Keysight Technologies
The Menu at the IoT Café: A Guide to IoT Wireless Technologies

Application Note
As a developer of devices with IoT (Internet of Things) connectivity, you have a wide selection of wireless IoT standards to use in your products. Each standard has strengths, and with enough work, many candidates can be adapted to serve in a given application. Some wireless standards have been on the IoT menu for years, and designers have applied them in many creative ways. The IoT standards also continue to evolve, offering ways to expand their use far beyond the concept of the original wireless protocol, which typically was single device to single computer or smartphone. One important trend is the development of Internet connectivity, cloud storage of data, and software application layers to integrate wireless sensors and actuators in the field with intelligent software in the cloud. This will yield real time (even virtual reality) views of the connected system. As soup-to-cloud IoT connectivity is becoming the expectation, new items recently added to the menu at the IoT Café offer options not available before. So how do you choose?

I will be your server tonight, and would like to point out how our menu is organized. We group the items per several criteria: Short range wireless versus longer range are the main sections, unlicensed (in the ISM bands) versus licensed (cellular IoT), and protocol-lean versus protocol-rich selections are presented in sequence. I will be back shortly to discuss your order.
Short Range Wireless Selections

In the short-range menu, we offer light and popular standards such as Bluetooth, ZigBee, and WiFi which operate in unlicensed frequency bands. Unlicensed bands are also called ISM bands (for Industrial, Scientific and Medical) and while they don’t require licenses in most jurisdictions, there are standards of operation for which devices must be tested. The disadvantage of the unlicensed bands is that there are lots of these devices in certain locations using the same RF bands with different on-the-air protocols, and interference is becoming a problem, especially in the crowded 2.4 GHz radio band.

![Crowded spectrum is common in certain RF bands](image)

The most commonly used ISM band is the 2.4 GHz region which is used worldwide for WiFi and other protocols. These wireless standards (Bluetooth, ZigBee, WiFi, and several others) have all been around for several years and have widespread support in both chips and integrated modules which you can design into your new IoT device. Designing at the chip level provides great flexibility to the IoT designer, who can choose the latest ICs with only the features and performance needed for the IoT device. RF Modules are small boards on which the chips, controller, software and even the antenna have already been tested for compliance with applicable standards of RF performance. Compliance with many testing standards is facilitated by using complete RF modules in your design, which can also shorten your development time and reduce or eliminate compliance test time, though at higher parts cost than full custom design based on RF integrated circuits.

Most short-range wireless standards are called “Personal Area Networks”, or PANs, and have typical ranges of about 10 to 30 meters (though under good conditions they can all provide greater range). I will refer to many of these as PANs, though some are called by other names like WLAN.

PAN devices are sometimes optimized for certain applications using protocol definitions called “application profiles” or similar labels. These adapt the device for specific types of operations such as health care, sports, industrial control, building automation and many others. The profiles allow devices to implement subsets of the complete wireless IoT standards, reducing firmware and device complexity, reducing cost and saving battery power. As these wireless IoT standards continue to evolve, similar names may be used for newer versions of standards which may not be fully compatible with earlier definitions. Over time, simple point-to-point RF links have developed definitions of higher levels of protocol for network, transport, and even application layers, so your final choice will probably include software considerations arising from the purpose and use of the data from your IoT device.
With billions of wireless devices on the air already, and many billions more projected to join them in the next few years, many radio frequency bands are becoming crowded, and interference is a growing problem. In some environments (such as some hospitals), new PAN devices are simply not expected to work well due to interference, so selection of spectrum for your new product should include this consideration. Of course, medical devices have many other risk reducing considerations, but the trend of crowding will be ubiquitous. Though some wireless standards have a level of interference detection and avoidance, they usually do not recognize signal protocols very unlike their own, so such efforts are not completely effective in a RF environment with different protocols actively using the spectrum. For example, Bluetooth can modify the frequencies used for hopping protocol if it recognizes interference, but may be unable to recognize spread spectrum WiFi signals as interference. Testing for proper device operation in high interference environments (called coexistence testing) is evolving, so look for coexistence testing standards such as IEEE/ANSI C63.27 and (for medical) AAMI TIR69 for guidance. Your new device should be designed and tested to cope with the predicted operating environment, whether that is home, hospital or coffee shop.

Bluetooth was designed in the mid-1990s specifically to be a PAN, connecting wearable devices, phones, computer peripherals and so forth. Bluetooth uses the 2.4 GHz ISM band, and while it was originally defined in IEEE 802.15.1, it is now managed by the Bluetooth Special Interest Group (SIG) which is an alliance of many thousand companies making Bluetooth devices. Over time, the Bluetooth IoT standards have diversified, adding Bluetooth Low Energy (BLE or Bluetooth Smart) in 2006 and Bluetooth 5 in 2016.

There are several types of on the air behaviors (media access protocols) defined by the Bluetooth SIG, some of which are not compatible with other Bluetooth MAC protocols. For use in an IoT device Bluetooth 5 offers faster, longer range and connectionless operations for low energy devices compared to earlier versions of the standard. On the air, Bluetooth physical (PHY) layer uses GFSK modulation, and Frequency Hopped Spread Spectrum (FHSS) or (in BLE) Direct Sequence Spread Spectrum (DSSS) protocols which have some interference avoidance features.

Bluetooth is popular in so many applications it is hard to define a typical use. It is very common in wireless peripherals for laptops and cell phones, such as wireless mouse or wireless headsets, but it is also the most common wireless standard for fitness bands and many wearable IoT devices. The newer versions of the protocol are capable of longer range and lower battery utilization and the many media access protocols make it easy to design smart advertising, security key exchange and remote controls.

The Bluetooth profiles (application focused protocols) have a lot of menu options, so you can order the short stack for lean, connectionless applications, or a full order which allows secure connection for reliable data transfer. Some Bluetooth devices such as printers are intended to be line powered and use short range wireless simply to eliminate a wired data connection, so they don’t attempt to have limitations on power consumption. But battery life is a key consideration for most battery operated IoT devices and 10-year battery life is often expected to reduce lifetime costs (maintenance) and maximize convenience. BLE and BT5 aim to make that 10-year life achievable with lean RF and software operation. With such a wide array of implementations and lean battery use, Bluetooth can be used in many ways as a short-range IoT wireless standard.
**802.15.4** – This is another IEEE technical standard for low power PANs in the 868 or 915 MHz, and 2.4 GHz bands and several radio protocols use it. It defines six Physical layer wireless protocols, including the original DSSS techniques and more recently Chirp Spread Spectrum (CSS) in the 2.4 GHz band, and Direct Sequence Ultra wideband (UWB) in the sub-1 GHz bands and the above 3 GHz bands. The MAC layer also allows channel hopping to reduce or avoid interference. 802.15.4 is the umbrella standard for many IoT standards which have defined higher layers of the network, including nearly direct connection to Internet because of the IP addressing called 6LoWPAN, which may simplify implementation of networks intended to directly send and receive data from the cloud.

**ZigBee** is one 802.15.4 standard, and is another PAN favorite for low power, low data rate, secure wireless networks. ZigBee uses the ISM (unlicensed) radio bands including 2.4 GHz. The other radio frequency bands vary in different regions of the world, and the ZigBee sub-1 GHz bands include 915 MHz in the US, 784 MHz in China, and 868 MHz in Europe. ZigBee inherently supports tree, star and mesh networking, so collections of devices can cooperatively pass data in short hops to controlling nodes. This can make it attractive for low data rate networks spread over a larger area than a simple point-to-point network could reach under similar conditions. The price for this may be shorter battery life for devices that serve as repeaters for more distant ZigBee IoT devices, sending data and acknowledgements between nodes, not only their own data. While ZigBee Pro can frequency hop to avoid interference, the whole network must move to another channel in case of interference. Data rates likewise vary in different regions, all around 10 to 200 KBits/sec. These speeds may be completely sufficient for many IoT devices, so expect lower throughput than you may have expected from WiFi protocols. But lower speeds usually mean much lower battery use (CPU or logic chips, RF power, etc) for a given range of operation, and so low data rate or infrequent data updates can give your device the long battery lifetime which is so attractive in the market.

Zigbee has been used in many different applications needing low power connectivity, including home automation and industrial networks. Your keyless front door lock and thermostat may be Zigbee devices.

ZigBee Alliance defines application profiles which are higher layer definitions and libraries tuned for various uses and which encourage interoperation between ZigBee devices from multiple vendors. More recently the alliance has defined a set of higher-layer protocols called “dotdot” which unifies the application profiles into libraries which the alliance hopes will become the basis of unified IoT networks using other wireless radio standards as well.
Quick Bites of other PAN Dishes

**Wireless Hart** is an industrial instrumentation standard that evolved from earlier 4-to-20 mA wired current loop standards. Based on IEEE 802.15.4, WiHart is a mesh network, operating at 2.4 GHz ISM frequencies, and is a time slotted FHSS wireless sensor network. A specialized standard, it may be just what you need for certain applications.

**Thread** is mid-layer protocol for 804.15.4 IoT devices, which uses 6LoWPAN to adapt simple IoT devices to communicate using the IPv6 Internet protocol, enabling communication over LAN and Internet. It can be layered atop other low layer standards.

**Z-Wave** is a home automation protocol that allows small data packets to be exchanged securely on sub-1 GHz ISM radio frequencies, and allows mesh networks to extend the range of the very low power transmissions. Z-Wave uses FSK or GFSK modulation and while the definition was originally proprietary, the definition is now a public specification ITU G.9959.

https://www.itu.int/rec/T-REC-G.9959-201501-I/en
http://z-wave.sigmadesigns.com/design-z-wave/z-wave-public-specification/

**EnOcean** is a sub 1 GHz technology which is intended for battery-less (energy harvesting) applications. It uses ultra-low power RF at 125 Kbits/sec and Pulse Amplitude Modulation (PAM) modulation, similar to the simple design of wireless remote key fobs and garage door openers. https://en.wikipedia.org/wiki/EnOcean

Other 802.15.4 Wireless standards include ISA 100.11a, MiWi and Snap, with different intended uses, but belong in this section by right of their on-the-air similarities.
WiFi

WiFi deserves its own section of the menu because of its huge popularity, though not necessarily in battery powered IoT. The WiFi family is a large and long established family and has names starting with 802.11. It was originally intended to replace the LAN cable as a link to the internet between higher powered devices such as laptops and printers, and so was developed to have high data throughput of 10 to 50 Megabits/second and not necessarily conservative of battery power. Like the American Cheeseburger, there are many varieties all falling under the IEEE 802.11xxx standards and provide something for almost every taste. Like haute cuisine, it is also constantly evolving as new ideas and technologies come along. The most popular form for IoT at present operate in the 2.4 and 5 GHz ISM Bands.

WiFi is commonly referred to as Wireless LAN or WLAN, because a most common application is allowing devices to access LAN and internet without the Ethernet cable connection. These networks are almost ubiquitous, found in most public spaces and almost anywhere a smartphone has a “hotspot” turned on.

Because WiFi in various forms has been around for decades it has many suppliers of chips and modules, giving designers many choices in hardware components for WiFi. But care should be taken in evaluating the radio (especially receiver) specs, because there can be large differences in performance (range, bandwidth, blocking, packet error rate and battery consumption) depending upon what chips are chosen. You should use only the best ingredients for successful device operation, so read the specifications of parts you are considering. Because it was intended for high speed data transfer (10s of Megabits per second), WiFi will typically use more power than other short range protocols, and so designers probably will not be aiming for 10-year lifetime from small batteries in a WiFi device. Measuring actual device power consumption at both quiescent and very short, high current active states is necessary to get a true picture of how a device is using its power budget. On the other hand, since WiFi inherently provides connection to local area networks and the Internet, some IoT devices which can handle the power needs will get to market quickly with WiFi RF links. And finally, since WiFi can directly connect to the wild and dangerous Internet, security concerns should factor into any such design, ensuring data privacy and proper device operation.

802.11b WiFi uses Direct Sequence Spread Spectrum (DSSS) modulation called Complementary Code Keying (CCK) in the 2.4 GHz ISM band and has Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) media access to avoid signal collisions with other 802.11b devices. CSMA/CA adds a few calories to the battery consumption, and provides actual speed to around 6 megabits per second, but using cooperative behaviors in a crowded spectrum is more efficient in transferring data than protocols without those behaviors. Unfortunately, not all 2.4 GHz wireless protocols are so polite in sharing the airwaves, so in a mixed signal environment this may not be an advantage.

802.11g WiFi is also a 2.4 GHz WiFi standard, and operates at higher data rates using OFDM modulation and CSMA/CA to reduce collisions. The Orthogonal Frequency Division Multiplex (OFDM) signal consists of many radio carriers, each simultaneously carrying part of the data flowing across the link. OFDM also allows radios to compensate for motion and multipath signal interference as may be found in buildings with a lot of metal, or WiFi users walking around. Though it has a different modulation scheme, it can cooperate with 802.11b to avoid interference, but mixed systems will have lower throughput than pure 802.11g installations. The radios can adaptively change modulation type to improve throughput in more favorable RF environments, yielding on-the-air speeds up to 54 Mbits/sec. Also, the hardware or firmware required for more complex
radio behavior may consume more battery than simpler protocols, so you must trade speed and complexity with needed data rates to decide which WiFi is best in your application.

802.11a uses OFDM radio signals in the 5 GHz band and is capable of variable data rates up to 54 MBits/second though net throughput peaks at around half that speed. Radios at each end of a link negotiate to achieve a workable modulation, and thus speed, based on the local radio environment. This can be a big advantage for devices needing high data rates or installations with many devices, since speed also means brief transmissions and less crowding. Since 802.11a uses the 5 GHz ISM radio band(s) there is more bandwidth available, but 5 GHz has other conditions which affect it. The physics of this band means the signals at this frequency will not penetrate objects as well as 2.4 GHz signals, and available channels vary by country. In addition, the 5 GHz band is also used by certain radars so some channels (called “DFS” channels) are disallowed for WiFi, or allowed only on the condition that they must vacate channels in which a radar signal is detected. If your equipment begins using these channels and later must vacate them when radar signals are detected, your equipment may end up with a substitute channel which will drop some Access Points off the network while they reconfigure. You can disable (thereby avoid using) these DFS channels in your equipment and avoid causing and receiving interference with radar and the hiccups in your network from reconfiguration at unpredictable times, but of course, have fewer channels continuously available.

One other consideration on 802.11a is that many wireless backhaul networks operate in this 5 GHz frequency range, so interference may result from high adjacent channel power or antenna beam patterns near these networks. All that being said, the 5 GHz region has lots of space for lots of high bandwidth signals, but with the same interference considerations as apply to all unlicensed spectrum.

802.11n and 802.11ac are amendments to the 802.11 standards which add more complex and capable physical layer functionality to 802.11 networks, including MIMO, beam forming, frame aggregation and wider channels. This enables higher data rates, but requires considerably more power, and appears most commonly in more complex line-powered equipment (wireless routers) and usually not in the IoT devices themselves, and so are beyond the focus of this paper.
Long Range Entrees

The second section of the menu of IoT devices covers devices with ranges greater than the PAN devices above. While IoT typically refers to the short-range standards listed above, there are many applications in which the IoT could be used over greater distances. These Low Power Wide Area Networks are frequently referred to by the acronym LPWAN. Applications include medical (ambulatory patient monitoring), resources (water quality, oil and mineral extraction), industrial (monitoring and control of large physical plants), agricultural (animal health and location, weather, crop health and water use), smart city (traffic, parking, air quality, utility and drainage metering), building monitoring, and so forth. These applications will revolutionize operations and allow real-time reporting and control of operation in plants that may already be automated, but not connected to integrated applications layer software.

Figure 2. LPWAN technologies are ideal for long range applications such as smart city (traffic, parking, air quality, utility and drainage metering) or medical applications (ambulatory patient monitoring)

Long range communication has historically meant larger, higher-powered devices that are rarely powered by batteries, but advances in modulation techniques and system on a chip (SoC) integration have greatly increased the range at which low powered devices can operate. Use of lower (sub-1 GHz) bands also enable different radio propagation characteristics which may be a big advantage to long range networks. These lower frequencies may also mean that efficient antennas will be larger than for the higher frequency radios. At 2.4 GHz, a quarter wave antenna is 31 mm long, but at 915 MHz the same antenna is about 82 mm long. For long range, low power budget products, the larger and more efficient antennas (if mechanically acceptable) may pay off in long battery lifetime by reducing the RF power required to span the required distance.
In addition, long range IoT is creating opportunities for communications services on a subscription basis, compared to completely captive short range installations. Companies with large installed radio infrastructure such as the cellular phone networks are rolling out services that span large areas with their existing networks covering whole regions or nations with new long range and low rate data services. For some companies, this means simply a software update to their existing LTE stations. These licensed spectrum offerings bring a different level of service and subscription fees. Commercial installations also allow simple connection to the Internet and the cloud. This portion of the menu is relatively new, and subject to rapid changes, but some exciting dishes are now available to IoT designers.

**Unlicensed spectrum offerings**

**LoRa** is a relatively new selection on our menu, and has a bit different character than the short-range wireless protocols described earlier. LoRa uses sub-1Gigahertz radio frequencies in unlicensed spectrum at VHF, UHF and 800-930 MHz depending upon regional allocations. Since it uses these lower radio frequencies, it has different RF characteristics than other (2.4 or 5 GHz) standards, and LoRa signals can penetrate deep into buildings and reach locations not accessible to higher frequency equipment.

LoRa modulation is a significant departure from other modulation types in this menu and is a significant advance in RF technology. Most of the short-range standards use some form of FSK, OFDM, or FHSS or DSSS Spread spectrum. LoRa is a set of modulation techniques patented by Semtech using Chirped Spread Spectrum (CSS) RF carrier, which varies (chirps) the radio carrier while transmitting. This makes the signal resistant to Doppler effect (for mobile users), multipath fading in a reflective RF environment, and a significant level of interference resistance. Low bit rates (down to 300 bits/sec) spread over a chirp frequency range can frequently avoid narrowband interferers such as FSK signals and still demodulate successfully. This can give a 15-dB boost to a LoRa link budget compared to a narrowband FSK signal using similar RF signal power. As far as noise is concerned, LoRa can comfortably operate below the ambient RF noise level and even 20 dB or more below narrowband interference sources due to processing gain of the spread spectrum modulation.

LoRa also allows various data rate and modulation combinations, which can be selected to increase sensitivity and achieve long range with low RF power in noisy environments, or to increase data rates (up to about 40 Kbits/sec) with less sensitivity and range when speed is required. Interestingly, different LoRa spreading factors (think speeds) transmissions can be active in the same channel without jamming each other. Since the CSS signal is simpler to decode than other spread spectrum, it can be done with less processing power. This can mean longer battery life for the IoT device, despite sophisticated RF modulation.

The basic LoRa definition focuses primarily on the lower (PHY) layers of radio operation and leaves the network structure to the LoRa Alliance, a consortium which defines higher level network specifications (which vary in different regions of the world). The data flows over LoRa RF links to Gateways (also called concentrators), which connect to Internet and Cloud/Application servers. The alliance also defines testing and certification to ensure interoperability of different LoRa devices in a network. LoRa has secure communications keys at both network and application layers for network and data security, which become more of a consideration when the radio signals are detectable over a larger area.
LoRa can be deployed either as a proprietary network, or in several areas of the world there are public operators of networks which sell connectivity via gateways for the LoRa devices to pass data up to the cloud. LoRa was first deployed in Europe, but is spreading to many parts of the world. Aside from Semtech, chips are becoming available from ST Micro and Microchip, giving designers second source flexibility for LoRA hardware designs.

Testing of devices is still required (such as the FCC Part 15.247) even if unlicensed spectrum is used. Tests for transmitter power, deviation, occupied bandwidth, harmonics and power spectral density are typically required for certification. Though a fairly new standard, both chips and modules are available to designers, and various test instruments and several testing labs already support LoRa certification and pre-certification testing.

**SigFox**

SigFox is another recent LPWAN technology development (and a connectivity service of the same name) and is in some ways like LoRa, and in other ways a very different method of accomplishing similar goals. SigFox is a proprietary radio protocol, operating in the sub-1 GHz bands, and provides a network of cellular-like gateways which connect to the Internet and the Cloud. In this way, it is like the LoRa commercial networks, but does not aim for private networks (where a company installs and maintains all its own network) whereas LoRa offers either. It is a one-hop star network with the gateways (cell sites) serving as the controller of the network. Like LoRa it also has long range and very low battery consumption as characteristics. But SigFox accomplishes this with a very different on the air transmission using “Ultra Narrowband” (UNB) very low data rate radio transmissions. SigFox is very light on protocol, not requiring RF handshake, and transmits a payload of 12 bytes (plus packet overhead such as radio ID and time) in a very narrow bandwidth D-BPSK modulation at either 100 or 600 bits per second - yes, as low as 100 bits per second - with 6 second transmissions. But slow and narrow means lean on battery and long on range.

Because of the very narrow bandwidth, the receivers can have a very low noise floor (are very sensitive) around -140 dBm, and link budgets around -160 dB when using gain antennas. This means that without coding (uses less CPU), with low transmitter power (14 dBm), low data rates, short and infrequent messages (no more than 140 messages per day) you can achieve long range and long battery life in a SigFox IoT device. With all these characteristics, SigFox may be the most “lean” selection on this LPWAN menu. The SigFox IoT network, starting in France, has installations in several European countries, with steady expansion of their network (at this writing, 32 countries).

**Long range WiFi**

There are some equipment suppliers who provide long range links using WiFi frequencies and modulation types combined with larger antennas driven by POE Ethernet connections. These can be configured as point-to-point or point-to-multipoint devices, and allow communications in unlicensed spectrum up to about 20 km distances. The use of unlicensed spectrum means that there may be interference in an area, and similar systems are in use by wireless internet service providers in both the 2.4 and 5 GHz bands in urban and suburban areas. For private backhaul networks, these products may supply an inexpensive way to transport data over longer distances, but with power consumption measured in watts, these will probably not be used for IoT end devices. Pairing a backhaul radio with a local Access Point may be a fast and simple way to reach a cluster of WiFi enabled devices in a remote area for recreational or agricultural data services. While marginally IoT related, these may be a good tool for long range networking needs.
Licensed spectrum specialties

Licensed spectrum refers in this case to cellular data networks, in which operators have purchased spectrum and control access, and provide voice and data connections. We are familiar with smart phones which pass voice calls and data over these networks. These phones are capable of high speed data transfer, but are not known for long battery life, requiring recharge almost daily. But the LTE networks are beginning to offer new lower speed data modes which allow low power devices to pass data through networks while offering long range, long battery life, low data rate connections to the almost ubiquitous cellular networks. The main offerings available for IoT designers are CAT M-1 and NB-IoT standards for faster and slower (respectively) data rates.

**NB-IoT** is a very recent addition to the IoT menu. NB-IoT uses licensed (cellular) spectrum and is a low data rate, long range addition to the LTE network. Because it uses licensed spectrum (for which operators paid billions of dollars) operators will charge data rates for its use and will require strict compliance testing which also means reliability. But NB-IoT offers the national coverage of the existing cellular network infrastructure, and due to the narrow bandwidth RF connection, even greater range than cell phones. NB-IoT offers from 20 to 250 Kbits/second data rates, depending upon what parts of the LTE "resource blocks" are being used. Some Network operators can add NB-IoT to their cellular networks with a software update to their equipment, so it will see rapid deployment in many areas. Because it is an extension of the existing standards, test equipment and software for checking NB-IoT compliance is already available. Solutions for modeling, design verification and manufacturing test are already available [https://www.youtube.com/playlist?list=PLvQ5Bzr3tM52F9KokdHz74PC-f4soW2s0](https://www.youtube.com/playlist?list=PLvQ5Bzr3tM52F9KokdHz74PC-f4soW2s0)

NB-IoT modules are similarly already available for designers, which ensure correct operation within the cellular networks.

**CAT-M1** is another very recent addition to our menu and like the NB-IoT system, utilizes the licensed spectrum of the cellular LTE network. Cat-M1 provides about 1 Megabit per second data rate on a half-duplex link. Because it is using the cellular network, subscriptions and data rates will apply, but Cat-M1 will provide a higher speed data link than NB-IoT devices. Certain applications that need this speed and the coverage of the existing cellular infrastructure will find Cat-M1 a deluxe selection. The first announcement of nationwide Cat-M1 availability came out in March, 2017 in the US. [https://www.benzinga.com/pressreleases/17/03/n9236121/verizon-launches-industrys-first-lte-category-m1-cat-m1-nationwide-netw](https://www.benzinga.com/pressreleases/17/03/n9236121/verizon-launches-industrys-first-lte-category-m1-cat-m1-nationwide-netw)

**Hybrid networks** mix short range PAN and long range (LPWAN) protocols into a single network in which local clusters of IoT devices using Bluetooth or ZigBee (for example) carry data to a central node where it is aggregated and placed onto long range backhaul networks such as LoRa or Cat-M1. This is a useful model for networks such as utilities in which water, gas, or electric meters collect a neighborhood of data via a short range IoT devices or mesh networks and periodically send the result to the cloud using long range RF or wired networks. This hybrid model can enable numerous low cost IoT devices to collect data and then connect with the Internet or the cloud. This is a new model for the way data will flow in the IoT to become available in very large amounts for real time monitoring and tuning of utilities, smart cities, agricultural, and industrial systems.

Consider combining ZigBee and Cat-M1 into a hybrid network for city utility monitoring and billing. ZigBee may serve as the lowest layer, linking a few dozen very low cost water meters in a neighborhood into a reliable mesh network which feeds low rate data into a Cat-M1 aggregator, which periodically connects to the cellular network to send reports to the water utility. The data rates will be low, perhaps only one report per day per meter,
though almost instant updates would be available in emergency or exceptional situations if the meters are intelligent and can change modes under command. The low-level ZigBee mesh network would be robust and able to maintain connectivity to more remote meters in case of failure of a node by reconfiguring the mesh network dynamically. The Cat-M1 connection will have approximately the reliability of the cellular network, and possible interference and data loss is avoided by the highly-controlled radio interface of the cellular IoT system.

In another example, an agricultural enterprise instrumenting center pivot irrigation equipment. This network may have Bluetooth or ZigBee sensors on pumps, water flow sensors on pipes and sprinklers, wheel motion sensors and strain gages on the trusses, all possibly powered by the energy harvesting of water flowing in the system. The IoT devices report operating conditions to a long-range network and integrated farm control software in the cloud monitors equipment health and controls flow based on energy cost, weather, and soil moisture, possibly including weather forecasts to tune the operation of the farm. Back in the shop, the farmer can get reports on his smart phone when a sprinkler fails or the price of power changes, and can run an efficient crop production operation with live data.
Full Custom IoT Design

This menu would not be complete without a mention of designer option to implement a completely new IoT device using custom protocol on any licensed or unlicensed spectrum. Many such products have been around for decades, serving medical, building monitoring and other applications and the choice is available to today's designers as well. In the US for example, there are many unlicensed frequencies available other than the common ones at 915 MHz, 2.4 GHz and 5.7 GHz. Governed by FCC CFR 47 Part 15, a dozen or more bands are available for use with only limited regulation of signal characteristics. In addition, there are certain bands assigned for medical IoT devices of various kinds. Depending upon the target market and the expected operating spectrum, the designer can choose frequencies, modulation types and on-the-air protocols to meet the key requirements for the IoT device. Great opportunities are found here for custom devices, but fewer standard recipes are available, so design verification and testing will be performed with more generic test equipment and software. This a la carte section is for the more experienced adventurer, but deserves mention in this menu.

Summary

Whether short range or long range, licensed or unlicensed, the Internet of Things will be an important part of our lives in the next decades. So many new capabilities are enabled by low cost connectivity that lives may be saved, quality of life improved, and efficiency of operations increased as IoT designers find creative applications for low cost automated communications. Understanding the IoT landscape helps engineers design and test these new devices and get them to the market quickly with assurance of reliable and compliant operation.

Are you ready to order? Let Keysight help you get all the IoT standards and IoT testing information you need, to make the right decision.

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- NB-IoT technology:
- Critical Test Parameters for NB-IoT:
- LoRa Webcast:
  http://www.keysight.com/main/eventDetail.jspx?cc=US&lc=eng&ckey=2766617&nid=-11143.0.00&id=2766617
- SystemVue 2017 for 802.11ax and NB-IoT:
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