6.2 Device (un)availability

The following directions, not for down-selection, are studied regarding the potential impact of device unavailability due to energy harvesting:

Direction 1: Reader does not provide information to a device regarding when the device may become available/unavailable.

Direction 2: Reader can provide information to a device based on which the device may become available/unavailable.

6.2.1 Direction 1 solution details

**Table 6.2.1-1: Details from Source [1, R1-2407611]**

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| **Source** | **Details** |
| **Source [1]** | Solution description  By implementation, the reader can provide the device enough time to charge. In addition, the reader can arrange the sequence of messages so that a device can perform its communications / operations spread out over time if possible to allow a device to remain available.  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  Additional benefits in availability of “ID associated with device(s) intended for the reception of R2D” when it is located at the front of the PRDCH, using a L1 R2D control information. |

**Table 6.2.1-2: Details from Source [2, R1-2407639]**

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| **Source** | **Details** |
| **Source [2]** | Solution description  The reader does not provide information to a device regarding when the device may become available/unavailable and the device behavior will entirely depend on the available energy in its energy storage and be highly implementation dependent  Observations or Analysis or Evaluations  Observation #1: RF energy harvesting is a suitable way to deploy Device 1 with capacitor size that is sufficient to complete at least an inventory round.  Observation #3: RF energy harvesting is not a suitable way to deploy Device 2. Other ambient sources, e.g., indoor lighting, vibration, etc., which are pervasive and continuous, and provide higher energy conversion, should be used.  Observation#4: It is expected that Direction 1 has no or less specification impact from both reader and device perspective.  Specification impacts, if any  There are no direct specification impact unless some mechanisms need to be specified to mitigate the potential drawbacks of Direction 1. |

**Table 6.2.1-3: Details from Source [3, R1-2407649]**

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| **Source** | **Details** |
| **Source [3]** | Solution description  The reader may be able to request the A-IoT devices to provide information on the current energy status and/or the ability on energy harvesting such as charging rate and capacity, which could be different depending on the device types. If needed, the reader can predict the device availability, but it does not mean the reader provide information on device availability to a specific device.  Observations or Analysis or Evaluations  Basically, the A-IoT device availability/unavailability cannot be controlled by the reader, which is up to its current energy status at the device. However, if the reader wants information relevant to energy harvesting, the device needs to provide information.  Specification impacts, if any  The spec needs to support necessary procedures and signaling such as indication on the A-IoT device to report the energy status. How to utilize the information is up to the reader implementation. |

**Table 6.2.1-4: Details from Source [4, R1-2407670]**

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| **Source** | **Details** |
| **Source [4]** | Solution description  The reader by implementation maintains the maximum time between the Paging messages as ≤ Tdischarge/2, ensuring that the device can switch to its ON duration after charging completely, receive the Paging message and complete the entire inventory procedure before running out of charge.  The device is expected to be fully charged and then switch to an ON duration to be able to receive the Paging message from the reader. The interval of the Paging messages would ensure that the device receives at least one Paging message before it runs out of charge.  Once the device completes the inventory procedure, the device maintains a state flag using an ultra-low power latch during the OFF duration such that the device does not perform inventory repeatedly after it completes a charging cycle.  If the device runs out of charge during the inventory procedure, or misses out on Paging messages during its OFF or charging duration, the device is simply expected to charge fully and then monitor for the next Paging message.  Any failed reception of Paging messages during the device charging time is handled by the higher layer re-access procedure.  The multi device inventory latency for direction 1 is 18.3 seconds, to reach 100% of the devices.  Observations or Analysis or Evaluations  The leakage current for a given capacitor size has to be much lesser than the output of the energy harvester in order to achieve satisfactory charging.  For capacitor sizes larger than 10 μF, the leakage current is in the order of micro amperes, resulting in a slow charging or continuous discharging using RF energy and hence is an unsuitable energy source for such capacitors.  For device 1, the discharging time is in the order of a few seconds, providing the devices with adequate time to complete an inventory round.  For device 2, the discharging time is in the order of milli seconds, which is too short a duration for the device to complete an entire inventory procedure.  For device 2 to be able to increase its discharge times, capacitors with larger capacitance, in the order of 1000 μF can be used, however, it would be infeasible to use RF energy as a source due to the high leakage current.  RF energy harvesting is not a suitable way to deploy devices with short discharge times, e.g. device 2, due to the following reasons:   * The discharge time is in the order of milli seconds, which is not enough for the device to complete an entire inventory round. * Increasing the capacitor size results in a high leakage current, resulting in a slow charging or continuous discharging, deeming RF energy as an unsuitable energy source. * Other ambient sources, e.g. indoor lighting, vibration, etc. which are pervasive and continuous, and provide higher energy conversion, should be used.   RF energy harvesting is a suitable way to deploy devices with long discharge times, and the reader’s scheduling implementation is able to appropriately handle the duration of an inventory round.  For calculating the multi device inventory latency, the charging time taken by the first set of devices that receive the first Paging message and are to participate in the first inventory round is taken into account when calculating the latency.  Specification impacts, if any  No specification impact.  Possible with proper implementation of devices with adequate charge/discharge times and capacitor size, as well as of the reader with the required time gap between the Paging messages, there is no specification impact. |

**Table 6.2.1-5: Details from Source [4, R1-2407670]**

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| **Source** | **Details** |
| **Source [4]** | Solution description  The device provides information to the reader pertaining to e.g. the remaining charge or charge status, such that the reader can optimally transmit the Paging messages to ensure that all devices are inventoried in the shortest amount of time.  The reader is expected to transmit a request message to the device, responding to which the device would provide the reader with a remaining charge status report.  The reader would then group the devices with similar amount of charge left and based on this grouping, the reader can then transmit the Paging message accordingly for each of these groups to participate in different inventory rounds.  For devices that did not have enough charge remaining to complete an inventory round, the reader would wait for a favorable report such that it can be inventoried in subsequent rounds.  Observations or Analysis or Evaluations  Solution 2:  The device cannot transmit remaining charge-related information to the reader without the reader requesting for such a report.  Transmission of the request message and corresponding report from each of the devices multiple times to the reader would cause a substantial overhead.  Additional hardware is required for the device to be able to determine the amount of charge remaining in its capacitor.  Specification impacts, if any  Solution 2:  Significant specification impact.  Request message and report might require new signals or channels.  Definitions of these messages are required.  Changes to the architecture to include additional hardware for the device to measure the remaining charge. |

**Table 6.2.1-6: Details from Source [5, R1-2407708]**

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| **Source** | **Details** |
| **Source [5]** | Solution description  The energy harvest and transition between states (ON and OFF) are achieved by device implementation  The device indicates to the reader before entering the OFF state.  Observations or Analysis or Evaluations  For device 1, reader can assume that device 1 with 10uF capacitor is always available during an inventory or command procedure, if the inventory/command procedure is immediately after the device is powered on.  For device 2, by implementing a larger capacitor, device 2 can be assumed available during an inventory or command procedure, if the inventory/command procedure is immediately after the device is powered on.  RF energy harvesting is not enough for larger capacitors (e.g., 100uF), other energy sources should be considered.  Before entering the OFF state, the device may indicate to the reader which may be beneficial for the reader to perform the subsequent scheduling or transmission.  Specification impacts, if any  no specification impact is needed for energy harvest and transition between states.  Indication design ( e.g., from device to reader) |

**Table 6.2.1-7: Details from Source [8, R1-2409026]**

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| **Source** | **Details** |
| **Source [8]** | Solution description:   * Signaling of energy status reporting * Energy aware segmentation   Observation:   * RAN1 is still discussing whether device 1 can support sleep state in addition to the ON and OFF state, however, it is clear that the device 2b can support ON; OFF and sleep state. * The RF based energy harvesting eliminates the negative consequence of device unavailability due to smaller capacitor size, * Even though, reader does not provide any information related to the device availability or unavailability as part of direction#1, reporting of coarse energy status helps reader schedule or not schedule subsequent R2D transmission to the device. * Since device may run out of charge during the transmission of larger payload size, retransmitting the entire packet requires more charging time. Hence, device can transmit part of the packet using segmentation based on the available energy while indicating to the reader about the subsequent packets to be transmitted after charging.   Specification impact:   * Device signaling its coarse energy status as part of the Msg-1 or Msg-3 transmission to the reader. Reader can schedule or not schedule subsequent R2D transmission to the device. Device behavior when the expected R2D transmission is not received. * RAN2 can discuss the energy-based segmentation. |

**Table 6.2.1-8: Details from Source [9, R1-2407863]**

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| --- | --- |
| **Source** | **Details** |
| **Source [9]** | Solution description  A-IoT device is assumed to have two states: ON, OFF.   * ON state supports transmission, reception for communication and does not support energy harvesting considering device has a single antenna for both communication and RF energy harvesting in TDMed manner. * OFF state supports at least energy harvesting and does not support at least transmission, reception for communication, maintaining a timer.   There are wo schemes for a device switching between ON and OFF states:   * Scheme 1 (OFF when fully discharged): The device switches to OFF when fully discharged and turns ON when there is stored energy and the incoming RF power is above the activation threshold. * Scheme 2 (OFF when energy < X%): The device switches to OFF when the stored energy falls below a threshold X, e.g., X=90% and turns ON when the stored energy exceeds that threshold and the incoming RF power is above the activation threshold.   Scheme 2 has advantages over scheme 1, such as shorter device downtime for energy harvesting and sufficient energy for communication once the target PRDCH is received. However, its implementation complexity and cost may be higher.  There are two options for a reader to transmit the PRDCH e.g., A-IoT paging triggering the random access (RA).   * Option 1 (P-R2D Tx): Reader transmits the PRDCH periodically. * Option 2 (A-R2D Tx): Reader transmits the PRDCH multiple times on demand.   Option 1, where the paging triggering the RA occurs periodically, remains transparent to the device as the reader cannot control or be aware of the device’s state. Additionally, the reader can use option 2 to decrease the likelihood that the device will miss the paging when it is in the OFF state.  Observations or Analysis or Evaluations  Evaluations and observations can be found in Table 6.2.2-1 [R1-2407863].  Specification impacts, if any  For both Schemes, it is expected to have no or minimal specification impacts. |

**Table 6.2.1-9: Details from Source [10, R1-2407907]**

| **Source** | **Details** |
| --- | --- |
| **Source [10]** | Solution description  In Direction 1, the reader does not provide information to a device nor be aware of a device regarding when the device may become available/unavailable. The device is assumed to have two states:   * ON state: Device can at least perform transmission and reception, run MHz sampling clock, and retain memory. * OFF state: Device cannot perform transmission and reception, no clock running. Device can harvest energy. Device can retain memory of being inventoried.   From reader perspective, it transmits paging messages with time interval shorter than the device sustainable time. To avoid devices running out of energy before successfully completing the inventory, the paging time interval can be comparable to half of the device sustainable time.  From device perspective, it becomes available when it is fully charged, and then keeps performing Tx/Rx procedure until it runs out of its available energy. Once a device finishes the inventory, it needs to retain a memory of being inventoried so that it does not re-enter the inventory procedure.    Observations or Analysis or Evaluations   1. Results for Device 1   Figure 3.2-2 and Figure 3.2-3 show the evaluation results of percentage of successfully inventoried devices with respect to the inventory time for Device 1, where Figure 3.2-2 provides results assuming {R2D, D2R} data rate of {56, 160} kbps and Figure 3.2-3 provides results assuming {R2D, D2R} data rate of {14, 40} kbps. The inventory completion time considering 99% and 100% of devices successfully complete inventory are summarized in Table 3.2-1. As the sustainable time of Device 1 is 4.75 s, and therefore two paging time interval of 2 s and 4 s are considered in the evaluation.    Figure 3.2-2: Percentage of successful inventoried devices with respect to inventory time for Direction 1 Device 1 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.2-3: Percentage of successful inventoried devices with respect to inventory time for Direction 1 Device 1 in case of {R2D, D2R} data rate of {14, 40} kbps.  Table 3.2-1: Inventory completion time for Direction 1 Device 1   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Successful rate | {R2D, D2R} Data rate | FDMA resources | Inventory completion time | | | Paging time interval = 2 s | Paging time interval = 4 s | | 99% | {56,160} kbps | 2 | 36.40 s | 46.40 s | | 4 | 36.40 s | 48.40 s | | {14,40} kbps | 2 | 36.40 s | 62.40 s | | 4 | 36.40 s | 58.40 s | | 8 | 36.40 s | 46.40 s | | 100% | {56,160} kbps | 2 | 39.42 s | 64.02 s | | 4 | 39.17 s | 59.64 s | | {14,40} kbps | 2 | 40.34 s | 69.63 s | | 4 | 39.83 s | 67.03 s | | 8 | 39.43 s |  |  1. Results for Device 2   Figure 3.2-4 and Figure 3.2-5 show the evaluation results of percentage of successfully inventoried devices with respect to the inventory time for Device 2, where Figure 3.2-4 provides results assuming {R2D, D2R} data rate of {56, 160} kbps and Figure 3.2-5 provides results assuming {R2D, D2R} data rate of {14, 40} kbps. The inventory completion time considering 99% and 100% of devices successfully complete inventory are summarized in Table 3.2-2. Two paging time interval of 20 ms and 40 ms are considered considering that the sustainable time of Device 2 is only 47.5 ms.    Figure 3.2-4: Percentage of successful inventoried devices with respect to inventory time for Direction 1 Device 2 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.2-5: Percentage of successful inventoried devices with respect to inventory time for Direction 1 Device 2 in case of {R2D, D2R} data rate of {14, 40} kbps.  Table 3.2-2: Inventory completion time for Direction 1 Device 2   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Successful rate | {R2D, D2R} Data rate | FDMA resources | Inventory completion time | | | Paging time interval = 20 ms | Paging time interval = 40 ms | | 99% | {56,160} kbps | 2 | 35.80 s | 48.44 s | | 4 | 35.80 s | 37.16 s | | {14,40} kbps | 2 | 36.34 s | 58.36 s | | 4 | 35.90 s | 55.32 s | | 8 | 35.84 s | 49.32 s | | 100% | {56,160} kbps | 2 | 35.99 s | 57.38 s | | 4 | 35.99 s | 53.55 s | | {14,40} kbps | 2 | 55.57 s | 72.66 s | | 4 | 51.18 s | 62.32 s | | 8 | 46.35 s | 57.34 s |   Observation 3: For Direction 1, when the paging time interval is comparable to half of the sustainable time, at least 99% of devices can be successfully inventoried before running out of energy and no device goes through recharging.  Observation 4: For Direction 1, with the increase of paging time interval, when the paging time interval is comparable to the sustainable time, there are devices cannot complete inventory before running out of energy and therefore the inventory completion time sufficiently increases.  Observation 5: For Direction 1, as the sustainable time of Device 1 can be up to several seconds, it is practical for a reader to transmit paging messages with a time interval comparable to half of device sustainable time, e.g., in the level of seconds.  Observation 6: For Direction 1, as the sustainable time of Device 2 can only last for tens of ms, a reader has to transmit paging messages very densely, e.g., in the level of tens of ms.  Specification impacts, if any  For Direction 1, no specification impact is expected at reader side nor device side. |

**Table 6.2.1-10: Details from Source [11, R1-2407971]**

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| **Source** | **Details** |
| **Source [11]** | Solution description  The reader can set a proper value of the interval in-between two paging messages, to ensure all the devices can complete at least one entire inventory procedure.  Observations or Analysis or Evaluations  The reader may or may not have the prior information on each device’s corresponding discharging time, which may rely on the deployment;  The R2D signalling overhead may also need to be considered.  Specification impacts, if any  No |

**Table 6.2.1-11: Details from Source [12, R1-2408049]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [12]** | Solution description  In Direction 1, an A-IoT device would become available after fully charged and become unavailable at the time of charging ort the energy in the storage running out. A-IoT devices can perform transmission and reception for communication in available state and perform energy harvesting in unavailable state. The switching between device availability and device unavailability is based on implementation without specification impact. In this case, carrier wave should always exist to provide energy for A-IoT devices.  Observations or Analysis or Evaluations  Observation 3: In Direction 1, carrier wave should always exist on to provide energy for A-IoT devices and is not guaranteed in the A-IoT field deployments for all A-IoT devices. The availability/unavailability of A-IoT devices are not fully controlled by the network during A-IoT operation due to the limitation of device within the carrier wave coverage.  Specification impacts, if any  In Direction 1, the switching between device availability and device unavailability is based on implementation without specification impact. |

**Table 6.2.1-12: Details from Source [13, R1-2408068]**

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| **Source** | **Details** |
| **Source [13]** | Solution description  Method 1:  The Reader sends continuous CW before paging message to ensure that all devices achieve a high energy storage state.  After the continuous CW, the reader transmits the paging message.  Devices can harvest energy from the CW while in unavailable state. Upon the end of the continuous CW through power detection, devices switch to the available state to receive the subsequent paging message and enter the random access process.  Figure 8 illustrates the transmission and reception between the reader and the device in Method 1.    Figure 8 Transmission and reception between reader and device in Method 1  Observations or Analysis or Evaluations  Method 1:  Before random access, Method 1 based on Direction 1 can ensure that devices receive the paging message at a high power level and enter the random access process  Specification impacts, if any  Method 1:  The energy node transmits the CW before paging message.  The device is required to detect the end of continuous CW and receive subsequent paging message. |

**Table 6.2.1-13: Details from Source [13, R1-2408068]**

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| **Source** | **Details** |
| **Source [13]** | Solution description  Method 2:   * The reader can transmit multiple paging messages in one access round. Wherein, each paging message includes an indicator that indicates whether the paging message is the initial paging message of the access round. * During one access round, the initial paging message indicates the total number of occasions that the access round contains and other paging messages indicate the remaining number of occasions after them. * If a device receives the initial paging message, it performs random access based on the number of occasions indicated by the initial paging message. * If a device receives a paging message for the first time, and this paging message is not the initial paging message, it will perform random access based on the number of occasions indicated by this paging message. * If a device receives a paging message that is neither the first paging message it has received nor the initial paging message, it will decrease its stored occasion counter.   To facilitate the comparison between the existing slotted-ALOHA and Method 2, Figures 9 and 10 respectively illustrate the function of paging message and R2D trigger (i.e. counter decrement command) of the two methods. It can be observed that Option 2 replaces some R2D triggers with paging messages in one access round.    Figure 9 Function of paging message and R2D triggers in slotted-ALOHA process    Figure 10 Function of paging messages and R2D triggers in Method 2  Observations or Analysis or Evaluations  Method 2:  Before random access, Method 2 based on Direction 1 can increase the probability of devices receiving the paging message without incurring additional R2D overhead.  Specification impacts, if any  Method 2:  Define the paging message transmission mechanism and relevant signaling indication.  Specify the device’s behavior after receiving a paging message. |

**Table 6.2.1-14: Details from Source [15, R1-2408148]**

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| **Source** | **Details** |
| **Source [15]** | Solution description  Since the reader does not provide any information (e.g., scheduling or coordination) that can be used by a device for switching from one operating state to another (e.g., for the purpose of power saving or energy harvesting), the state transition in a device is expecting to be based on its implementation choice. For example,   * For a device that supports only 2 states (ON / OFF), the state transition is expecting to be based on device energy storage level (i.e., switch to the ON state when the storage level is charged above a X% and switch to the OFF state when the storage level is dropped below a Y%, where X could be 50/80/100 and Y could be 20/10/0 depending on device implementation choice). That is, a device could be power-ON only when it is fully charged and power-OFF only when it is fully dis-charged. Therefore, it is not possible / infeasible for a device to perform energy re-charging in the middle of an inventory or command process, and as such, the device should complete an inventory or command process as soon as power-ON and before it is fully dis-charged. * For a device that supports 3 states (ON / OFF / SLEEP), the timing/determination of state transition between ON and SLEEP will be also sorely base on its implementation choice (since the reader does not provide any information). It is mentioned in the past, a device may employ a duty-cycle based ON / SLEEP state switching/transition. For example, for every duty-cycle period (which is to be determined by the device implementation), the device switches to the ON state for a small amount of time to monitor/receive any paging message from the reader and switches back to the SLEEP state for a longer duration for energy re-charging. The device repeats this duty-cycle state switching operation to keep its energy storage level high, until it detects during a ON period a paging message that triggers an inventory or command process, then it remains in the ON state to complete the process.   In order to cater for the above possible state transition behaviours, it is mentioned in one solution that the reader periodically transmits a paging message triggering an inventory or command process with a periodicity equal to ½ of the expected sustainable operating time (ON duration) of a device (where the triggered process also finishes within the periodicity). If the device power-ON or switches to the ON state with a remaining energy level that is or near 100% full, even if the next paging message is transmitted ½ of the expected sustainable operating time later, the remaining energy level should still be able to sustain device operation for the entire process.  Observations or Analysis or Evaluations  For A-IoT devices that support only 2 states (ON / OFF), the reader should frequently transmit a paging message triggering an inventory or command process in order to ensure a device does not spend a lot of energy monitoring the channel for a paging message. Although the above-described solution is in-principle workable from the view point of a device sustainable operating time, however, this does not take into account when the number of devices trying to access the same process is more than the capacity that can be handled within a process, then TX collision will occur and some devices would not complete the process. Subsequently, these devices may re-attempt in the next period / triggered process, take up time and frequency resources, but not be able to finish the process. Furthermore, these device with failed attempts will take 10’s of seconds to be re-charged to 100%, wake-up and try a new process again until they complete one round of inventory or command process. As seen, this type of mechanism is prone / exposed to TX collisions and long latency delays.  For A-IoT devices support 3 operating states (ON / OFF / SLEEP), the reader does not need to frequently transmit the paging message as devices are always in a high energy storage level. But the drawback would be the inventory / command process completion time for multiple devices. Even to make an inventory of just one device, the reader may need to transmit the paging message multiple times, as the device ON timing and duration is not influence by any information from the reader. Reader transmission of a paging message that falls within the device ON period will be purely coincident. To make an inventory of a large number of devices, at the beginning the paging transmission may easily coincide with one or multiple devices, which is fine. But when only a few devices remained, the coincident may not happen often.  Based on the above solution description and analysis, the following observations are reached for Direction 1:   * When the device supports only two operating states (ON / OFF), * the reader should frequently transmit a paging message triggering an inventory or command process in order to ensure a device does not spend a lot of energy monitoring the channel for a paging message, and * for a mechanism where a paging trigger is periodically transmitted and the periodicity is ½ of the expected sustainable operating time of the device, this type of mechanism may be prone / exposed to TX collisions and long latency delays to complete a round of inventory or command process with the reader. * When the device supports three operating states (ON / OFF / SLEEP), * when a device employs a duty-cycle based ON / SLEEP state transition scheme, device energy storage could always remain in a high level, but the inventory / command process completion time for multiple devices may be long, since the timing of a paging message transmission that falls within the ON duration of a device is based on coincident.   Specification impacts, if any  Behaviour(s) and restriction(s) for autonomous state transition in a device may need to be specified (e.g., TS 38.213 or 214) in order to ensure the overall operation of an inventory or command process (A-IoT communication) is not negatively impacted. Detailed behaviour(s) and restriction(s) should be further studied and discussed |

**Table 6.2.1-15: Details from Source [17, R1-2408234]**

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| **Source** | **Details** |
| **Source [17]** | Solution description  Reader scheme: Transmits PRDCH multiple times.  Device scheme: Either continuous On until fully discharged or continuous On until discharged to a threshold.  Observations or Analysis or Evaluations  Reader does not control the device state  Specification impacts, if any  no specification impact |

**Table 6.2.1-16: Details from Source [21, R1-2408411]**

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| **Source** | **Details** |
| **Source [21]** | Solution description  The device is assumed to always have sufficient energy to receive commands from the reader at any time.  Observations or Analysis or Evaluations  The power consumption of the device must be less than the achievable rate of energy harvesting. The range from device to CWE is limited by the power consumption of the device. CWE power consumption and interference are greater for this direction than for direction 2.  Specification impacts, if any  Specification impacts are minimal. |

**Table 6.2.1-17: Details from Source [24, R1-2408536]**

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| **Source** | **Details** |
| **Source [24]** | Solution description  When CW and communication is same frequency,   * To use only this direction can work.   When CW and communication are different frequencies,   * After one transaction (inventory or command) or multiple of transactions, reader is not required to call the successful communication device again. In such situation, the reader does not provide information to a device regarding when the device may become available/unavailable as next inventory or command are sufficiently future like 1 hour or 1 days later. * On the other hand, during one transaction or multiple of transactions, when communication is possible needs to be aligned between the reader and the devices. If not, the reader is not able to initiate the communication. This operation is controlled by the timer between ON and RETENTION.   Observations or Analysis or Evaluations  If the device is able to know no more transaction is expected after successful communication, the device can go for OFF. This may be realized by "no intention for the more paging for now" kind of the message by the reader. Or other implicit means.  If the device is not sure no more transaction or not even after successful transaction, the device needs to repeat the transition between ON and RETENTION by the timer for possible future paging when CW and communication are different frequencies.  Specification impacts, if any  What information needs to be kept in volatile Memory and what timers are required to be run during RETENTION.  When CW and communication is same frequency, how the device distinguish them using the start-indicator part.  When CW and communication is different frequency, in what condition, the device is not required to repeat the transition between ON and RETENTION. |

**Table 6.2.1-18: Details from Source [27, R1-2408648]**

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| **Source** | **Details** |
| **Source [27]** | Solution description  Define a minimum and a maximum time between two PRDCHs providing random access triggering messages such that the device is not required to monitor a potential R2D transmission during the minimum time, if the device does not participate the corresponding random access round. During the minimum time, the device may transition into the PS state. After the minimum time, the device is require to monitor a potential R2D transmission at least until the maximum time from the preceding PRDCH reception.  Define a minimum time for a device, who successfully finished the random access procedure, such that the device is not required to monitor a potential R2D transmission during the defined minimum time. The minimum time may be dependent on the count of the current random access round.  Define a minimum time for a device to continuously monitor a potential R2D transmission, whenever the device becomes active after unavailable periods from energy harvesting, such that a reachability from a reader to the device is guaranteed.  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  N/A |

**Table 6.2.1-19: Details from Source [30, R1-2408702]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [30]** | Solution description  Applicable primarily to Device 1 (ultra-low-power devices)  Relies on the device's long availability duration (e.g., >10 seconds)  Reuse simple slotted-ALOHA based access mechanism  R2D includes end timing information for scheduled D2R or R2D transmission  Devices make autonomous decisions based on their remaining energy and the scheduled transmission duration  Observations or Analysis or Evaluations  Device 1 operates at ultra-low power (~1μW) and can rely solely on RF energy harvesting.  Long availability duration (>10 seconds) is possible with a 10 μF capacitor for Device 1.  This approach is suitable when the device's available duration is long enough to cover the period of slotted-ALOHA.  Devices can estimate their remaining energy using the formula P1 = (M1 – N1)/M1, where M1 is the minimum available duration and N1 is the counted slot number after entering the available state.  By providing end timing information, devices can autonomously decide whether to participate in scheduled transmissions based on their energy status, potentially avoiding D2R or R2D failures due to energy shortage.  Specification impacts, if any  Device: Definition and test requirement on M1, counting behavior for N1, skip and go unavailable if identifying energy shortage for upcoming scheduling, reporting behavior of remaining energy information  Reader: Command periodicity for initial contact with the device based on M1 value, end timing information in R2D transmissions for scheduled D2R or R2D transmissions |

**Table 6.2.1-20: Details from Source [31, R1-2408742]**

| **Source** | **Details** |
| --- | --- |
| **Source [31]** | Solution description  RAN1 assumes the device has enough energy for at least for one message (e.g., Msg1) then leave it to RAN2 to add signaling from the device to indicate to the reader if it does not have enough energy for follow up messages (e.g., energy status report in Msg1).  Observations or Analysis or Evaluations  RAN1 can assume the device has enough energy, with a fallback energy status report.  Specification impacts, if any  RAN2 specification impact, if RAN2 decides to add an energy status report. |

**Table 6.2.1-21: Details from Source [33, R1-2408788]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [33]** | Solution description  Each device reduces a duration of contiguous unavailable time and reader transmits paging frequently  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  E.g., a threshold of energy storage is defined to do state transition for energy harvesting.  E.g., device behavior to monitor paging/re-paging and to perform Msg1 TX is defined in consideration of missing a lot of paging/re-paging. |

**Table 6.2.1-22: Details from Source [34, R1-2408852]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [34]** | Solution 1 description  Reader continues to try reaching A-IoT device until it becomes available  Observations or Analysis or Evaluations  The simple solution for a reader to communicate with an unavailable A-IoT device is to wait until the device is available after charging. Without the knowledge/controllability of device availability/unavailability, the reader has to repeat/retry the communications over time.  For example, suppose the case where a reader wants to do inventory for A-IoT devices. The reader should repeat msg-0 over time so that whenever the target device is available, it can receive the msg-0. If there is no msg-0 received during an available time duration, the device is not aware of the inventory procedure from the reader. Therefore, the reader should send msg-0 at least once per device available time duration. The reader should send msg-0 at least once per these time durations.  Unavailable time duration for charging depends on Rx power, RF EH efficiency, capacitor size, etc. Therefore, the reader is not able to identify when and how long each device becomes available. The best thing that a reader can do is to continue the tries as much as possible and as long as possible.    Fig. A1 Direction 1: a reader has no idea and cannot control when a device is available/unavailable  A typical inventory procedure is a slotted-ALOHA based contention-access procedure. If there are a large number of devices, a number of devices compete with each other in the slotted-ALOHA msg-1 transmissions. In such case, the inventory procedure for a device may not be able to be completed within the available time duration. Once the device becomes unavailable, the device will not be available for tens or hundreds of seconds due to charging. As such, congestion of the contention-access procedure would further increase the time duration where a reader has to try.  Observation A1:   * Direction 1 is the case where a reader has no idea and cannot control when a device is available/unavailable due to the amount of energy in the storage. * As a solution, a reader should try to reach the target device in blind manner. * Take an inventory procedure as an example, reader should transmit msg-0 multiple times until msg-1 is received, where the msg-0 transmission should be at least once per device available time duration. * If an A-IoT communication activity (e.g., message exchanges for contention-based access procedure) cannot be completed within an available time duration of a device for some reason (e.g., congestion of slotted-ALOHA), the device becomes not accessible (unavailable) due to charging again, which leads additional delay for the reader.   Solution 2 description  Improved energy harvesting efficiency by deployment/implementation  Observations or Analysis or Evaluations  The other solution is to improve energy harvesting efficiency by deployment/implementation. For example, network can deploy energizers densely such that all the devices are always fully energized and available. Or, device can implement energy harvesting sources such as solar, vibration, etc, which increases the form factor of the A-IoT devices.  Note that large capacitor size for a device does not resolve the issue. With a large capacitor size, the device available time duration gets longer. However, it also prolongs the device unavailable time duration for charging. There must be cases where some devices has (almost) zero available energy when a reader starts repeat/retry of inventory procedure, and such devices needs longer charging time until it becomes first time available after the start of the reader’s inventory.  Observation A2:   * Another solution for direction 1 to improve energy harvesting efficiency by deployment/implementation. * A network can deploy energizers densely such that all the devices are always fully energized and available. * Devices can implement energy harvesting sources such as solar, vibration, etc, which increases the form factor of the A-IoT devices. * Using large capacitor size cannot be a solution for direction 1 * In direction 1, reader cannot make sure all the devices are fully charged when the reader starts the overall inventory procedure   Specification impacts, if any  No specification impact is envisioned for direction 1. |

**Table 6.2.1-23: Details from Source [36, R1-2408920]**

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| --- | --- |
| **Source** | **Details** |
| **Source [36]** | Solution description  When the energy storage is full or reaches a certain level, or the device receives a RF power larger than an activation threshold, the device wakes up to detect the R2D signal and then transmit the D2R signal.  When the procedure of inventory/command is completed or the energy storage is not enough to process the following communication, the device switches to OFF and only performs the energy harvesting.  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  How and when to transmit CW for energy harvesting, for example, controlled by the reader  Energy harvesting in Topology 2, for example, when the RF energy source and the UE are the same node, the impacts of different RRC states (IDLE/Inactive/Connected mode)  Transmitting power of RF energy source |

6.2.2 Direction 2 solution details

**Table 6.2.2-1: Details from Source [1, R1-2407611]**

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| --- | --- |
| **Source** | **Details** |
| **Source [1]** | Solution description  A device is (nearly) fully charged when it first becomes available.  A device monitors R2D transmissions to determine whether it should participate in a round of communications. If a device is not among the device or a group of devices scheduled to participate, it can use a next scheduled opportunity field in the R2D transmission to determine when it can/should be available. This field indicates the next round of communications. A device then may become unavailable and can harvest energy. When the device determines it is near the next scheduled opportunity, and it has sufficient energy for a round of communications, a device can become available to process the PRDCH. If a device is (nearly) fully charged, it may become available at any time.  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  Availability of “ID associated with device(s) intended for the reception of R2D” is located at the front of the PRDCH, using a L1 R2D control information. Availability of a next scheduled opportunity for another round of communications, using a L1 R2D control information. The next scheduled opportunity field can represent a number of events, such as R2D transmissions. |

**Table 6.2.2-2: Details from Source [2, R1-2407639]**

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| --- | --- |
| **Source** | **Details** |
| **Source [2]** | Solution description  Support for wake-up signal in the SLEEP state  Observations or Analysis or Evaluations  Observation #1: There is a need to study a solution for extending the sustainable operation time for devices with short discharge times and long charge time by harvesting only RF energy.  Observation #2: The state transitions to or from the OFF states can be based on an energy level of the device, which can be on implementation issue. On the other hand, the state transitions between ON and SLEEP states need to be studied as it involves a monitoring behavior of a device, which may be a potential scope of specification.  Observation #3: Following benefits are achievable by reader controlling the device’s state transition between the ON and SLEEP:   * Avoiding very long unavailable time duration after the reader starts inventory: Since the consumed energy in the energy storage in each available time duration is quite limited, the time duration that a device is unavailable for energy harvesting is short. * Keeping large amount of energy in the storage all the time: Whenever a device joins inventory, the energy storage is (almost) full. This avoids the case where a device joins inventory but the remaining amount of energy is not sufficient.   Specification impacts, if any  At least a wake-up signal needs to be specified. The wake-up signal support should be specified in a way so that it is transparent for (and can be ignored by) devices that do not support it. |

**Table 6.2.2-3: Details from Source [4, R1-2407670]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [4]** | Solution description  The following states and the corresponding functions of the device for each of the states are considered, where their duration is determined by device implementation.:   * ON state – Device is fully operational – it can transmit and receive communication messages, run a clock, maintain memory. * OFF state – Device is not operational – it cannot transmit or receive any messages, nor run a clock. In this state, the device performs energy harvesting and maintains an inventory flag. * SLEEP state – Device is semi-operational – it cannot transmit or receive communication messages, but it can run a clock and perform energy harvesting. It may also maintain memory.   The objective of this solution is not to force all the devices to adhere to a single configuration to periodically shift between the ON and SLEEP states, but rather to ensure that all devices shift to ON state when the Paging messages are being transmitted.  To achieve this, we propose an on-demand shifting of states where the reader controls the device to switch to the ON state from the SLEEP state using an indicator which would inform the device of the duration it has to remain in the SLEEP state.  The device is expected to perform energy harvesting and charge itself during the OFF state, and when its fully charged, it would shift to the ON state and listen for the indicator to be transmitted by the reader.  The indicator would indicate the time left for the inventory procedure to start and for the device to receive a Paging or Query message.  The reader transmits the indicator in an aperiodic manner, controlled by reader implementation, such that the device has to be in an ON state for only a short time, enabling it to switch to the SLEEP state until the next Select or Query message is expected to be received to conserve energy.  At the indicated time, the device will shift to the ON state and perform the inventory procedure, ensuring that the device would have enough energy to be able to complete the procedure during the ON state.  Within an inventory round, if the device failed to receive a Query message, the device can remain in ON state until it receives the indicator, after which it can go to SLEEP state until the next expected Query message, based on the indicated duration.  The following are the possible transitions that the device would be expected to perform.   * OFF to ON state – Transition based on when the device is fully charged. * ON to OFF state – Transition based on when the device runs out of charge, or is discharged. * ON to SLEEP state – Transition based on when the device receives the indicator. * SLEEP to ON state – Transition based on when the device completes the time indicated. * SLEEP to OFF state - Transition based on when the device runs out of charge, or is discharged.   The multi device inventory latency for direction 2 is 18.3 seconds.  Observations or Analysis or Evaluations  During the SLEEP state, it has to be ensured that the power consumption of the device while running the clock is lower than the charging rate of the capacitor.  The on-demand shifting of states does not require the device to maintain any fixed duration of the states or a periodicity to shift between states, thus avoiding any potential need for the device to be preconfigured with any information.  Specification impacts, if any  Minor specification impact.  The indictor needs to be specified to indicate the time left for the inventory procedure to start, which can be a higher layer message carried on the PRDCH. |

**Table 6.2.2-4: Details from Source [5, R1-2407708]**

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| --- | --- |
| **Source** | **Details** |
| **Source [5]** | Solution description  Duty cycle-liked solution (with sleep state)  The device indicates to the reader before entering the OFF state.  Observations or Analysis or Evaluations  Reader can provide an indication to the device to perform sleep state transition.  Energy threshold based transition can be up to implementation.  Timer or counter based transition can be considered  Before entering the OFF state, the device may indicate to the reader which may be beneficial for the reader to perform the subsequent scheduling or transmission.  Specification impacts, if any  Sleep-state and state transition conditions  Indication or timer/counter design for state transition |

**Table 6.2.2-5: Details from Source [8, R1-2409026]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [8]** | Solution description:   * Wake up signal for the device or configuring device monitoring periods * Configuring the duty cycles and aligning duty cycle among group of devices * Energy aware scheduling and selection of subset of device in each access round within the inventory   Observation:   * Reader can control the power states of device 2b - ON; OFF and sleep and help to extend the operational time of devices. * The device can be periodically configured to transition from sleep to the ON state as part of the duty cycle for monitoring the trigger from the reader. Contrary to it, wake up signaling indicating an identifier associated to a device or a group of device wakes up selected device for the access round. * Contrary to the traditional Q based device scheduling implemented in UHF RFID, devices can be selected for each access occasion where each access occasion reserve resources for multiple devices. * Energy aware selection of device for each access round decrease the storage size as shown in our analysis.   Evaluation:   * Comparing the sustainable operation time of device supporting always ON with that of duty cycle and energy harvesting is provided in Fig. 3. * Energy aware scheduling benefits illustrated in Fig. 6.   Specification impact:   * Wake up signal design and content otherwise device monitoring periodicity * Duty cycle configuration for a group of devices * Energy aware scheduling using selecting a subset of devices for each access round. |

**Table 6.2.2-6: Details from Source [9, R1-2407863]**

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| --- | --- | --- |
| **Source** | **Details** | |
| **Source [9]** | Solution description  A-IoT device is assumed to have three states: ON, OFF, SLEEP.   * SLEEP state supports maintaining a timer, maintaining a memory content from ON state, energy harvesting and does not support transmission, reception for communication. * The functions for ON and OFF states supported and unsupported are the same as those captured for direction 1.   Under direction 2, one scheme for a device switching between ON and SLEEP states:   * Scheme 3 (SLEEP w R2D control): Device switches between ON and SLEEP states under reader’s control.   The reader can provide the time duration for ON or SLEEP and their periodicity for the device to perform ON and SLEEP state transition. Thus, only periodic paging transmission, i.e., Option 1 (P-R2D Tx) is used for reader to imitates RA.  Observations or Analysis or Evaluations  The detailed evaluation methods and simulation assumptions listed in Table 3-3 can be found in section 3.3 of [R1-2407863].  Case 1: For 2 RA resources and paging period of 6ms and 16ms   |  |  | | --- | --- | | 1. Paging period = 6ms | 1. Paging period = 16ms |   Figure 1. Time required to inventory 100% of devices for 2 RA resources and 6/16ms paging period  Table 1: Time required to inventory 100% of devices using 2 RA resources per paging message   |  |  |  | | --- | --- | --- | | Schemes | Totally inventory time [s] | | | Paging period: 6ms | Paging period: 16ms | | OFF when fully discharged w P-R2D Tx | 21.16 | 55.69 | | OFF when energy <90% w P-R2D Tx | 17.918 | 42.019 | | SLEEP w R2D control w P-R2D Tx | 6.309 | 12.833 | | OFF when fully discharged w A-R2D Tx | 19.677 | 44.179 | | OFF when energy <90% w A-R2D Tx | 13.30 | 23.747 |   Case 2: For 4 RA resources and paging period of 6ms and 16ms   |  |  | | --- | --- | | 1. Paging period = 6ms | 1. Paging period = 16ms |   Figure 2. Time required to inventory 100% of devices for 4 RA resources and 6/16ms paging period  Table 2: Time required to inventory 100% of devices using 4 RA resources per paging message   |  |  |  | | --- | --- | --- | | Schemes | Totally inventory time [s] | | | Paging period: 6ms | Paging period: 16ms | | OFF when fully discharged w P-R2D Tx | 10.567 | 28.538 | | OFF when energy <90% w P-R2D Tx | 7.805 | 22.732 | | SLEEP w R2D control w P-R2D Tx | 2.50 | 6.67 | | OFF when fully discharged w A-R2D Tx | 10.441 | 22.684 | | OFF when energy <90% w A-R2D Tx | 7.284 | 12.081 |   Observations based on above Case 1 and Case 2  Observation 1:   * Decreasing the paging period reduces total inventory latency across all schemes. * For 2 RA resources scheduled by a single paging message, when the paging period is reduced from 16ms to 6ms, * Schemes 1 and 2 reduce the time to inventory all devices by about 62% and 57% for periodic R2D transmission, and by about 55% and 44% for aperiodic R2D transmission. * Scheme 3 achieves about 51% reduction for periodic R2D transmission. * For 4 RA resources scheduled by a single paging message, when the paging period is reduced from 16ms to 6ms, * Schemes 1 and 2 show about 63% and 66% time reduction for periodic R2D transmission, and 54% and 40% for aperiodic R2D transmission. * Scheme 3 shows about 62% latency reduction for periodic R2D transmission.   Observation 2:   * Increasing the random access (RA) resources for D2R transmission scheduled by a single A-IoT paging reduces total inventory latency significantly across all schemes. * For 6ms paging period, when RA resources is increased from 2 to 4, * Scheme 1 and 2 reduce the time to inventory all devices by about 50% and 56% for periodic R2D transmission, and 47% and 45% for aperiodic R2D transmission. * Scheme 3 show about 60% latency reduction for periodic R2D transmission with the reduced paging period from 16ms to 6ms. * For 16ms paging period, when RA resources is increased from 2 to 4, * Schemes 1 and 2 show about 49% and 46% time reduction for periodic R2D transmission, and about 48% and 49% for aperiodic R2D transmission. * Scheme 3 shows about 48% latency reduction for periodic R2D transmission.   Observation 3:   * For Scheme 1 and Scheme 2, aperiodic R2D transmission can further reduce the inventory time, especially for long paging period, although it results in more paging overhead than the periodic R2D transmission. * For 2 RA resources, compared to 6ms/16ms-period R2D transmissions, Scheme 1 and 2 further reduce the time to inventory all devices by about 7%/21% and 26%/43% with additional aperiodic R2D transmission * For 4 RA resources, compared to 6ms/16ms-period R2D transmissions, Scheme 1 and 2 further reduce the time to inventory all devices by about 1.2%/20% and 6.7%/49% with additional aperiodic R2D transmission   Observation 4:   * Devices under Scheme 1 needs to recharge more often compared to Scheme 2 and Scheme 3. * Scheme 3 generally offers the shortest inventory time, while Scheme 1 has the longest. * For scheme 1 and scheme 2 that reader cannot control or be aware of the device state, short paging period and/or aperiodic R2D transmission can reduce inventory latency. For scheme 3, to achieve the tradeoff between the inventory latency and R2D overahed, it is advisable to set the paging period and the ON to SLEEP time ratio to allow device harvest enough energy.   Specification impacts, if any  For scheme 3, it may have following specification impacts:   * Define SLEEP, ON, and OFF states for the A-IoT device with their functions. * Include signaling from the reader to the device for transitioning between ON and SLEEP states. * Detail the device's monitoring behavior, transmission, and reception procedures. |

**Table 6.2.2-7: Details from Source [10, R1-2407907]**

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| **Source** | **Details** |
| **Source [10]** | Solution description  In Direction 2, solutions to extend device availability for both stages before the inventory starts and during the inventory procedure are proposed. The device is assumed to have three states:   * ON state: Device can at least perform transmission and reception, run MHz sampling clock, and retain memory. * OFF state: Device cannot perform transmission and reception, no clock running. Device can harvest energy. Device can retain memory of being inventoried. * SLEEP state: Device cannot perform transmission and reception. Device can run a low accuracy clock, retain memory, may or may not harvest energy (depends on the relationship of the consumed power and the input power).   Solution before inventory starts  From reader perspective, it provides indication of the potential starting time or remaining time of the future paging message. By implementation, the reader can provide the indication in a shorter time interval, so that a device does not need to drain its energy to monitor the indication.  From device perspective, it becomes available when it is fully charged and monitors the indication of the transmission time of the upcoming paging message. The device transits to SLEEP state to save or harvest energy, if necessary. During SLEEP state, the device needs to retain a clock for time counting.    Solutions during inventory procedure  B1: Non-slot-ALOHA based solution  This solution is a proposed new random access solution for Ambient IoT, and is not based on the slot-ALOHA solution specified in UHF RFID.  From reader perspective, it provides duty cycle information in paging message, which includes at least number and duration of ON occasions.  From device perspective, upon receiving a paging message, it randomly selects an ON occasion for random access, and transits to SLEEP state, if necessary, to conserve and harvest energy. During SLEEP state, the device needs to retain memory regarding its ON occasion information and runs a clock for time counting. The device transits to ON state till the selected ON occasion is coming. Within the ON occasion, the device performs random access upon receiving triggering message. If collision occurs, devices transit to SLEEP state and wait for the next paging message. If a device does not successfully access before running out of available energy, it recharges until fully charged again.    B2: Slot-ALOHA based solution  This solution is an optimization based on the slot-ALOHA solution specified in UHF RFID.  From reader perspective, it additionally sends a slot decrement indication to inform the decrement progress to devices.  From device perspective, upon receiving a paging message and acquires the Q value, it first randomly selects an access slot within [0, 2Q-1]. The device transits to SLEEP state before the selected access slot, if necessary. During SLEEP state, the device needs to retain memory regarding its access slot information and runs a clock for time counting with an assuming slot duration. The device transits to ON state when it counts to the selected slot. The device monitors the decrement indication to obtain the actual slot decrement progress and determines whether it re-transits to SLEEP state or keeps monitoring to its upcoming access slot. If a device finds out that its access slot has passed, it responds immediately in the follow-up slot. If collision occurs, devices transit to SLEEP state and wait for the next paging message. If a device does not successfully access before running out of available energy, it recharges until fully charged again.  Observations or Analysis or Evaluations  Necessity of Direction 2 for Device 1  Figure 3.3-4 to Figure 3.3-7 show the comparison results between Direction 1 and Direction 2 for Device 1.    Figure 3.3-4: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 1 Solution 1 versus Direction 1 Device 1 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.3-5: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 1 Solution 1 versus Direction 1 Device 1 in case of {R2D, D2R} data rate of {14, 440} kbps.    Figure 3.3-6: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 1 Solution 2 versus Direction 1 Device 1 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.3-7: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 1 Solution 2 versus Direction 1 Device 1 in case of {R2D, D2R} data rate of {14, 440} kbps.  Observation 7: For Device 1, the inventory completion time for Direction 1 is shorter than Direction 2 for all evaluation cases.  Observation 8: At least for Device 1 implemented with large capacitor size (e.g., 10 uF), it seems not necessary to study Direction 2.  Results for Direction 2 Device 2  B1. Results for Solution 1 (Solution A + Solution B1)  Figure 3.3-8 and Figure 3.3-9 show the evaluation results of percentage of successfully inventoried devices with respect to the inventory time for Solution 1, where Figure 3.3-8 provides results assuming {R2D, D2R} data rate of {56, 160} kbps and Figure 3.3-9 provides results assuming {R2D, D2R} data rate of {14, 40} kbps. The inventory completion time considering 99% and 100% of devices successfully complete inventory are summarized in Table 3.3-1. In addition, we also provide comparison between Direction 1 and Direction 2 Solution 1, as shown in Figure 3.3-10 and Figure 3.3-11.    Figure 3.3-8: Percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 1 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.3-9: Percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 1 in case of {R2D, D2R} data rate of {14, 40} kbps.  Table 3.3-1: Inventory completion time for Direction 2 Solution 1   |  |  |  |  | | --- | --- | --- | --- | | Successful rate | {R2D, D2R} Data rate | FDMA resources | Inventory completion time | | 99% | {56,160} kbps | 2 | 43.08 s | | 4 | 41.44 s | | {14,40} kbps | 2 | 59.97 s | | 4 | 43.09 s | | 8 | 41.46 s | | 100% | {56,160} kbps | 2 | 43.96 s | | 4 | 42.09 s | | {14,40} kbps | 2 | 67.11 s | | 4 | 43.69 s | | 8 | 42.10 s |     Figure 3.3-10: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 1 versus Direction 1 Device 2 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.3-11: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 1 versus Direction 1 Device 2 in case of {R2D, D2R} data rate of {14, 40} kbps.  B2. Results for Solution 2 (Solution A + Solution B2)  Figure 3.3-12 and Figure 3.3-13 show the evaluation results of percentage of successfully inventoried devices with respect to the inventory time for Solution 2, where Figure 3.3-12 provides results assuming {R2D, D2R} data rate of {56, 160} kbps and Figure 3.3-13 provides results assuming {R2D, D2R} data rate of {14, 40} kbps. The inventory completion time considering 99% and 100% of devices successfully complete inventory are summarized in Table 3.3-2. In addition, we also provide comparison between Direction 1 and Direction 2 Solution 2, as shown in Figure 3.3-14 and Figure 3.3-15.    Figure 3.3-12: Percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 2 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.3-13: Percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 2 in case of {R2D, D2R} data rate of {14, 40} kbps.  Table 3.3-2: Inventory completion time for Direction 2 Solution 2   |  |  |  |  | | --- | --- | --- | --- | | Successful rate | {R2D, D2R} Data rate | FDMA resources | Inventory completion time | | 99% | {56,160} kbps | 2 | 43.68 s | | 4 | 39.84 s | | {14,40} kbps | 2 | 107.68 s | | 4 | 76.96 s | | 8 | 61.60 s | | 100% | {56,160} kbps | 2 | 44.06 s | | 4 | 41.05 s | | {14,40} kbps | 2 | 107.68 s | | 4 | 87.73 s | | 8 | 71.87 s |     Figure 3.3-14: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 2 versus Direction 1 Device 2 in case of {R2D, D2R} data rate of {56, 160} kbps.    Figure 3.3-15: Comparison of percentage of successful inventoried devices with respect to inventory time for Direction 2 Device 2 Solution 2 versus Direction 1 Device 2 in case of {R2D, D2R} data rate of {14, 40} kbps.  Observation 9: For Direction 2, and for both Solution 1 and Solution 2, when considering higher {R2D, D2R} data rate of {56, 160} kbps, at least 99% of devices can be successfully inventoried before running out of energy and no device goes through recharging.  Observation 10: For Direction 2, and for both Solution 1 and Solution 2, when considering lower {R2D, D2R} data rate of {14, 40} kbps, there are devices cannot complete inventory before running out of energy and therefore the inventory completion time sufficiently increases.  Observation 11: For Direction 2, and for both Solution 1 and Solution 2, when compared to Direction 1 assuming paging time interval is comparable to half of the device sustainable time:   * In case of higher {R2D, D2R} data rate of {56, 160} kbps, Direction 2 consumes longer inventory completion time when at least 99% of device successfully complete inventory, since the first paging message is sent at the time when the farthest device finish energy harvesting in Direction 2. * In case of lower {R2D, D2R} data rate of {14, 40} kbps, Direction 2 consumes longer inventory completion time when at least 99% of device successfully complete inventory, since there are devices goes through recharging for Direction 2 but there is no device goes through recharging for Direction 1.   Observation 12: For Direction 2 Solution 1, when compared to Direction 1 assuming paging time interval is comparable to the device sustainable time, Solution 1 has benefits in the following cases:   * Considering 99% devices successfully complete inventory, in case of higher {R2D, D2R} data rate of {56, 160} kbps and 2 FDMA resources; in case of lower {R2D, D2R} data rate of {14, 40} kbps and 4/8 FDMA resources. * Considering 100% devices successfully complete inventory, in case of higher {R2D, D2R} data rate of {56, 160} kbps and 2/4 FDMA resources; in case of lower {R2D, D2R} data rate of {14, 40} kbps and 2/4/8 FDMA resources.   Observation 13: For Direction 2 Solution 2, when compared to Direction 1 assuming paging time interval is comparable to the device sustainable time, Solution 2 has benefits in the following cases:   * Considering 99% devices successfully complete inventory, in case of higher {R2D, D2R} data rate of {56, 160} kbps and 2/4 FDMA resources. * Considering 100% devices successfully complete inventory, in case of higher {R2D, D2R} data rate of {56, 160} kbps and 2/4 FDMA resources.   Specification impacts, if any  For Direction 2, potential specification impact is expected at both reader side and device side.  From reader perspective,   * Before the inventory starts, the reader provides indication of the potential starting time or remaining time of the future paging message. * During the inventory procedure, for Solution 1, the reader provides duty cycle information at least including number and duration of duty cycle ON occasions. * During the inventory procedure, for Solution 2, the reader provides slot decrement indication to inform the slot decrement progress.   From device perspective,   * Before the inventory starts, the available device monitors the starting time indication of the paging message and can transits to SLEEP state, if necessary. * During the inventory procedure, for Solution 1, the device randomly selects a duty cycle ON occasion for random access. During SLEEP state, the device retains memory regarding its ON occasion information and runs a clock for time counting.   During the inventory procedure, for Solution 2, the device randomly selects an access slot and can transits to SLEEP state, if necessary. During SLEEP state, the device retains memory regarding its access slot information and runs a clock for time counting with an assuming slot duration. The device transits to ON state when it counts to the selected slot, monitors the decrement indication to obtain the actual slot decrement progress and determines whether it can re-enter SLEEP state or keeps monitoring to its upcoming access slot. |

**Table 6.2.2-8: Details from Source [11, R1-2407971]**

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| --- | --- |
| **Source** | **Details** |
| **Source [11]** | Solution description  The device can switch to “SLEEP” state to recharge the power and wake up before the selected access occasion starting time If a device has selected a later access occasion based on the indicated “Q” value  Observations or Analysis or Evaluations  The SLEEP state may need to be defined in which the device can maintain a timer and the memory content from ON state;  The device’s SFO may need to be taken into account.  Specification impacts, if any  Designing a timer to control the time length of “SLEEP” state and/or additional information carried in the R2D command like “QueryRep” [RAN2]. |

**Table 6.2.2-9: Details from Source [12, R1-2408049]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [12]** | Solution description  In Direction 2, A-IoT devices perform transmission and reception for communication in available state. The devices would become unavailable during charging or after running out the stored energy. While for A-IoT devices in unavailable state, devices may perform energy harvesting or just be in a fully charged state without the requirement of transmission and reception for communication. The unavailable devices do not become available to perform transmission and reception for communication until receiving the status switching information provided by the reader. Direction 2 has more specification impacts, e.g. specify the content and the form of the information. In addition, carrier wave should not always exist to provide energy for A-IoT devices since the devices may be fully charged in unavailable state.  Observations or Analysis or Evaluations  Observation 5: In Direction 2, carrier wave should not always exist on to provide energy for A-IoT devices.  Observation 6: In Direction 2, A-IoT devices are unavailable when they are in a fully charged state without the requirement of transmission and reception for communication  Specification impacts, if any  In Direction 2, at least the content and the form of the information used for switching A-IoT devices to become available needs to be specified. |

**Table 6.2.2-10: Details from Source [15, R1-2408148]**

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| **Source** | **Details** |
| **Source [15]** | Solution description  In Direction 2, since a reader provides assistance or coordination information to assist a device to determine whether/when to become available or unavailable, it is assumed the device should support 3 operating states (ON, OFF, SLEEP), such that the device can switch from SLEEP-to-ON based on an internal clock (time counting). Switching from OFF-to-ON is, in general, based on device implementation (e.g., whenever the energy storage level has reached X % full, where X=70/80/100). To switch between ON/SLEEP for energy harvesting (e.g., based on time counting via an internal clock), the main intention is to prolong/extend the sustainable operating time of a device such that the device has sufficient energy to complete at least a round of inventory or command process. Energy harvesting for a device should focus on two stages: before and after an inventory or command process is triggered.  Before an inventory or command process is triggered:   * A device power-ON once it is sufficiently charged and receives information from the reader relating to the timing/periodicity of future inventory/command processes to be triggered. * Device selects one of the periodic inventory / command processes and switches to SLEEP state for power saving and energy harvesting. * Before start of the selected inventory / command process, device switches to ON state to receive paging message from the reader.   After an inventory or command process is triggered:   * After receiving the paging message that triggers an inventory or command process and selecting an access slot (q) as part of slotted-ALOHA, the device switches to SLEEP state for power saving and energy harvesting/re-charging.   The device counts the time (via internal clock) or detects number of paging repeat messages or timing acquisition signals / R2D preambles, and switches to ON state before the start of the selected access slot (q) to carry out a random-access procedure with the reader.  Observations or Analysis or Evaluations  Based on the solution descriptions, the goal / intention is for a device to be in the ON state once when it is necessary, i.e., for the selected process (before the inventory / command process is triggered) and the selected access slot (after the inventory / command is triggered). In other time, the device switches / remains in the SLEEP state for energy harvesting. Hence, the energy storage level in the device remains in a high level and the sustainable operating time is maximized to ensure the device is able to complete an inventory/command process with the reader.  Specification impacts, if any  To ensure the energy storage level in a device is maximized for prolonging the sustainable operating time and to ensure a smooth operation of running an inventory or command process, a unified state transition behaviour(s) based on reader signaling or assistance/coordination information should be specified. |

**Table 6.2.2-11: Details from Source [17, R1-2408234]**

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| --- | --- |
| **Source** | **Details** |
| **Source [17]** | Solution description  Solution 1:  Reader scheme: Transmits indications multi times to notify the next access occasion(s).  Device scheme: Random On to receive the indication and select the access occasion by device.  Observations or Analysis or Evaluations  Solution 1: Reader does not control the device state  Specification impacts, if any  Solution 1: minor specification impact. |

**Table 6.2.2-12: Details from Source [17, R1-2408234]**

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| --- | --- |
| **Source** | **Details** |
| **Source [17]** | Solution description  Solution 2:  Reader scheme: Periodically transmits PRDCH.  Device scheme: Periodically On to access according to the reader configuration.  Observations or Analysis or Evaluations  Solution 2: Reader controls the device state  Specification impacts, if any  Solution 2: has specification impact for both reader and device. |

**Table 6.2.2-13: Details from Source [18, R1-2408251]**

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| --- | --- |
| **Source** | **Details** |
| **Source [18]** | Solution description  Each device can be associated with a number of "unavailable time windows", within which the device is not available for communications e.g. due to charging by energy harvesting.  The reader can implicitly or explicitly indicate the "unavailable time windows" (or how to determine them) to a device. For example, if a device successfully receives an R2D transmission carrying A-IoT paging message intended for a specific device group NOT including the device, it can be a good indication that the device will not miss anything even if it stops transmissions/receptions for a period of time right after the the R2D transmission, and that period of time can be a "unavailable time window" for the device. Precision in definition of a "unavailable time window" can take the SFO of a device into account.  Observations or Analysis or Evaluations  "Unavailable time windows" for A-IoT devices can be exploited for energy harvesting, minimizing the negative impacts to communication delays due to charging by energy harvesting.  Specification impacts, if any  The reader needs to indicate "unavailable time windows" (or how to determine them) to a device, implicitly or explicitly. |

**Table 6.2.2-14: Details from Source [21, R1-2408411]**

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| --- | --- |
| **Source** | **Details** |
| **Source [21]** | Solution description  The device operates on a duty-cycled basis for channel monitoring and reception. The reader indicates the times at which the device should be ON and when the device may sleep. The reader can only communicate with the device when the device is ON. The device indicates to the reader the maximum ratio of ON to OFF time, based on the power consumption and energy harvesting rate of the device.  Observations or Analysis or Evaluations  The range from CWE to device is not limited by the power consumption of the device. The range is limited by the threshold at which energy can be harvested. Devices that are further from the CWE operate with a longer duty cycle. Devices that are close to the CWE can operate in “direction 1 mode”. CWE power consumption and interference are less than for direction 1. The reader needs to signal the duty cycle timing to the device. The device needs to signal its supported duty cycles to the reader, based on current energy harvesting conditions.  Specification impacts, if any  Procedures for duty cycle operation need to be defined.  Reader needs to be signal the ON / OFF duty cycle to the device. The device needs to signal its desired ON / OFF duty cycle to the reader. |

**Table 6.2.2-15: Details from Source [22, R1-2408434]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [22]** | Solution description  The reader can group the devices in the same “available duration” for scheduling. Reader indicates to the devices the time for activity cycle allowing the devices to monitor R2D transmissions during the same available duration. To adjust timing drift of devices due to clock inaccuracy, the reader transmits a “Sync Align” outside the activity cycle to help devices to align with the same available duration.  Optionally, the Reader can indicate a minimum applicable duty cycle (ratio of available to total time) for the device in the Sync Align message. If a device can determine its duty cycle, it follows the indication if its duty cycle is higher than the indicated minimum. This enables grouping devices by their duty cycle.  Observations or Analysis or Evaluations  By having a common “available duration” among different devices, the reader can schedule multiple devices in the same duration. Broadcast/groupcast message can be then transmitted during the common available duration.  The solution is suitable for all device types and can achieve better coexistence between device type 1 and type 2a/2b.  Specification impacts, if any  Introducing R2D broadcast message to indicate information related to activity cycle. |

**Table 6.2.2-16: Details from Source [23, R1-2408467]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [23]** | Solution description  Define a duty-cycle based paging procedure where each cycle include ‘monitoring period’ and ‘nonActive period’, where reader tranmits paging command within ‘monitoring’ period to trigger inventory procedure.  An A-IOT device maintains a running clock to count the timing location of ‘monitoring period’ and ‘nonActive period’.  An A-IOT Device moves to ‘ON’ state if it wants to involve a paging procedure; Otherwise, it moves to ‘Sleep’ state for RF energy havesting.  This is one solution in Direction 2.  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  Define a duty-cycle based paging procedure where each cycle include ‘monitoring period’ and ‘nonActive period’, where reader tranmits paging command within ‘monitoring’ period to trigger inventory procedure.  Introduce a signal to indicate the duty-cycle configuration. |

**Table 6.2.2-17: Details from Source [24, R1-2408536]**

|  |  |
| --- | --- |
| **Source** | **Details** |
| **Source [24]** | Solution description  When CW and communication is same frequency,   * The start-indicator part can be used to switch CW and communication. There is no need to indicate it in advance.   When CW and communication are different frequencies,   * During one transaction (inventory or command) or multiple of transactions, the reader would inform or specify "when Msg 0 and/or 2 and/or 4" are to be sent. This situation is "reader provide the information to a device on which the device become available.   Observations or Analysis or Evaluations  Without such some level of (rough) aligned timing operation, reader and device are not able to communicate well.  Specification impacts, if any  When CW and communication is different frequency,the timer value related to "when Msg 0 and/or 2 and/or 4" are to be sent. |

**Table 6.2.2-18: Details from Source [27, R1-2408648]**

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| **Source** | **Details** |
| **Source [27]** | Solution description  R2D signaling indicating a device to go dormancy and the allowed time duration.  R2D wake-up signal to instruct a device to transition into an active state and monitor a potential R2D transmission.  Direct indication of the one or more timers described under Direction 1.  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  N/A |

**Table 6.2.2-19: Details from Source [30, R1-2408702]**

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| --- | --- |
| **Source** | **Details** |
| **Source [30]** | Solution description  Applicable to both Device 1 and Device 2 (higher power devices)  Reader provides counter information in R2D transmission for slotted-ALOHA mechanism  Includes periodicity information of potential Reader command occasions (or expected device monitoring occasions)  Remaining energy estimation and report of the information by device  Scheduling commands provide end timing information for R2D reception or D2R transmission (utilization of remaining energy information)  Observations or Analysis or Evaluations  Necessary for resolving unavailability impact on slotted-ALOHA mechanism.  Helps devices align to periodic occasions of potential Reader commands.  Allows devices to estimate remaining energy and adjust behavior accordingly.  Enables Reader to optimize communication based on device energy information. Examples to improve successful R2D or D2R transmissions,  Small payload: Higher priority for devices with low remaining energy  Large payload: Higher priority for devices with high remaining energy  Addresses challenges when devices are scattered in a wide region with unaligned availability.  Specification impacts, if any  Define format for counter information in R2D transmission.  Specify periodicity information format for potential Reader command occasions.  Define end timing information format in scheduling commands.  Explicit: Indication of transmission time/length  Implicit: Derived from TBS and data rate indicated  Establish protocol for devices to report remaining energy information to Reader.  Design of initial R2D periodicity to ensure efficient initial contact with unaligned devices. |

**Table 6.2.2-20: Details from Source [33, R1-2408788]**

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| --- | --- |
| **Source** | **Details** |
| **Source [33]** | Solution description  Device provides information on when paging/re-paging are potentially transmitted, and device wakes up based on the information.  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  E.g., what kind of information is provided and how/when.  E.g., detailed conditions to wake-up in consideration of energy storage status and the indicated information.  E.g., device monitors temporarily periodic R2D sync signals. |

**Table 6.2.2-21: Details from Source [34, R1-2408852]**

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| --- | --- |
| **Source** | **Details** |
| **Source [34]** | Solution description  Device duty-cycle monitoring (DCM)  Observations or Analysis or Evaluations  We believe a feasible solution for all A-IoT devices is device duty-cycle monitoring (DCM). The essence of DCM is quite simple: A device shortens/controls the available time duration. Outside the available time duration, the device is unavailable, and harvests energy from RF without communication activities.  A benefit of device DCM is that the device unavailable time duration becomes shorter.  Figure B1 illustrates an image of how inventory procedure with DCM looks like. Similar to the case of direction 1, different devices may become available at different timings due to different energies. However, by shortening/controlling device available duration, DCM enables much shorter available/unavailable cycles for a device. In case of inventory, devices can receive msg-0 from the reader at very early stage of the inventory procedure that the reader tries.    Fig. B1 Duty-cycle monitoring (DCM)  Even after a device joins the inventory procedure running by a reader, the DCM can still work for longer sustainable operation. For example, in an inventory procedure that has multiple contention-access procedures, if a device has received msg-0 and transmitted msg-1 but failed to receive the corresponding msg-2, the device can consider the current contention-based access has failed and expect another msg-0 reception in future for the retry. If the device knows the reader’s msg-0 periodicity/frequency, or the expected available/unavailable cycle for the device, the device can behave such that it can make use of DCM to save the energy consumption as an example being illustrated in Fig. B2.    Fig. B2 DCM example after a device joins inventory procedure from a reader  DCM can be realized by a device by counting the time after it becomes available and switches the device state from available state (ON state) to an unavailable state. As for the unavailable state, two options can be considered. The first option is to define a SLEEP state. During the SLEEP state, the device may retain a certain memory and run a low-power sleep clock (e.g., 30kHz) while harvesting energy from RF. With the SLEEP state, the device is able to identify when it should be available (switch to ON state) again.    Fig. B3 Switch between ON state and SLEEP state  The other option to realize DCM is to use OFF state as the unavailable state. In the OFF state, the device may not retain a memory and may not run a clock. Therefore, the device is not able to control the unavailable time duration. The unavailable time duration is determined by the time to charge the energy storage until the ‘Turn-on’ threshold, which depends on Rx power, RF-EH efficiency, and the amount of energy consumed during available time duration.    Fig. B4 Switch between ON state and OFF state  Observation B1:   * Direction 2 is the case where a reader has some ideas on when/how a device is available/unavailable, and possibly is able to control the device availability/unavailability. * As a solution, device duty-cycle monitoring (DCM) is promising. * For DCM, a device shortens/controls the available time duration, and for outside the available time duration, the device is unavailable and harvests energy from RF without communication activities. * The device counts the time after it becomes available and switches the device state from available state (ON state) to an unavailable state. * As for unavailable state, two options can be considered: * Opt.1: SLEEP state * In the SLEEP state, the device may retain a certain memory and run a low-power sleep clock (e.g., 30kHz) while harvesting energy from RF * In the SLEEP state, the device is able to identify when it should be available (switch to ON state) again * Opt.2: OFF state * In the OFF state, the device may not retain a memory and may not run a clock while harvesting energy from RF * In the OFF state, the device is not able to identify when it should be available (switch to ON state) again * The device is switched from OFF state to ON state once the amount of energy in the storage reaches the ‘Turn-on’ threshold * An appropriate DCM operation enables efficient energy usage of a device and reduced unavailable time duration for charging   Let us consider the following readers transmission behavior: (1) before starting inventory, the reader transmits RF for energy harvesting as the pre-inventory charging phase; (2) then the reader starts inventory which contains multiple contention-based access procedures, each of which is triggered by a msg-0.    Fig. B5 Inventory model  In each round, reader transmits a msg-0 triggering of up to M msg-1 transmissions from devices. The contention-based access procedure is assumed to contain following steps:   * Msg-0: Reader transmits a msg-0 that triggers msg-1 transmissions from devices * Msg-0 indicates a set of msg-1 resources * Msg-1: A-IoT device that has received a msg-0 selects one of the msg-1 resources and transmit msg-1 * Multiple A-IoT devices may select a same resource, in which case collision occurs * Msg-2: Reader transmits a msg-2 as a response to each msg-1 * In case of msg-1 collision, msg-2 reception fails; then the devices does not proceed this round * Msg-3: A-IoT device who has received the msg-2 transmits a msg-3 as a response to the msg-2 * Msg-4: Reader transmits a msg-4 as a response to the devices that were successfully identified     Fig. B6 The model of random-access procedure for each msg-0  Other assumptions/parameters are listed in the table below. For simplicity, we assume following:   * All devices are assumed to have same Rx power, -28dBm or -32dBm, same RF-EH efficiency * Separate evaluations for device 1 and device 2 (no mixed scenario)   The baseline is no DCM. For DCM, we evaluated two cases.   * Case 1: SLEEP-based msg-0 monitoring before the device joins inventory * Device switches ON state and SLEEP state until it detects msg-0 first time * Device uses SLEEP state during contention-based access procedures after it detects the first msg-0 whenever possible * This enables controlled duty-cycle monitoring all the time * However, SLEEP state consumes a certain amount of energy for sleep clock/memory, leading to long unavailable time duration when device cannot sustain SLEEP state due to low Rx power * Case 2: OFF-based msg-0 monitoring before the device joins inventory * Device switches ON state and OFF state until it detects msg-0 first time * Device uses SLEEP state during contention-based access procedures after it detects the first msg-0 whenever possible * This enables controlled duty-cycle monitoring after the first msg-0 detected * Until a device detects msg-0 first time, there is no/negligible power consumption during OFF state   Note that in both cases, if a device consumes all the available energy during ON or SLEEP state, the device is in OFF state until it is fully charged.    Fig. B7 Case 1 and Case 2 of DCM  Table B1 Evaluation parameters/assumptions    In Fig. B8, X = 0 is the time that the reader starts inventory (the timing that the first msg-0 is transmitted by the reader), and Y-axis indicates the ratio (%) of A-IoT devices that are not yet completed the contention-based access procedure. Fig. 9 shows that in case no DCM, the ratio of non-inventorized devices linearly decreases as the time from the start of the inventory increases. This is because available time of different devices are distributed in time and hence in each msg-0 timing, some devices are available. However, this implies that when the reader starts inventory, there can be devices that has almost zero available energy. Such devices are accessible only after they are charged until ‘Turn-on’ threshold. This is observed as the bottleneck, i.e., inventory completion time from the reader perspective cannot be better than the charging time for these unavailable devices.  On the other hand, DCM achieves much shorter inventory completion time. This is because the device unavailable time is much shorter than the case of no DCM. Between two cases of DCM, case 1 DCM is sensitive to the Rx power; it can achieve much shorter inventory completion time under relatively high Rx power (e.g., > -28dBm) compared to no DCM, while it requires similar completion time as no DCM with low Rx power (e.g., < -30dBm). This is because SLEEP state is assumed to consume a certain power. The actual gain of Case 1 DCM highly depends on power consumption of SLEEP state. On the other hand, case 2 DCM offers significant performance benefit for all the evaluated cases.    (a) Device 1, Rx power = -28dBm    (b) Device 1, Rx power = -32dBm    (c) Device 2, Rx power = -28dBm    (d) Device 2, Rx power = -32dBm  Fig. B8 Performance evaluation of inventory with and without duty-cycle monitoring  Observation B2:   * Simulation results indicate that duty-cycle monitoring is essential for A-IoT to complete inventory in a reasonable time duration. * Case 1 DCM is sensitive to Rx power (or RF EH efficiency) since SLEEP state consumes a certain power; it works if Rx power (or RF EH efficiency) is relatively high. * Case 2 DCM works with various range of Rx power (or RF EH efficiency). * With no DCM, inventory completion time is limited by device charging time for large amount of energy (from ‘Turn-off’ threshold to ‘Turn-on’ threshold)   Specification impacts, if any  For direction 2, specification impacts can be considered for reader and/or device perspective. For example, if msg-0 transmission periodicity/frequency for contention-access procedure is specified (or is designed as configurable), the device DCM operation can be designed to fit with that. On the other hand, if device DCM related behaviors, such as the duration of ON state or duty-cycle periodicity, are specified (or are designed as configurable), the reader’s inventory/communication procedure can be designed to fit with that.  Further, accuracies of device ON state duration and/or SLEEP state duration would need to be understood. If the device clock error is assumed to be quite large, e.g., +/- 10%, for DCM operation, the uncertainty of timings/durations may need to be taken into account in the specifications related to resource/timing.  Observation B3:   * For direction 2, impacts on specifications and designs are envisioned. * If msg-0 transmission periodicity/frequency for contention-access procedure is specified (or is designed as configurable), the device DCM operation can be designed to fit with that. * If device DCM related behaviors, such as the duration of ON state or duty-cycle periodicity, are specified (or are designed as configurable), the reader’s inventory/communication procedure can be designed to fit with that. * Accuracies of device ON state duration and/or SLEEP state duration would need to be discussed. * If the device clock error is assumed to be quite large, e.g., +/- 10%, for DCM operation, the uncertainty of timings/durations may need to be taken into account in the specifications related to resource/timing. * SFO correction (clock calibration) framework would offer better clock accuracy such as clock error of < +/-10% for direction 2. |

**Table 6.2.2-22: Details from Source [36, R1-2408920]**

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| **Source** | **Details** |
| **Source [36]** | Solution description  For direction 2, the reader can control the time of ON and Sleep and the device will switch the states. As shown in Figure 1, when the energy storage is full or reaches a certain level, or the device receives a RF power larger than an activation threshold, the device switches to ON to detect the R2D signal and transmit the D2R signal. By explicit or implicit way, for example, indicated by the reader, the device switches to Sleep state from ON state. After the sleep time, the device switches to ON. Additionally, it is possible that the device switches to OFF state from ON/Sleep state if the energy storage is not enough.    Figure 1 An illustration of device’s states  Observations or Analysis or Evaluations  N/A  Specification impacts, if any  The device’s states transition, including the device behavior in each state, the explicit or implicit indication, transition time, etc.  The energy status reporting from the device  Impacts of random access procedure  If the RF energy source is applied, the impacts in proposal 19 can also be considered. |