ITU-R M.[IMT.MTC/NB.BB.IOT/SPECTRUM]

Recommendation ITU-R M.1450: Characteristics of broadband radio local area networks

Recommendation ITU-R M.2002: Objectives, characteristics and functional requirements of wide-area sensor and/or actuator network (WASN) systems

Report ITU-R SM.2153: Technical and operating parameters and spectrum requirements for short-range devices,

Report ITU-R SM.2351: Smart grid utility management systems,

[ETSI TR 102 889-2 V1.1.1](http://www.etsi.org/deliver/etsi_tr/102800_102899/10288902/01.01.01_60/tr_10288902v010101p.pdf) (2011-08): Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Part 2: Technical characteristics for SRD equipment for wireless industrial applications using technologies different from Ultra-Wide Band (UWB),

ECC Report 206: Compatibility studies in the band 5 725-5 875 MHz between SRD equipment for wireless industrial applications and other systems,

ERC Recommendation 74-01: Unwanted emissions in the spurious domain",

ECC Recommendation (02)05: "Unwanted emissions",

EN/IEC 61784-2:2010: "Industrial communication networks – Profiles – Part 2: Additional fieldbus profiles for real-time networks based on ISO/IEC 8802-3",

EN/IEC 62591: "Industrial communication networks – Wireless communication network and communication profiles –WirelessHART®",

IEEE 802.11-2016: "IEEE Standard for Information technology – Telecommunications and information exchange between systems - Local and metropolitan area networks – Specific requirements - Part 11: Wireless LAN Medium Access, Control (MAC) and Physical Layer, (PHY) Specifications",

IEEE 802.15.1-2005: "IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.1: Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs)",

IEEE 802.15.4: "IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low‑Rate Wireless Personal Area Networks (WPANs)".

[*Editor’s note: WP 5A seeks further contributions on the framework and structure of this report. Items for consideration in this structure may include the Technical and operational aspects of M2M/IoT which may require liaising with external organizations. In addition, the M2M/IoT report being developed by WP5D may provide an example and guidance on the framework for this report.*]

# 4 Definitions and terminology

The following definition and terms are used in the Report.

## 4.1 Definitions

*[To be completed as necessary]*

## 4.2 Terminology

*[To be completed as necessary]*

For the purpose of this report, the following terms have the meanings given below.   
However, these terms do not necessarily apply for other purposes.

End-to-end latency

Parameter for characterizing the communication service delay from an application point of view

Jitter

Variation of latency

Node

Node refers to a generic network element (e.g. a base station, an access points, radio terminals, core network element) that is involved in the related network operations.

Survival time

The survival time specifies the time an application may continue without an anticipated message.

## 4.3 Abbreviations

CEPT Conference of Postal and Telecommunications Administrations

IoT Internet of Things

M2M Machine-to-Machine

MTC Machine Type Communications

WIA Wireless Industrial Application

# 5 Overview of existing and possible future IoT/M2M applications

## 5.1 Internet of Things – IoT

## 5.2 Machine-to-Machine – M2M

### 5.2.1 Wireless industrial applications – WIA

Modern automation technology applications are increasingly using wireless technologies to transfer data. But, industrial automation applications require robust technologies to be used for their critical wireless communication. The advantages of wireless technologies are savings of often complex and expensive cables, cable protection and plugs, the increased mobility and flexibility as well as the wear and tear free transmission medium.

The majority of wireless systems for industrial automation applications use the bands designated for Industrial, Scientific and Medical applications (ISM) and Short Range Devices (SRDs). The main incentive for using some of these bands is their broad harmonisation and their license-exempt status.

Details of the current use, technology and related deployments can be found in Annex X.

### 5.2.2 …

# 6 Information on the existing and planned/future usage of Mobile Service frequency bands by IoT/M2M applications

# 7 Technical and Operational Aspects of existing and possible future IOT/M2M applications

# 8 Enabling and existing technologies

# 9 Deployments scenarios and architectures

# 10 Summary

Annex 1:

Annex 1

Wireless industrial automation (WIA) applications

# 1 Scope

This Annex provides information on wireless industrial automation application. This includes information on how current radio systems for wireless industrial automation, their evolution, and/or potentially new radio interface technologies and system approaches could be appropriate, taking into account the impact of the propagation characteristics related to the possible future operation of wireless industrial applications.

# 2 Introduction

Wireless industrial automation applications would require appropriate consideration of the following demands:

– very low latency and high reliability machine-centric communication;

– high user density;

– maintaining high quality (e.g. robustness and low-latency real-time behaviour) at high mobility.

Furthermore the Report ITU-R M.2370-0 describes that machine to machine communication (M2M) is a growing market in future. For that reason it is necessary to consider the technical feasibility of current and future radio interfaces for wireless industrial automation application within the framework of advanced manufacturing and Industry 4.0.

There has been recent academic and industry research and development related to suitability of wireless industrial automation applications. For that reason the [ETSI TR 102889-2](http://www.etsi.org/deliver/etsi_tr/102800_102899/10288902/01.01.01_60/tr_10288902v010101p.pdf) was developed to describe the requirements of wireless industrial automation applications. Based on the ETSI TR 102889-2, CEPT utilises the frequency range from 5 725 MHz to 5 875 MHz for wireless industrial automation application. The results of compatibility studies within the frequency range can be found in ECC Report 206.

*[Editor’s note: The other relevant frequency bands could be considered later on based on input contributions.]*

# 3 Typical WIA Applications

*[Editor's note: This chapter describes typical WIA with application related requirements.]*

## 3.1 Factory Automation

Factory automation is used as synonym for discrete manufacturing where products are produced, assembled, tested or packed in many discrete steps (automotive, general consumer electronic, goods production). For factory automation, in-time deliveries of messages and high reliability (robustness) are very important to avoid interruptions in the manufacturing process. Redundancy, cyber security and functional safety are also very important for factory automation. Typically, every manufacturing step involves many sensors and actuators controlled by a single controller (e.g. Programmable Logical Controller): many of these use wired connections which are often stressed by repeated movements and/or rotations and other harsh conditions.

Today more and more devices, especially sensor and actuator nodes with relaxed requirements, are connected using wireless technology to improve productivity and increase availability compared to wired sensors/actuators at difficult locations.

Motion control is characterized by high requirements on the communications system regarding latency, reliability, and availability.

Application examples *[to be completed]*

– Automatic guided vehicles (AGV);

– Single and collaborating mobile robots;

– High-bay storage / Intra logistics;

– Portal crane;

– Assistance systems for workers and operators:

• Video cam & display (e. g. Hololense);

• Human machine interface (HMI).

## 3.2 Process Automation

*[Editor’s note: Process Automation: this includes applications in the higher levels of the automation hierarchy e.g. at the control or enterprise level, where the data volume rises, so throughput, security and availability becomes more important, but real–time communications requirements decrease.]*

Process automation is defined as an automation application for industrial automation processes. It is typically associated with continuous operation, with specific requirements for determinism, reliability, redundancy, cyber security, and functional safety. Process Automation is typically used for continuous production processes to produce or process large quantities or batches of a certain product (like fluids, chemical, or an "endless" product like e.g. wires, cables).

Process applications also require deterministic behaviour and therefore require low latencies in the range between 100 ms and a few seconds. Process automation can cover relatively large areas and so wide wireless transmissions ranges are required. The end nodes (sensors) in process automation applications potentially have to have a battery life of several years.

On the sensor level you can find mesh networks for field instruments, based on different wireless mesh protocols. The mesh structure helps to achieve a large range coverage with standard low power levels and to be robust. On higher levels of the automation hierarchy e.g. at the control or enterprise level, where the data volume rises (e.g. portable supervisory stations), so throughput, security and availability becomes more important, but real–time communication requirements decrease.

Process automation covers, for example, the following industries: oil & gas, refining, chemical, pharmaceutical, mining, pulp & paper, water & wastewater and steel.

Application examples *[to be completed]*

– Portable supervisory station (commissioning, maintenance);

– Environmental sensors;

– …

## 3.3 Audio-visual interaction

Audio-visual interaction is characterized by a human being interacting with the environment or people, or controlling a device, and relying on audio-visual feedback.

## 3.4 Remote control

Remote control is characterized by a device being operated remotely, either by a human or a computer.

## 3.5 Mobile Robotics and Vehicles

Mobile robots and vehicles are playing an increasingly important role in modern factories. This includes mobile units for taking care of the supply of items and material on the shopfloor level, such as autonomous guided vehicles (AGVs) or intelligent fork lifters, but also mobile manipulators, which may be flexibly used at different locations and possibly even facilitate a close human-machine collaboration. In general, the performance and efficiency of such mobile units can be significantly increased if they are interconnected with each other as well as the environment using a powerful wireless system. For example, relatively simple and thus inexpensive AGVs may form a larger swarm by coordinating their actions based on information exchanged between them and thus jointly realize complex tasks, such as lifting items that would be too heavy or big for one unit alone. The more reliable and the faster the connectivity is, the safer and faster the coordination can take place. If the wireless system could additionally provide a sufficiently accurate information about the current location of a mobile unit (in the range of 10 – 50 cm), this could be beneficially exploited in many cases, for example for autonomous navigation or collision prevention.

# 4 Characteristics for WIA applications

*[Editor's Note: This chapter will describe the characteristics of the WIA system operations. This would include e.g. channel models to be developed to perform radio performance simulations and the impact of radio propagation.]*

## 4.1 Operation and maintenance characteristics

### 4.1.1 Ease of use

Communication networks should be able to be planned, set up, operated, and maintained without in-depth knowledge of communication technologies and with a minimum of time effort. The communication network should provide communication services with clearly defined quality levels, which simply can be used without understanding of how these communication services are realized.

### 4.1.2 Isolation

Many applications, with different QoS requirements, will use the same network. For instance, in a manufacturing environment, industrial control will coexist with the control of autonomous vehicles, manufacturing operations management, video monitoring, building-automation, etc. The priority of these applications from a productivity and safety point of view is often different, and their network resource consumption, too. For instance, monitoring cameras in a factory hall readily surpass the needed network capacity of fire-safety applications, but connectivity for the latter absolutely has to be available at all times. In practice, vertical applications will, at a minimum, be virtually separated from each other. Also, different actors with different roles will need access to the same network. For instance, factory maintenance might be delegated to an external organization, which needs dedicated access to only the machinery it is responsible for. For an appropriate use of the infrastructure, all applications and tenants may not adversely influence each other. For instance, huge communication resource demands for autonomous vehicles may not adversely impact motion control.

### 4.1.4 Multicast

Domain multicast is required for some automation applications.

### 4.1.5 Multi-tenancy

Vertical applications increasingly need to handle different stakeholders who are using the same network for running their services. Examples are operation, maintenance, emergency response, etc. This requirement has to be supported while still assuring the communication service quality level and excluding conflicts between the stakeholders’ interests. This is especially the case if a provider network is used.

### 4.1.6 Network recovery

Not only should it be possible to isolate communication services consumed by different applications and/or tenants against each other (see isolation), but networks should also provide functionality that regulates the network recovery and reconnection of UEs in a controlled fashion. For instance, in a factory setting, after recovery from a network failure, industrial control application should be provided with communication service access before the outbound logistics applications.

### 4.1.7 Quality of service (QoS) description

Distributed industrial solutions do not stop at national or service provider borders. Therefore, a common understanding and definition of industry-grade QoS across national borders and between providers would be helpful. This is the only way to provide service guarantees beyond connectivity in an end-to-end fashion. To assure that such end-to-end services can be setup in a timely manner, fundamental industrial service / SLA profiles including the required monitoring should be available, globally accepted and offered. By so doing, long lasting negotiation periods with several network service operators and undue overhead when merging two networks can be avoided.

### 4.1.8 Service response (Negotiation of QoS levels)

Some automation applications can operate at more than one communication QoS setting. Therefore, if a certain QoS level is requested by the application but cannot be met by the network, an alternative should be proposed by the network. For instance, if the requested end-to-end latency of 10 ms cannot be guaranteed, the communication service indicates what end-to-end latency is instead feasible. The automation application has then the option to request communication services at a refined QoS level.

### 4.1.9 Service deployment time

Today, end-to-end services traversing many network domains, covering large distances or asking for specific quality properties need a long time (in the order of weeks to months) to be setup by the service provider. The reasons for this are suboptimal processes, technical inflexibilities, required manual interventions, missing suitable interfaces, etc. For remote services on demand and many other services this is not acceptable. Significantly reduced lead times of approximately several hours are needed.

### 4.1.10 Simplified certification

Industrial solutions are foreseen for international use. In many cases, certifications have to be applied before this is legally possible. This includes the certification of communication solutions, especially if these solutions leverage wireless interfaces. Region/nation-specific certification procedures which are not accepted amongst each other, are very cumbersome and expensive.   
Thus WIA systems should be able to successfully pass such certification processes.

### 4.1.11 Technology availability (long-term availability of technology and the related infrastructure)

The lifetimes of industrial solutions are typically in the range of several decades. In order to ensure continuity, any underlying communication solution has to be available throughout the whole lifetime. Therefore an availability of WIA systems (components, spare parts, and infrastructure) over at least 20 years has to be assured. In this context also backward compatibility is of major importance.

### 4.1.12 Non-standard operating conditions

The absence of low-voltage power supply can be an issue in the field, creating the need for battery- or energy-harvester-powered ultra low-power area networks with a corresponding low bandwidth. For battery powered WIA devices a lifetime of than 10 years (and more) is required.

Harsh environments, including wind and weather, vibrations, heat, dust or even hazardous gases may also be a challenge for communication equipment.

### 4.1.13 Operation of private network infrastructures

Leveraging the full potential of WIA systems can only be achieved if from the very beginning the setup and operation the wireless network infrastructures can be done also in a local and closed environment without the involvement of a 3rd party network provider and without sharing the infrastructure with other (potentially less controlled) users/applications.

The need to keep the operation of local/closed wireless networks in the responsibility of the industrial operator are mainly due to system criticality: the dependence on 3rd parties is minimized, the transparency in the level of compliance with required quality levels is intrinsically given, and responsibilities and liabilities are much easier to determine. All this leads to a significantly reduced risk for the industrial operator. In addition, maintenance strategies of the industrial solutions will be very different to the ones applied by a 3rd party network service operator.

## 4.2 Impact and challenges of radio propagation

*[Editor's note: In case of channel model, other groups in ITU-R have responsibility to develop and define the documents regarding channel model. Therefore, this section can describe the necessity to develop channel model in due course.]*

*[Editor's note 2: Consider to mention that industrial channels are typically very challenging due to lots of metal, interference, etc., but that there is currently a general lack of appropriate channel models]*

WIA applications require different propagation characteristics:

– Spectrum to cover areas also under NLOS conditions:

• Use with moving devices (example: Automatic Guided Vehicles, AGVs);

• Use with small bandwidth and good penetration of walls (e. g. sensors and actuators).

– Spectrum to cover areas under LOS inside production halls, high density of systems (see table [A1-1], Connection density for Factory automation):

• Protection of other systems outside the production halls.

## 4.3 Coverage

*[Editor's note: Coverage characteristics including propagation loss, penetration loss, attenuation and transmission distance can be described in this section.]*

See table [A1-1], column Service area

## 4.4 Mobility

*[Editor's note: Mobility characteristics including path loss and NLOS transmission can be described in this section.]*

WIA systems can be stationary or mobile, depending on the application. Mobile WIA systems can move with up to 50 km/h. Transmission conditions for moving systems can change between LOS, OLOS and NLOS very quickly.

## 4.5 Transmitter parameters

### 4.5.1 Transmitter Output Power/Radiated Power

e.i.r.p. up to [250] mW is specified.

### 4.5.2 Antenna Characteristics

No restrictions on antenna characteristics.

### 4.5.3 Bandwidth

*[Editor's note: Bandwidth characteristics to fits the requirements of WIA.]*

As different technologies are used, the typical occupied bandwidth for a single device varies between [1] MHz and [20] MHz. Specific applications like location tracking may even use the complete available (sub-)band.

Frequency Hopping as well as non-frequency hopping technologies are used.

### 4.5.4 Unwanted emissions

[*Editor’s note: Are there other references which could be included in addition to ECC ones.*]

The unwanted emissions will be in accordance to ECC Recommendation (02)05 *[add link to reference.]*

## 4.6 Receiver parameters

### 4.6.1 Spurious emissions

The spurious emissions will be in accordance to ERC/REC 74-01 *[add link to reference]*

### 4.6.2 Receiver sensitivity

Most of the technologies used in the industrial applications are based on specifications such as IEEE 802.11 *[reference]*, IEEE 802.15.1 *[reference]* and IEEE 802.15.4 *[reference]*. Therefore, the relevant receiver parameters including the receiver sensitivity can be found in those standards.

### 4.6.3 Other receiver parameters

The performance of certain sharing mechanisms may require certain specific receiver requirements.

*[Editor's note: To be considered]*

## 4.7 Channel access parameters

For maximised spectrum efficiency, including sharing among all wireless industrial applications present, a spectrum sharing mechanism may be appropriate for industrial applications.

An example of that is Frequency Agility. Frequency Agility is the ability of a system to operate according to frequency or channel assignments of a centralized or distributed control mechanism, which will define the configuration of all devices within an industrial site or subarea thereof, Configurations may change over time depending on the application requirements. If non-contiguous spectrum is assigned, then the Frequency Agility feature is supposed to operate across all assigned sub-bands.

## 4.8 Other characteristics

*[Editor's note: Other characteristics can be described in this section.]*

### 4.8.1 Performance characteristics

In the following table the performance requirements for WIA systems are given. All the values in this table are targeted values. They are taken from the work of the 3GPP SA1 working group and 3GPP TS 22.261 “Service requirements for the 5G system; Stage 1”. (Values in [] are for further study.)

Table [A1-1]

Performance requirements for low-latency and high-availability services.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Service | End-to-End Latency | Jitter | Survival time | Availability | Experienced data rate | Payload | Traffic density  NOTE 7 | Connection density | Service area  NOTE 6 | Coverage  NOTE 1 | Comments |
| Factory automation - Motion Control | 1 ms | 1 µs | 0 ms | 99,9999% | 10 Mbps | Small | 1 Tbps/km2 | 100 000/km2 | 100 x 100 x 30 m | Very high | NOTE 2 |
| Factory automation | 10 ms | 100 µs | 0 ms | 99,99% | 10 Mbps | Small to big | 1 Tbps/km2 | 100 000/km2 | 1000 x 1000 x 30 m | Very high |  |
| Process automation –Remote Control | 50 ms | 20 ms | 100 ms | 99,9999% | 100 Mbps | Small to big | 100 Gbps/km2 | 1 000/km2 | 300 x 300 x 50 m | Very high |  |
| Process automation  Monitoring | 50 ms | 20 ms | 100 ms | 99,9% | 1 Mbps | Small | 10 Gbps/km2 | 10 000/km2 | 300 x 300 x 50 | Very high |  |
| Audio-visual interaction | [10 ms] | [TBC] | [TBC] | [99,9%] | [250 Mbps] | [Big] | [Low] | Low] | [TBC] | [High] | NOTE 3 |
| Remote control | [5 ms] | [TBC] | [TBC] | [99,999%] | [From low to 10 Mbps] | [Small to big] | [Low] | [Low] | [TBC] | [Very high] |  |
| Mobile Robotics and Vehicles | [TBC] | [TBC] | [TBC] | [TBC] | [TBC] | [TBC] | [TBC] | [TBC] | [TBC] | [TBC] |  |
| NOTE 1: The coverage requirement applies to the service area, e.g., inside a factory.  NOTE 2: Traffic prioritization and hosting services close to the end-user may be helpful in reaching the lowest latency values.  NOTE 3: Audio-visual interaction requires very low-delay audio and video coding, and high video frame rates (e.g., 120 fps).  NOTE 6: Estimates of maximum dimensions; the last figure is the vertical dimension.  NOTE 7: Based on the assumption that all connected applications within the service volume require the maximum experienced data rate.  NOTE 8: All the values in this table are targeted values and not strict requirements. | | | | | | | | | | | |

# 5 Enabling technologies toward WIA applications

*[Editor's note: This chapter will introduce and describe various enabling technologies to facilitate the implementation of WIA systems.]*

# 6 Deployment scenarios and architectures

*[Editor’s note: This section is intended to address the different deployment scenarios and architectures for radio systems of WIA. This section would describe how those deployment scenarios and architectures could be utilized for WIA systems and how they are to be taken into account in assessing the technical feasibility of implementing WIA systems in specific bands.]*

## 6.1 Presentation of system or technology concept

*[Editor's note: Section 6.2 of TR 102 889-2 provides a detailed technical description]*

Typical industrial sites are manufacturers of goods or providers at any place within the delivery chain towards these goods (e.g. oil/gas/energy producers, suppliers of parts or components of these goods up to final assembly of the goods, after- production processes such as water/waste management).

Examples of existing communication network solutions are standardized in EN/IEC 61784-2 *[reference]* and EN/IEC 62591 *[reference]* for wireless solutions for so-called PROFINET based on IEEE 802.11/IEEE 802.15.1 *[reference]* and WirelessHART (see EN/IEC 62591) based on IEEE 802.15.4 *[reference]*.

Industrial automation requires "robust" wireless technologies to be used for their wireless links in industrial applications. More and more wireless solutions are being considered nowadays for these applications.

The advantages of wireless are savings of often complex and expensive cabling, cable protection and plugs the increased mobility and flexibility as well as the wear and tear free transmission medium. These advantages are particularly high in the area of:

– Monitoring and mobile worker communication.

– Wireless sensors and actuators at moving parts.

Different functions can be mastered substantially more efficient by a wireless network of data acquisition terminals, robotic type equipment or automated guided vehicles.

For the sensor and actuator type of applications in industrial automation, the main requirement is the real time behaviour. Real time means a maximum response time defined by the type of application. E.g. on the factory floor of discrete manufacturing, very short latencies of a few ms and a very high reliability (high robustness) is necessary in order to avoid interruptions in the manufacturing process.

In higher levels of the automation hierarchy e.g. at the control or enterprise level, the data volume rises, so throughput, security and reliability becomes more important, but real–time communication requirements decrease.

To meet these requirements, both application categories require specific wireless technologies for specialised sensor/actuator networks. Some technologies being developed for these applications are listed above.

## 6.2 Deployment scenarios

*[Editor’s note: This section is intended to describe the deployment scenarios of subdivisions of WIA system. For example: WIA system deployment in manufacturing cell, factory halls and at plant level]*

# 7 Current technologies in bands studied for WIA applications

*[Editor's note: This chapter can describe what kinds of technologies are today being implemented in bands under study in this document.]*

Annex X

[*Editor’s note: This is a place holder for other industry wireless applications.*]