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| Technical Report |
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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

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In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# Introduction

In recent years, IoT has attracted much attention in the wireless communication world. More 'things' are expected to be interconnected for improving productivity efficiency and increasing comforts of life. Further reduction of size, complexity, and power consumption of IoT devices can enable the deployment of tens or even hundreds of billions of IoT devices for various applications and provide added value across the entire value chain. It is impossible to power all the IoT devices by battery that needs to be replaced or recharged manually, which leads to high maintenance cost, serious environmental issues, and even safety hazards for some use cases, for example, wireless sensors in electrical power, and petroleum industries.

Most of the existing wireless communication devices are powered by batteries that need to be replaced or recharged manually. The automation and digitization of various industries opens numerous new markets requiring new IoT technologies of supporting batteryless devices with no energy storage capability or devices with energy storage that do not need to be replaced or recharged manually.

An example type of application is asset identification, which presently has to resort mainly to barcodes and RFID in most industries. The main advantage of these two technologies is the ultra-low complexity and small form factor of the tags. However, the limited reading range of a few meters usually requires handheld scanning which leads to labor intensive and time-consuming operations, or RFID portals/gates which leads to costly deployments. Moreover, the lack of interference management scheme results in severe interference between RFID readers and capacity problems, especially in case of dense deployment. It is hard to support a large-scale network with seamless coverage for RFID.

In contrast, this study investigates the feasibility of a new IoT technology to open new markets within 3GPP systems, whose number of connections and/or device density can be orders of magnitude higher than existing 3GPP IoT technologies, and which can provide complexity and power consumption orders-of-magnitude lower than existing 3GPP LPWA technologies such as NB-IoT and LTE-MTC.

# 1 Scope

The present document reports on the feasibility of meeting the design targets for relevant use cases of a new 3GPP IoT technology, on the basis of suitable deployment scenarios in a 3GPP system, which relies on ultra-low complexity devices with ultra-low power consumption for very-low end IoT applications. It intends to provide a clear differentiation, i.e. addressing use cases and scenarios that *cannot* otherwise be fulfilled based on existing 3GPP LPWA IoT technology.

In terms of energy storage, the study considers the following device characteristics:

- Pure batteryless devices with no energy storage capability at all, and completely dependent on the availability of an external source of energy.

- Devices with limited energy storage capability that do not need to be replaced or recharged manually.

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TR 22.840: "Study on Ambient power-enabled Internet of Things".

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# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

## 3.2 Symbols

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

ASK Amplitude-shift keying

DO Device-originated

DT Device-terminated

DO-A Device-originated – autonomous

DO-DTT Device-originated – device-terminated triggered

EPC Electronic product code

FSK Frequency-shift keying

IoT Internet of Things

LPWA Low-power, wide-area

LTE-MTC Long Term Evolution – Machine Type Communication

NB-IoT Narrowband IoT

OOK On-off keying

RFID Radio-frequency identification

rUC representative Use Case

UHF Ultra-high frequency

# 4 Deployment scenarios, use cases, services

## 4.1 Use cases/services

### 4.1.1 Representative use cases

Two sets or levels of grouping were defined. The first, Grouping A, is on the basis of the deployment environment(s) described for a use case in TR 22.840 [2], and the second, Grouping B, is on the basis of functionality/application described in TR 22.840 [2].

Grouping A:

- Indoor

- Outdoor

- Indoor/outdoor

Grouping B:

- Inventory

- Sensors

- Positioning

- Command

These two groupings are then used to form representative use cases (rUCs) as follows, which are used in Clause 4.2 – Deployment scenarios and connectivity topologies.

- rUC1: Indoor inventory

- rUC2: Indoor sensors

- rUC3: Indoor positioning

- rUC4: Indoor command

- rUC5: Outdoor inventory

- rUC6: Outdoor sensors

- rUC7: Outdoor positioning

- rUC8: Outdoor command

This resulted in the following mapping from SA1 use cases and traffic scenarios onto RAN rUCs:

Table 4.1.1-1: Mapping between RAN representative use cases and SA1 use cases

|  |  |
| --- | --- |
| rUC | Applicable SA1 UCs / traffic scenarios |
| rUC1: Indoor inventory | 5.1 Automated warehousing5.2 Medical instruments inventory management and positioning5.4 Non-Public Network for logistics5.5 Automobile manufacturing5.7 Airport terminal / shipping port5.15 Smart laundry5.16 Automated supply chain distribution5.18 Fresh food supply chain5.27 End-to-end logistics6.1 Flower auction6.3 Electronic shelf label |
| rUC2: Indoor sensor | 5.6 Smart homes5.13 Base station machine room environmental supervision5.15 Smart laundry5.20 Smart agriculture5.23 Smart pig farm6.2 Cow stable |
| rUC3: Indoor positioning | 5.8 Finding Remote Lost Item5.9 Location service5.10 Ranging in a home5.12 Personal belongings finding5.14 Positioning in shopping centre5.21 Museum Guide |
| rUC4: Indoor command | 5.11 Online modification of medical instruments status5.17 Device activation and deactivation5.26 Elderly Health Care5.29 Device Permanent Deactivation6.3 Electronic shelf label |
| rUC5: Outdoor inventory | 5.2 Medical instruments inventory management and positioning5.4 Non-public network for logistics5.7 Airport terminal / shipping port5.16 Automated supply chain distribution |
| rUC6: Outdoor sensor | 5.3 Smart grids5.19 Forest Fire Monitoring5.22 Dairy farming5.24 Smart manhole cover safety monitoring5.25 Smart bridge health monitoring |
| rUC7: Outdoor positioning | 5.8 Finding remote lost item5.9 Location service5.12 Personal belongings finding |
| rUC8: Outdoor command | 5.11 Online modification of medical instruments status5.17 Device activation and deactivation5.26 Elderly Health Care5.30 Controller in smart agriculture |

## 4.2 Deployment scenarios and connectivity topologies

### 4.2.0 Introduction

Deployment scenarios for Ambient IoT have been studied on the basis of a list of characteristics, and the representative use case(s) applicable to a scenario. The possible descriptions of the characteristics are as follows:

Table 4.2.0-1: Characteristics of deployment scenarios

|  |  |
| --- | --- |
| Characteristic | Possible description entries |
| Environment (of the device) | IndoorOutdoorIndoor or outdoor |
| Basestation characteristic (if any) | Macro-cell-based deploymentMicro-cell-based deploymentPico-cell-based deploymentNone |
| Connectivity topology | See section 4.2.1 |
| Spectrum | Licensed FDDLicensed TDDUnlicensedNote: In each connectivity topology of the study, if a BS is present, it is assumed that the BS uses licensed spectrum |
| Coexistence with existing 3GPP technologies | Deployed on the same sites as an existing 3GPP deployment corresponding to the basestation type.Deployed on new sites without an assumption of an existing 3GPP deployment. |
| Traffic assumption | Device-terminated (DT)Device-originated (DO)DO traffic includes DO autonomous (DO-A), and DO device-terminated triggered (DO-DTT) |
| Device characteristic | See Section 4.3:Device ADevice BDevice C |

The study has considered Ambient IoT deployments in-band to NR, in guard-band of NR, and in standalone band from NR.

### 4.2.1 Connectivity topologies

#### 4.2.1.0 Introduction

The following connectivity topologies for Ambient IoT networks and devices are defined for the purposes of the study. In all these topologies, the Ambient IoT device may be provided with a carrier wave from other node(s) either inside or outside the topology. The links in each topology may be bidirectional or unidirectional.

BS, UE, assisting node, or intermediate node could be multiple BSs or UEs, respectively. The mixture of indoor and outdoor placement of such nodes is regarded as a network implementation choice. Account would need to be taken of potential impact on device or node complexity. In the connectivity topologies, this does not imply the existence of multi-hop assisting or intermediate nodes.

#### 4.2.1.1 Topology 1: BS ↔ Ambient IoT device



Figure 4.2.1.1-1: Topology 1

In Topology 1, the Ambient IoT device directly and bidirectionally communicates with a basestation. The communication between the basestation and the ambient IoT device includes Ambient IoT data and/or signalling. This topology includes the possibility that the BS transmitting to the Ambient IoT device is a different from the BS receiving from the Ambient IoT device.

#### 4.2.1.2 Topology 2: BS ↔ intermediate node ↔ Ambient IoT device



Figure 4.2.1.2-1: Topology 2

In Topology 2, the Ambient IoT device communicates bidirectionally with an intermediate node between the device and basestation. In this topology, the intermediate node can be a relay, IAB node, UE, repeater, etc. which is capable of Ambient IoT. The intermediate node transfers Ambient IoT data and/or signalling between BS and the Ambient IoT device.

#### 4.2.1.3 Topology 3: BS ↔ assisting node ↔ Ambient IoT device ↔ BS



Figure 4.2.1.3-1: Topology 3 with downlink assistance



Figure 4.2.1.3-2: Topology 3 with uplink assistance

In Topology 3, the Ambient IoT device transmits data/signalling to a basestation, and receives data/signalling from the assisting node; or the Ambient IoT device receives data/signalling from a basestation and transmits data/signalling to the assisting node. In this topology, the assisting node can be a relay, IAB, UE, repeater, etc. which is capable of ambient IoT.

#### 4.2.1.4 Topology 4: UE ↔ Ambient IoT device



Figure 4.2.1.4-1: Topology 4

In Topology 4, the Ambient IoT device communicates bidirectionally with a UE. The communication between UE and the ambient IoT device includes Ambient IoT data and/or signalling.

### 4.2.2 Deployment scenarios

#### 4.2.2.1 Deployment scenario 1: Device indoors, basestation indoors

With Ambient IoT device indoors and basestation indoors, this deployment scenario is characterized according to Table 4.2.2.1-1.

Table 4.2.2.1-1: Characteristics of deployment scenario 1

|  |  |  |
| --- | --- | --- |
| Applicable representative use cases | Characteristics | Description (NOTE 1) |
| Indoor inventoryIndoor sensorIndoor positioningIndoor command | **Environment (of device)** | Indoor |
| **Basestation characteristic (if any)** | Micro- or pico-cell |
| **Connectivity topology** | Topology (1), (2), (3) |
| **Spectrum** | Licensed FDD, licensed TDD, unlicensed |
| **Coexistence with existing 3GPP technologies** | Co-site or new site |
| **Traffic assumption** | DT and DO |
| **Device characteristic** | Device A or Device B or Device C |

NOTE 1: Descriptions may not be applicable for some Devices (A, B).

#### 4.2.2.2 Deployment scenario 2: Device indoors, basestation outdoors

With Ambient IoT device indoors and basestation outdoors, this deployment scenario is characterized according to Table 4.2.2.2-1.

Table 4.2.2.2-1: Characteristics of deployment scenario 2

|  |  |  |
| --- | --- | --- |
| Applicable representative use cases | Characteristics | Description (NOTE 1) |
| Indoor inventoryIndoor sensorIndoor positioningIndoor command | **Environment (of device)** | Indoor |
| **Basestation characteristic (if any)** | Macro- or Micro- cell BS |
| **Connectivity topology** | Topology (1), (2), (3)Note: The location of intermediate or assisting node (if any) is indoor or outdoor |
| **Spectrum** | Licensed FDD, licensed TDD, unlicensed |
| **Coexistence with existing 3GPP technologies** | Co-site or new site |
| **Traffic assumption** | DT and DO |
| **Device characteristic** | Device C may support Topology (1), (2), (3),Device A may support Topology (2), Device B may support Topology (2), (3) |

NOTE 1: Descriptions may not be applicable for some Devices (A, B).

#### 4.2.2.3 Deployment scenario 3: Device indoors, UE-based reader

With Ambient IoT device indoors and UE-based reader, this deployment scenario is characterized according to Table 4.2.2.3-1.

Table 4.2.2.3-1: Characteristics of deployment scenario 3

|  |  |  |
| --- | --- | --- |
| Applicable representative use cases | Characteristics | Description (NOTE 1) |
| Indoor inventoryIndoor sensorIndoor positioningIndoor command | **Environment (of device)** | Indoor |
| **Basestation characteristic (if any)** | None |
| **Connectivity topology** | Topology (4) |
| **Spectrum** | Licensed FDD, licensed TDD, unlicensed |
| **Coexistence with existing 3GPP technologies** | NA |
| **Traffic assumption** | DT and DO |
| **Device characteristic** | Device A or Device B or Device C |

NOTE 1: Descriptions may not be applicable for some Devices (A, B).

#### 4.2.2.4 Deployment scenario 4: Device outdoors, basestation outdoors

With Ambient IoT device outdoors and basestation outdoors, this deployment scenario is characterized according to Table 4.2.2.4-1.

Table 4.2.2.4-1: Characteristics of deployment scenario 4

|  |  |  |
| --- | --- | --- |
| Applicable representative use cases | Characteristics | Description (NOTE 1) |
| Outdoor inventoryOutdoor sensorOutdoor positioningOutdoor command | **Environment (of device)** | Outdoor |
| **Basestation characteristic (if any)** | Macro- or Micro- cell BS |
| **Connectivity topology** | Topology (1), (2), (3) |
| **Spectrum** | Licensed FDD, licensed TDD, or unlicensed. |
| **Coexistence with existing 3GPP technologies** | Co-site or new site |
| **Traffic assumption** | DT and DO |
| **Device characteristic** | Device C may support Topology (1), (2), (3),Device A may support Topology (2),Device B may support Topology (2), (3) |

NOTE 1: Descriptions may not be applicable for some Devices (A, B).

#### 4.2.2.5 Deployment scenario 5: Device outdoors, UE-based reader

With Ambient IoT device outdoors and UE-based reader, this deployment scenario is characterized according to Table 4.2.2.5-1.

Table 4.2.2.5-1: Characteristics of deployment scenario 5

|  |  |  |
| --- | --- | --- |
| Applicable representative use cases | Characteristics | Description (NOTE 1) |
| Outdoor inventoryOutdoor sensorOutdoor positioningOutdoor command | **Environment (of device)** | Outdoor |
| **Basestation characteristic (if any)** | None |
| **Connectivity topology** | Topology (4) |
| **Spectrum** | Licensed FDD, licensed TDD, unlicensed |
| **Coexistence with existing 3GPP technologies** | NA |
| **Traffic assumption** | DT and DO |
| **Device characteristic** | Device A or Device B or Device C |

NOTE 1: Descriptions may not be applicable for some Devices (A, B).

## 4.3 Device categorization

Ambient IoT devices are characterized in the study according to their energy storage capacity, and capability of generating RF signals for their transmissions.

The study considers that a device has either:

- No energy storage at all; or

- Limited energy storage

Relying on these storage capacities, the study considers the following set of Ambient IoT devices:

- Device A: No energy storage, no independent signal generation/amplification, i.e. backscattering transmission.

- Device B: Has energy storage, no independent signal generation, i.e. backscattering transmission. Use of stored energy can include amplification for reflected signals.

- Device C: Has energy storage, has independent signal generation, i.e., active RF components for transmission.

A limited energy storage can be different among implementations within Device B or implementations within Device C, and different between Device B and Device C. Such storage is expected to be order(s) of magnitude smaller than an NB-IoT device would typically include.

Device A, B, and C are able to demodulate control, data, etc from the relevant entity in RAN according to connectivity topology.

# 5 RAN design targets

## 5.1 Device power consumption

For Device A, the power consumption target during transmitting/receiving is ≤ 1 μW or ≤ 10 μW,

For Device B, the target during transmitting/receiving is such that:

- Device A power consumption ≪ Device B power consumption < Device C power consumption; or

- Device A power consumption ≤ Device B power consumption < Device C power consumption.

The device power consumption during transmitting/receiving for Device C is ≤ 1 mW to ≤ 10 mW.

## 5.2 Device complexity

For Device A, the complexity target is to be comparable to UHF RFID ISO18000-6C (EPC C1G2).

For Device B, the target is such that:

- Device A complexity < Device B complexity < Device C complexity.

For Device C, the complexity target is to be orders-of-magnitude lower than NB-IoT.

## 5.3 Coverage

The coverage target for both DL and UL is represented by the maximum distance:

- Between Ambient IoT device and basestation in Topology (1) and (3)

- Between Ambient IoT device and intermediate or assisting node in Topology (2) and (3), respectively

- Between Ambient IoT device and UE in Topology (4).

Details relevant to the maximum distance such as sensitivity, BLER, transmit power, etc. are for WG expertise to study further.

The design target of coverage is:

By indoor / outdoor, grouping different Devices into a range that WGs can sub-select within

- the maximum distance of 10 – 50 m for indoor

- the maximum distance of 50 – 500 m for outdoor

NOTE: Different target values within these ranges may apply to different devices A/B/C and deployment scenarios 1-5.

NOTE: If BS is present, then continuous coverage (from the device perspective) based on a typical ISD between base stations is assumed. This does not imply an assumption of any particular topology.

NOTE: For Device A & B, the emitter-to-tag distance should be reported as part of the assessment.

## 5.4 User experienced data rate

The user experienced data rate target is, for the uplink and downlink, maximum not less than 5 kbps, and minimum not less than 0.1 kbps.

## 5.5 Maximum message size

The design target of maximum message size is approximately 1000 bits to be received by the Ambient IoT device, and approximately 1000 bits to be transmitted from the Ambient IoT device, based on the maximum application layer packet size.

RAN1/RAN2 can refine as needed for TB size design.

## 5.6 Latency

The one-way end-to-end maximum latency targets, as defined in TR 22.840, are:

- Longer latency target: 10 seconds

- Shorter latency target: 1 second

A use case is assigned to a latency target according to TR 22.840. RAN WGs can refine a definition of latency suitable for their work within the above.

NOTE: The time for charging the Ambient IoT device storage (if present) is not included in the latency defined above. Time for energy harvesting, charging, etc. is regarded as an implementation issue only.

NOTE: The one-way end-to-end maximum latency is assumed to also include query/triggering time.

## 5.7 Positioning accuracy

The design target of absolute positioning accuracy when performed by the cellular network (including assisting nodes when present) is:

- 1~3 meters @ 90% indoor location.

- Several tens of meters @ 90% outdoor location.

The design target of relative ranging accuracy for topology 4 is:

- 1~3 meters @ 90% indoor and outdoor location

## 5.8 Connection/device density

According to the consolidated potential KPIs in TR 22.840, the maximum connection density target is:

- 150 devices per 100 m2 for indoor scenarios.

- 20 devices per 100 m2 for outdoor scenarios.

RAN WGs will define the 2D or 3D distribution(s) of devices.

## 5.9 Moving speed of device

The design target of moving speed of Ambient IoT device is 10 km/h, at least for indoor scenarios.

NOTE: Absolute speed is used in Topology (1), (2) and (3). Relative speed is used in Topology (4).

# 6 Comparison and assessment

6.1 Preliminary feasibility assessment

### 6.1.1 Device power consumption

Feasibility of power consumption for Device A at ≤1 μW level has been reported by reference to [3], [4], [5], [6], and at ≤ 10 μW level by [7] depending on component choices such as in [8]. Feasibility of power consumption for Device C at ≤1 mW level has been reported by reference to [9], [10], [11], [12], [13], and by reference in part to the receiver architectures discussed in the Rel-18 SI on low-power wake up signal/receiver [14] [15] at ≤10 mW level. For Device B, which adds energy storage to Device A and has been described as also potentially including (without limitation), e.g. reflection amplification, feasibility of power consumption in the order of hundreds of uW has been reported by [7] depending on component choices such as in [16].

### 6.1.2 Device complexity

Feasibility assessment for this aspect was presented on a qualitative basis by companies describing exemplary waveform, and/or transmitter, and/or receiver architectures which, according to their analysis, would satisfy the device power consumption design target. It was also observed that the amount of energy storage could affect device complexity. Examples of considered waveforms include OOK/FSK, and ASK. Examples of considered transmitter architectures for Device A/B include those based on backscattering technology, and receiver architectures based on envelope detection, while for Device C, very low power consumption heterodyne/homodyne architectures were reported as satisfying the complexity design target.

On the other hand, aspects such as the memory required for security, authentication, etc., and hardware used for encryption processing would add to the complexity of the device. There were also discussions of the quality required in circuitry such as energy harvesting, backscattering, and PAs which, as their efficiency increases, tend to have higher complexity.

Detailed analysis of designs which meet the device complexity requirement is considered to require WG-level technical expertise.

### 6.1.3 Coverage

Feasibility of a coverage target was assessed by sources differently for Devices A, B, C. In addition to typical elements comprising a 3GPP coverage evaluation, such as BS/intermediate/assistant node transmit power and receive sensitivity, device receiver sensitivity, propagation losses, etc. (which vary according to the specific calculation method), aspects particular to Ambient IoT devices were added. These include:

- Device A/B backscattering activation power threshold

- Device B amplification (if any)

- Device A/B reflection loss

- Distance from carrier wave source to Ambient IoT device, for Device A/B

- Power of carrier wave source and/or incident power at Device A/B from carrier wave source

Although different evaluation methodologies were adopted by sources [17] – [25], the coverage of Device A is reported as less than Device B (with or without amplification), which is less than Device C. The coverage of Ambient IoT devices relying on backscattering technology was reported to increase as the carrier wave source gets closer to the Ambient IoT device, due to the higher incident power on the device.

### 6.1.4 User experienced data rate

Full user-experienced data rate assessment was noted as requiring WG-level technical expertise, and detailed assumptions on air interface design. For TSG-level purposes, companies used simplified approximants. Peak data rate was one such approximant, where companies reported values above 5 kbps for uplink and downlink to be achievable according to various sets of assumptions including sufficient bandwidth, and in one case noted that the components assumed by reference to [26] would need further investigation whether the device power consumption target could be simultaneously met. One source [17] estimated data rate by accounting for device charging time and operation time, resulting in data rates 0.14 – 2.24 kbps for uplink and downlink.

### 6.1.5 Maximum message size

Companies’ study of the feasibility of this design requirement was by reference to e.g. RFID which supports message sizes larger than about 1000 bits. It was also observed that the different Devices could be regarded as feasible for different maximum message sizes.

### 6.1.6 Latency

Feasibility of latency was reported typically by comparing a message size to a data rate, for example 5 kbps / 1000 bit = 200 ms latency for the largest message size at the target peak rate. Feasibility would also depend on a consideration of signalling procedures and possible random access-like procedure.

### 6.1.7 Positioning accuracy

Feasibility assessment for this aspect has been reported by reference to technologies of a similar complexity level, such as UHF RFID achieving 2-3 m accuracy in [27], [28], [29] indoors, and ultra-narrow IoT achieving from several tens to 100 or 150 m in [30], [31], [32] outdoors. It is also observed that Device A and B need to have a carrier wave source in an appropriate distance to be able to transmit signals for positioning.

### 6.1.8 Connection/device density

Feasibility of the target was discussed from the basis of assuming cell access procedures, and device addressing. It was discussed as applying a requirement on the design of such procedures, identities, etc. rather than being a matter for feasibility assessment before starting such designs.

### 6.1.9 Moving speed of device

The feasibility aspects that were reported related to the impact of Doppler shift or channel coherence on the possible types of modulation contemplated by companies for especially Device A and B. It was observed, without limiting RAN WG design scope, that at least for low-order non-OFDM modulation, Doppler impacts at the low moving-speed level implied in Clause 5.9 would likely be acceptable, although the impact on transmission times potentially a multiple of the coherence time should also be studied in RAN WGs.

## 6.2 Required RAN functionalities

The assumptions on required functionality have been studied on the basis of supporting certain RAN design targets as well as other requirements. At least the following potential functionalities are identified in different sets, respectively, according to the purpose of each functionality assumed to be mainly used for. An entry in the tables below neither implies nor precludes RAN specification impact.

Table 6.2-1: Required RAN functionality set #1: for supporting RAN design target

|  |  |
| --- | --- |
| Design target | Functionality |
| Device power and complexity | - Ultra-low power transceiver / Device architecture - Transmitting based on backscattering (including carrier wave provision for backscattering) for Device A and Device B- Low-complexity waveform / modulation / coding / signal / channel / synchronization scheme, if applicable to Device, robust to frequency error and timing error- Compact protocol stack and lightweight signaling procedure |
| Coverage | - Techniques for the required coverage with low device complexity (e.g., forward error correction, enough receiver sensitivity and transmitted power, reflection gain enhancement), if applicable and needed to the Device type |
| User experienced data rate | - Compact protocol stack and lightweight signaling procedure- Potential schemes as applicable, such as, e.g. flexible modulation/code rate, resource allocation, multiple access methods |
| Maximum message size | - Compact protocol stack and lightweight signaling procedure- Signal/channel design which can deliver the maximum message size |
| Latency | - Access mechanisms and signaling procedures which allow meeting the latency target |
| Positioning support | - Positioning method(s) applicable to the connectivity topologies for the required positioning accuracy for Ambient IoT device |
| Connection density | - Efficient multiple access methods and contention handling - Ability to control the operation for one or more of the Ambient IoT devices, within the applicable area, including e.g. the selection of devices |
| Moving speed of device | - Physical layer design (low-order modulation, reference signal etc. and others) robust to the appropriate ranges of moving speeds |

Table 6.2-2: Required RAN functionality set #2: for supporting other requirements

|  |  |
| --- | --- |
| Requirement | Functionality |
| Device management | - RAN aspects of identification, activation/deactivation, and other management functionalities of Ambient IoT devices and other involved devices (e.g. readers) if applicable, and related signalling to/from the CN if any/needed |
| Security\* | - Authentication (when needed), encryption, data integrity, authorization (when needed) |
| Mobility | - Mobility management (at least cell selection/re-selection -like function) for device C- Handling for Devices A and B |
| Interference management and coexistence | - Interference management/coordination scheme- Potential full duplex capability of BS/UE, including self-interference suppression, may be required for BS/UE to communicate with Device A and Device B, if carrier wave transmission and backscatter reception is performed simultaneously at least on the same band by the same BS/UE.- Coexistence with existing and adjacent network infrastructure, and possibility to reuse existing network deployments or use new network deployments. |
| CN connectivity | - RAN functionality for Ambient IoT to support CN (when present), with possibility of potential lightweight protocol stack architecture and simplified signaling procedures. |
| Compatibility among connectivity topologies | - From the perspective of the Ambient IoT device, strive for operation to be agnostic to RAN connectivity topologies. |

\*NOTE: This does not necessarily mean security has RAN impact, further study is needed.

The required functionalities may not all be addressed in the same Release.

In the above, both existing and new techniques may be considered.

# 7 Conclusions and recommendations

## 7.1 Summary

The study has described eight rUCs in RAN, being indoor/outdoor for each of inventory, sensors, positioning, and command. These rUCs encompass the UCs or traffic scenarios from TR 22.840 as shown in Table 4.1-1.

Four general connectivity topologies were studied in Clause 4.2.1: BS ↔ Ambient IoT device, BS ↔ intermediate node ↔ Ambient IoT device, BS ↔ assisting node ↔ Ambient IoT device ↔ BS, and UE ↔ Ambient IoT device.

Three devices were studied: Device A, B, and C, differentiated according to inclusion of backscattering transmission or independent signal generation, and inclusion or not of energy storage.

Together with other characteristics, the topologies and devices were used to study deployment scenarios for Ambient IoT, shown in Clause 4.2.2, differentiated according to whether the device and basestation/UE-based reader are respectively indoors or outdoors.

A set of RAN design targets were developed, complementary to, and/or derived from, the requirements reported in TR 22.840, in Clause 5. Further details of these targets are assumed to be provided by WG-level expertise.

A non-exclusive list of functionalities needed in Ambient IoT from the RAN perspective was formulated on the basis of supporting the RAN design targets, and for supporting other requirements. The study has not investigated in detail the implication of CN-related functionalities.

Finally, a preliminary feasibility assessment was conducted on the basis of the set of design targets in Clause 5. This was by a mixture of reference to external sources, characteristics of, or hardware used by, other technologies, and companies’ own analyses.

## 7.2 Recommendations

It is concluded in preliminary feasibility analysis at TSG-RAN level that Ambient IoT is feasible and beneficial, and further WG-level study is recommended prior to normative work.

For the initial WG-level study of Ambient IoT

- RAN is recommended to down-select further starting from:

- Deployment scenario 1 with Topology 1

- Deployment scenario 2 with Topology 1

- Deployment scenario 2 with Topology 2

- Deployment scenario 4 with Topology 1

- Deployment scenario 4 with Topology 3

- FR1 licensed spectrum is recommended

- Note: selection or prioritization between FDD and FDD/TDD is to be decided

- RAN is recommended to down-select to one or more of:

- Spectrum in-band to NR, in guard-band to LTE/NR, and in standalone band(s)

It is recommended to direct the RAN WGs to use the design targets reported in Clause 5. The RAN WGs are expected to refine the design targets according to their technical expertise, as needed.

Annex A:
Energy sources for energy harvesting

Companies have reported the following energy sources for energy harvesting in literature: RF, solar/light, piezoelectric (kinetic/vibration), electromagnetic, electrostatic, heat/thermal, thermoelectric, magnetic, wind/water, acoustic, etc.

Annex B:
Change history

|  |
| --- |
| Change history |
| Date | Meeting | TDoc | CR | Rev | Cat | Subject/Comment | New version |
| 2022-12 | RAN#98e | RP-223073 |  |  |  | Skeleton for Study on Ambient IoT (Internet of Things) in RAN | 0.0.1 |
| 2022-12 | RAN#98e | RP-223526 |  |  |  | Skeleton for Study on Ambient IoT (Internet of Things) in RAN | 0.0.2 |
| 2023-03 | RAN#99 | RP-230419 |  |  |  | TR 38.848 v0.1.0 Study on Ambient IoT (Internet of Things) | 0.1.0 |
| 2023-06 | RAN#100 | RP-231208 |  |  |  | TR 38.848 v0.2.0 Study on Ambient IoT (Internet of Things) | 0.2.0 |
| 2023-09 | RAN#101 | RP-232230 |  |  |  | TR 38.848 v0.3.0 Study on Ambient IoT (Internet of Things) | 0.3.0 |
| 2023-09 | RAN#101 | RP-232695 |  |  |  | TR 38.848 v1.0.0 Study on Ambient IoT (Internet of Things) | 1.0.0 |
| 2023-09 | RAN #101 | - |  |  |  | Approved by RAN #101 and put under CR control | 18.0.0 |