Internet of What? Things!

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The Internet have made our world a global village, changing almost every aspect of our lives. Add to that wireless mobile communications technologies, the Internet becomes accessible everywhere we go, even while jogging, driving or taking a plane ride.

Each device connected to the Internet is called a *host*. Hosts include *clients* that access Internet-based services and *servers* that provide them. Communications over the Internet follow the *Internet Protocol* (IP). For example, desktops, laptops, and smartphones, are clients. They are used to access and interact with servers that provide various services including the Web, audio/video streaming, banking, e-commerce, and so on.

That is the traditional view of the Internet. The power and usefulness of the Internet can be greatly extended with *IoT* (**I**nternet **o**f **T**hings) where we also connect devices called "*Things*".

Here we discuss IoT, its purposes, applications, impact, and potential. A good grasp of IoT as a technology will make you a better computational thinker.

This post is part of our *Computational Thinking* (CT) blog where you can find many other interesting and useful articles.

In the Beginning

The phrase "*internet of things*" was coined by Kevin Ashton in 1999, when the Internet was still in its infancy. The initial idea was to connect everyday devices and objects to the Internet, enabling them to communicate with each other and with humans who can control and use them for specific purposes.

The very first IoT device was a toaster built and demonstrated by John Romkey and Simon Hackett in 1989. The toaster was connected to a network

via TCP/IP (an Internet protocol) and had one control to turn the toaster on/off. Toast darkness was by controlling how long the power was kept on. Even though this toaster had little practical value by itself, it really was *the toaster that changed the world*!

The concept of IoT began to take shape in the early 2000s, as technology advanced and more devices became capable of connecting to the Internet. At this stage, the focus was primarily on connecting devices such as smartphones, laptops, and computers to the Internet.

As the technology evolved, the scope of IoT expanded to include other devices such as sensors, cameras, and other smart devices. These devices could be used to gather data and provide insights into various aspects of our lives, such as home security, energy consumption, air quality, and even personal health.

With the advent of machine learning and artificial intelligence (AI), IoT devices became smarter and more capable of processing data in real-time. This led to the development of advanced applications–such as smart homes, voice-controlled assistants, smart cities, connected vehicles, fully automated ports–that can revolutionize the way we live, work, and interact with the world around us.

Tody new IoT technologies and applications emerge all the time. As more **things** (devices and objects) become connected to the Internet, the potential for IoT to transform our lives in countless ways continues to grow.

IoT Devices

So, what things or devices are ready to become part of an IoT network? Basically, an IoT-ready device has these main characteristics:

- **Connectivity**: The device is able to connect to the Internet or a network using a wireless or wired connection. It should support standard network protocols such as Wi-Fi, Ethernet, Bluetooth, Zigbee, or cellular.
- **Sensors**: The device has one or more sensors that can measure and collect data. Such a sensor may detect temperature, humidity, light, motion, and so on.
- **Processing Abilities**: The device possesses sufficient processing ability to perform its intended functions, such as collecting, sending, receiving, and processing data, running machine-learning algorithms, or responding to user input.
- **Efficient Power Usage**: An IoT device is usually small and runs on batteries. It should be designed to conserve power and maximize battery life. This is particularly important for devices that are intended to operate in remote or hard-to-reach places/locations, where frequent battery charging or replacement may be difficult or even impossible.
- **Security**: The device often has built-in security features to protect against unauthorized access, data breaches, and cyber-attacks. This could include encryption, authentication, access control, and secure communication protocols.
- **Compatibility**: The device is compatible with standard IoT platforms and protocols, allowing it to be easily integrated into an IoT network.

Overall, an IoT-ready device should meet specific needs and be compatible with standard IoT protocols and platforms.

Household IoT

The most popular IoT consumer devices include smartphones, smart TVs, smart printer/copiers, smart speakers, connected thermostats, home security

systems, domestic robots, smart bulbs, energy monitors, connected appliances, smart door locks, and connected car devices.

For example Amazon Echo is an IoT smart speaker backed by an Internet-connected voice assistant. It understands voice commands in major languages including English, German, Spanish, Italian, and Chinese. The device can help set alarms, manage your purchases, provide weather and news information, play music, and make calls via your enabled cellphone.

Here are some more examples: Google Home, smart thermostats like Nest and Ecobee, smart home security systems like Ring and SimpliSafe, smart lighting systems like Philips Hue and LIFX, and smart locks like August and Yale.

Remote Monitoring Systems

An important IoT application is in remote monitoring systems with cameras that allow users to check on their elderly or disabled parents from their own homes. These types of devices are becoming increasingly popular as people seek ways to monitor and care for their aging loved ones from a distance.

Such remote monitoring systems typically consist of video cameras, microphones, or other sensors placed in the elderly person's home, which can be accessed remotely by family members using a smartphone app or web portal.

Some systems also include features such as two-way audio communication, motion detection, and alerts that notify family members of any unusual activity or changes in the elderly person's behavior or condition. Wearable devices for remote vital signs monitoring can help greatly in such cases.

In addition to providing peace of mind for family members, these types of systems can also help elderly individuals remain independent and stay in their own homes for longer. They can also provide valuable insights into the elderly person's daily routines and habits, which can be used to identify potential health or safety issues early on.

Smart Cities

Moving out of households, IoT can be deployed city-wide. Let's first look at control and management of city traffic.

Smart traffic lights and signs are great examples of IoT applications that are designed to improve traffic flow and reduce congestion in urban areas. These devices use sensors, cameras, and other technologies to collect and analyze real-time traffic data, which is then used to adjust traffic signal timing and provide drivers with up-to-date information on traffic conditions.

Several cities around the world have implemented smart traffic lights and signs. Examples include Singapore, Barcelona, and Los Angeles.

Additional smart city IoT applications include:

- **Smart waste management**: IoT sensors are used to monitor waste bins to optimize garbage collection routes.

- **Smart energy management**: IoT devices are used to optimize energy use in buildings, streetlights, and other city infrastructure.
- **Smart parking**: IoT sensors monitor available parking spots, enabling the system to guide drivers to the nearest space available or to indicate estimated wait time for a free spot.
- **Smart water management**: IoT sensors can monitor water usage, detect leaks, and optimize water distribution, improving efficiency and reducing waste.
- **Public safety**: IoT devices such as cameras and sensors can help monitor public spaces and detect potential safety threats, improving public safety and emergency response.
- **Air quality monitoring**: IoT sensors are placed at well-selected locations to monitor air quality in real-time, detecting pollutants and providing data to help city officials make decisions about pollution control measures.

IoT in Transportation

IoT applications in transportation must cover much wider areas and control objects that move large distances. Examples include air traffic control, sea port control, and package delivery.

- **Air Traffic Control**: The Federal Aviation Administration (FAA) is currently testing an IoT system that uses sensors to track planes in real-time. The system, called the Automatic Dependent Surveillance-Broadcast (ADS-B), allows air traffic controllers to see the location, altitude, and velocity of every plane in the sky. This information can be used to optimize flight paths, reduce delays, and improve safety.
- **Sea Port Control**: The Port of Rotterdam in the Netherlands is using IoT technology to optimize the movement of cargo ships in and out of the port. The system, called Port of the Future, uses sensors to monitor the location, speed, and direction of ships in real-time. This information is then used to optimize shipping routes, reduce fuel consumption, and improve safety.

- **Package Delivery**: Amazon has developed an IoT system called Amazon Scout, which uses autonomous delivery robots to deliver packages to customers. The robots use sensors to navigate sidewalks, avoid obstacles, and deliver packages to customers' doorsteps. The system is currently being tested in several cities in the United States.

  Another example of IoT in package delivery is the use of GPS tracking and sensors in delivery trucks to optimize routes, reduce fuel consumption, and improve delivery times. Companies like UPS and FedEx use IoT systems to track their trucks and optimize their delivery routes.

  Also, the global shipping company Maersk uses IoT technology to monitor the condition of shipping containers. Sensors are placed on the containers to monitor temperature, humidity, and other environmental factors. This information is used to ensure that the contents of the containers are kept in optimal conditions during transit.

People-less Ports

Yangshan Deep Water Port in Shanghai (上海洋山深水港 China) is a fully automated sea port that uses IoT technologies to speed up and optimize port operations while improving efficiency, safety and security.

Yangshan Deep-Water Port, China (image:VGC 2023)

In particular, the port uses a variety of sensors and IoT devices to collect real-time data on various aspects of port operations, such as container location, traffic flow, and equipment performance. This data is then analyzed

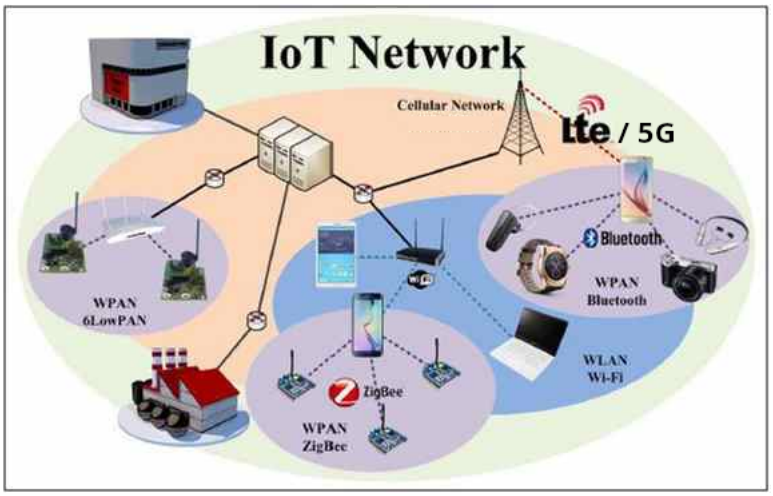
by the port's centralized control center, which uses artificial intelligence and machine learning algorithms to optimize port operations.

For example, sensors placed on container cranes can monitor the movement of containers and track their location. This information can be used to optimize the positioning of the cranes and to reduce wait times for ships. Similarly, sensors placed on unmanned guided vehicles (UGVs) can monitor their location and performance, allowing the control center to optimize their routing and improve efficiency.

In addition to optimizing port operations, IoT technologies can also improve safety and security in the port. For example, sensors can be used to detect potential hazards, such as overheating equipment or leaking containers, and alert port authorities in real-time. This can help to prevent accidents and reduce the risk of damage to cargo or equipment.

The largely unmanned fully automated container ports in China use a combination of advanced IoT, Beidou (北斗) satellite navigation, 5G (mobile), AI, and driverless vehicle technologies. As of April 2023, in addition to Yangshan, China has two other such ports: Qingdao (青岛) Port and Tianjin (天津) Port and is completing a fourth.

IoT Network Protocols and Topology



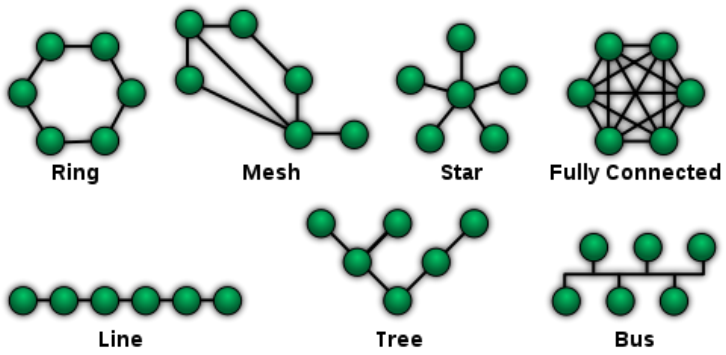
Having seen various applications, it is now time for us to take a closer look at the IoT technology itself, namely its protocols and network configurations.

Of course IP (Internet Protocol) is the most basic for communication over the Internet. In addition an IoT network and the connected IoT-ready devices may use one or more of the following IoT protocols:

- **Zigbee**: Zigbee is a wireless protocol that is commonly used in home automation and industrial control applications. It supports mesh networking, low-power consumption, and a range of data rates.
- **CoAP (Constrained Application Protocol)**: CoAP is a simple protocol that is designed for use in constrained networks, such as those found in IoT devices. It is used for data transfer between devices and servers, and supports resource discovery and management.
- **Bluetooth**: Bluetooth is a wireless protocol that is widely used in consumer electronics for short-range communication. It is often used in IoT devices for communication between smartphones and other devices.
- **MQTT (Message Queuing Telemetry Transport)**: MQTT is a simple messaging protocol that is commonly used in IoT networks for its low bandwidth and power requirements. It is used to send messages between devices and servers, and supports a publish/subscribe model for data communication.
- **LoRaWAN (Long Range Wide Area Network)**: LoRaWAN is a wireless protocol that is designed for long-range communication in low-power devices. It is often used in IoT applications for remote monitoring and control.
- **HTTP (Hypertext Transfer Protocol)**: HTTP is a standard protocol used for web-based communication, and is often used in IoT networks for communication between devices and servers. It is commonly used for data transfer and control of IoT devices.
- **4G LTE and 5G (mobile network)**: These are used for IoT applications involving mobile devices usually over a wide area.

These are just a few examples of the IoT protocols that an IoT-ready device may need to support. The exact protocols used in a network will depend on the specific use case and requirements of the network.

These various protocols are useful in forming IoT networks for different purposes. Different applications also require appropriate IoT network configurations (called network topologies) to better perform intended tasks.



Various Network Topologies

In small-scale IoT networks, the most common topology is a star topology, where all leaf-node devices are connected to a central hub or gateway, such as a WiFi router, smartphone, or cable modem. This hub or gateway acts as a mediator between the devices and the Internet, and allows for easy management and control of the network. Another common topology for small-scale IoT networks is a mesh topology, where devices communicate with each other directly, creating a self-organizing network that can handle failures and ensure reliable communication.

In large-scale IoT networks, the topology becomes more complex and may include a combination of various topologies. For example, a hierarchical topology may be used, where smaller sub-networks are connected to larger networks through gateways or routers. This can help manage the flow of data and ensure that the network is efficient and reliable. Another common topology for large-scale IoT networks is a tree topology, where devices are connected in a hierarchical structure with a single root node at the top.

In general, the topology of an IoT network depends on the specific use case, the number of devices, the geographical distribution of the devices, and the requirements for reliability, security, and scalability.

IoT Takes Flight

Recent years have seen the rapid development of drones that are relatively light weight and inexpensive. Drones can become IoT devices because they can be equipped with cameras, microphones, satellite positioning and other types of sensors. And they can be connected to IoT networks via wireless mobile links. Thus, drones can collect all kinds of data and transmit them in real-time.

Drones can provide valuable insights into areas that are difficult to access, such as remote or dangerous locations, and can be used for a variety of purposes, such as surveillance, inspection, mapping, and delivery of items.

Advances in mobile networking, especially 5G technologies, are crucial in enabling using drones as IoT devices. With high-speed connectivity and low latency, 5G networks can support the real-time data transfer necessary for drone operations, allowing for more precise control and safer flights. 5G also enables the use of high-resolution cameras and other sensors that produce large amounts of data, which can be processed quickly and efficiently.

Smart Agriculture (image: digi.com)

The integration of smart drones as IoT devices, powered by 5G mobile network technologies, opens up a new dimension of possibilities for various industries, enabling them to gather critical data and insights that were previously inaccessible. Here are some real-world examples:

- **Agriculture**: Drones with multispectral cameras and other sensors are used to monitor crops, detect crop diseases, and assess soil moisture levels. This information can be used to optimize crop yields, reduce the use of fertilizers and pesticides, and improve overall farm management. For example, the American Farm Bureau Federation used drones to survey crop damage caused by Hurricane Florence in 2018. The drones can also efficiently and quickly spray fertilizers or pesticides on crops.

- **Clean Energy**: Drones can help inspect and maintain power lines, wind turbines, and other energy infrastructure. Using drones with thermal cameras, companies can detect problems such as hotspots, which can be indicative of potential failures. In 2018, Southern Company used drones to inspect a 50-mile stretch of transmission lines in Alabama.

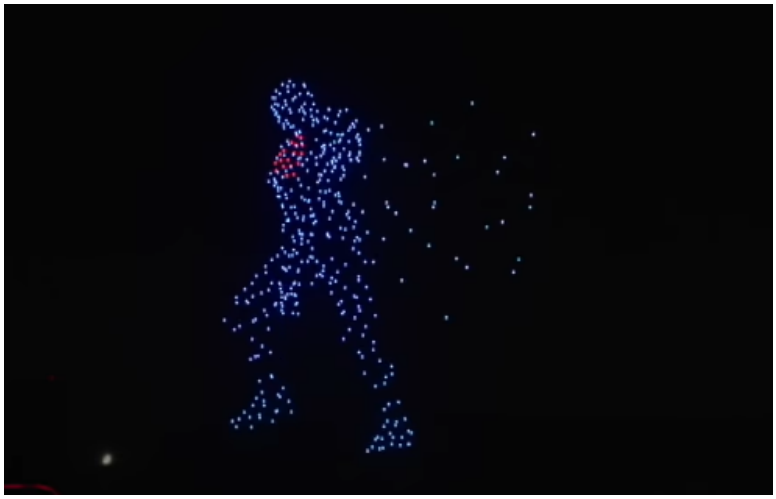
- **Construction**: Drones are used to monitor construction sites, conduct surveys, and inspect buildings. Using drones with lidar sensors, construction companies can create highly detailed 3D models of sites, which can be used for planning and design purposes. Skycatch, a company specializing in drone surveying, has worked with construction companies such as Bechtel and Mortenson to survey construction sites.

- **Emergency response**: Drones can be used to provide situational awareness and support during emergencies. For example, drones equipped with thermal cameras can help locate missing persons in search and rescue missions. Drones serving as emergency mobile transmission towers can quickly restore mobile communication to a remote disaster area. In 2019, DJI, a leading drone manufacturer, partnered with the European Emergency Number Association to develop guidelines for the use of drones in emergencies.

- **Retail**: Drones can be used to deliver packages and products to customers. In 2016, Amazon began testing its Prime Air delivery service, which uses drones to deliver packages to customers within 30 minutes of ordering. Other companies, such as UPS and DHL, are also testing drone delivery services.

- **Entertainment**: Synchronized drone shows can be a big draw for important festivals and other public events, especially at night. Such a spectacular and crowd-pleasing show also presents a unique venue for

advertising and public announcements. It also demonstrates the power and potential of combining IoT, 5G, drones and real-time control of a large number of unmanned flying objects.



500-Drone Light Show (image: CGTN)

These are just a few examples of how drones are being used as IoT devices. Weather balloons also become flying IoT devices that use LoRaAWAN gateways, for example, for weather monitoring and forecasting purposes. There are also IoT enabled/enabling blimps. As the technology continues to develop and become more widespread, we can expect to see even more innovative use cases emerge.

The IoT Market

The stakeholders in the IoT marketplace are diverse and include hardware manufacturers, software developers, cloud service providers, telecommunications companies, system integrators, and end-users.

The size of the IoT market is difficult to estimate precisely, as it includes a wide range of products and services across multiple industries. However, according to a report by MarketsandMarkets, the global IoT market size was valued at $250 billion in 2020 and is expected to grow to $1.4 trillion by 2026, with a compound annual growth rate (CAGR) of 24.9

The global 5G IoT market is projected to grow from $13.2 billion in 2023 to $59.7 billion by 2028, at a Compound Annual Growth Rate (CAGR) of 35.1

In the End

Starting from a simple and silly idea of connecting a household toaster to the Internet, IoT has grown, expanded, and evolved into something significant. In fact, IoT has opened up a new dimension of the Internet.

With the convergence of new devices, sensors, protocols, networking techniques, drones, and 5G mobile networks, IoT has transformed, in may respects, the way we live, work, conduct business, play and much more. The IoT market size is significant and will grow rapidly going forward.

Embedding sensors, processing and networking power in physical objects and connecting them to the Internet is a small step indeed. But gather enough small steps you get a brand new situation. Electronic circuit integration and chip technology development are also examples obvious to computational thinkers.

That is the "quantity to quality" law of transformation, demonstrated by increasing the temperature of water enough degrees you end up with something new—steam. However, that has always been the case and the way civilizations evolve and advance. The idea of sharpening a stone to make a simple tool has led to much bigger things indeed.

Computational thinkers understand this well and are ready to take any new idea and maximize its impact.