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Wireless LANs

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| Long Range Low Power (LRLP) Operation in 802.11: Use Cases and Functional Requirements: Guidelines for PAR Development |
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Abstract

This document contains the output of the Long Range Low Power TIG, intended to describe the use cases, requirements, and technical feasibility of Long Range Low Power operation in 802.11.

**Introduction**

The evolution of 802.11 has brought a series of amendments increasing the throughput. New use cases can be enabled by extending the standard in the other direction, towards longer range and lower power at lower rates. LRLP defines new functionality to support Smart Grid, IoT, and a variety of other use cases that cannot be met by 802.11 currently. The key aspect of LRLP that distinguishes it from other standards or other 802.11 PHYs is the integration with broad-market 802.11 infrastructure. LRLP is intended to be implemented at zero incremental cost into next genearation of 802.11 silicon used in APs and routers. Eventually the capability will be universally available. This is the reason for the primary focus on the 2.4 GHz band for LRLP. It remains the one default band for entry level, cost constrained equipment. LRLP does not exclude other PHYs and bands, however. The expectation of universal support in commodity infrastructure, and the Internet connectivity that such infrastructure provides, is an essential part of the value proposition for LRLP. Other standards require deployment of a radio embedded in the device, as well as another radio device and some type of bridging or routing to provide connectivity to the Internet. The other key value of LRLP is the ability to define an asymmetrical STA and AP. An LRLP-only STA can have a simpler implementation, with lower cost and lower power consumption, compared to a full 802.11 STA. Finally, the operating characteristics of an LRLP device can be parameterized to optimize for long range or low power. Both extremes of LRLP devices, as well as standard 802.11 devices, can all operate simultaneously in a BSS connected to an LRLP-enabled AP.

This document summarizes contributions on LRLP Use Cases, Metrics, Requirements, and Technical Feasibility that were discussed in the LRLP TIG.

* **LRLP use cases and metrics**
	1. Smart Grid [11]
		+ Residential and commercial demand response load control: Smart Thermostats, hot water heaters, pool pumps, etc
		+ In-home energy displays and gateways
		+ Smart Charging for electric vehicles
		+ Smart inverters for solar photovoltaic systems
		+ Residential and commercial energy storage management
	2. IoT
		+ Home Theater [4]: Indoor use case where audio and video devices in a smart home connect to the LRLP AP
		+ Home Security [4]: Indoor use case where the home security appliances (smoke detector, glass sensor, gas sensor, etc.) connect to an LRLP AP for enhanced protection
		+ Indoor Device Control [4]: Indoor use case where the devices equipped with LRLP STAs are remotely controlled
	3. At-home [12]: Use case discusses about point-to-point with single aggregation point among devices for smart lighting and climate control, smart-access and security, connectivity of smart appliances in home, activity detection, smart phone detection, and smart display and control Building Energy Management Systems (BEMS) [5]: Indoor use case with the heating, ventilation, and air conditioning (HVAC) within a building is centrally controlled remotely through the LRLP AP
	4. Full function in STA [6]: An indoor use case where legacy STAs equipped to operate in LRLP mode use the LRLP network for extended range
	5. Industrial Connected Worker [7]: An indoor use case where workers within an industrial floor are equipped with LRLP devices communicating with an LRLP AP
	6. Precision Agriculture [7]: An outdoor use case where LRLP STAs distributed in a farmhouse exchange data with a centrally located LRLP AP
	7. Drone for Aerial Imaging [13]: Transmisison of low resolution image of 4k recorded video at the drone to a remote AP
	8. Digital Health [8]: Two use cases discussed on health care and wellness;
		+ Assisted living - The LRLP device delivers a user’s movement and vital sign data to the health cloud monitored remotely; the user may also wear an LRLP fall-down analyzer, which detects falling down event and sends an alert to the facility personnel’s pagers using facility’s Wi-Fi network
		+ Medication reminder – User possessing an LRLP-capable medicine dispenser that detects when medicines are scheduled to be taken and sends alert to the user’s personal device

**Metrics**

**Data transmission rate:** Lowdata throughput typical of applications in sensor or actuator networks, e.g., 100kbps of limited size file transfer

**Transmission range:** Increased transmission range must be accomplished despite a fixed transmit power.

**Peak power consumption:** This metric controls the power consumption during activity periods in specified duty cycle of LRLP operation

* + - Battery life:Battery life time is directly related to capacity and is measured in mAh (mA hours)
			* Capacity is dependent on rate of discharging the battery (e.g., 230-240mAh at 500uA rate of discharge, while 150mAh at 3mA rate of discharge)[[1]](#footnote-1)
			* Capacity is dependent on pulse duration (ON time of an LRLP device)

**Average current consumption:** Battery life time is inversely related to this metric and is measured in mA. Lower average current consumption for a fixed battery capacity improves battery life time

**Fast link set-up**: Fast link set-up is related to fast authentication and association procedure that applies to low power LRLP devices

**Reliable data delivery**: Data exchange between LRLP devices need to be exchanged securely

**Power efficienct network discovery**: This metric is directly related to the active scanning procedure in identifying APs for potential association

**Latency of a packet reception**: Latency is measured in milliseconds (mS). Average power consumption of a STA is inversely proportional to the latency of a packet reception [10].

* **LRLP requirements**
	1. Integration and backward compatibility with legacy 802.11 [2]
		+ LRLP AP has both HE/legacy and LRLP capability to ensure WLAN coexistence
			- The 2.4 GHz band is the primary objective, although other bands are not ruled out. LRLP is band agnostic.
		+ Mechanisms for Sub20MHz operation
		+ LRLP STA not required to support legacy 20MHz Tx or Rx [2]
		+ I.e. No detection or transmission of legacy preambles required for LRLP STA [3] LRLP AP will be required to support legacy 20MHz Tx & Rx
			- Perform CCA and legacy network access
			- Protect DL LRLP transmissions using legacy preambles
	2. Protect UL LRLP transmissions using legacy preambles sent from the AP to trigger UL traffic from LRLP STAs [3] Long Range (approx. 10dB improvement above existing 20 MHz operation)
		+ Improved coverage edge performance
	3. Ultra Low Power consumption – peak and average current
		+ LRLP non-AP STA supports ultra low power operation
			- Non-AP STAs may be battery-operated or connected to the AC mains; if the devices are battery-operated, the power consumption in active mode has to be minimized significantly with respect to the current Wi-Fi products
		+ Light-weight non-AP STA protocol [2]
		+ Narrowband (e.g., 2MHz) + low MCS only transceiver design can allow power reduction compared to legacy 20MHz transceiver
			- Rx expected to be able to achieve significant reduction (E.g. >50% reduction)
			- Tx reductions expected to be more modest (assuming equivalent Tx power: >10dBm)
			- Listen (LRLP Preamble detect + preamble decode) will target most significant reductions [3]
	4. Fast link set up
		+ There may be significant benefit in defining some form of persistent association (analogous to “pairing” in Bluetooth) that allows much of the association and authentication activities to be optimized once the persistent association is established.
	5. Power efficient network discovery - This metric is directly related to the active scanning procedure in identifying APs for potential association
	6. Reliable data delivery [8] - Data exchange between LRLP devices need to be exchanged securely
	7. Low-power consumption and low-latency data delivery [10] – Average power consumption of a STA is less than TBD µW at the latency of a data delivery less than TBD mS

**Subjects for Technical feasibility demonstration**

1. Longer Range

Nominal range of 500m

One technical approach to achieving this is to narrow the occupied bandwidth to 2MHz (for reasons discussed below), using existing OFDM MCS schemes 0-3. Submission [9] has analyzed the link budget for this approach and a range of 500m outdoors and of an additional 1-2 floors and walls indoors appears to be achieveable with this mechanism.

TBD: It is unclear from the presentation regarding link budget whether the stated approach provides sufficient range to meet the stated objective. Additional consideration of the existing presentation and alternative approaches appears to be needed.

* + 1. 10 dB, 20dB stretch goal

2. Ultra Low Power consumption

* + 1. Average power consumption: 50uW
		2. Battery life longer than 5 years. (Note: peak power requirement may dictate battery technology choice. E.G. coin cell may not provide peak power sufficient for longest range)
		3. Low-power consumption and low-latency data delivery
		4. One technical approach to achieve this is to use a LP-WUR (low-power wake-up receiver) described in [10]. It has been shown in [10] that the average power consumption of a STA is less than 10 µW at a data delivery latency at 100 ms. It has been shown in [14] that the OFDM transmitter on the AP can be reused to generate a wakeup packet. It has been shown in [15] that the size of a LP-WUR design by Lund University is approximately 0.07 mm2 in 65nm CMOS.

3. Parameterizable – the longest range and lowest power may not be available simultaneously.

* + 1. Tradeoffs between low power operation and latency.



* + 1. Provides benefits even at limits: e.g. even at the “low power” end, the range is better than legacy, and the power is lower than legacy at the “higher power” end.
		2. For home security use case, fast wakeup and secure reconnection are required.

4. Relatively low aggregate data rate ~ 512Kbps

* + 1. Actual PHY data rate may be higher

5. Details of narrowband transmission and reception

* + 1. A reduced channel width for LRLP may be effective to accomplish both goals of long range and lower power.
			1. 2 MHz is a basic channel width for 802.11ah
			2. 2 MHz is proposed as 802.11ax UL-OFDMA allocation block [1]
		2. APs and Full-function STAs support both 2 MHz and 20 MHz
		3. LRLP-only STA may be designed with a total receiver BW of 2 MHz
		4. Power consumption benefits come from the ELIMINATION of the requirement to receive in a 20MHz (or wider) channel far more than from the ABILITY to receive in a 2MHz channel.
			1. See submission [1] for a preliminary quantification of the possible power savings for RF and digital domain versus 20MHz channel width.
			2. This will enable significant reduction in power consumption when the STA’s receiver is enabled, an attempt to quantify the saving is underway and hopefully will be ready for submission at the January 2016 meeting
				1. No submission on this topic has been received as of Februarh 2016.
		5. 2 MHz Bandwidth at the STA
			1. Support standardized operation of next generation billion IoT devices
				1. Includes remote sensors with coin cell batteries
			2. Design of a narrowband, specifically 2MHz transceiver will provide reduced power consumption when compared to 20MHz transceiver [1]
				1. 25%-52% reduction in RF domain during RX depending on MCS
				2. 4 times reduction in digital domain during RX
				3. Not significant gain in terms of power consumption in TX
		6. Able to leverage MU-MIMO with 10 simultaneous LRLP users in 20 MHz channel for lowest power
			1. Compatibility with the smallest OFDMA channel proposed in 802.11ax
			2. Wideband operation for longest range
				1. If range is limited by multipath, 20 MHz gives better performance
				2. If range is limited by attenuation, narrow channel can be better
				3. If range is limited by frequency selective fading, wider channel is better
				4. If range is limited by adjacent channel, narrow is better
				5. If range is interference limited, narrow is better
				6. Easier to increase TX power in narrow channel
				7. Narrow channel at legal limit is more cost effective and power efficient
		7. Spectrum efficient MAC
			1. Non-AP STAs could be grouped in frequency and time in an efficient way exploiting OFDMA
			2. Protocol overhead (signaling, headers etc.) minimized
		8. Consider whether defining narrowband in terms of sub-multiples of 5 MHz channel spacing in 2.4 GHz band provides benefits.

6. Integration with 802.11

* + 1. Integrated in air interface: Able to operate concurrently with existing network without adverse effect on existing devices
			1. Non-AP STA need not to support HE/Legacy
				1. In order to keep device requirements minimal
			2. AP that supports LRLP also supports HE/Legacy
				1. Minimum requirement for AP would be the ability to protect LRLP transmissions from HE/Legacy transmissions and vice-versa
		2. Integrated into mainstream devices: Does not require additional hardware and components for implementation. Assumes new silicon (aligned with 802.11ax silicon generation)
			1. “Zero” marginal cost for implementation
			2. Available in “all” next-generation 802.11 chipsets
		3. LRLP non-AP STA does not have to support legacy

7. Compatibility with 802.11

* + 1. Mixed BSS of LRLP and non-LRLP supported without introducing degradation or significant interference: Coexistence and limited impact on primary BSS or overlapping BSS.
		2. Protection mechanisms, media occupancy limit, duty cycle limit, etc.
			1. If transmissions by LRLP non-AP STAs occur pursuant to LRLP Trigger frames, the AP is able to enforce the medium occupancy limit
			2. A possible approach to achieving coexistence is to have LRLP STAs transmit during service periods defined by the LRLP AP. See [3] for some preliminary discussion of this mechanism.
		3. Potential Protection Framework
			1. Beacons transmitted in 20MHz for legacy compatibility
				1. LRLP devices unable to decode legacy Beacon (due to range or BW)
				2. Restructure LRLP beacons – shorter, maybe less frequent

Only include elements relevant to LRLP PHY. Minimum of information on BSS and basic capability. Everything else the station requires may be obtained using the Request Element in Probe frames.

The LRLP should have a DTIM in every one of its beacons, with an appropriately longer LRLP beacon interval. The Listen Interval, or something like it, would be available for stations that do not want to wake up for every LRLP beacon

* + - 1. Trigger frames in 802.11ax planned to be sent in 20MHz
				1. 11ax uses trigger frames for MU UL frames
				2. Specialized trigger frames for UL from LRLP devices
			2. AP supervises heterogeneous network of conventional and LRLP (IoT) STAs
		1. Limitation of Impact on Network
			1. Specify Medium Occupancy Limit for LRLP operation
				1. Comparable to full rate packets
				2. Additionally, specify a maximum average time on air (duty cycle).
			2. Intended applications are focused on M2M and IoT
				1. Not for bulk data transfer
				2. Low offered load is assumed

Doesn’t require a low data rate – could be high rate low duty cycle

Use best available rate for link and power constraints

8. Coexistence with other 802 wireless protocols

* + 1. This should differ from other 802.11 PHYs mainly by having narrower occupied bandwidth
		2. A submission is needed on how this narrowband transmission is likely to appear to a wideband receiver

**Technical material needed to initiate standardization**

* 1. Supported combinations of LRLP operation in the 802.11 architecture
	2. Parameterization of features and capabilities for optimizing range or low power.
	3. Comparative study of all low power technologies in use today
	4. To facilitate ongoing technical discussion, especially pertaining to MAC issues, the work in the TIG can be based on a set of proposed mechanisms – less detailed than an actual protocol proposal – which can serve as a basis to analyze both operational benefits and interoperability issues {proposed by Tim Godfrey}.

**References:**

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[3] Technical Feasibility for LRLP <https://mentor.ieee.org/802.11/dcn/15/11-15-1108-00-lrlp-technical-feasibility-for-lrlp.pptx>

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[7] Use Cases of LRLP Operation for IoT <https://mentor.ieee.org/802.11/dcn/15/11-15-1365-00-lrlp-use-cases-of-lrlp-operation-for-iot.pptx>

[8] LRLP Digital Health Use Case <https://mentor.ieee.org/802.11/dcn/15/11-15-1380-00-lrlp-lrlp-digital-health-use-case.pptx>

[9] Link Budget Analysis <https://mentor.ieee.org/802.11/dcn/15/11-15-1308-00-lrlp-link-budget-analysis.pptx>

[10] LP-WUR: Enabling Low-Power and Low-Latency Capability for 802.11

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[11] EPRI Use Case Repository <http://smartgrid.epri.com/Repository/Repository.aspx>

[12] At home, IoT Use Case(s) for LRLP <https://mentor.ieee.org/802.11/dcn/16/11-16-0016-00-lrlp-at-home-iot-use-case-s-for-lrlp.pptx>

[13] Usage Scenarios and Applications for Long Range Wi-Fi https://mentor.ieee.org/802.11/dcn/16/11-16-0058-03-lrlp-usage-scenarios-and-applications-for-long-range-wifi.pptx

[14] LP-WUR (Low-Power Wake-Up Receiver) Follow-Up <https://mentor.ieee.org/802.11/dcn/16/11-16-0341-00-lrlp-low-power-wake-up-receiver-follow-up.pptx>

[15] Discussion of Wake-Up Receivers for LRLP <https://mentor.ieee.org/802.11/dcn/16/11-16-0381-00-lrlp-discussion-of-wake-up-receivers-for-lrlp.pptx>

1. IEEE 11-15/0775r1: Integrated Long Range Low Power Operation for IoT [↑](#footnote-ref-1)