3GPP TSG RAN Meeting #96
Budapest, Hungary, June 6 – 9, 2022

RP-221707

Document for: Discussion and Decision
Agenda Item: 9.1
Source: Huawei, HiSilicon

Motivation for a study on passive IoT

Background

- **Moderator's conclusion on Passive IoT from pre-RAN#94e discussions is copied as follows [1]**

There is interest in further discussions in 3GPP on the category of IoT referred to in this discussion as passive IoT, occupying a segment below NB-IoT/eMTC in metrics such as power consumption and cost.

Further discussions in 3GPP should address how a potential study is organized within 3GPP considering the following areas/objectives

- Precise definitions for the ultra-low power consumption and ultra-low cost IoT devices of interest, i.e., targets for power consumption and cost
- Use cases of interest not captured elsewhere in 3GPP, e.g., identification, tracking, monitoring, actuating and sensing for applications in sectors such as logistics, transportation, healthcare etc.
- Scenarios of interest including public/private network, indoor/outdoor environment, macro/micro/pico cells, connectivity to gNBs/UEs with/without relay/UE assistance, traffic models, TDD/FDD and frequency bands (including whether both licensed and unlicensed spectrum should be considered)
- Existing solutions that address the use cases of interest (e.g., RFID)
- Determination of feasibility of use cases and scenarios
- Design targets including link budget, data rate, power consumption, cost, supported energy sources or energy harvesting techniques, connectivity requirements (e.g., connection to gNBs/UEs with/without relays and the targeted range), positioning accuracy etc. considering trade-offs, e.g., between coverage and power consumption.
- Coexistence with UEs and infrastructure in frequency bands for current 3GPP technologies

[1] RP-212688, RAN94e-R18Prep-28 - Version 0.0.6, Oct. 2021.

Background (cont.)

- **SA1 SID: Study on Ambient power-enabled Internet of Things**

This study is to support ambient power-enabled Internet of Things. The energy is provided through the harvesting of radio waves, light, motion, heat, or any other power source that could be seen suitable.

The objectives include:

- Study use cases of ambient power-enabled Internet of Things and identify potential service requirements, including:
    - Security aspects, e.g., authentication and authorization, etc.
    - Network selection, access control, connection, mobility and identification management
    - Charging (e.g., per data volume, per message)
    - Aspects related to stakeholder models (e.g., involving interactions in PLMNs, NPNs or other parties)
    - Positioning
    - Aspects on device life cycle management related to 3GPP system.
- Study traffic scenarios, device constraints (e.g., power consumption) and identify potential performance requirements and KPIs
- Gap analysis between the identified requirements for ambient power-enabled Internet of Things and what is already defined by existing 3GPP requirements.

Note 1: Specifics of how the device performs energy harvesting are not in the scope of the study.

[1] S1-220192, New SID: Study on Ambient power-enabled Internet of Things, Feb. 2022

Considerations on why 3GPP needs to start work on passive IoT

- Observations:
  - Asset tracking is a requirement in many industry sectors such as logistics and supply chain, manufacturing, agriculture, etc.
  - RFID is the primary technology on the market, and the number of RFID connections is expected to reach 49 billion by 2031
  - RFID has its merits (e.g. low cost, no need of battery) but also shortcomings (e.g. coverage, no operator control)

- Design targets for passive IoT :
  - Maintain the merits of existing RFID, i.e. the design of passive IoT shall enable extremely low complexity implementation and does not require battery for operation
  - Improve the link budget (coverage) compared to existing RFID technology, e.g. by exploiting features such as FEC, higher EIRP in operator licensed band compared to unlicensed ISM bands
  - Build up the intrinsic core network functions to manage and authenticate the passive IoT connections, enabling operators to build a business case out of it

- Passive IoT is NOT to replace NB-IoT or eMTC

- Passive IoT aims to enable massive numbers of connections – orders of magnitude higher than existing 3GPP IoT technologies

Passive IoT targets at new low-end IoT markets requiring batteryless device

Typical use cases can be sorted into two categories, both of which require or prefer batteryless device.

Category 1: Pre-stored data report

- Information (e.g., identity) is pre-stored in a small size, ultra-low cost, and batteryless tag
- Typical use cases include object identification and tracking in industries such as logistics and supply chain, transportation, healthcare, etc.

Barcode printed on thermal paper

Short-range manual scanning one by one

Automatic inventory

Current: Barcode

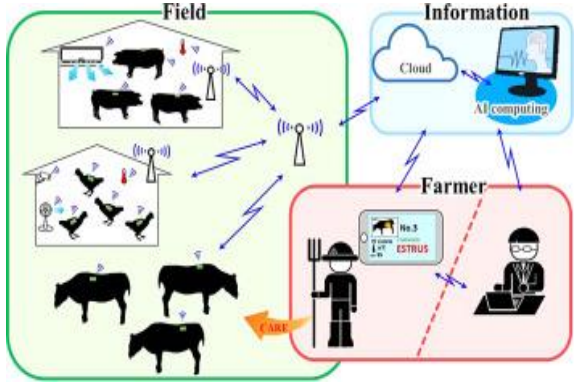
- No battery
- ultra-low cost & very small size
- Handheld LOS scanning (labor intensive)
- Slow one-by-one scanning (time consuming)

To be: Passive IoT tag

- No battery
- ultra-low cost & very small size
- Automatic remote reading
- Hundred times faster reading

Category 2: Sensing data report

- Information (e.g., temperature) is generated and transmitted by wireless sensor without battery replacement during long lifetime
- Typical use cases include wireless sensor for environment, equipment, and living things monitoring in industries such as electric power, petroleum, livestock farming, manufacturing, etc.



Battery-operated device

- Cost for batteries and replacement
- Increased device size
- Infrequent transmissions for battery life
- Environmental issue (Lithium, lead, etc.)

Batteryless device

- Low maintenance cost
- Miniaturized device
- No limits on transmission period
- Environmental friendly

Different from all existing cellular technologies, Passive IoT focuses on the support of ultra-low cost batteryless device.

Market of Batteryless Devices Will Grow Rapidly in Coming Years

- RFID supports batteryless tag, predicted to have explosive market growth
  - RFID tag is mainly used for identity detection, especially in retail and logistics industries
    - More R&D on applying RFID for sensing in recent years
  - With the acceleration of digitalization in various industries, global RFID market volume is predicted to exceed 49 billion units by 2031 at a compound annual growth rate (CAGR) of 9.3% [1]
    - The market will grow more rapidly from 2026

- Global sensor market is predicted to grow from $193.9B in 2020 to $332.8B in 2025, at a CAGR of 11.4% [2]
  - Considering the average cost of 0.5$ for sensors [3], there may be hundreds of billion connections in the near future
    - It is impractical to replace battery regularly for such a huge volume of sensors
- Once competing technologies seize the huge amount of connections, it will be difficult for cellular-based technology (e.g., Passive IoT) to regain the market share

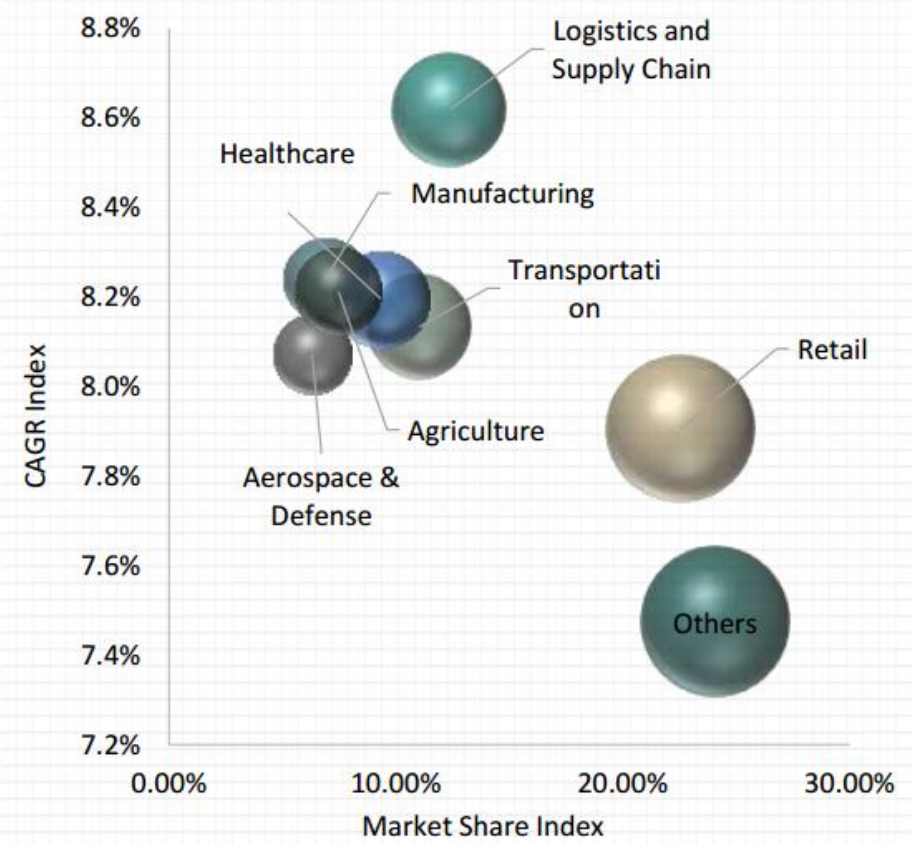
[1] Global RFID Sensor Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2021-2031, Transparency Market Research, June 2021

[2] Sensors: Technologies and Global Markets (https://www.bccresearch.com/market-research/instrumentation-and-sensors/sensors-technologies-markets-report.html), BCC Research

[3] Status of the MEMS industry 2018, YOLE, 2018

Target Markets of Passive IoT Requires Capabilities beyond RFID

Global RFID market analysis by end use industry



- **Retail** gains the **largest share** in the global RFID market, which is cost sensitive
- Other industries enjoy **higher CAGR**, especially **logistics and supply chain**

With superior coverage and new functionalities, such as sensing and positioning, Passive IoT will be more attractive than RFID in the following markets

- Incremental market of some traditional industries
  - Logistics and supply chain, transportation, manufacturing, healthcare, agriculture, etc.
- New markets in industries requiring batteryless sensor urgently
  - energy (electricity/oil): battery-operated device are forbidden for safety reasons
  - livestock farming: low cost tag with thin and small form-factor

End User industry	Market volume in 2020 (Million unit)	Market volume in 2031 (Million unit)	CAGR (2021~2031)	Advantages of Passive IoT			
				Coverage	Positioning	Sensing	Cost
Transportation	2042.3	5496.6	8.1%	✓	✓	✓	
Logistics and Supply Chain	2300.3	6501.9	8.6%	✓	✓		
Manufacturing	1276.7	3474	8.2%	✓	✓	✓	
Healthcare	1730.5	4687.8	8.2%	✓		✓	
Aerospace and Defense	1165.4	3115.7	8.1%				
Agriculture	1382.4	3750.9	8.2%	✓		✓	
Livestock farming	1281.3	3380.1	-	✓	✓	✓	
Energy (electricity/oil)	-	-	-	✓		✓	
Retail	4166.2	10956	7.9%				✓
Others(Sports, Advertisement, etc.)	4432.5	11155.7	7.5%				

[1] Global RFID Sensor Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2021-2031, Transparency Market Research, June 2021

Link Budget of UHF RFID is Insufficient for Practical Deployment

- **Theoretical link budget of commercial UHF RFID is as**
  - EIRP of signals should not exceed **36 dBm** in the ISM band for UHF RFID
    - The UHF RFID bands locate in 840~845 MHz or 865~869 MHz or 920-928 MHz in different countries and regions
  - Activation threshold of commercial passive RFID tag is mostly around **-20 dBm**
  - Optimal receiver sensitivity of existing commercial RFID reader is **-92 dBm** [1]
    - The receiver sensitivity is hard to be further improved due to the too simple transmission scheme defined by the protocol standardized in 2005

Downlink		Uplink		Unit
		Tag return loss	**-8**	dBc
EIRP of downlink signal	***36***			dBm
		EIRP of reflected signal	***-28***	*dBm*
		Reader antenna gain	**6**	dBi
Tag activation threshold	**-20**	Reader receiver sensitivity	**-92**	dBm
MCL	**56**	MCL	**70**	dB

Forward link MCL = Reader Tx EIRP - Tag activation threshold

Reverse Link MCL = Tag activation threshold + Tag return Loss + Reader antenna gain + Reader receiver sensitivity

- **In practice, coverage of a commercial RFID reader is less than 10 meters**
  - Some non-ideal issues will cause the loss of link budget
    - E.g., polarization mismatch between the antennas of reader and tag may cause 3 dB loss
  - **53 dB MCL** corresponds to a effective communication range of **<5 m** in InF-DL NLOS channel
- **Poor coverage of RFID leads to very dense deployment of readers**
  - As concluded in a GSMA report, "Implementation of the infrastructure requires significant disruption" for RFID trailed in a factory [2]

[1] IMPINJ R700 RAIN RFID READER DATASHEET
[2] 5G FOR SMART MANUFACTURING (GSMA report, April 2020)—INSIGHTS ON HOW 5G AND IOT CAN TRANSFORM INDUSTRY, PA Knowledge Limited, April 2020

Passive IoT Network is controllable for MNO, while RFID is not

RFID architecture ✗ | EPC: Electronic Product Code | **Passive IoT architecture** ✓

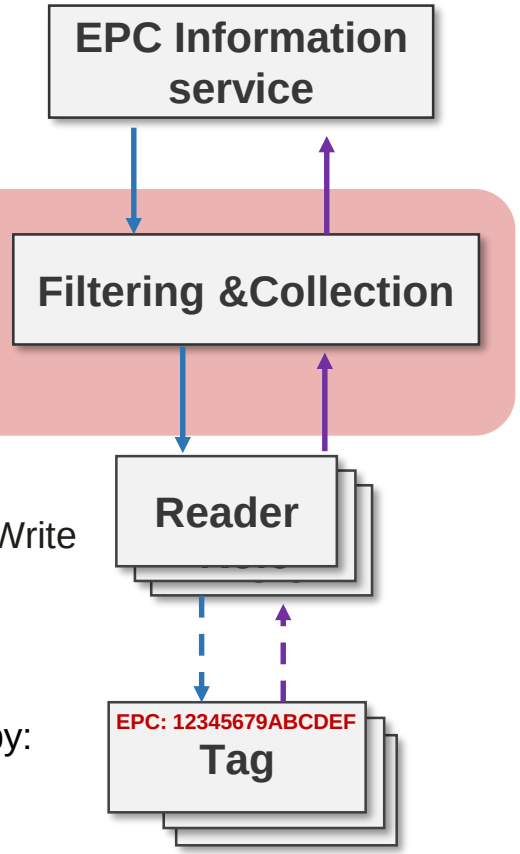
EPCIS, RFID application layer

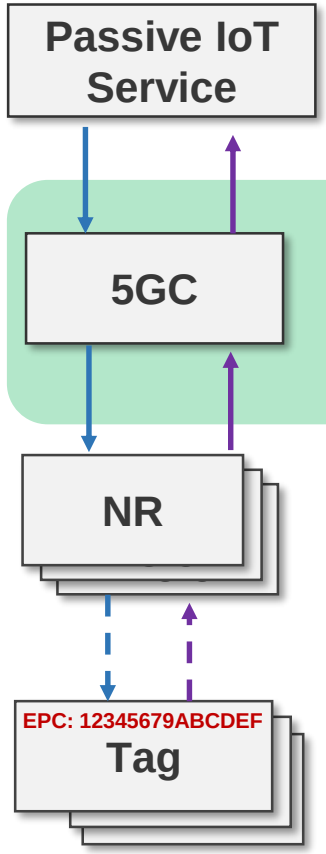
Filtering & Collection
only simple operations, e.g. data management, Readers coordination

No Tag management!

Reader, interacting with tag for Read/Write

RFID Tag, containing EPC allocated by:
- EPC manager for global use case, or
- Vertical itself for local use case





Passive IoT Service, application layer

Tag management as 5GC function
- Tag authentication
- Tag billing and charging
- Support of mobility for outdoor usage

NR, interacting with tag for Read/Write

PIOT Tag, containing EPC allocated by:
- EPC manager for global use case, or
- Vertical itself for local use case

RFID does NOT support tag management

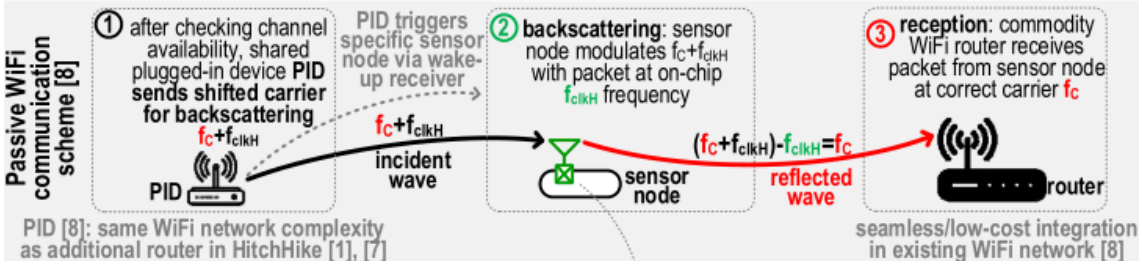
Passive IoT in 5G framework facilitates MNO management of tags

Batteryless Tag under Investigation for Non-3GPP Air Interfaces

- **Enabling small batteryless device with long communication range becomes a hot academic topic**
- **Once competing technologies seize the huge amount of connections, it will be difficult for cellular based technology (e.g. Passive IoT) to regain the market share**

WiFi[1]

- **Low power**: **2.5μW**
  - Powered by a **22-mm²** thin-film solar cell at **indoor 500lux lighting**
- **Short/Medium range**: **~8m**



UWB[2]

- **Low power**: **microwatt** level
  - UHF-band RF energy harvesting
- **Small size** and **light weight**:
  - **4.2cm × 2.9cm**
  - **0.93g**
- **Wearable for remote vital-sign monitoring**

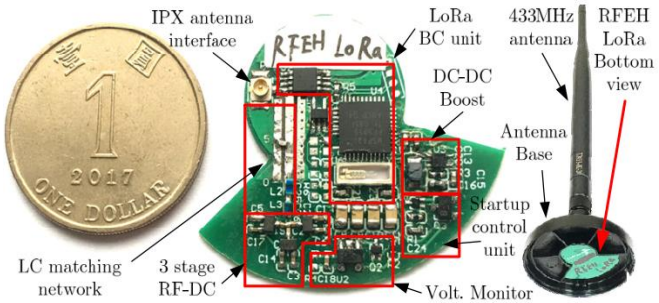
Bluetooth[3]

- **Good compatibility**
  - Data embedded on **BLE exciting signals** via backscattering
  - **Commodity BLE device** can decode
- **Larger range**:
  - **25 m** for indoor
  - **56 m** for outdoor

(a) BLE transceivers (b) RBLE tag prototype

LoRa[4]

- **Good compatibility**:
  - implemented with **COTS components**
- **Low power**:
  - **130 μA** working current
  - **52 nA** standby current
- **Larger range**:
  - **28m** power transfer range with **30 dBm EIRP**
  - **381m** communication range



[1] Battery-Less IoT Sensor Node with PLL-Less WiFi Backscattering Communications in a 2.5-μW Peak Power Envelope, 2021 Symposium on VLSI Circuits, June 2021
[2] A UHF/UWB Hybrid RFID Tag With a 51-m Energy-Harvesting Sensitivity for Remote Vital-Sign Monitoring, IEEE Transactions on Microwave Theory and Techniques, Nov. 2020
[3] Reliable and Practical Bluetooth Backscatter With Commodity Devices, IEEE/ACM Transactions on Networking, April 2021
[4] Self-sustainable Long Range Backscattering Communication Using RF Energy Harvesting, IEEE Internet of Things Journal, March 2021

Passive IoT Device Should Support uW-level Power Consumption

- **Output power of energy harvester is typically from *~1 uW* to *~100 uW* for practical cases**
  - Many applications require devices with limited size (e.g., thin form-factor with area of a few square centimeters)
  - Energy conversion efficiency is usually low, especially for low cost device with limited size

Typical energy sources for energy harvesting [1][2]

Energy source	Size	Power density	Conversion efficiency	Harvested Power	Advantages	Disadvantages
Solar (Sunny day)	Good	15~100mW/cm^2	10~24%	10mW/cm^2 *	Environmental, high output voltage	Not always available, deployment constraints
Artificial light		10~100uW/cm^2		10μW/cm^2	Abundant in indoor, easy to implement	Low power density
Airflow	Poor	100mW/cm^2	-	-	Environmental, available day and night	Fluctuating density, hard to implement
Motion	Fair	200uW/cm^2	-	-	Light weight, compact configuration	Charge leakage, highly variable output
Thermal	Good	~50uW/cm^2	3%	-	Low-maintenance, scalable	Not always available, require efficient sinking
Radio frequency	Fair	1~10uW/cm^2	50%	0.1uW/cm^2	Abundant in urban lands, allows mobility	Low power density, distance dependent

**: In cloudy or rainy days, measured output power is 100~150uW/cm^2 between 10:00AM to 16:00PM according to our test in Chengdu, China*

- **Existing cellular devices cannot work well with energy harvesting due to power consumption of higher than 10mW**
  - The power consumption is hundreds or thousands of times higher than the output of an energy harvester
  - Integration with high capacity rechargeable battery or supercapacitor leads to high cost, which can be as high as 1$ or more
- **To fit the capability of energy harvesting, Passive IoT device shall support power consumption at the same level as the output power of an energy harvester**

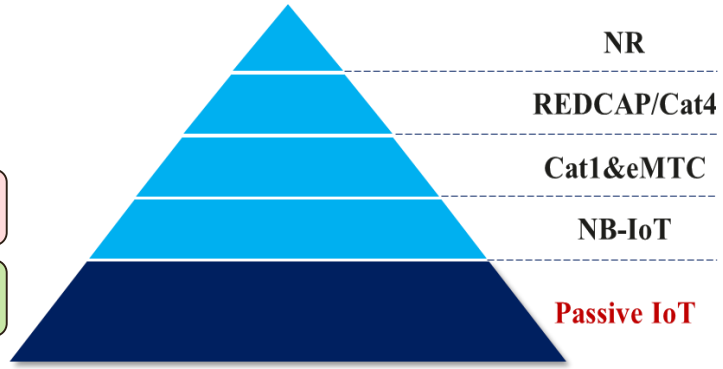
[1] Internet of Hybrid Energy Harvesting Things, IEEE INTERNET OF THINGS JOURNAL, VOL. 5, NO. 2, 2018
[2] Energy Harvesting Technologies for Achieving Self-Powered Wireless Sensor Networks in Machine Condition Monitoring: A Review, Sensors, 2018

Passive IoT Supports Low-Cost Batteryless Device with Proper Deployment

- **Ultra low power**
  - Power consumption low enough to work with energy harvesting (**1~100 uW**)
- **Ultra low cost**
  - For logistics management, no significant cost increase compared with barcode printed on heat sensitive paper (**0.01$ level**)
  - For wireless sensor, cost comparable with sensor itself (**0.1$ level**)
- **Deployment: co-deployment with 5G network to achieve seamless coverage**
  - Indoor small cell
    - **~30 m** between neighboring pico remote radio units
    - InF NLOS channel: ~70 dB
  - Outdoor micro cell
    - **~200 m** between neighboring base stations
    - UMi NLOS channel: ~100 dB

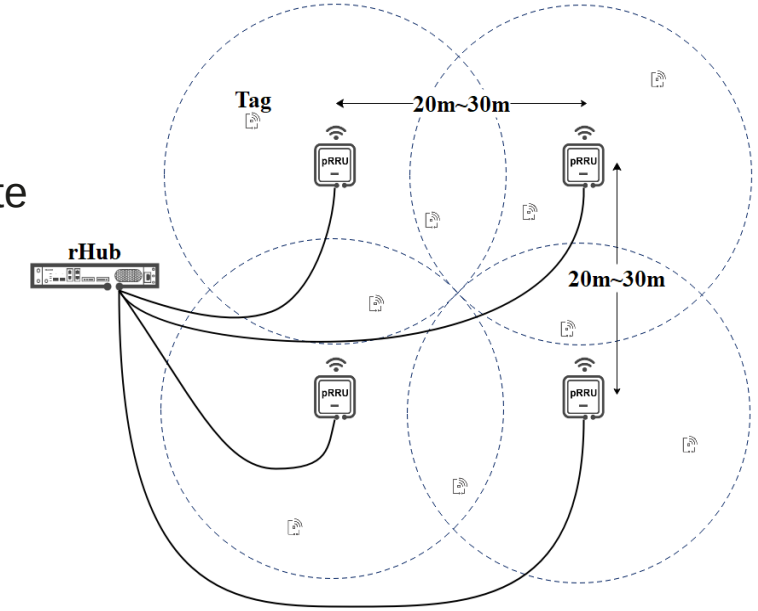
Targets on device

	Power	Cost
LPWAN	>10 mW	>1$
Passive IoT	1~100 uW	0.01~0.5$

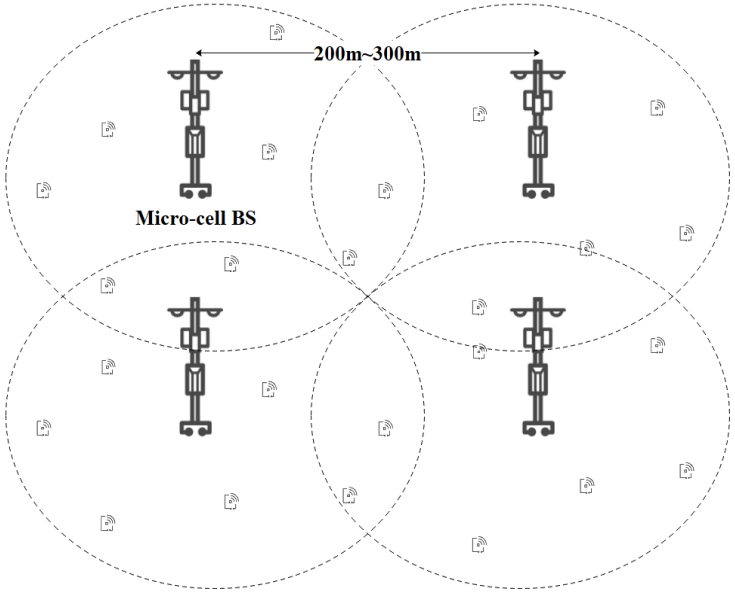


Passive IoT targets at new IoT markets from all existing cellular technologies

Indoor deployment



Outdoor deployment



Proposal for the Study of Passive IoT in Rel-18

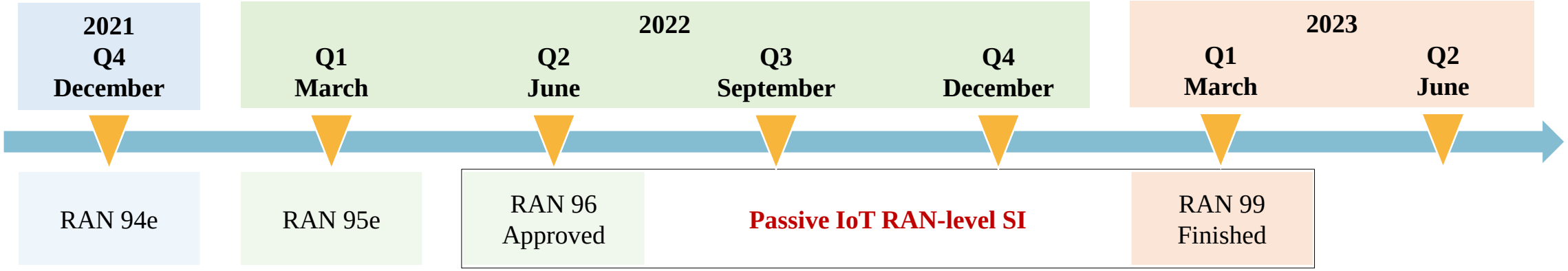
In the moderator summary of pre-meeting email discussion, it is proposed that “Further discussions in 3GPP should address how a potential study is organized within 3GPP“.

It is proposed to at least study Passive IoT at RAN-level for Rel-18 and finish the design in Rel-19

- Urgent demand from the new IoT markets drives increasing research and investment of competitive non-3GPP technologies to supporting batteryless device.
- Once competing technologies grab the huge amount of connections, it will be difficult for cellular based technology (e.g. Passive IoT) to regain the market share.
- Existing 3GPP technologies can hardly meet the requirements of ultra-low cost batteryless device.

Proposal: RAN#96 to discuss a timeline for establishing a passive IoT project, with a view to a Rel-18 SI based on the formulation identified in the pre-RAN#94-e email discussion final moderator’s summary.

Proposed timeline for the study of Passive IoT in Rel-18



Proposed Objectives for the Study of Passive IoT in Rel-18

This study targets at a new cellular IoT technology supporting ultra-low complexity and ultra-low power devices for the IoT applications requiring no energy storage, or energy storage up to that available from ambient sources, with the following objectives:

- Identify the suitable deployment scenarios for the ultra-low complexity and ultra-low power IoT devices of interest, for the relevant use cases such as identification, tracking, monitoring, etc. in various sectors such as logistics, transportation, healthcare, etc.
  - Aspects to consider include public/private network, indoor/outdoor environment, macro/micro/pico cells, connectivity to gNBs with/without relay (e.g. IAB and UE relay), traffic models (including bidirectional data transaction), TDD/FDD and frequency bands in licensed spectrum, coexistence with UEs and infrastructure in frequency bands for current 3GPP technologies, etc.
- Study the key design targets of the ultra-low complexity and ultra-low power IoT devices based on the relevant use cases and deployment scenarios:
  - Precise definitions for the ultra-low complexity and ultra-low power IoT devices of interest, i.e., targets for power consumption and complexity, including the possibility to define multiple types of such IoT devices (e.g. corresponding to different power consumption and complexity targets).
  - Other design targets including link budget, data rate, positioning accuracy etc. considering trade-offs among the relevant design targets
- Identify the required techniques to address the key design targets of the ultra-low complexity and ultra-low power IoT devices. Aspects to consider for meeting the design targets including waveform, protocols and signaling overhead, security, supported bands, etc.

Note: This study shall target for an IoT segment well below the existing 3GPP IoT technologies, e.g. NB-IoT, eMTC, RedCap, etc. The study shall not aim to replace existing 3GPP LPWA technologies.

Note: Following types of devices shall be considered in this study:

- Pure batteryless devices with no energy storage capability at all, and completely dependent on the availability of the ambient source of energy it is harvesting
- Devices with energy storage capability (e.g. up to that available from ambient sources) that do not need to be replaced or recharged manually, and which can manage short periods of ambient energy unavailability.

Note: The study shall aim to provide better coverage compared to existing non-3GPP technologies for the relevant use cases

Note: The study shall coordinate with relevant work in SA.

Thanks!