Chapter 9

Internet of Things

Internet of Things (IoT) is a new vision to connect all types of objects to the Internet, making it possible to digitize every phenomenon and processes of interest. IoT is arguably seen as the next Internet revolution promising unprecedented benefits in all socio-economic sectors. Currently there is a massive interest from industry, academia, and standards organizations in this topic. This chapter will provide an introduction to IoT discussing the business opportunities and the recently standardized wireless networking technologies to support the need of IoT.

8.1 What are Things?

Internet has been there for more than 4 decades. It has connected all types of computers, such as servers, desktops, laptops, tablets, and smartphones from all over the world into a seamless gigantic virtual network. This seamless connectivity of the entire world made the Internet as one of the wonders of the modern era. People from anywhere in the world are now able to access, share, and contribute information at anytime.

IoT is the next evolution of the Internet. Instead of simply connecting computers, IoT promises to connect all type of *things*, such as wristbands, thermostats, cars, bikes, streetlamps, electric meters, washing machines, air conditioners, fridge, and the list goes on and on. This will enable not only the humans, but also the *things* to access, share, and contribute information to take the automation to the next height. Besides the everyday objects, many types of environmental sensors are expected to be deployed and connected to the Internet for remote monitoring of agricultural fields, chemical plants, mining sites, and so on. Basically, things are any physical objects except the computers as illustrated in Figure 9.1. It is clear that there are more things to connect than computers and indeed we are at a pivotal point in the Internet history where more IoT are connected to the Internet than non-IoT.

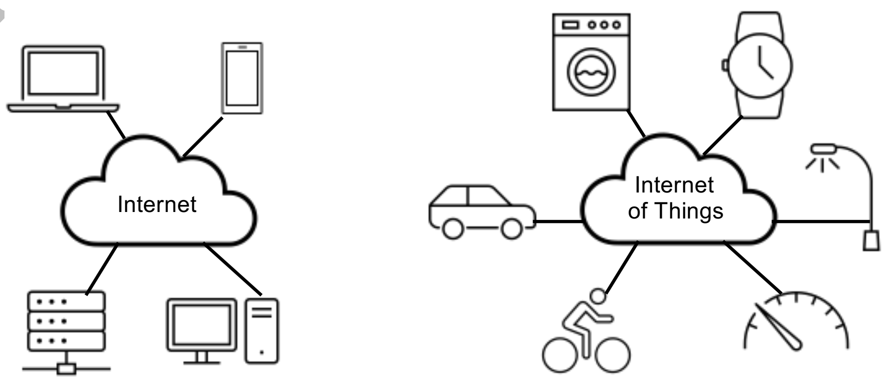

Figure 9.1 Internet vs. Internet of Things

Connecting things and objects to the Internet is not an entirely new concept. We have already connected many things to the Internet. We have fax machines, printers, security cameras, TV, etc. already connected to the Internet for remote access. With the emergence of new IoT standards and products, the IoT connections have already surpassed the total non-IoT connections. Despite this progress, at this moment, only a small fraction of all things is connected. With the rapid market uptake of IoT, the connectivity is expected to rise exponentially to hundreds of billions in the next few years, which will connect processes, data, things, people, and even animals, such as pets, farm animals, wildlife etc. This dramatic shift in connectivity scale is what makes IoT the next big Internet evolution.

8.2 Why IoT now?

The basic idea of IoT has been cultured for more than a decade. But why IoT is gaining this huge momentum now?

To answer this question, we need to look at the basic technical requirements of IoT, which are sensing, communication, and computation. Sensor technology has matured over the last 10-15 years. We can now buy all types of micro-sensors, such as temperature, moisture, pressure, air quality, and so on., dime a dozen. We now have various types of tags, such as radio frequency (RFID), Quick Response (QR) and so on, which can be readily attached to objects to track them over the Internet. We also have very low-power communication technologies, such as Bluetooth, NB-IoT, LoRaWAN etc., which can meet the wireless communication needs of an object with a small battery. Microcomputing platforms, such as micro multi-core chips, Raspberry Pi, Intel Curie, and so on are available at less than $20. Cloud computing has become very affordable making little or no local computing a possibility for the smart objects. Finally, we have open source micro operating systems, such as Tiny Core Linux, that can be easily ported to small objects. With all these developments in the recent years, we suddenly have a new opportunity for realizing the vision of IoT at a large scale.

8.3 IoT Applications and Business Opportunities

IoT is impacting all vertical sectors of the industry and all walks of life. For example, the power grid is now able to connect all of its power generation, supply, and consumption equipment to dramatically improve its efficiency in meetings its dynamic demands. Everyday wearable objects, such as shoes, watches, sunglasses, and even clothes can be connected to the Internet to constantly provide data about our daily fitness and health making healthcare more precise, personalized, and affordable. Similarly, connected objects will make our homes, cities, industries much smarter and more efficient.

Basically, IoT helps digitize processes with unprecedented details, which in turn help achieve smarter products and services. To gain deeper insights to how IoT achieves this, let us a take a look at some of the real case studies of IoT from around the world.

8.3.1 Smart Whitegoods

Manufacturers of home appliances, such as washing machines, dishwashers, and refrigerators, are seeking cost-effective ways to monitor the distribution and usage of their products over time. China Telecom is aiming to use NB-IoT, a specialised cellular connectivity solution recently standardized by 3GPP to connect IoT devices at mass scale and low cost, to connect about 1.2 million whitegoods in schools and apartments in Beijing, Shanghai, Guangzhou, Shenzhen and Chengdu [China-NBIOT]. The NB-IoT connectivity can be used to collect data from on-board sensors, such as a gyroscope, an accelerometer and temperature and humidity monitors to monitor the appliance's operational status, the environment in which it is located and track fault information. The NB-IoT data transfer costs can be covered using a business model as follows: the whitegoods providers pay the first three years of data traffic fees to the mobile operators, after which the users can optionally continue the service and pay the connectivity bills themselves.

As we shall see later in the chapter, NB-IoT was designed for deep penetration to basements, underground car parks, and enclosed compartments within buildings, which proves very useful to provide constant connectivity to whitegoods installed in basement laundries. The cost-effectiveness and coverage of NB-IoT has enabled appliance manufacturers to deployment of machines that can be rented on a per use basis. Together with a leading white goods maker and Huawei, China Telecom launched the Commercial Laundry Room at the Beijing University of Chemical Technology. After registering using a QR code via WeChat, students and staff can make a laundry service reservation, pay, and then remotely follow the laundry cycle through an app.

8.3.2 Smart smoke and gas detectors

As toxic gases and fires can kill people and ruin homes and workplaces, householders and businesses are increasingly looking to use innovative solutions for timely detection of smokes and gases with minimal cost. Connected smoke and gas detectors can act as automated sentries, able to detect smoke or gas leaks in real time and alert building residents as well as notify relevant fire management platforms and any deployed actuators such as sprinkler systems.

With NB-IoT, large number of gas detectors from densely populated areas can be connected to a central management platform cost effectively and reliably. Once connected, the gas detectors can not only transmit sensing data to the management platform, they can also be updated remotely by pushing updated version of the firmware. Following successful trials, China Unicom plans to deploy 170,000 NB-IoT connected smoke detection and alarm devices in rental homes in Hangzhou [China-NBIOT]. The detectors will transmit data on smoke levels, power consumption and network signal strength to a backend platform, which will enable constant monitoring of the gas level as well as the devices themselves. The deployment is expected to reduce the cost of fire monitoring and firefighting as well as minimise response times in the event of a fire.

China mobile operators are considering two different business models to support the connected smoke detectors. One model involves supplying the SIM card and connectivity to the smoke detector vendors and the other purchasing the smoke detectors and supply them to the residents as rental devices.

8.3.3 Smart bikes

With improvements in battery technology, there has been a surge in the use of electric bikes. For example, there are about 3 million electric bikes in the city of Zhengzhou, China, alone. While increased use of electric bikes are helping citizens moving through the city conveniently without contributing to traffic congestion and pollution, they are causing higher risk of accidents, thefts, and fire hazards. To address these issues, Zhengzhou city administration has partnered with China Mobile and a local satellite positioning company to equip the electric bikes with NB-IoT-enabled positioning modules [China-NBIOT]. This has allowed the city administration to collect the position, speed, time, and temperature of an electric bicycle at regular intervals to a central bike management platform. Using this platform, the electric bike owners can register for a license and monitor the status of the bike in real-time to mitigate the risks of theft, accident, and fire.

8.3.4 Smart Waste Management

City of Canada Bay, located within the greater Sydney area in Australia, is using IoT technology to monitor garbage bin levels [CanadaBay]. City garbage bins are currently serviced using a fixed schedule, which is proving very inefficient as different bins are filled at different rates. Using low-cost LoRaWAN, a new open-access IoT networking technology operating with unlicensed spectrum, city bins are fitted with sensors that can detect bin level and transmit the data periodically to a central garbage management platform. The data is then used to infer how quickly bins are filling and when they need to be serviced, if more or less bins are required in a given area, if empty bins are serviced unnecessarily, and which bins need more frequent service. With low-power consumption of LoRaWAN, bins sensors are lasting 3-5 years without having to be replaced or recharged.

8.4 Wireless standards for IoT

IoT poses new challenges for wireless communications not faced previously. Existing WiFi and cellular standards were designed for personal mobile devices to support high data rate applications like web browsing, social media uploads, video streaming and so on. As a result, they were energy hungry requiring large batteries and frequency recharging. They also cannot reach devices located deep inside basements, forests, or in underground locations. Although Bluetooth was relatively low-power consuming, it could not reach objects beyond a about 10 meters.

For IoT, energy efficiency of the communication becomes a major issue as many of the small objects will be battery powered. Also, many objects are expected to be located in deep non-line-of-sight locations such as in underground mines, deep forests, residential and industrial basements, in urban underground tunnels and so on. Connecting these devices at scale with minimal infrastructure requires wireless standards that can reach long distances and difficult locations while consuming ultra-low power. Fortunately, IoT does not require high data rates as devices sleep most of the time and wake up only once in a while to transmit a small message. Thus, all the major wireless technologies, i.e., Bluetooth, WiFi, and cellular, have released new extensions for IoT. Even completely new technologies dedicated entirely to IoT have emerged. A taxonomy of IoT connectivity solutions are provided in Figure 9.2 and the recent developments, including the extensions of existing technologies, are summarized below.

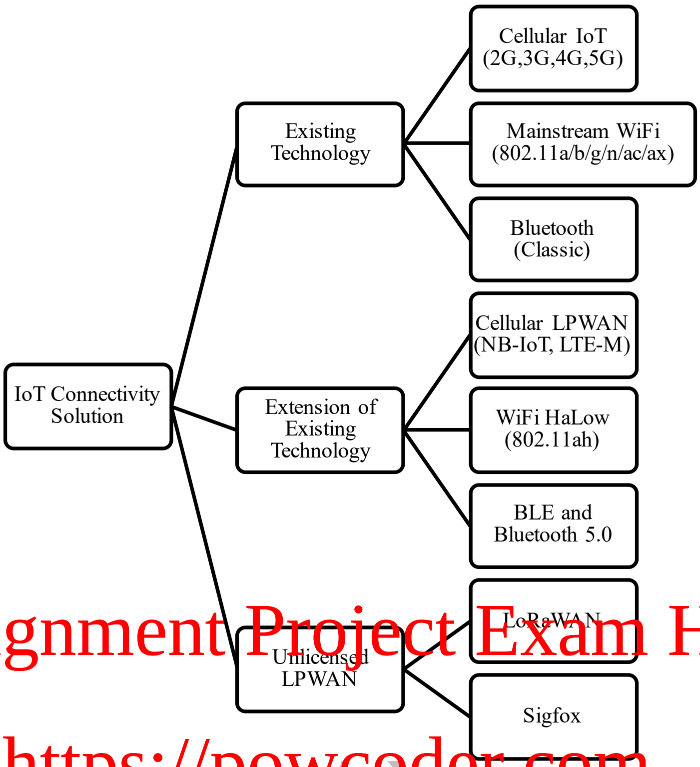

Figure 9.2 Taxonomy of IoT connectivity solutions.

8.4.1 IoT Extensions for Bluetooth

The original Bluetooth, a.k.a. Bluetooth Classic, was designed for exchanging continuous, streaming data at close range. The typical use cases have been wireless headsets for talking or music streaming, wireless speakers, file transfer between two devices at close proximity, and so on. While these applications led to huge popularity of Bluetooth, many IoT applications require much lower power consumption and short message transfer capabilities at longer range.

Bluetooth Low Energy (BLE) was released in 2010 to meet these IoT demands. BLE was designed to sleep most of the time and wake up only to transmit a short message and then going back to sleep again. It extended the range and reduced the power consumption of Bluetooth significantly. BLE is incompatible with the classic version but addresses the need for many IoT sensors which must operate for many years on a single coin battery. BLE is also known as Bluetooth 4.0. Typical applications of Bluetooth 4.0 include industrial monitoring sensors, data updates from wristbands to smartphones, targeted location-based advertising (e.g., iBeacon) etc.

Later, in 2016, Bluetooth 5.0 [BT5] was released to further extend the communication range of 4.0 without increasing the power consumption. Version 5.0 can extend the range 4X (to ~250m) compared to 4.0 (at ~50m) at the expense of reducing the data rates to only a few hundred kbps, which suits IoT sensor data updates. Version 5.0 is compatible with 4.0. More details of all of these versions will be examined at a later chapter.

8.4.2 IoT Extensions for WiFi

WiFi was mainly designed for high speed wireless communications at short ranges typically within a building. This made WiFi a very popular wireless local area networking technology, but it consumes high power, cannot reach long distances or penetrate significant obstacles. Since IoT would require ultra-low power consumption with many sensors located in hard-to-reach places, new WiFi extensions were required for IoT.

As explained in Chapter 6, IEEE 802.11ah, a.k.a. HaLow, was released recently to address the IoT requirements. Specially, it achieved long range by shifting the frequency to 900MHz, which not only can travel longer distances at low power but also can penetrate deep into buildings where many IoT devices may be located. The longer range can be achieved by reducing the data rates to as small as 150kbps. Finally, the low data rate allows HaLow APs to connect 4 times more devices than existing WiFi, which is very important for densely deployed IoT.

8.4.3 IoT Extensions for Cellular Networks

Cellular networks were already designed for connecting devices in a wide area and hence is inherently suitable to connect IoT devices and sensors deployed at city-scale. However, the conventional cellular network, such as 2G, 3G, 4G, etc. were designed for sustained data transfers at high data rate from personal mobile devices, such as mobile phones. Cellular network connection therefore was considered the most power-hungry compared to Bluetooth and WiFi.

Many IoT devices are 'meter reading' or 'status update' type of devices. These devices send only a small amount of data at some regular intervals and they are not delay sensitive. However, these devices are often deployed in places without power supply, which makes them necessary to run completely from battery. As battery replacement can be expensive for remote relocations and due to the sheer number of these devices, the battery lifetime often dictates the lifetime of the device. Low energy consumption therefore is a prime objective of any new cellular technology vying for the IoT market. In addition, the coverage has to be significantly higher than existing cellular technology because these devices are often deployed in hard to reach locations.

Also, due to the large numbers of these devices, they must be in the low-cost range, which means that any new cellular technology has to be much simpler than existing LTE for it to be IoT friendly. Finally, to keep the cost low for the mobile operators, existing cellular infrastructure must be reused for any new services as much as possible.

To address the new market of large scale IoT connectivity, 3GPP, i.e., the organization responsible for standardizing cellular networking, has recently introduced two new modes of cellular communications namely NB-IoT (narrowband IoT) [NBIOT] and LTE-M (M represents machines) [LTEM]. These two modes are designed to support low data rate and low power intermitted data transfers from a large number of devices over a wide area of coverage using the same mobile towers and infrastructure. Due to their low-power consumption, these technologies are also referred to as Low Power WAN (LPWAN). The reuse of existing towers makes these services cost-effective for the mobile operators to support a new market. As these two services are offered by cellular network operators, they are also often referred to as Cellular LPWAN. It should be noted that unlike Bluetooth and WiFi, which uses unlicensed spectrum, Cellular LPWAN uses licensed spectrum.

NB-IoT

NB-IoT is a fast growing cellular LPWAN technology connecting a wide range of new IoT devices, including smart parking, utilities, wearables, and industrial solutions. Standardized by 3GPP in 2016, it is classified as a 5G technology. It has the following characteristics: enhanced coverage, massive connectivity (up to 50,000 per cell), low power consumption, low cost, reuse of installed LTE base.

Although IoT devices transmit a small amount of delay insensitive data, they can still overwhelm the cellular network with the signalling overhead due to the sheer number of them. Thus, many features of LTE, such as real-time handover, guaranteed bit rates, etc., which are essential for voice and video calls, are not available for NB-IoT. A different air-interface is therefore designed for NB-IoT. However, the existing cellular towers can still support both NB-IoT and normal user equipment by tagging the IoT devices with a new user equipment category as illustrated in Figure 9.3.

Enhanced coverage of up to 28dB compared to existing LTE is achieved by using narrow band and allowing high number of retransmissions. NB-IoT uses the same framing and resource allocation structure of LTE, but it allocates only a single resource block (RB), which amounts to 180kHz. A data frame is allowed to be retransmitted up to 128 times in the uplink. Such high number of retransmissions can increase latency, but that is not an issue for NB-IoT devices.

New power classes are defined for NB-IoT devices which allow them to operate with significantly low transmit power suitable for coin cell batteries. Finally, NB-IoT defines new sleep modes that allows an IoT device to remain in complete sleep for extended period of time when the base station cannot reach time. These sleep modes further help optimize the energy consumption and battery lifetime of NB-IoT devices. NB-IoT

LTE-M

Similar to NB-IoT, LTE-M also supports IoT devices that send small amount of data infrequently and need to operate with low energy. However, unlike NB-IoT, LTE-M can support higher bandwidth, high-speed mobility, roaming between countries and operators, and efficient firmware updates. These services can be useful for applications such as asset tracking where an asset typically moves from one country to another. LTE-M also has a lower latency than NB-IoT, which can be beneficial for connecting devices that have more delay-sensitive communication needs, such as an alarm or a self-driving car. Finally, LTE-M can also support voice. Clearly, LTE-M is more complex and costly that NB-IoT but filling a different segment within the IoT market.

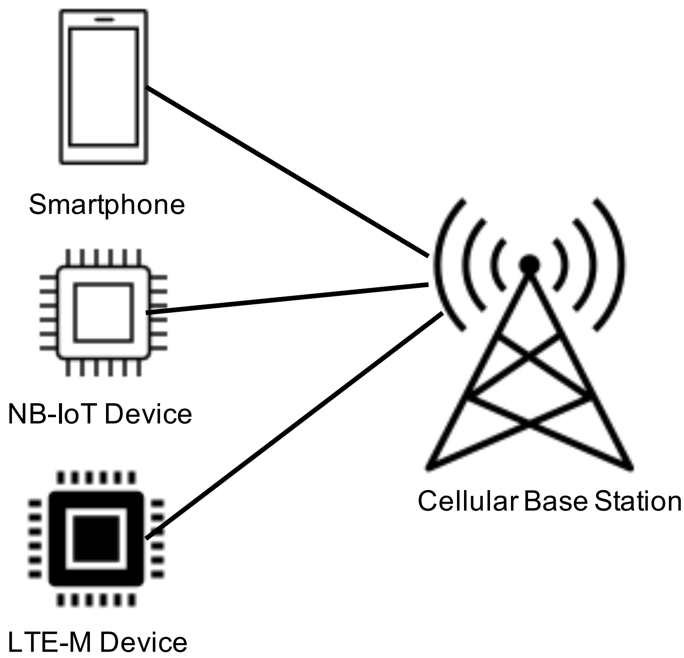

Figure 9.3 Using different air interfaces, existing cellular towers can connect both traditional user equipment (e.g., a smartphone) as well as the new IoT devices fitted with NB-IoT and LTE-M connectivity modules.

8.4.4 New Unlicensed LPWAN Technologies

While the cellular industry deployed NB-IoT and LTE-M air interfaces to serve the IoT needs of the future through the licensed spectrum, parallel developments took place to solve the problem using unlicensed spectrum. The notable unlicensed LPWAN technologies include LoRaWAN [LORA] and Sigfox [SIGFOX]. Both need to set up their own infrastructures to roll out the service. Despite this, the unlicensed LPWAN has become equally competitive with their licensed counterpart. We examine LoRaWAN in details in a later chapter.

8.5 Chapter Summary

1. IoT refers to connecting things that are not computers.
2. Only a small fraction of things is connected today and yet the number of connected IoT devices has surpassed the total number of traditional connected devices, i.e., mobile phones, laptops, data center computers, etc. The scale of IoT makes it the next big Internet evolution.
3. Advancements in sensor technology and low-cost computing platforms have worked as catalyst for the IoT movement today.
4. There exist many different connectivity options for IoT. While early IoT deployments relied on the classical wireless networking, e.g., Bleutooth, WiFi, and cellular, specialized versions of these technologies are being created to better serve the IoT needs. Even new IoT networking technologies, e.g., LoRaWAN and Sigfox, have been designed and deployed from scratch.

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