Low power wide-area networking alternatives for the IoT

Richard Quinnell - September 15, 2015

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Wireless network technologies such as WiFi, ZigBee, and Bluetooth are fine for consumer applications of the Internet of Things (IoT), but many civic, industrial, and other IoT applications need to operate over vastly greater territory than these technologies can handle. Cellular and satellite machine-to-machine (M2M) technologies have traditionally filled the gap, but cost, power, and scalability concerns make these choices less appealing for the future. A number of low-power, wide-area networking (LP-WAN) alternatives have arisen that need careful consideration by developers looking to address these wide-ranging IoT applications.

The uses for wide-area IoT technology are legion. Civic infrastructure systems such as parking resources, traffic control, utilities monitoring and distribution control, and environmental monitoring are only a beginning. Agricultural uses such as monitoring of crop conditions and livestock movements need wide-area coverage. Asset monitoring and tracking, from taxicabs to refrigerated produce shipments need regional, national, or even worldwide coverage. Transportation infrastructures such as rail lines and roadways need wide-area monitoring. Even consumer applications such as health monitoring could benefit from having an alternative to cellphones for their wide-area connectivity.

LP-WAN Essentials

While the applications are diverse, they have many common attributes on their network wish lists. These include:

> **Low cost** – Most wide-area IoT applications anticipate a need for many hundreds or thousands of end-node devices for each installation. In some cases, such as city-wide parking space/meter monitoring, the numbers can get into the millions. With such high volumes, unit price is a major consideration in determining the return on investment (ROI) for the application.
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> **Low energy consumption** – Few of the applications for wide-area IoT have the luxury of a local power generator. Most will depend on batteries and some may even need to use energy harvesting. For those with batteries, replacing depleted batteries can represent a major logistical challenge as well as a substantial cost. The longer the battery life in the end node device, the better.
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> **Extended range** – All wireless networks connecting to the Internet need to work through an access point (AP) of one kind or another: gateway, concentrator, or the like.

So an IoT design needs to consider both the endpoint cost and the cost of the access point infrastructure needed to support the application. The network's operating range, or allowable distance from an end node to its access point, can have a significant impact on that infrastructure cost. Range dictates the number and location of access points needed to cover the application's operating area, so in general the longer the range the lower the infrastructure cost.

Scalability – A given installation using a wide-area wireless IoT network may work well and the network may well have the capacity to handle any anticipated single user. But over time it's reasonable to expect that many different installations will be made in the same geographic area. If these different installations share common access points, like cellphones share towers, then the number of devices an access point can support can become a limiting factor and require increases infrastructure to overcome. Even if they don't share access points but do share the frequency spectrum, an increase in installations can erode the operational range of application through increased noise levels. In the worst cases, available channel capacity can fill and prevent new installations from operating at all.

Among the more established wireless networking technologies, only cellular and satellite communications offer the extended ranges that these applications require. Mesh networks such as ZigBee can potentially cover large areas but have limited scalability due to the need to forward traffic.

Unfortunately cellular and satellite communications technologies short in the other attributes. Their radio requirements involve higher energy use and complex protocols that lower battery life and increase cost beyond what many applications can sustain. This arises in part from their history; they were originally designed to handle voice traffic. The networks are ill adapted to handling short data messaging.

Still, some IoT applications and services – often called machine-to-machine (M2M) – did arise to leverage cellular and satellite communications networks. Many of them were based on the CDMA, or "2G" cellular technology. Unfortunately, those networks are now starting to be phased out by service providers in order to free spectrum for more advanced cellular technologies. However, the cellular community has made some strides toward improving the situation for M2M. The most recent specification for LTE (release 12) defined communications Category 0 designed around the needs of M2M traffic. Energy use and cost still remain concerns, however.

This situation has opened a door for alternative approaches to wide-area wireless networking for the IoT, approaches that focus on the low-power, low-cost requirements. At least six different approaches are currently defined with network deployment growing or getting started, and three more are in development. While all these approaches seek to provide the same key core attributes, they have different takes on numerous other system attributes that can affect their suitability for various IoT applications.

Desirable LP-WAN Attributes

These other attributes that vary in importance among applications but still need consideration include:

Roaming – Many applications call for end nodes to be fixed in their position, but others may require that nodes operate while moving within and even across sectors served by different access points. Most wide-area IoT networking alternatives allow movement of nodes from one sector to another, but they can vary in how quickly the network adapts to the altered relationships.

Penetration – Some applications call for the end node to be located inside a building or underground while the access point is in another room or outside and above ground. In these applications the network's range can be considerably reduced by the absorption of walls and dirt. Such absorption is frequency-dependent, with lower frequencies generally offering better penetration than higher ones.

Short message handling – While some IoT applications will need to send substantial amounts of data frequently, many will need to send only brief messages, often infrequently. The ability of a wireless network to handle short messages efficiently can have a beneficial effect on the network's scalability and the end node's energy consumption. Such handling includes any overhead for connection setup, interrogation, acknowledgement, or the like.

Bidirectional communications – Some end nodes may only have a need to report data, not receive commands, so a unidirectional link may seem adequate for such applications. A bidirectional link, however, allows for such things as handshaking with the access point to improve the reliability of data transfers, authentication exchanges for greater security, and with sufficient bandwidth allows for remote software updates and management of end nodes.

Secure communications – Sensitive data will need a secure communications link between end node and access point, but even if the data is not sensitive, security may still be a concern. Without a secure link an IoT application is more vulnerable to such attacks as spoofing, where a fraudulent end node injects false data into the network or a fraudulent access point hijacks end node data.

Higher level services – A given wide-area IoT networking alternative may define any number of levels in the OSI model, from just the physical and data link layers through the application layers. In some cases the network itself is operated and managed by a service provider that leases time on the network to users running their protocols and provides users with cloud services. Other alternatives define only the lower layers and have their access point connect to the Internet or to a private network, leaving the higher OSI layers to the user's choice. In such cases an ecosystem of higher-level service providers usually becomes available over time.

The various low-power, wide-area networking schemes on offer address these many needs and considerations in a variety of ways. Each has made a different choice of tradeoffs among interacting attributes such as battery life, data rate, operating frequency, achievable range, and scalability. Further, they have made different choices around attributes such as security, OSI levels defined, and roaming support. This diversity makes it impossible to provide a comprehensive side-by-side comparison, but it is possible to provide a start.

Comparing LP-WAN Alternatives

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Comparison of Low-Power WAN Alternatives

Name of Standard	Weightless			SigFox	LoRaWAN	LTE-Cat M	IEEE P802.11ah (low power WiFi)	Dash7 Alliance Protocol 1.0	Ingenu RPMA	nWave
	-W	-N	-P							
Frequency Band	TV whitespace (400-800 MHz)	Sub-GHZ ISM	Sub-GHZ ISM	868 MHz/902 MHz ISM	433/868/780/915 MHz ISM	Cellular	License-exempt bands below 1 GHz, excluding the TV White Spaces	433, 868, 915 MHz ISM/SRD	2.4 GHz ISM	Sub-GHz ISM
Channel Width	5MHz	Ultra narrow band (200Hz)	12.5 kHz	Ultra narrow band	EU: 8x125kHz, US 64x125kHz/8x125kHz, Modulation: Chirp Spread Spectrum	1.4MHz	1/2/4/8/16 MHz	25 KHz or 200 KHz	1 MHz (40 channels available)	Ultra narrow band
Range	5km (urban)	3km (urban)	2km (urban)	30-50km (rural), 3-10km (urban), 1000km LoS	2-5k (urban), 15k (rural)	2.5- 5km	Up to 1Km (outdoor)	0 – 5 km	>500 km LoS	10km (urban), 20-30km (rural)
End Node Transmit Power	17 dBm	17 dBm	17 dBm	10µW to 100 mW	EU:<+14dBm, US:<+27dBm	100 mW	Dependent on Regional Regulations (from 1 mW to 1 W)	Depending on FCC/ETSI regulations	to 20 dBm	25-100 mW
Packet Size	10 byte min.	Up to 20 bytes	10 byte min.	12 bytes	Defined by User	~100 -~1000 bytes typical	Up to 7,991 Bytes (w/o Aggregation), up to 65,535 Bytes (with Aggregation)	256 bytes max / packet	Flexible (6 bytes to 10 kbytes)	12 byte header, 2-20 byte payload
Uplink Data Rate	1 kbps to 10 Mbps	100bps	200 bps to 100 kbps	100 bps to 140 messages/day	EU: 300 bps to 50 kbps, US:900-100kbps	~200kbps	150 Kbps ~ 346.666 Mbps	9.6 kb/s, 55.55 kbps or 166.667 kb/s	AP aggregates to 624 kbps per Sector (Assumes 8 channel Access Point)	100 bps
Downlink Data Rate	1 kbps to 10 Mbps	No downlink	200 bps to 100 kbps	Max 4 messages of 8 bytes/day	EU: 300 bps to 50 kbps, US:900-100kbps	~200kbps	150 Kbps ~ 346.666 Mbps	9.6 kb/s, 55.55 kbps or 166.667 kb/s	AP aggregates to 156 kbps per Sector (Assumes 8 channel Access Point)	--
Devices per Access Point	Unlimited	Unlimited	Unlimited	1M	Uplink:>1M, Downlink:<100k	20k+	8191	NA (connectionless communication)	Up to 384,000 per sector	1M
Topology	Star	Star	Star	Star	Star on Star	Star	Star, Tree	Node-to-node, Star, Tree	Typically Star. Tree supported with an RPMA extender	Star
End node roaming allowed	Yes	Yes	Yes	Yes	Yes	Yes	Allowed by other IEEE 802.11 amendments (e.g., IEEE 802.11r)	Yes	Yes	Yes
Governing Body	Weightless SIG			Sigfox	LoRa Alliance	3GPP	IEEE 802.11 working group	Dash7 Alliance	Ingenu (formerly OnRamp)	Weightless SIG
Status	Limited deployment awaiting spectrum availability	Deployment beginning	Standard in development. Scheduled release 4Q 2015	In deployment	Spec released June 2015, in deployment	Release 13 expected 2016	Targeting 2016 release	Released May 2015	In Deployment	In Deployment

The table above (click on the image to download a full-size pdf of the table) offers an overview of the major alternatives currently available or emerging for low-power, wide-area wireless networking for IoT applications. The attributes covered can give developers a quick sense of whether or not an alternative is viable for their application. The table entries must be viewed with caution, however. Most are not as simple as they look, and there is much to keep in mind during evaluation.

> **Frequency band** – These are the wireless frequencies used in the approach. Most are in the ISM bands defined worldwide for unlicensed use subject to local regulations on transmit power, signal bandwidth, and the like. Weightless-W and LTE do have licensing requirements, however, and developers choosing them may need a service provider to be involved. And as mentioned above, frequency affects the penetration an alternative can achieve.
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> **Channel width** – This attribute is a factor in the network capacity available to an application and the scalability of the network as a whole. Some systems offer traditional frequency or time division multiplexing to have end-nodes share channel capacity, but others use frequency hopping or orthogonal modulation schemes to achieve bandwidth sharing. This is an area that needs closer examination by interested developers.
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> **Range** – The ranges given for each alternative are, for the most part, estimates based on ideal or generic conditions and should be viewed with some skepticism. In some cases, though, the networks have been in operation long enough to gather field experience that can provide a reliable empirical estimate. In either case, though, developers needing long range will need to perform more detailed analysis using a link budget that includes

their own values for such factors as the desired signal to noise ratio, antenna gain, absorption, data rate, fading and multipath budget, and the like, to be sure of meeting their range goals. A handy link budget calculator is available from the LoRa Alliance.

End node transmit power – For the most part this value is limited by regulations regarding unlicensed use of the ISM bands. It can be useful in estimating the total energy consumption of an end node, however, when combined with values for packet length and data rate to determine the time spent transmitting, and estimates on how frequently transmissions must occur. Some of these are open to user definition and some are affected by the elements of the network's operating mode over which the user has no control.

Packet size – How much data an end node can send or be sent varies widely among the approaches. Many allow users to define the size of the payload, but some, like SigFox, have hard limits.

Uplink/downlink data rates – The speed at which an end node sends data affects many other calculations, including such things as the energy budget (via time spent transmitting), range attainable (Shannon's Law relating data rate, bandwidth, signal to noise ratio, and bit error rate), and fading budget in the link calculations. Some alternatives, like the LoRaWAN, employ an adaptive data rate scheme managed by the network server to optimize the system's capacity. Downlink data rates determine the feasibility of remote software updates, handshaking and authentication protocols, and the like.

Devices per access point – How many end node devices a given access point can support can vary with many factors. The IEEE 802.11ah scheme, for instance, has a limit in the number of unique addresses it can recognize. Schemes such as RPMA, on the other hand, can support as many devices as their channel capacity will allow. The longer and more frequent the data transmissions from an end node, the fewer the access point will support. For the most part, the values presented here represent estimates based on reasonable assumptions regarding such factors, and should be investigated more closely if high node count is a design requirement.

Topology – Most alternatives use a star topology, where end nodes communicate to an access point that is wired to the Internet. Some, however, use a tree structure, where the access point communicates to another device that then connects to the Internet, serving as an aggregator for many access points. The Dash 7 protocol also allows node-to-node communications. Developers should explore the nature, function, and ownership of access points for the network alternative they are investigating.

End node roaming – While all the alternatives support the relocation of an end node from one access point to another, the speed at which the network can adapt to the change will vary. Some alternatives offer true roaming of the type that cellphone users enjoy by having higher levels of the network hand off mobile end nodes from one access point to another. Others schemes only update their network maps at scheduled intervals and will ignore until after the update any nodes that have moved. Developers needing true roaming should investigate network operation more closely.

Governing body – Many of the LP-WAN alternatives are being developed or managed by industry organizations as open standards. This means that developers can create devices using the relevant standard without paying licensing or royalty fees. However, the governing organization may require membership in order to obtain access to the standards or to services for certifying a device's compliance with the standard. Other alternatives are the property of an individual company that licenses its technology or operates the network as a service to its customers. In the case of the LoRaWAN, the protocol is managed by the LoRa Alliance, but the physical layer's modulation scheme is owned by Semtech and available only through licensing or by purchasing radios from licensed manufacturers. Developers should check with the governing bodies for details.

Status – The development of LP-WAN alternatives for the IoT is ongoing and new alternatives are arising. This entry of the table provides some insight into the amount of real-world experience available to guide development as well as the amount of third-party support that might be available. Those alternatives already in deployment are more likely to have both experience and support. Some of the standards, such as the IEEE 802.11ah and LTE Category M, are still being defined and even the listed attributes are subject to change.

Summary of LP-WAN Alternatives

Summary of LP-WAN Alternatives

Because the comparison table is extensive and not readily visible on mobile devices, individual summaries of each alternative and its attributes are available on the following pages. Clicking on the links below will take you to summaries of the listed alternatives. Links on each of those pages will provide access to the other alternatives as well as a return to this document.

- Ingenu RPMA and SigFox
- Dash 7 Alliance Protocol, LoRaWAN, and nWave
- Weightless -W, -N, -P
- IEEE 802.11ah and LTE Cat-M

In addition to the alternatives listed here, there are several turn-key systems being offered. These provide the developer with all elements of the system, from end-node device to the back-end cloud support. These offerings target applications where the user wants off-the-shelf hardware in order to focus strictly on the data analytics.

The most established of these turn-key alternatives is Telensa, which now has 9 million devices installed worldwide, many in civil applications such as parking meters, utility monitoring, street lighting, and environmental monitoring. The Telensa system uses bidirectional ultra narrow band communications at low data rates in the sub-GHz ISM bands.

For sensor type IoT applications, Helium is offering a system – now coming in use by beta customers -- structured to provide distributed computing. The Atom end nodes have some processing power and the Element access points have even more. Users thus have the flexibility to define how much raw data gets sent to the network and what kinds of processing and actions can be taken on the edge. The system uses radios based on the 802.15.4 standard.

Startup Samsara also targets sensor type IoT applications, but technical details on their offering are sparse. The company has currently made its technology available only to select customers, although it is open to others requesting early access to its systems.

For those seeking a cellular alternative and unable to wait for LTE Cat - M to become available, companies such as M2M Spectrum Networks are building cellular networks dedicated to the needs of IoT applications. M2M is providing devices and services to end users while also working with network service providers to expand their support of such devices.

As the wide and growing range of alternatives demonstrates, the LP-WAN landscape is still in considerable flux. It may be some years before the choices narrow to a few strong, stable candidates. To help accelerate the process so that the industry can benefit from the growth opportunities that widespread standardization and interoperability can stimulate, a Wireless IoT Forum has formed. The organization has formed working groups to look at existing standards for APIs and radio access in order to help drive industry consensus around a few core choices.

Until such a consensus arises, however, developers will need to choose carefully which LP-WAN alternative they base their IoT system around. This will involve not only technical evaluation of the many choices but also an evaluation of their potential for survival as the industry undergoes its inevitable consolidation.

Ingenu RPMA and SigFox

Ingenu

The RPMA LP-WAN developed by Ingenu (formerly OnRamp) offers developers transceiver modules that can connect to a network of access points the company and its partners are building worldwide. Those networks forward messages from end nodes to the user's IT system. Access point devices and network appliances are also available for those seeking to build private networks.

The RPMA (random phase multiple access) transceivers and access points work together to manage the capacity, data rate, and range of their communications. Access points and end modes are synchronized with end nodes transmitting their signals within a predefined frame, but using a random delay from the start of frame. End nodes also choose a spreading factor to transmit with based on the received access point signal strength. The access points de-spreads, de-interleaves, Viterbi decodes, then performs a CRC check on the received signal before accepting it. As network usage increases, the access point can command end nodes to lower their transmitter signal strength in order to reduce the number of nodes it must handle.

Security for Ingenu's RPMA includes two-way authentication, 256-bit encryption, and a 16-byte hash to protect message traffic. This allows the network to offer authenticated firmware upgrades to end nodes as well as ensure message integrity and replay protection.

Name of Standard	Ingenu RPMA
Frequency Band	2.4 GHz ISM
Channel Width	1 MHz Channels (40 Channels Available in 2.4 GHz Band)
Range	2000 miles (Line-of-Sight)
End Node Transmit Power	20 dBm Maximum
Packet Size	6 bytes to 10 kbytes
Uplink Data Rate	AP aggregates to 624 kbps per Sector (Assumes 8 channel Access Point)

Downlink Data Rate	AP aggregates to 156 kbps per Sector (Assumes 8 channel Access Point)
Devices per Access Point	Up to 384,000 per sector
Topology	Typically Star. Tree supported with an RPMA extender
End node roaming allowed	Yes
Governing Body	Ingenu (formerly OnRamp) (proprietary)
Status	In Deployment

SigFox

The SigFox LP-WAN offering is a complete end-to-end system beginning with a certified modem and ending with a web-based application that users configure to forward device messages to their IT systems. Developers must either license the modem technology from SigFox or acquire a modem from a certified manufacturer to integrate into their IoT end node device design. Third-party service providers make SigFox-compatible access point networks available to handle traffic between the end nodes and SigFox servers. The SigFox servers manage the end-node devices and make their data traffic and other information available to the user through a web-based API.

To provide security the SigFox system uses frequency hopping to avoid message interception and anti-replay mechanisms in their servers to avoid replay attacks. The content and format of data sent in the transmission is user-defined and the SigFox system is transparent to that data. Only the user knows how to interpret their device information.

Name of Standard	SigFox
Frequency Band	868 MHz/902 MHz ISM
Channel Width	Ultra narrow band
Range	30-50km (rural), 3-10km (urban), 1000km LoS
End Node Transmit Power	-20 dBm to 20 dBm
Packet Size	12 bytes
Uplink Data Rate	100 bps to 140 messages/day
Downlink Data Rate	to 4 messages of 8 bytes/day
Devices per Access Point	1M
Topology	Star

End node roaming allowed	Yes
Governing Body	SigFox (proprietary)
Status	In deployment

Dash 7 Alliance Protocol, LoRaWAN, and nWave

Dash7

The Dash-7 protocol defines the communications mechanisms among end nodes, sub-controllers, and gateways. A typical configuration calls for nodes to communicate with sub-controllers that then relay the messages to the gateway for passage to the Internet. End nodes may also communicate directly with one another. The communications use an asynchronous command-response scheme, with end nodes periodically waking up to scan for commands. End nodes can also request that a sub-controller immediately initiate communications with them when they have a message to send. The system can send property-based multi-cast queries to end nodes and have them respond only if they meet the criteria, such as all nodes with a temperature sensor or even those reporting a temperature outside a specific threshold.

For security the protocol uses AES-128 encryption and offers a "stealth mode" wherein end nodes can be configured to respond only to pre-approved devices.

Name of Standard	Dash7 Alliance Protocol 1.0
Frequency Band	433, 868, 915 MHz ISM/SRD
Channel Width	25 KHz or 200 KHz
Range	0 – 5 km
End Node Transmit Power	Depending on FCC/ETSI regulations
Packet Size	256 bytes max / packet
Uplink Data Rate	9.6 kb/s, 55.55 kbps or 166.667 kb/s
Downlink Data Rate	9.6 kb/s, 55.55 kbps or 166.667 kb/s

Devices per Access Point	NA (connectionless communication)
Topology	node-to-node, star, tree
End node roaming allowed	Yes
Governing Body	Dash7 Alliance
Status	Released May 2015

LoRaWAN

The LoRaWAN architecture is a "star of stars" structure with gateways serving as a transparent bridge between end node devices and network servers. The wireless hop between end nodes and gateway use a proprietary chirp spread spectrum radio scheme available from Semtech and its licensees. The network structure allows three classes of end-node device. Class A (bidirectional) devices have a scheduled uplink transmission window followed by two, short downlink receive windows. Class B devices have additional, scheduled downlink windows and Class C devices have nearly continuously open receive windows. The radio scheme allows the network server to manage the data rate for each connected device via an adaptive rate algorithm to ensure optimal system performance under local radio conditions. The LoRa connections allow a tradeoff between payload and range.

Security for LoRaWAN includes use of unique network, application, and device keys for encrypting data at different OSI levels.

Name of Standard	LoRaWAN
Frequency Band	433/868/780/915 MHz ISM
Channel Width	EU: 8x125kHz, US 64x125kHz/8x125kHz Modulation: Chirp Spread Spectrum
Range	2-5k (urban), 15k (rural)
End Node Transmit Power	EU:<+14dBm US:<+27dBm
Packet Size	Defined by User
Uplink Data Rate	EU: 300 bps to 50 kbps US:900-100kbps
Downlink Data Rate	EU: 300 bps to 50 kbps US:900-100kbps
Devices per Access Point	Uplink:>1M Downlink:<100k
Topology	Star on Star
End node roaming allowed	Yes

Governing Body	LoRa Alliance
Status	Spec released June 2015, in deployment

nWave

The nWave technology is an ultra narrow band (UNB) radio technology and communications scheme that now serves as the template for the new Weightless-N standard. The nWave company offers radio modules, universal modems, and base station transceivers for developers seeking to build their own private networks, and is working with the Weightless SIG to develop similar public networks.

Name of Standard	nWave
Frequency Band	Sub-GHz ISM
Channel Width	Ultra narrow band
Range	10km (urban), 20-30km (rural)
End Node Transmit Power	25-100 mW
Packet Size	12 byte header, 2-20 byte payload
Uplink Data Rate	100 bps
Downlink Data Rate	--
Devices per Access Point	1M
Topology	Star
End node roaming allowed	Yes
Governing Body	Weightless SIG
Status	In Deployment

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Weightless-W, -N and -P

Weightless

Weightless is a collection of three LP-WAN standards under the control of the Weightless SIG. The original Weightless-W called for use of television whitespace for the wireless link using technology originally developed by Neul. Packet size and data rates are flexible, depending on user need and link budget. Both acknowledged and unacknowledged messaging is available as is multicast from the access point and interrupt messaging from the end node. For security a shared secret key used by the end node and the server permit AES-128 encryption. Some private Weightless-W installations have been made, but the SIG has put public network installations on hold until international agreements on whitespace utilization are in place.

The Weightless-N standard is based on nWave's ultra narrow band LP-WAN technology and targets low-cost applications needing only unidirectional data transmission. Weightless-N base stations can be operated by different service providers and still interoperate with devices, with each base station querying a central database to determine with which network an end node is associated. The standard was recently released and deployments have begun in London and other European cities. Weightless-N uses the same kinds of security techniques as Weightless-W.

The Weightless-P standard is under development and scheduled for release in late 2015 with hardware available in early 2016. The Weightless-P link is based on networking technology originally developed by M2 Communication and will provide fully-acknowledged bidirectional communications. Weightless P shares its MAC layer with Weightless-W, and will support fast network acquisition with hand-over of roaming end node devices across base stations.

Name of Standard	Weightless		
	-W	-N	-P
Frequency Band	TV whitespace (400-800 MHz)	Sub-GHZ ISM	Sub-GHZ ISM
Channel Width	5MHz	Ultra narrow band (200Hz)	12.5 kHz
Range	5km (urban)	3km (urban)	2km (urban)
End Node Transmit Power	17 dBm	17 dBm	17 dBm
Packet Size	10 byte min.	Up to 20 bytes	10 byte min
Uplink Data Rate	1 kbps to 10 Mbps	100bps	200 bps to 100 kbps
Downlink Data Rate	same	No downlink	same
Devices per Access Point	Unlimited	Unlimited	Unlimited
Topology	Star	Star	Star
End node roaming allowed	Yes	Yes	Yes
Governing Body	Weightless SIG		

Status	Limited deployment awaiting spectrum availability	Deployment beginning	Standard in development. Scheduled release 4Q 2015

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802.11ah and LTE Cat-M

802.11ah

With WiFi so popular for consumer IoT applications, it is no wonder that the IEEE is working to expand the approach to low-power wide-area networking applications. The approach being taken is to create modified PHY and MAC layers that offer support for IoT applications. The PHY layer RF link will use orthogonal frequency division multiplexing (OFDM) with either 32 or 64 tones, and is essentially a sub-GHZ variation of the IEEE 802.11ac PHY. The OFDM approach will support a variety of modulation schemes including BPSK, QPSK, and 16- to 256-QAM.

The MAC layer allows three types of stations. Traffic indication map (TIP) stations listen to access point beacons to determine when to send or receive data. Non-TIM stations negotiate with an access point to establish a transmission time allocation and can renegotiate its transmission time as needed. Unscheduled stations send poll frames to the access point to request channel access as needed. The standard is still under development, with initial release targeted for 2016.

Name of Standard	IEEE P802.11ah (low power WiFi)
Frequency Band	License-exempt bands below 1 GHz, excluding the TV White Spaces
Channel Width	1/2/4/8/16 MHz
Range	Up to 1Km (outdoor)
End Node Transmit Power	Dependent on Regional Regulations (from 1 mW to 1 W)
Packet Size	Up to 7,991 Bytes (w/o Aggregation), up to 65,535 Bytes (with Aggregation)
Uplink Data Rate	150 Kbps ~ 346.666 Mbps
Downlink Data Rate	150 Kbps ~ 346.666 Mbps
Devices per Access Point	8191

Topology	Star, Tree
End node roaming allowed	Allowed by other IEEE 802.11 amendments (e.g., IEEE 802.11r)
Governing Body	IEEE 802.11 working group
Status	Targeting 2016 release

LTE Cat. M

The 3GPP is in the midst of defining a new release for LTE cellular technology that will define a Category-M device class targeting IoT applications. It is intended as a replacement for current 2G cellular IoT system designs. Among the planned power-saving measures is extension of the end node device's sleep mode option from 2.5 seconds max to near 15 minutes, and lower data rate that current Cat-0 devices. Bidirectional communications use half-duplex operation. The standard is still in definition, however, and the details listed here are subject to change.

Name of Standard	LTE-Cat M*
Frequency Band	Cellular
Channel Width	1.4MHz
Range	2.5- 5km
End Node Transmit Power	100 mW
Packet Size	~100 -~1000 bytes typical
Uplink Data Rate	~200kbps
Downlink Data Rate	~200kbps
Devices per Access Point	20k+
Topology	Star
End node roaming allowed	Yes
Governing Body	3GPP
Status	Release 13 expected 2016

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