Summary and recommendation for AMP IoT

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Abstract

This presentation summarizes the design of ultra-low energy consumption, ultra-low complexity and battery-less AMP devices with energy harvesting.

Motivation： Battery-less and Maintenance-free Devices

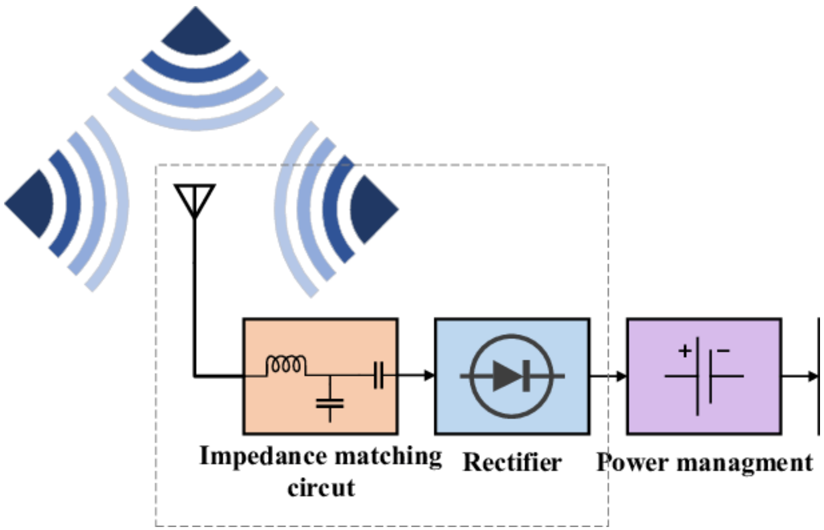
- The Wi-Fi IoT network is competitive from deployment cost perspective, thanks to widespread deployment and use of unlicensed frequency band.

- However, there remain lots of use cases and applications that can not be addressed using existing Wi-Fi IoT technologies:
  - a device powered by a conventional battery is not applicable, e.g., under extreme environmental conditions (e.g., high pressure, extremely high/low temperature, humid environment) or maintenance-free devices are required (e.g., no need to replace a conventional battery for the device)
  - ultra-low complexity, very small device size/form factor (e.g., thickness of mm), and longer life cycle etc. are required

Solution: Support AMP WLAN Devices

- A new type of WLAN devices, which is powered by ambient power such as radio waves, solar, heat, vibration etc., is a promising way to fulfill the unmet requirement and enable many to-B and to-C applications.

- The device is powered by energy harvested from a variety of ambient power sources including radio waves, light (sunlight), motion, heat, etc. → the conventional battery can be removed
- Ultra-low power consumption: typical peak power less than 1 mw due to the low ambient power density
- Smaller size and ultra-low complexity → low cost massive deployment

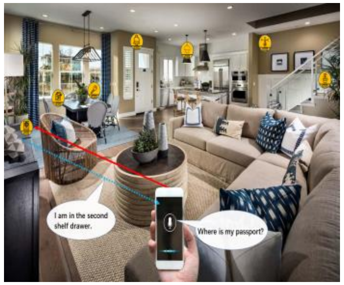


Note: The standardization of AMP devices have begun in global standardization organizations, e.g., 3GPP begin to study ambient power-enabled IoT since Rel-19 [S1-220192 New SID: Study on Ambient power-enabled Internet of Things, OPPO]

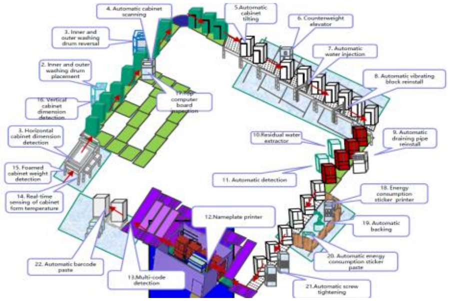
Why support AMP WLAN device in 802.11

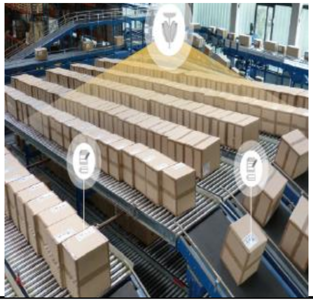
- From technical perspective, there are many advantages to support AMP IoT in 802.11
  - Many emerging implementations in 802.11 network demonstrating both feasibility and technical/business potentials [15]
  - With potential enhancement, the legacy infrastructure can be reused [13]
  - Easy for AMP function design by building upon the existing 802.11 features, such as 802.11ba, 802.11ah and legacy 802.11 power management mechanism.
    - Minimize design efforts by reusing the existing mechanism, e.g. 802.11ba WUR and OOK, simplified 802.11ah MAC, access control mechanism. power management mechanism, etc.
- From business perspective, AMP devices and Wi-Fi eco-system are mutually beneficial
  - Create new IoT service opportunities in many to-Business and to-Customer areas by enriching WLAN IoT applications
  - Explore the high WLAN market share and further expand Wi-Fi ecosystem market portfolio
  - Achieve much lower CapEx and OpEx for the verticals with unlicenced frequency band and existing deployment
  - Good matching to the local area deployment requirement

Summary(1): Use Cases



- **Use case 1 Smart manufacturing**: inventory, asset tracking/positioning, and environment/production line sensing and monitoring
- **Use case 2 Data Center**: environmental monitoring, facility monitoring and asset management
- **Use case 3 Smart home**: asset management, home environment monitoring and home security.
- **Use case 4 Logistics and warehouse**: goods tracking and inventory check
- **Use case 5 Smart agriculture**: monitoring of soil moisture, soil fertility, temperature, wind speed, plant growth etc., and controlling of the agricultural facilities
- **Use case 6 Indoor positioning**: positioning in giant shopping mall, factories, warehouses, etc.
- **Use case 7 Smart Power Grid**: Sensing of sound, heat, pressure, etc., smart meter to achieve awareness of device/equipment status
- **Use case 8 Fresh Food supply chain,** Route the RTI, sense temperature etc.





Summary(2): Requirements of the Use Cases

Use case	Coverage	Peak Data rate	Positioning accuracy	Other requirements
#1Smart manufacturing	30m indoor 100m outdoor	100kbps	1~3 m Horizontal indoor	Battery-less Maintenance-free
#2 Data center	30m indoor 100moutdoor	100kbps	-	Battery-less Maintenance-free
#3 Logistics/Warehouse	10-30 m for indoor case	-	1~3 m Horizontal indoor	Battery-less, Maintenance-free 99.5% identification accuracy Ultra-low cost and ultra-small size
#4 Smart Home	10m	-	1~3 m Horizontal	maintenance-free Battery-less Long service life., e.g., more than 10 years Low complexity and small size
#5 Smart Agriculture	30m indoor, 200m outdoor	-	-	Battery-less, Low complexity and small size, Processing (i.e., reading IDs) hundreds to thousands of devices per second
#6 Indoor positioning	10-30 meters indoor	-	1~3 m horizontal accuracy and 1~2 m vertical accuracy	Small size, maintenance-free, battery-free, and ultra-low-cost IoT devices; Moving speed: 1.5-2 m/s
#7 Smart Grid	10-30 m indoor, up to 200 m outdoor	20kbps for sub-station, 3kbps for high voltage transmission line.	-	Maintenance-free and battery-less
#8 Fresh Food Supply Chain	10-20m	0.12bps		Maintenance-free, ultra low cost, sticker form factor with low BOM Traffic interval =15 minutes

Summary(3): Gap analysis for the Use Cases

Use cases	Issues for state-of-the-art solutions	Benefits of AMP IoT
#1 Smart manufacturing #2 Data center #3Logistics/Warehouse #8 Fresh Food Supply Chain	1. Manual scanning of labels of barcode or RFID tags for inventory/attendance check 2. Massive deployment of readers due to short communication distance 3. Limited performance on communication distance, system efficiency 4. No IP stack is defined.	1. Automatic scanning 2. Lower density deployment of APs 3. Improved performance in terms of communication distance, sensitivity and system efficiency 4. Battery-less and Maintenance free 5.Inherent, standardized and secured internet connectivity 6. Location services
#4 Smart Home	1. Need to replace battery for many devices 2. High cost/ larger size for applications such as finding small items at home	1. Battery-less and Maintenance free 2. Small size/low cost to support more applications 3. Support positioning 4. Enable communication between non-AP STA (e.g., smart phone) and AMP IoT devices
#6 Indoor positioning	1. High deployment cost for indoor navigation and positioning systems 2. High maintenance cost	1. Small size/low deployment cost 2. Enable positioning by non-AP STA (e.g., smart phone), with 1~3m horizontal positioning accuracy 3. Battery-less and Maintenance free
#5 Smart Agriculture #7 Smart Grid	1. Power supply with wire cable or battery is needed for sensors 2. High maintenance cost 3. Inaccessible in case of and hazardous operation conditions	1. Battery-less so that deployment of AMP IoT devices can be flexible and low deployment cost 2. Maintenance free 3. Lower device cost

Summary(4): Device types

❑ AMP-only WLAN device

- Ultra-low complexity, ultra-power consumption, very small form factor
- Battery-less (i.e., not using conventional battery) and may not need power storage or has limited power storage only (e.g., a capacitor).

❑ AMP-assisted WLAN device

- Higher power storage capability than AMP-only WLAN device
- Similar as legacy 802.11 (e.g., 802.11n/11ah) device and can reuse the current PHY design but with enhanced MAC features to well adapt to operation with a specific kind of ambient power.
- Optimized for the power consumption and sustainability to adapt to ambient power usage and achieve maintenance-free

Summary(5) :Candidate Techniques

❑ Candidate Techniques

- **Narrow bandwidth operation**
- **Simpler waveform/modulation/coding scheme**: OOK/FSK, Manchester coding, etc.
- **Backscattering**
- **Light-weight MAC protocol design and enhanced power saving/management**:
- **Coexistence schemes with legacy devices**

❑ Potential Techniques combinations:

- **AMP-only WLAN devices**: Ultra-low power receiver + Backscattering/Ultra-low power active transmitter + Simplified MAC+ Enhance power saving
- **AMP-assisted WLAN devices**: Legacy PHY design with MAC enhancement

Summary(6): Ambient Power and Energy Storage

- **Ambient power**
  - RF
  - Solar
  - Thermal
  - Vibration

Energy Source	Method	Power Density	Application Environment	Energy Conversion Factors	Feature	Advantages	Disadvantages
Radio Frequency	Antenna	0.1~10 μW/cm^2 (Artificial)	(Semi-)urban environments; Dedicated transmitter setup;	Source transmission power; Distance from source; Antenna gain; Antenna design;	Partly controllable Partly predictable	Ambient or dedicated techniques; High conversion efficiency; Available anywhere;	Requires tuning to frequency bands; Energy availability limited by safety; Distance dependent; Low-power density
		0.001(WiFi)~0.1(GSM) μW/cm^2					
Solar	Photovolatic	10~100 mW/cm^2 (Outdoor Sun Light)	Natural light; Brightly lit indoor spaces;	Light intensity; Temperature gradient; Material properties;	Uncontrollable Predictable	High voltage output; Predictable; Low fabrication costs	Long periods of natural absence; Natural prediction limited; Unavailable at night and non-controllable;
		10~100 μW/cm^2 (Indoor Art. Light)					
Thermal	Thermoelectric	20~60 μW/cm^2	Industrial waste heat; Household water; Domestic heaters; Body heat;	Spatial temperature gradient; Temporal temperature gradient; Cycle frequency;	Uncontrollable Predictable	Long life due to stationary parts; High reliability;	Requires constant thermal gradient; Low conversion efficiency; Performs poorly on small gradients;
Mechanical Vibration	Electromagnetic	300-800 μW/cm^3	Industrial machinery; transportation; Human activity; Roads and infrastructure;	Vibration frequency; Vibration acceleration;	Partly controllable	High-output currents; Robustness; Low-cost design; Controllable	Relatively large size; Unpredictable;
	Electrostatic	50-100 μW/cm^3				High-output voltage; Possibility to build low-cost devices	Requires bias voltage; Unpredictable
	Piezoelectric	4-250 μW/cm^3				High voltage output; High power density; Simplicity design and fabrication	Highly variable output; Unpredictable;

- **The ambient power lacks of stability and the power density is limited.**
  - Energy storage element is needed for some AMP IoT devices.
- **Capacitor and solid-state battery can be considered as the possible energy storage elements.**

Summary(7): Feasibility of support AMP WLAN devices

- **Preliminary link budget for different AMP WLAN device types**
  - Communication distance of up to 180 meters can be achieved in Sub-1 GHz and up to 50 meters for 2.4 GHz [Section 4.4.1, 12]
- **Co-existence with legacy 802.11 systems**
  - AMP device can co-exist with legacy devices in both Sub-1 GHz and 2.4 GHz
- **Carrier generation for backscattering**
  - Wideband carrier signal spanning the whole channel bandwidth, e.g., the signal spanning across the 20 MHz channel bandwidth at 2.4 GHz
- **Regulation considerations**
  - Based on the review of the frequency regulation in US, EU, China, etc., the intended use-cases can be covered.

Summary(8): Prototype Presentation(1)

- Several prototypes are collected to show the potential communication techniques, the applicable ambient powers and the achieved performance.
  - Prototype using RF power and backscattering (Figure 2/3) [11]
  - Prototype using thermal energy (Figure 4) [11]
  - Prototype using induced current (Figure 5) [11]

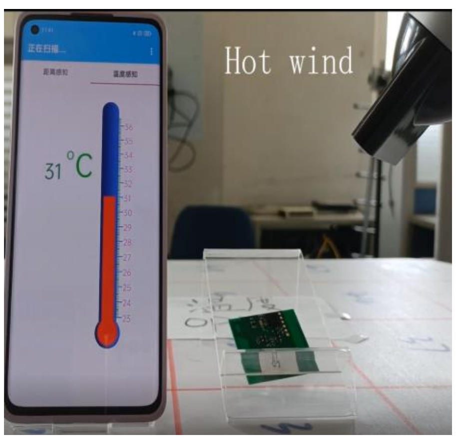


Figure 2

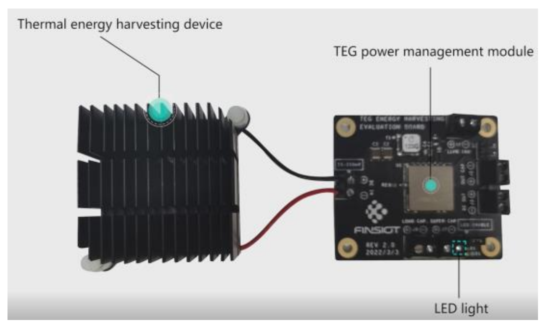


Figure 4

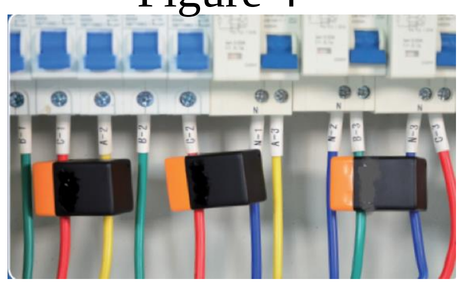


Figure 5

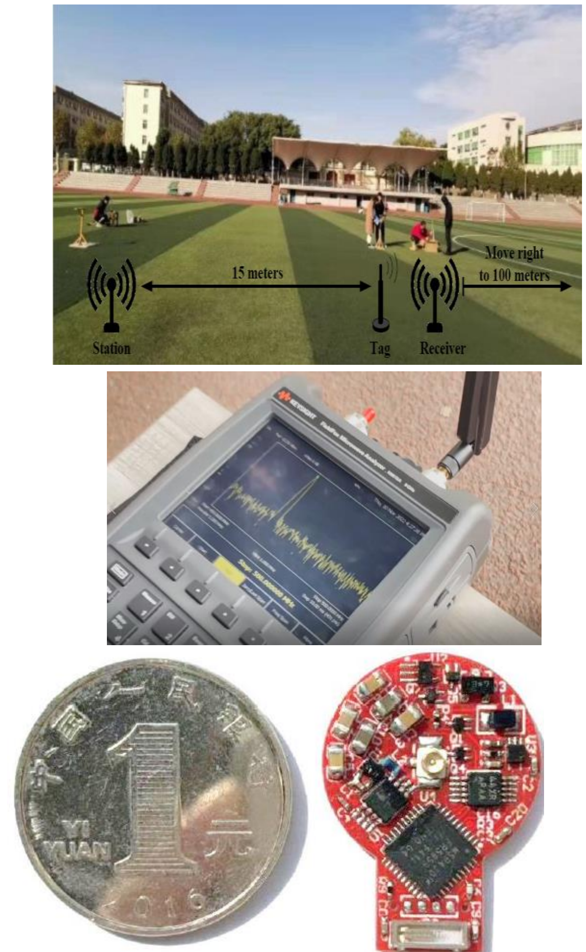


Figure 3

Summary(8): Prototype Presentation(2)

- 802.11 compatible backscatter prototype(Figure 6) [15]
- RF energized ultra-low power ambient device

  Demo (Figure 7) [14]
  - Ultra-low power transmitter and high sensitivity RF energy harvester

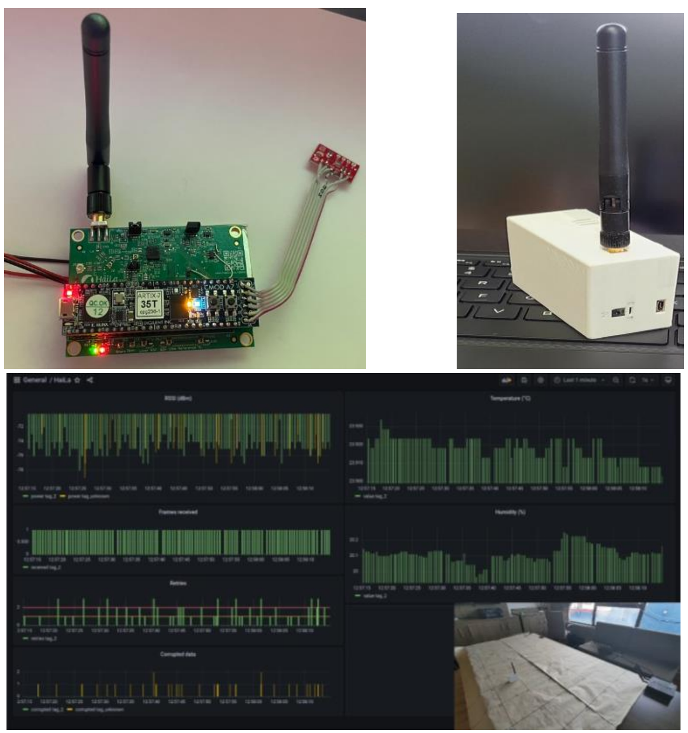


Figure 6

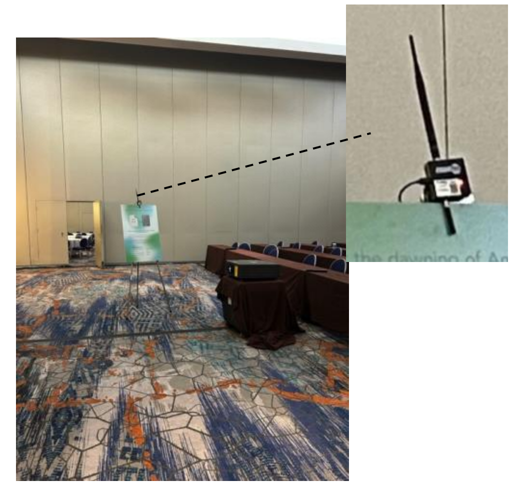
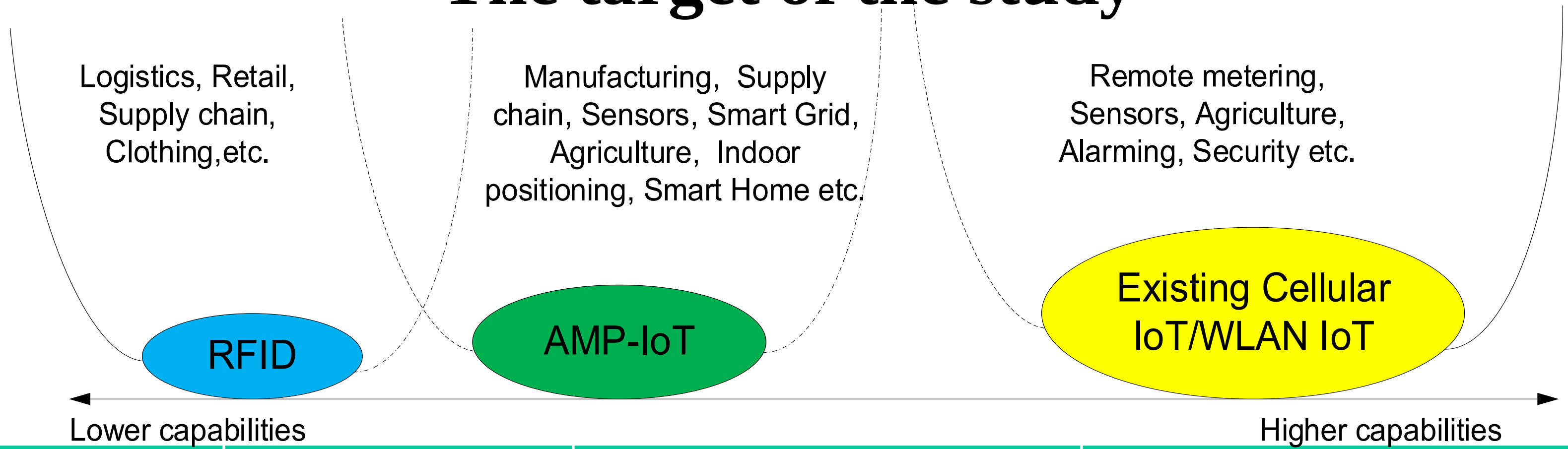


Figure 7

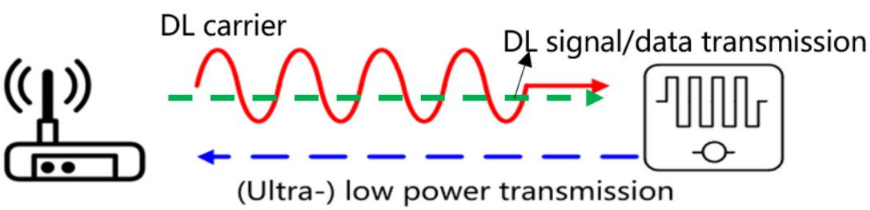
The target of the study

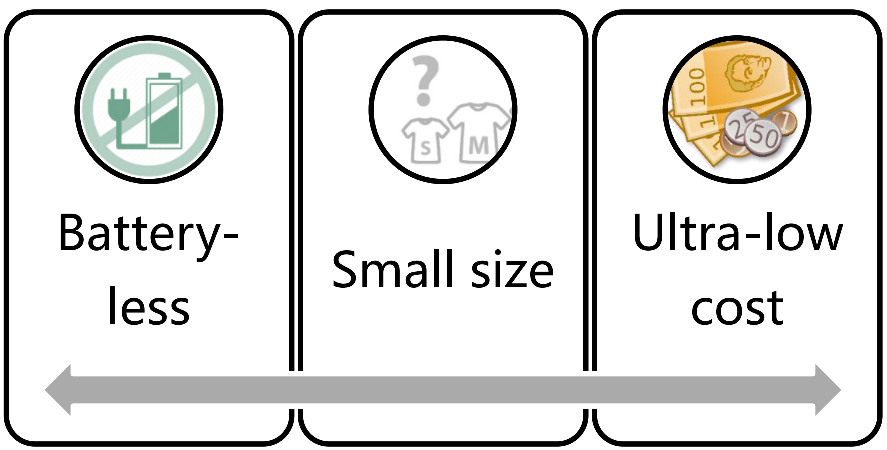


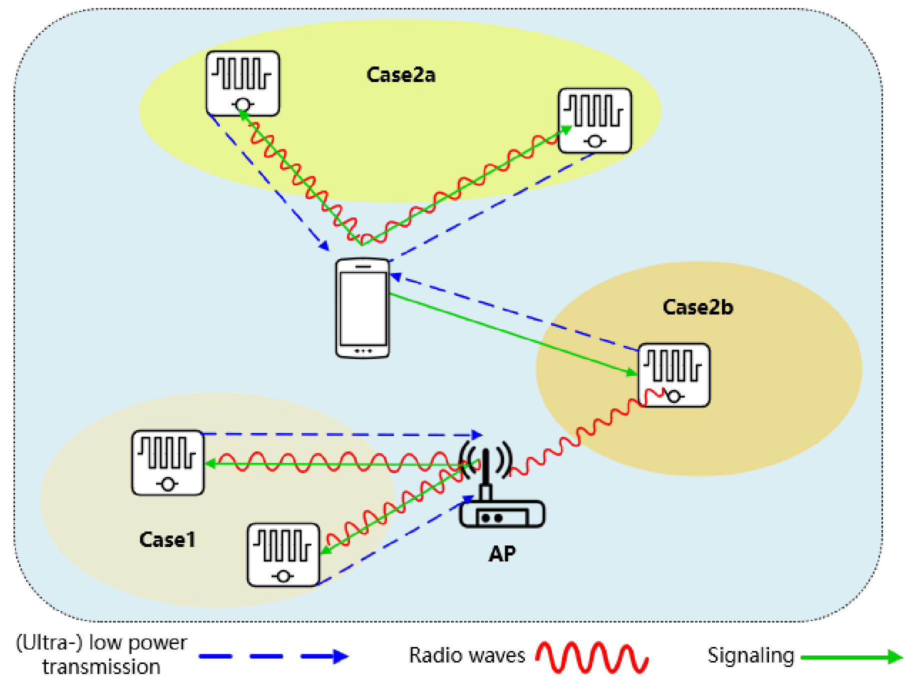
	RFID	AMP WLAN device	Existing WLAN IoT(e.g. 802.11 ah)
Coverage	**<10 m**	**10m~30m (RF power);** **Up to 200m(other ambient power)**	**>=1000m**
Power Source	**RF power only**	**Various ambient power**	**Battery**
Techniques	**RF power harvesting** **Backscattering**	**Backscattering/Active transmitter** **WUR receiver** **Enhanced power saving** **Power management**	**OFDM** **Narrow bandwidth** **Relaxed processing** **eDRX(TWT)** **PS-Poll** **Energy limited operation**
Power Consumption	**1uw~10uw**	**<1mw**	**100x mw**
Device Cost (Relatively)	**Low**	**Medium**	**High**
Maintenance/operation cost	**Labor cost for operation**	**Maintenance-free** **Automated operation**	**Replace/Recharge the battery/Automated operation**

Overview of Ambient Power Enabled IoT for WLAN

Design targets: support both the communication between AP and the AMP devices and the communication between mobile AP and the AMP devices







Study scope for AMP IoT SG(1)

- To support an ultra-low-power-consumption AMP device in WLAN, e.g. peak power consumption for transmission and reception is lower than 1mw.
  - PHY: WUR(100x uW) + Simplified UL PHY (10x uW~100x uW)
    - In the DL, WUR(802.11ba) like design as the starting point.
      - Reuse legacy design as much as possible, such as OOK, channel structure, waveform, PPDU formats, etc.
      - Additional signaling in WUR to transmit additional signaling or payload data.
      - Some re-design may be necessary if AMP in WLAN is implemented in frequency band other than 2.4GHz, e.g., Sub-1 GHz.

      Note: Other schemes than 802.11ba are not precluded if useful.
    - In the UL, legacy design as a starting point for the UL PHY, e.g., 802.11ba OOK, 802.11b DSSS modulation, etc.
      - Both active transmitter and backscatter transmitter can be supported.
        - The carrier for backscattering shall be specified considering the regulation requirement
        - Optimizations for full-duplex operation in case of backscatter modulation can be considered

        Note: other schemes, e.g., FSK/PSK are not precluded if useful.
      - The carrier and bandwidth of backscattering signal should be specified including signal of narrow bandwidth or wide bandwidth and carrier signal using the existing signal can also be considered.

Study scope for AMP IoT SG(2)

- MAC: Simplified MAC + Enhanced power saving/ power management (Note 2, Note 3)
  - Efficient PLCP and MAC for limited payload message sizes, e.g., 100bits.
  - Coordination of AMP device channel access (e.g., may not be able to use conventional CSMA-like approaches since backscattering devices potentially undetectable by other devices)

Note 1: Energy harvesting (except RF power) is based on implementation and can be transparent to specification. For RF power, TBD.

Note 2: Use of existing 802.11 MAC wherever possible with necessary modifications and extensions to support AMP specific requirements.

Note 3: Enhanced power saving/ power management mechanism can be extended to existing Wi-Fi devices.

Note 4: Consider Sub 1 GHz and 2.4GHz frequency band. The existing frequency regulations need to be complied with.

Note 5: Other issues such as additions to the optimized security measures to enable battery free operation will also be considered if necessary.

Summary

- **This submission summarize the work of AMP IoT, including:**
  - Use cases and the requirements
  - Gap analysis of the use cases and benefits from AMP IoT
  - Device types
  - Candidate techniques and the feasibilities
  - Prototype presentations

- **Based on the above work, it is recommended to form a study group (SG) to further study AMP IoT and develop the PAR and CSD documents**

Reference

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