3GPP RAN#103

RP-240116

Maastricht, Netherlands, March 18-21, 2024

Agenda Item: 9.2.3

Views on Ambient IoT scope

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Introduction

Ambient IoT SI scope

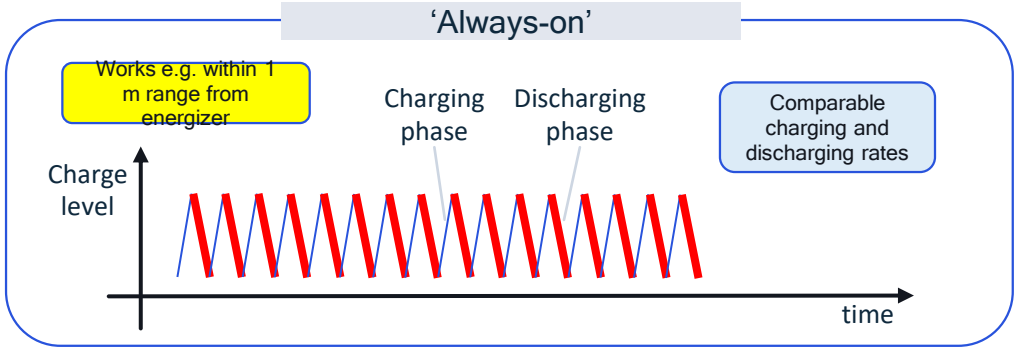
- There has been some level of controversy in RAN1#116 regarding the following
  - Whether the discussion of the nature of energy harvesting and its impact on air-interface operation and topology is in scope of the SI or not
  - Whether device type 2 should focus on RF energy harvesting or on other means of energy harvesting

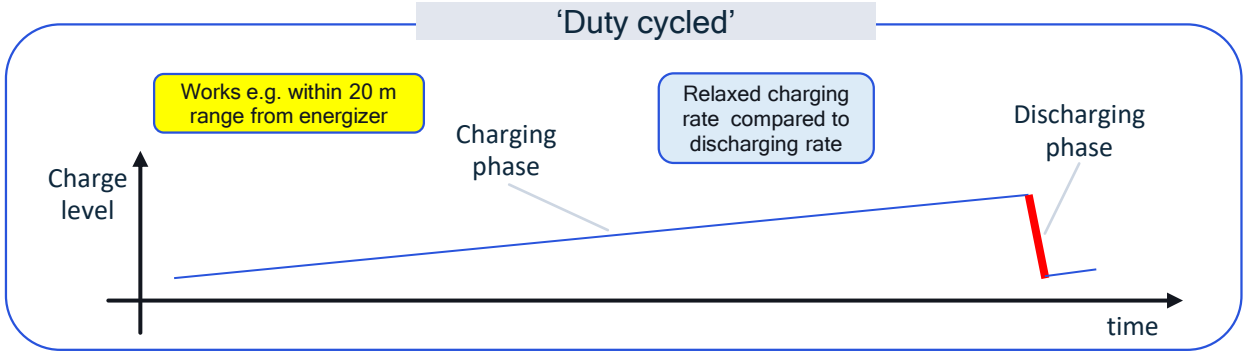
- In this contribution, we describe our views regarding these

The purpose of energy storage and duty cycled operation

Duty cycled operation for A-IoT is essential for extending the supportable range for RF energy harvesting

- The fundamental range limitation for A-IoT is not the communication range but RF energy harvesting range
- To support 'always on' operation, even device type 1 (device peak power consumption is just a few uW) would require about -20dBm constant Rx power (assumes 10% energy harvesting efficiency)
  - -20dBm is a very high power level, requiring very close range between energy source and device
  - -20dBm is the upper limit that cellular devices can tolerate, therefore this level and above would disable cellular (non A-IoT) devices in the area
  - At closer than at the edge of energy harvesting range, there would be human exposure concerns
- **Duty cycled operation together with energy storage, allows for decoupling the supportable charge and discharge rates**
  - → Required charging rate can be relaxed
  - → Required received Rx power can be reduced from -20dBm to about -30…-36dBm
  - → Supportable range for energy harvesting is extended
  - → RF energy harvesting range and communication range can be much better balanced

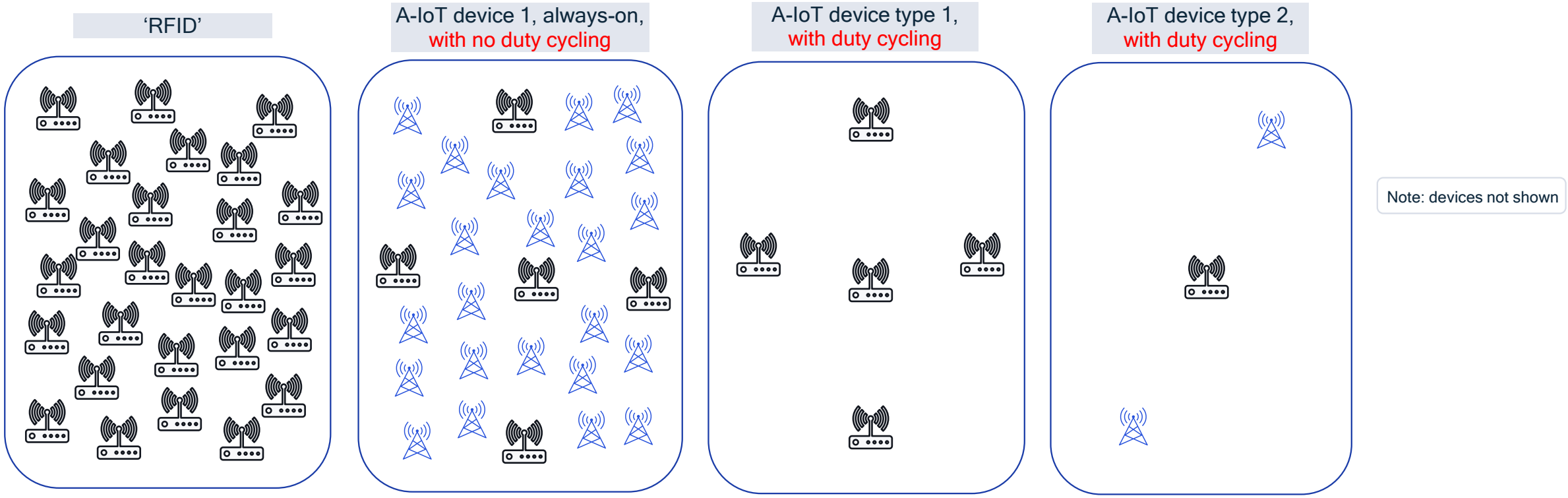




Required node deployment densities

in order to support both communication and energy harvesting

- **The purpose of energy storage** is to equalize the supportable maximum ranges for communication and RF energy harvesting, by way of a long charging time – short discharge time duty cycled operation as described previously



RF Energy Source for Device 2

Background

- Three Devices (1/2a/2b) were identified for A-IoT study [1][2].
- SA1 TR22.840 has identified various energy sources (RF, solar, thermal difference, etc) for A-IoT devices [3] for diverse use cases.

Device types	Peak power	Tx signal generation method	Potential amplification in DL/UL	Energy storage	A-IoT energy sources identified in 22.840
Device 1	~1uW	Backscattering	No	Assumed (e.g., capacitor)	RF signal, solar, thermal difference, mechanical vibration
Device 2a	a few 100uW	Backscattering	Yes	Assumed (e.g., capacitor)	
Device 2b	a few 100uW	Active signal generation	Yes	Assumed (e.g., capacitor)	

- Rel-19 A-IoT SI has focus use case of inventory and command (i.e., indoor warehouse) [1].

- In RAN1#116, companies showed different views on energy sources applicable to Device 2.
  - View 1: RF energy is applicable to Device 2.
  - View 2: RF energy is not applicable to Device 2, i.e., Device 2 should rely on other energy source.
- For future WG progress, it would be good to rethink this issue of viable energy sources of A-IoT device for inventory use case.

[1] RP-234058 New SID: Study on solutions for Ambient IoT (Internet of Things) in NR
[2] RAN1#116 Chairman's note
[3] 22.840 Study on Ambient power-enabled Internet of Things

RF Energy Source for Device 2

RF energy should be considered as baseline energy source for A-IoT study (1/2a/2b).

Proposal: For study purpose, RAN1 should consider device 2 based on RF energy source only as baseline. There is no need to consider other energy sources (other than RF energy) in Rel-19 study.

- Observation 1) RF energy is controllable (by network), reliable, and most available energy source which is suitable in addressing inventory use case.
- Observation 2) The cost of energy harvester for other energy source is quite expensive (e.g., solar cells $-$$, thermoelectric generator $$, piezoelectric generator $$) relative to expected A-IoT device cost (cents ~ tens of cents).
- Note that Rel-19 AoT SI's target use case is inventory (e.g., in warehouse), where extremely low-cost device is requited(<<1$). Note that RAN1 does NOT target sensor or tracker use case.
  - RF energy harvester is the cheapest and the most viable solution for inventory use case.
- Observation 3) Average power consumption of device 2 (both 2a and 2b) is in fact quite low (order of uW level).
  - Harvest/Sleep/Tx strategy could be used for Device 2 (see next slide). Thus, RF signal can provide enough energy for device 2.

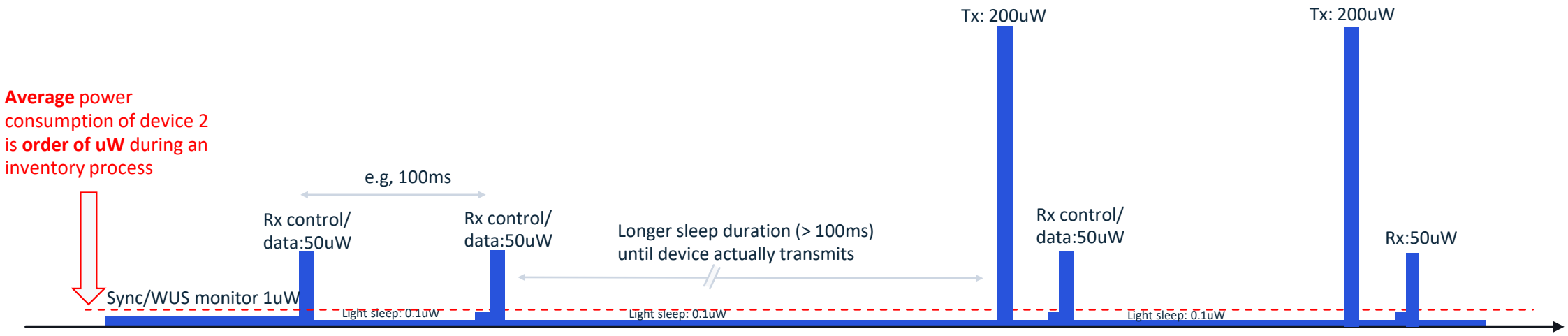
UHF 915 MHz Roll Stock Label RFID Labels

[1] RP-234058 New SID: Study on solutions for Ambient IoT (Internet of Things) in NR
[2] RAN1#116 Chairman's note
[3] 22.840 Study on Ambient power-enabled Internet of Things

RF Energy Source for Device 2

Average power consumption of device 2 is order of uW.

- A few hundreds of uW is peak power consumed when device transmits.
- Transmission duration is quite short (order of ms) during an inventory process which can last for a few sec.
- Average power consumption of device 2 is order of uW.
- Harvested and accumulated energy before inventory process start could be used for device sleep/rx/tx operation during an inventory process.



A typical power consumption timeline of an A-IoT device during an inventory process (other devices' timeline are not shown.)

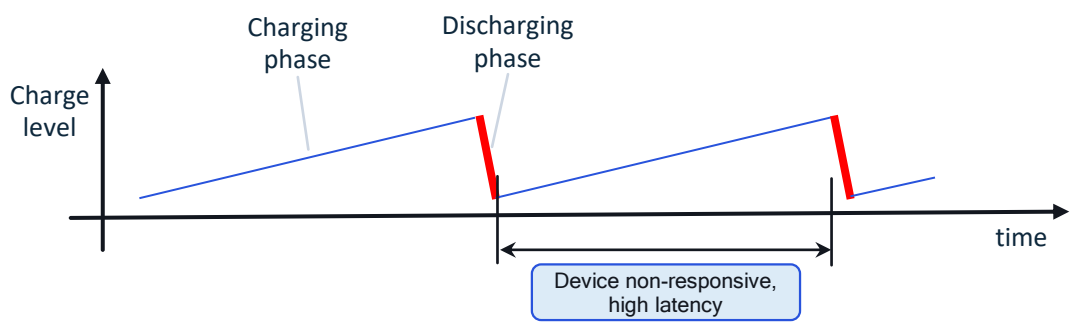
Types of duty cycled operation

Latency and synchronization

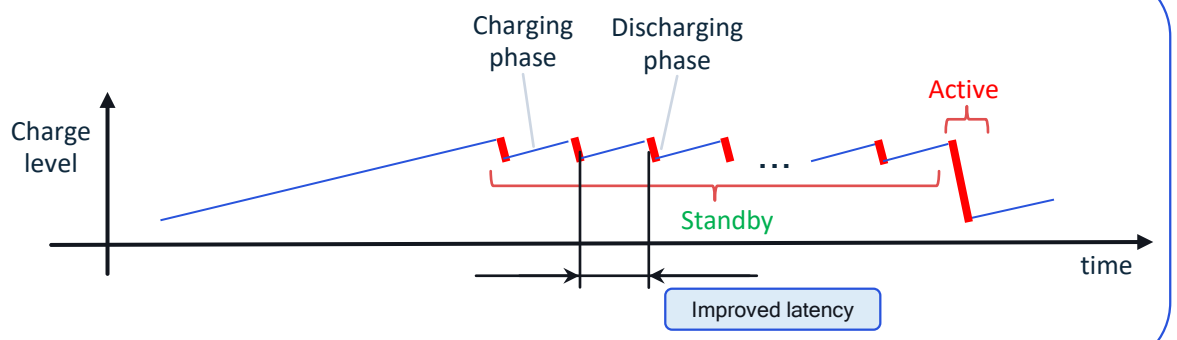
- Essentially two types of duty cycling modes have been discussed
  - Full discharge deep cycle, fully asynchronous
    - Device first fully charges
    - Upon reaching full charge level, device turns on and keeps continuous operation until fully discharged
    - Memory erased, cycle repeats
  - Partial discharge, potentially partially synchronous
    - Device first fully charges
    - Devices turns on for a short time to check for queries
    - If no query for active transmission, device goes to light sleep, charges again while retaining memory
    - Cycle repeats until active transmission is requested

- Because of the impact to reader operation, the types of charge/discharge duty cycles need to be addressed in the Study Item
- Cannot assume that all devices are always charged at the beginning of an inventory query in the full discharge deep cycle mode

Full discharge deep cycle mode



Partial discharge mode

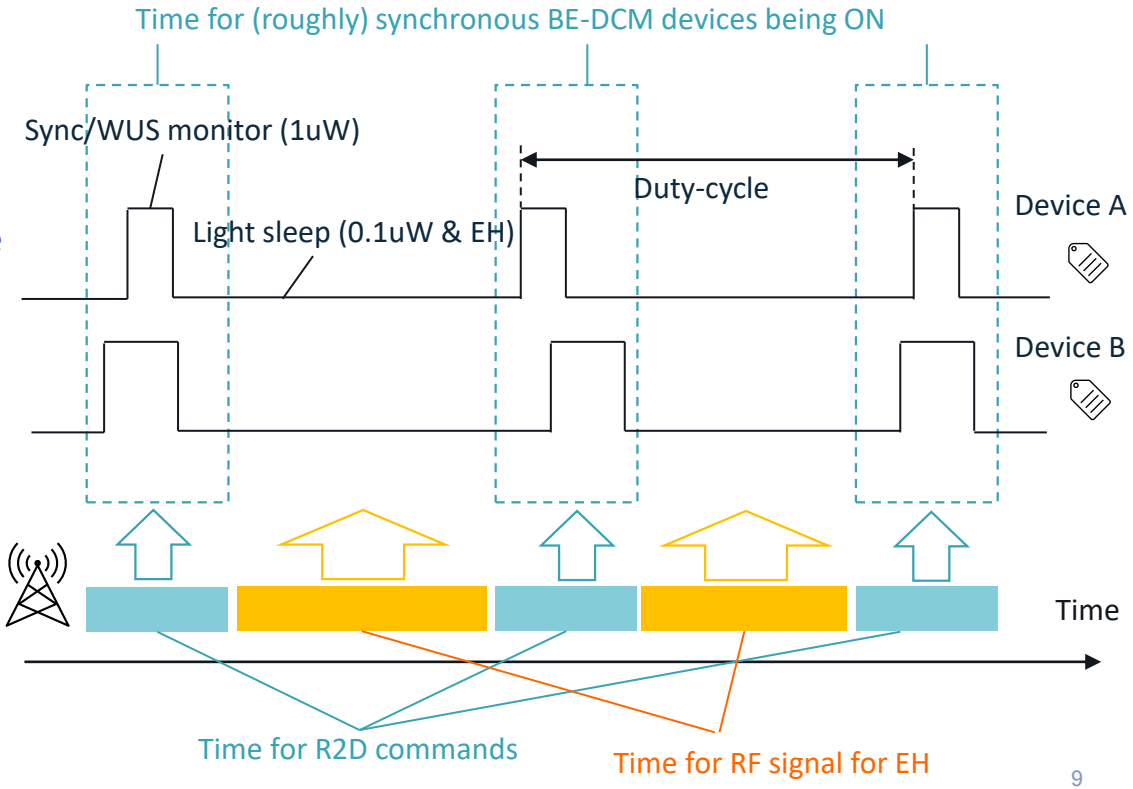


Best-effort Duty-cycle Monitoring (BE-DCM) a Key Enabler for A-IoT

- A-IoT device can monitor sync/wake-up sequence (WUS) in duty-cycled manner as long as energy is available
  - During light sleep, **no wake-up by Rx power**; runs a low power (e.g., 0.1uW) clock, retains memory, and **harvests energy from RF**
  - The ON period of different A-IoT devices can be controlled to be (roughly) synchronous by reader
    - E.g., reader can send command, sync/WUS signal, etc, when it is about to communicate with A-IoT devices, bursty first then periodically sometime

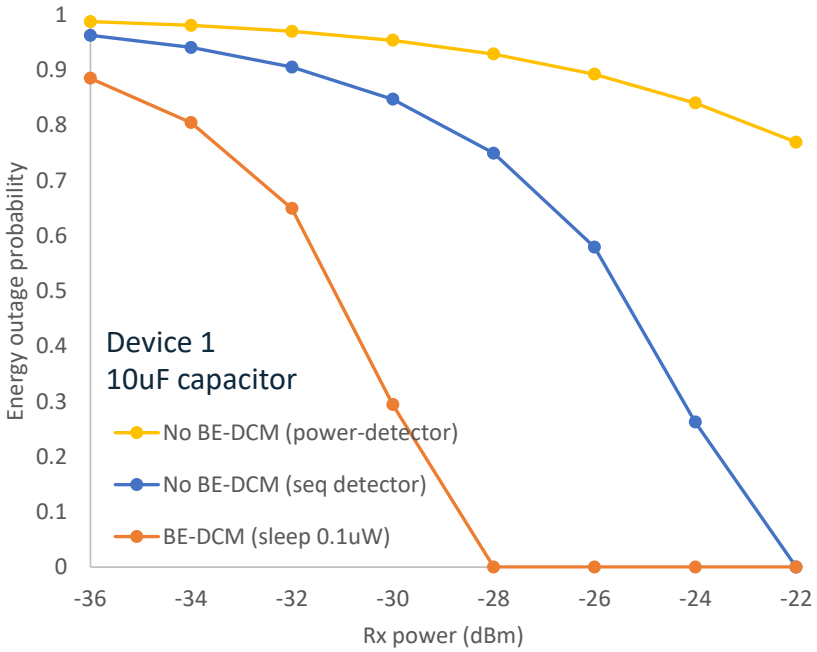
- Benefits:
  - Network/reader can transmit R2D command such that it falls in the time that the devices are supposed to be ON
    - Minimizes miss detection probability of R2D command due to energy outage
  - Network/reader can transmit RF signal for EH such that it falls in the time that the devices are supposed to be sleep
    - Maximizes EH efficiency as no false-alarm during sleep state

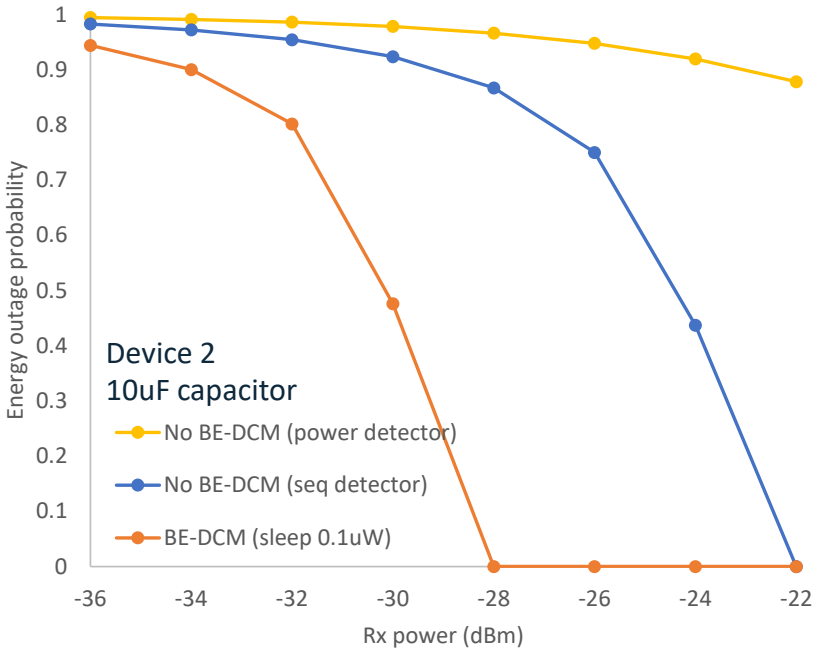
- Without BE-DCM:
  - Wake up by Rx power; false-alarm drains the energy
    - Lower wake-up sensitivity results in more frequent false-alarm
    - Higher wake-up sensitivity reduces coverage
    - Less RF signal reduces false-alarm but slows down RF EH



Analysis of BE-DCM benefit

- Energy outage probability: a probability that a Query cannot fall into time that the device is able to complete an inventory procedure
  - Assumption for analysis: 10uF capacitor with available energy 2.5uJ. Available energy other than necessary energies of inventory for devices 1 & 2 are considered as 2.4uJ & 1.1uJ respectively
  - A device wakes up & harvests energy under a given Rx power. Once the storage is empty, it does not wake up until it is fully charged by RF EH. Wake-up and EH are time-switched. EH efficiency is 10% of Rx power
- Case 1: No BE-DCM (power-detector)
  - A device wakes up based on Rx power and searches sync/WUS as long as Rx power is kept
  - Assumption for analysis: probability of incoming RF is 20%
- Case 2: No BE-DCM (early seq detector)
  - A device wakes up based on Rx power and searches sync/WUS for a while; if not found, goes to OFF state and harvest energy from RF
  - Assumption for analysis: 1ms search and then 2ms OFF; probability of oncoming RF is 20%
- Case 3: BE-DCM
  - A device wakes up in duty-cycle manner and searches sync.WUS during ON; stay sleep other than ON time
  - Reader can maximize RF-based EH without causing false-alarm
  - Assumption for analysis: 1ms ON and 49ms sleep; RF for EH is always during sleep
- **Observation: BE-DCM reduces the probability that a device is outage due to lack of energy**

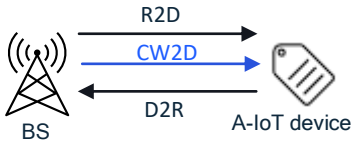
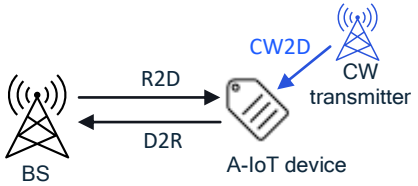
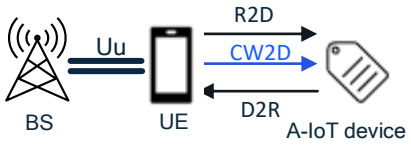
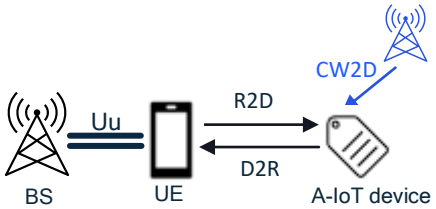




Network controlled CW Transmitter / Energizer

- CW inside and outside the topology [1]:
  - For D2R transmission of device 1/2a, **CW for backscattering** is needed, which can be used for energy harvesting but may not be sufficient.
    - Assuming small frequency shift for D2R backscattering, the CW for backscattering can be transmitted in the same spectrum as D2R.
    - The CW for backscattering may use single-tone waveform for easy interference cancellation.
  - However, for R2D transmission of device 1/2a/2b, additional **CW for RF energy harvesting** is needed to activate the device and receive the R2D.
    - Assuming same antenna is shared for RF energy harvesting and R2D reception, the CW for energy harvesting can be transmitted in the same spectrum as R2D.
    - The CW for energy harvesting may use same waveform as R2D for efficient power conversion, i.e., no new waveform.

Study cases for CW for backscattering agreed in RAN1#116 [2]

	CW inside topology	CW outside topology
Topo1	 Case 1-1 CW2D/D2R in DL Case 1-2 CW2D/D2R in UL	 Case 1-4 CW2D/D2R in FDD-UL
Topo2	 Case 2-2 CW2D/D2R in UL	 Case 2-3 CW2D/D2R in FDD-DL Case 2-4 CW2D/D2R in FDD-UL

[1] RP-234058 New SID: Study on solutions for Ambient IoT (Internet of Things) in NR
[2] RAN1#116 Chairman's note

- **Proposal: RAN1 to study the BE-DCM procedure based on CW for RF energy harvesting used for device 1/2a/2b.**
  - **CW inside/outside the topology is network controlled.**

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Thank you

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