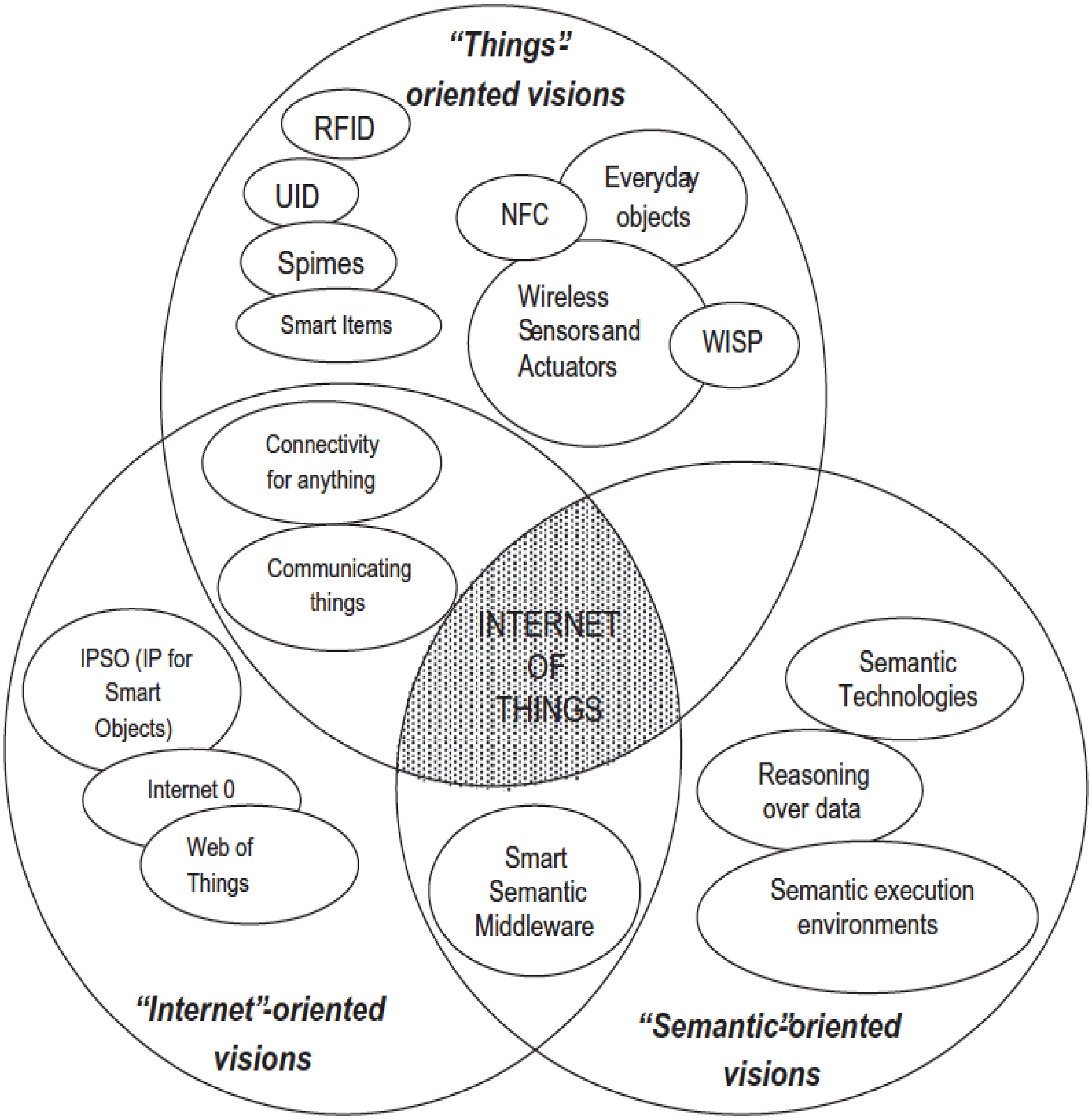
Internet of Things (IoT)

What is IoT?

A phenomenon which connects a variety of ***things.***
– Everything that has the ability to communicate

Connection of Multiple Visions


"Things"-oriented visions
RFID
UID
Spimes
Smart Items
NFC
Everyday objects
Wireless Sensors and Actuators
WISP
Connectivity for anything
Communicating things
INTERNET OF THINGS
IPSO (IP for Smart Objects)
Internet 0
Web of Things
Smart Semantic Middleware
Semantic Technologies
Reasoning over data
Semantic execution environments
"Internet"-oriented visions
"Semantic"-oriented visions

IoT Definitons

- The Internet of Things, also called The Internet of Objects, refers to a wireless network between objects, usually the network will be wireless and self---configuring, such as household appliances. **(Wikipedia)**

- The term "Internet of Things" has come to describe a number of technologies and research disciplines that enable the Internet to reach out into the real world of physical objects. **(IoT 2008)**

- “Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts”. **(IoT in 2022)**

Any---X Point of View

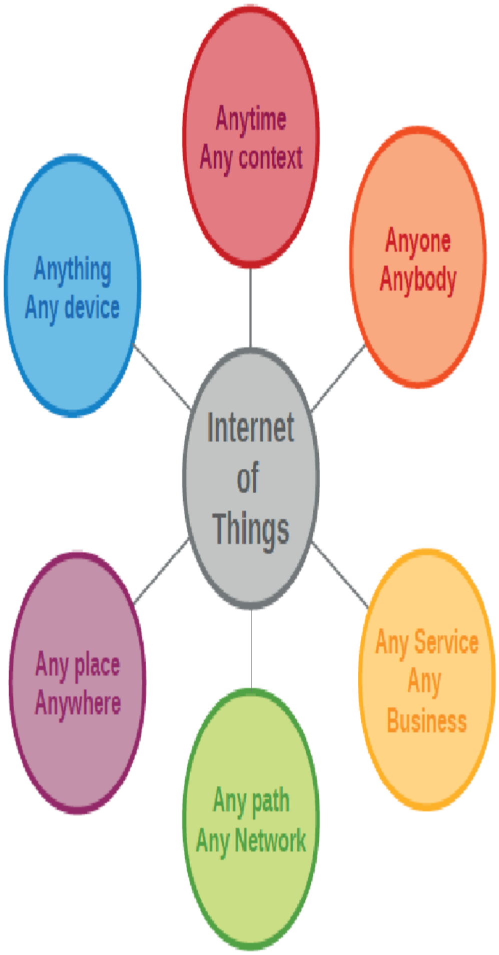
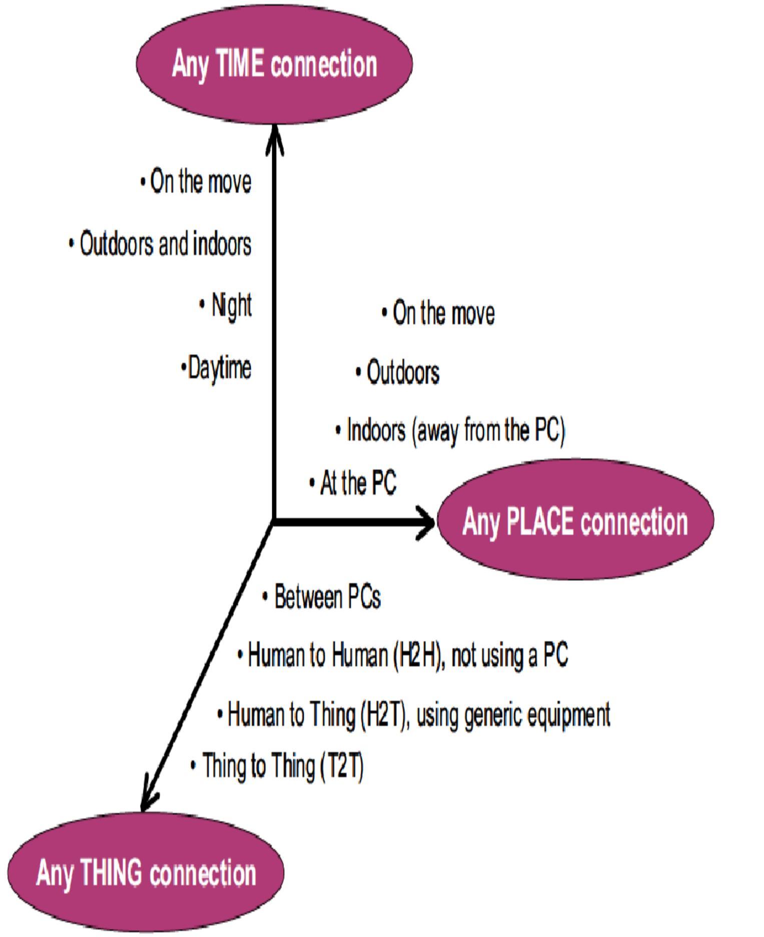


Figure 1 – A new dimension



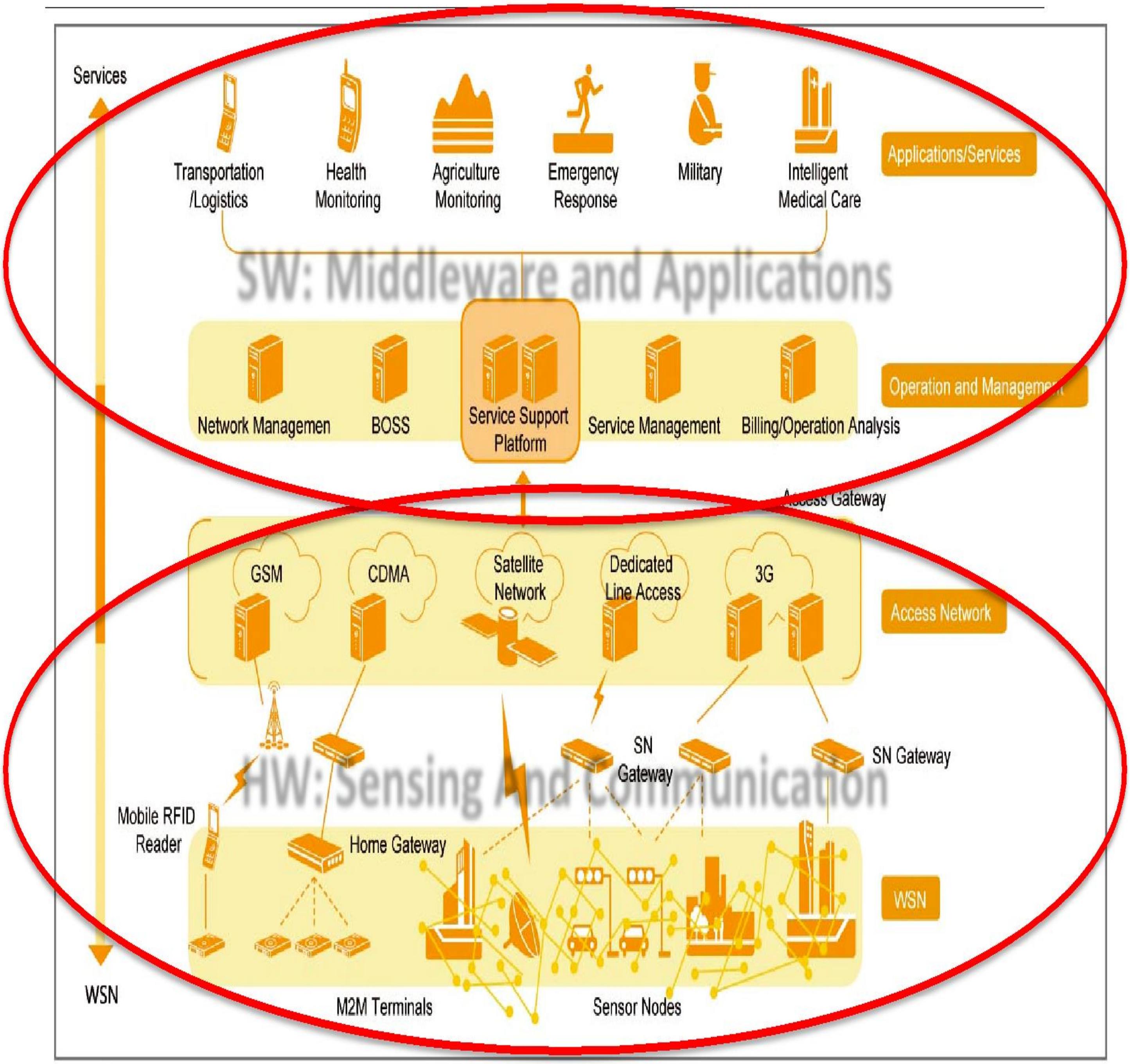
Source: ITU adapted from Nomura Research Institute

- The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/ network and Any service.

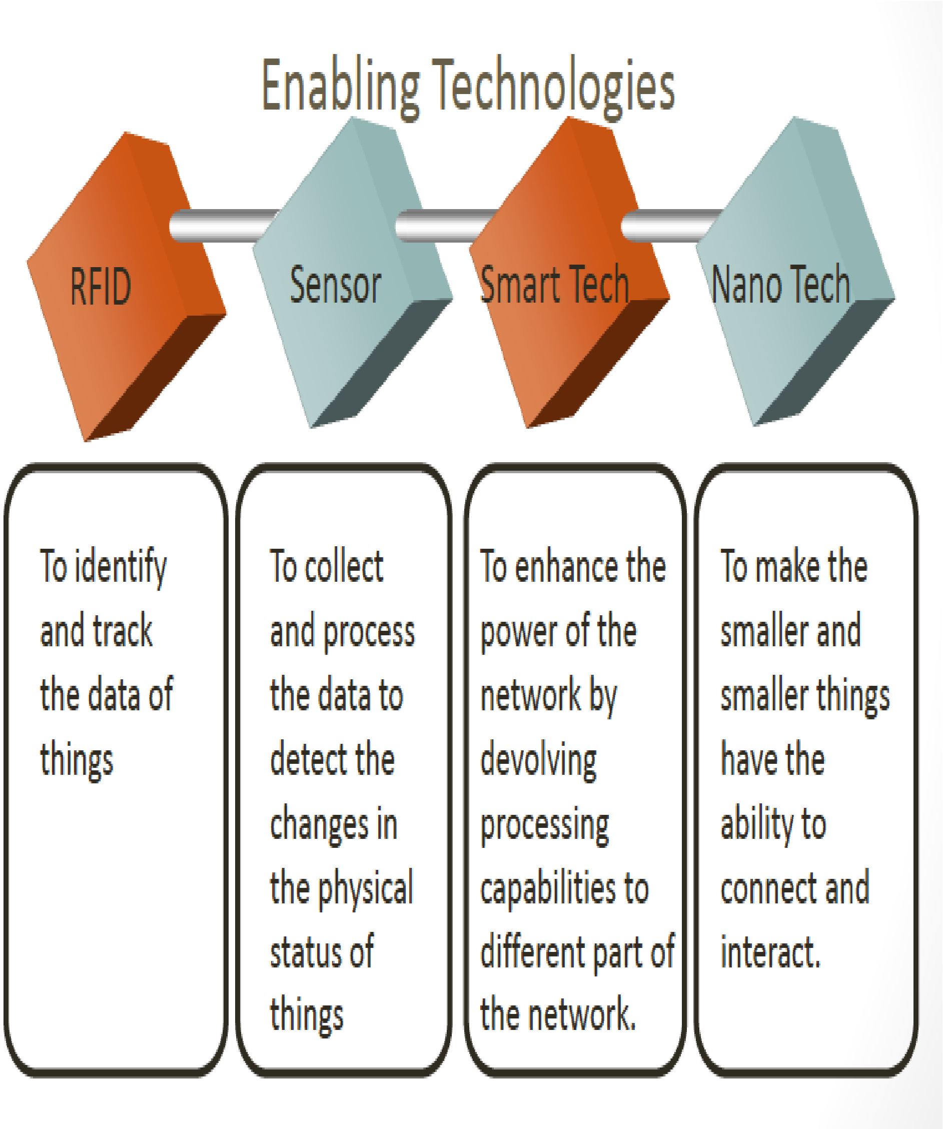
Characteristics of IoT

1. Intelligence
   - Knowledge extraction from the generated data
2. Architecture
   - A hybrid architecture supporting many others
3. Complex system
   - A diverse set of dynamically changing objects
4. Size considerations
   - Scalability
5. Time considerations
   - Billions of parallel and simultaneous events
6. Space considerations
   - Localization
7. Everything-as-a-service
   - Consuming resources as a service

IoT Layered Architecture



Networking and Communication



Enabling Technologies

RFID

To identify and track the data of things

Sensor

To collect and process the data to detect the changes in the physical status of things

Smart Tech

To enhance the power of the network by devolving processing capabilities to different part of the network.

Nano Tech

To make the smaller and smaller things have the ability to connect and interact.

- RFID to smallest enabling technologies, such as chips, etc.
- Mobile platforms, such as sensors, phones, etc.

RFIDs

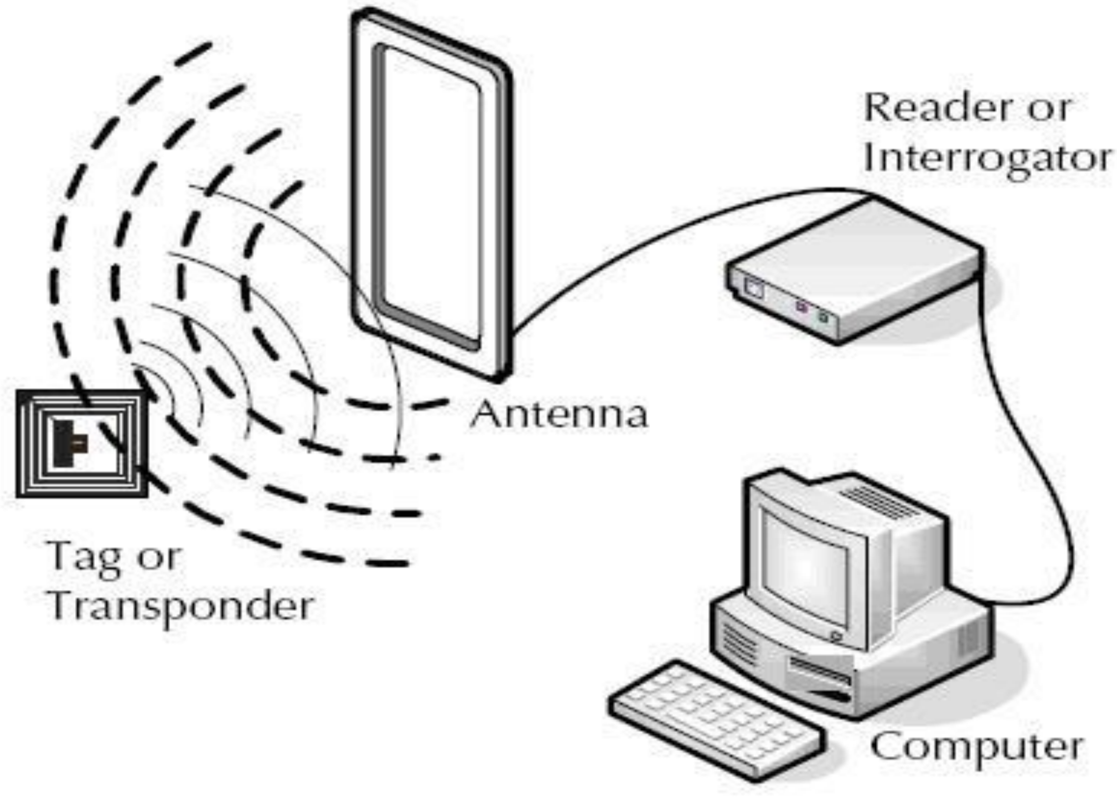
• The reduction in terms of size, weight, energy consumption, and cost of the radio takes us to a new era

– This allows us to integrate radios in almost all objects and thus, to add the world ‘‘anything” to the above vision which leads to the IoT concept

• Composed of one or more readers and tags

• RFID tag is a small microchip attached to an antenna

• Can be seen as one of the main, smallest components of IoT, that collects data



Wireless Technologies

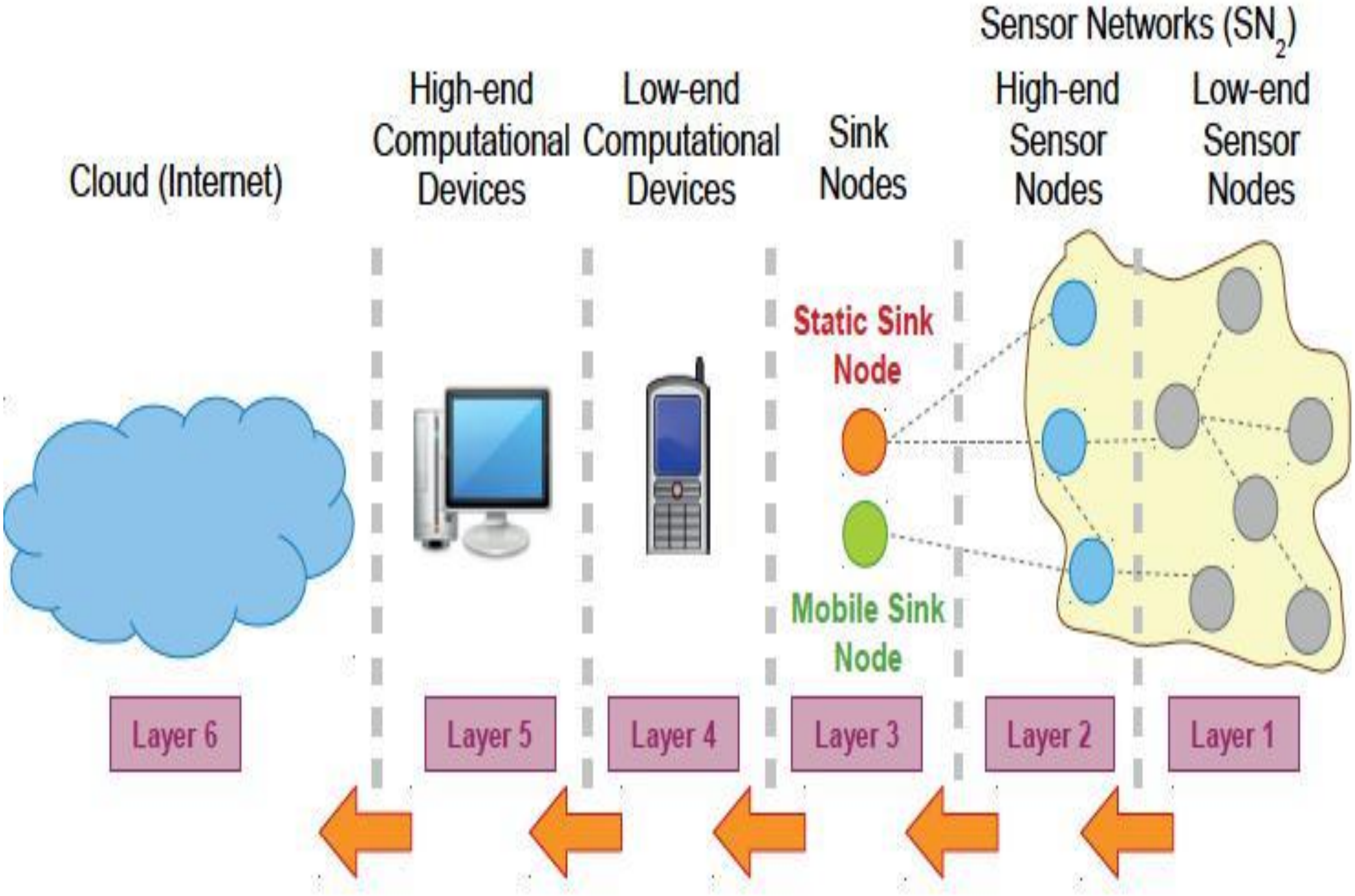
- Telecommunication systems
  - Initial/primary service: mobile voice telephony
  - Large coverage per access point (100s of meters – 10s of kilometers)
  - Low/moderate data rate (10s of kbit/s – 10s of Mbits/s)
  - Examples: GSM, UMTS, LTE
- WLAN
  - Initial service: Wireless Ethernet extension
  - Moderate coverage per access point (10s – 100s meters)
  - Moderate/high data rate (Mbits/s – 100s)
  - Examples: IEEE 802.11(a---g), Wimax
- **Short range**:
  - Direct connection between devices – sensor networks
  - Typical low power usage
  - Examples: Bluetooth, Zigbee, Z-wave (house products)
- **Other examples:**
  - Satellite systems
- Global coverage
- Applications: audio/TV broadcast, positioning, personal communications

- **Broadcast systems**

- Satellite/terrestrial
- Support for high speed mobiles
  - Fixed wireless access
- Several technologies including DECT, WLAN, IEEE802.16, etc.

Sensor Networks (SNs)

- Consist of a certain number (which can be very high) of sensing nodes (generally wireless) communicating in a wireless multi-hop fashion



Sensor Networks (SNs)

- SNs generally exist without IoT but IoT cannot exist without SNs

- SNs have been designed, developed, and used for specific application purposes

  – Environmental monitoring, agriculture, medical care, event detection etc.

- For IoT purposes, SNs need to have a middleware addressing these issues:

  – Abstraction support, data fusion, resource constraints, dynamic topology, application knowledge, programming paradigm, adaptability, scalability, security, and QoS support

Example: Indoor Localization

- An indoor positioning system (IPS) is a solution to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices.

- For indoor localization:

  – Any wireless technology can be used for locating

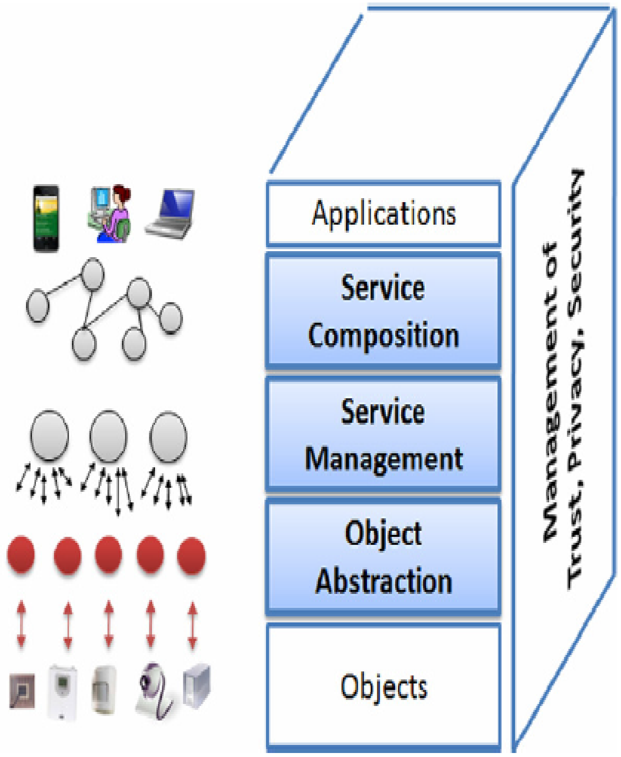
  – GPS, WiFi, Bluetooth, RFID, Ultrawide band, Infrared, Visible light communication, Ultrasound

Middleware

- Middleware is a so/ware layer that stands between the networked opera4ng system and the applica4on and provides well known reusable solu4ons to frequently encountered problems like heterogeneity, interoperability, security, dependability .
- IoT requires stable and scalable middleware soluPons to process the data coming from the networking layers

Service Oriented Architecture (SOA)

- Middleware soluPons for IoT usually follow SOA approaches
- Allows SW/HW reuse
  - Doesn’t impose specific technology
- A layered system model addressing previous issues
  - AbstracPon, common



Other Middleware Examples

- Fosstrak Project

– Data disseminaPon/aggregaPon/filtering/interpretaPon

– Fault and configuraPon management, lookup and directory service, tag ID management, privacy

- Welbourne et al.

– Tag an object/create--edit locaPon info/combine events collected by antennas

- e---Sense Project

– Middleware only collects data in a distributed fashion and transmits to actuators

- UbiSec&Sens Project

– Focuses on security - secure data collecPon, data store in memory, etc.

Open Problems and Challenges

- Lack of standardizaPon

- Scalability

– Addressing issues

– Understanding the big data

- Support for mobility

- Address acquisiPon

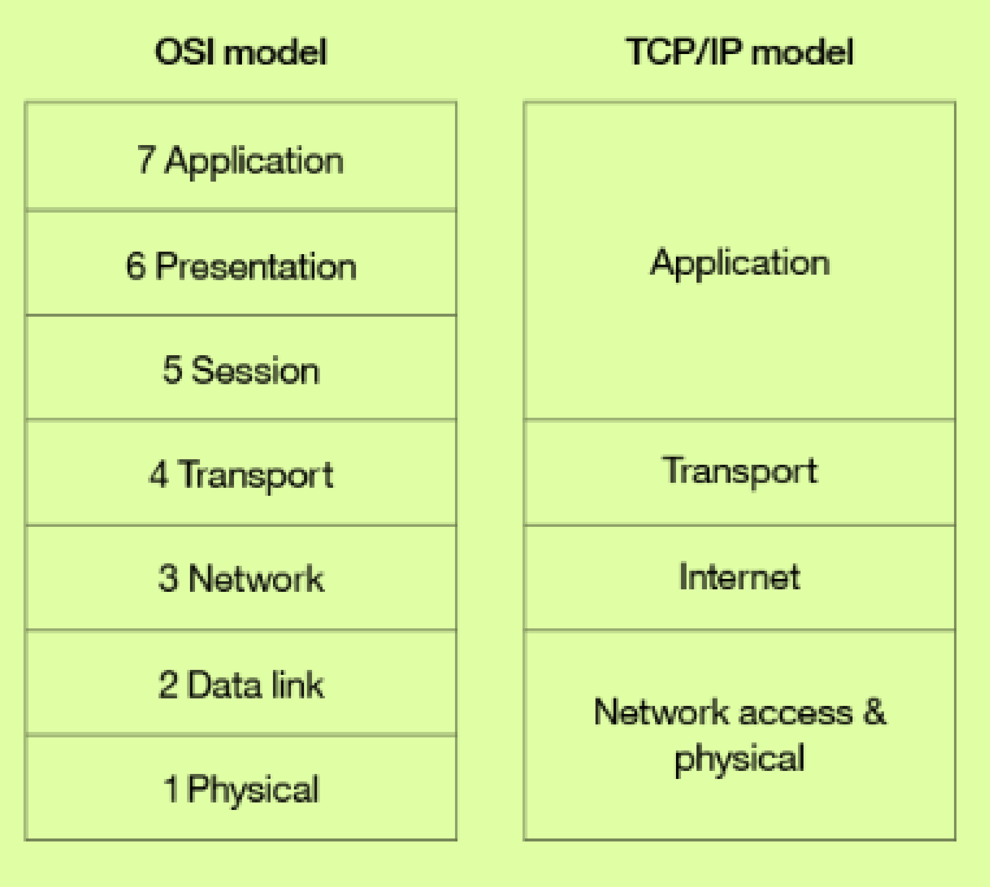
- New network traffic pa@erns to handle

- Security/Privacy issues

NETWORKING STANDARDS AND TECHNOLOGIES

- The Open Systems Interconnection (OSI) model is an ISO-standard abstract model is a stack of seven protocol layers.

- From the top down, they are: application, presentation, session, transport, network, data link and physical. TCP/IP, or the Internet Protocol suite, underpins the internet, and it provides a simplified concrete implementation of these layers in the OSI model.



OSI model	TCP/IP model
7 Application	Application
6 Presentation	
5 Session	
4 Transport	Transport
3 Network	Internet
2 Data link	Network access & physical
1 Physical	

Figure for OSI and TCP/IP networking models

The TCP/IP model includes only four layers, merging some of the OSI model layers:

- **Network Access & Physical Layer**

This TCP/IP Layer subsumes both OSI layers 1 and 2. The physical (PHY) layer (Layer 1 of OSI) governs how each device is physically connected to the network with hardware, for example with an optic cable, wires, or radio in the case of wireless network like wifi IEEE 802.11 a/b/g/n). At the link layer (Layer 2 of OSI), devices are identified by a MAC address, and protocols at this level are concerned with physical addressing, such as how switches deliver frames to devices on the network.

- **Internet Layer**

This layer maps to the OSI Layer 3 (network layer). OSI Layer 3 relates to logical addressing. Protocols at this layer define how routers deliver packets of data between source and destination hosts identified by IP addresses. IPv6 is commonly adopted for IoT device addressing.

- **Transport Layer**

The transport layer (Layer 4 in OSI) focuses on end-to-end communication and provides features such as reliability, congestion avoidance, and guaranteeing that packets will be delivered in the same order that they were sent. UDP (User Datagram protocol) is often adopted for IoT transport for performance reasons.

- **Application Layer**

The application layer (Layers 5, 6, and 7 in OSI) covers application-level messaging. HTTP/S is an example of an application layer protocol that is widely adopted across the internet.

Although the TCP/IP and OSI models provide you with useful abstractions for discussing networking protocols and specific technologies that implement each protocol, some protocols don't fit neatly into these layered models and are impractical. For example, the Transport Layer Security (TLS) protocol that implements encryption to ensure privacy and data integrity of network traffic can be considered to operate across OSI layers 4, 5, and 6.

NETWORK ACCESS AND PHYSICAL LAYER IOT NETWORK TECHNOLOGIES

IoT network technologies to be aware of toward the bottom of the protocol stack include cellular, Wifi, and Ethernet, as well as more specialized solutions such as LPWAN, Bluetooth Low Energy (BLE), ZigBee, NFC, and RFID.

NB-IoT is becoming the standard for LPWAN networks, according to Gartner. This IoT for All article tells more about NB-IoT.

The following are network technologies with brief descriptions of each:

– **LPWAN** (Low Power Wide Area Network) is a category of technologies designed for low-power, long-range wireless communication. They are ideal for large-scale deployments of low-power IoT devices such as wireless sensors. LPWAN technologies include LoRa (LongRange physical layer protocol), Haystack, SigFox, LTE-M, and NB-IoT (Narrow-Band IoT).

- **Cellular** The LPWAN NB-IoT and LTE-M standards address low-power, low-cost IoT communication options using existing cellular networks. NB-IoT is the newest of these standards and is focused on long-range communication between large numbers of primarily indoor devices. LTE-M and NB-IoT were developed specifically for IoT, however existing cellular technologies are also frequently adopted for long-range wireless communication. While this has included 2G (GSM) in legacy devices (and currently being phased out), CDMA (also being retired or phased out), it also includes 3G, which is rapidly being phased out with several network providers retiring all 3G devices. 4G is still active and will be until 5G becomes fully available and implemented.

- **Bluetooth Low Energy (BLE)**

BLE is a low-power version of the popular Bluetooth 2.4 GHz wireless communication protocol. It is designed for short-range (no more than 100 meters) communication, typically in a star configuration, with a single primary device that controls several secondary devices. Bluetooth operates across both layers 1 (PHY) and 2 (MAC) of the

OSI model. BLE is best suited to devices that transmit low volumes of data in bursts. Devices are designed to sleep and save power when they are not transmitting data. Personal IoT devices such as wearable health and fitness trackers, often use BLE.

– **ZigBee** ZigBee operates on 2.4GHz wireless communication spectrum. It has a longer range than BLE by up to 100 meters. It also has a slightly lower data rate (250 kbps maximum compared to 270 kbps for BLE) than BLE. ZigBee is a mesh network protocol. Unlike BLE, not all devices can sleep between bursts. Much depends on their position in the mesh and whether they need to act as routers or controllers within the mesh. ZigBee was designed for building and home automation applications. Another closely related technology to ZigBee is Z-Wave, which is also based on IEEE 802.15.4. Z-Wave was designed for home automation. It has been proprietary technology, but was recently released as a public domain specification.

- **NFC** The near field communication (NFC) protocol is used for very small range communication (up to 4 cm), such as holding an NFC card or tag next to a reader. NFC is often used for payment systems, but also useful for check-in systems and smart labels in asset tracking.

- **RFID** RFID stands for Radio Frequency Identification. RFID tags store identifiers and data. The tags are attached to devices and read by an RFID reader. The typical range of RFID is less than a meter. RFID tags can be active, passive, or assisted passive. Passive tags are ideal for devices without batteries, as the ID is passively read by the reader. Active tags periodically broadcast their ID, while assisted passive tags become active when RFID reader is present. **Dash7** is a communication protocol that uses active RFID that is designed to be used within Industrial IoT applications for secure long-range communication. Similar to NFC, a typical use case for RFID is tracking inventory items within retail and industrial IoT applications.

-**Wifi** Wifi is standard wireless networking based on IEEE 802.11a/b/g/n specifications. 802.11n offers the highest data throughput, but at the cost of high-power consumption, so IoT devices might only use 802.11b or g for power conservation reasons. Although wifi is adopted within many prototype and current generation IoT devices, as longer-range and lower-power solutions become more widely available, it is likely that wifi will be superseded by lower-power alternatives.

- **Ethernet** Widely deployed for wired connectivity within local area networks, Ethernet implements the IEEE 802.3 standard. Not all IoT devices need to be stationery wireless . For example, sensor units installed within a building automation system can use wired networking technologies like Ethernet. Power line communication (PLC), an alternative hard-wired solution, uses existing electrical wiring instead of dedicated network cables.

INTERNET LAYER IOT NETWORK TECHNOLOGIES

Internet layer technologies (OSI Layer 3) identify and route packets of data. Technologies commonly adopted for IoT are related to this layer, and include IPv6, 6LoWPAN, and RPL.

- **IPv6** At the Internet layer, devices are identified by IP addresses. IPv6 is typically used for IoT applications over legacy IPv4 addressing. IPv4 is limited to 32-bit addresses, which only provide around 4.3 billion addresses in total, which is less than the current number of IoT devices that are connected, while IPv6 uses 128 bits, and so provides 2^{128} addresses (around 3.4×10^{38} or 340 billion billion billion billion) addresses. In practice, not all IoT devices need public addresses. Of the tens of billions of devices expected to connect via the IoT over the next few years, many will be deployed in private networks that use private address ranges and only communicate out to other devices or services on external networks by using gateways.

- **6LoWPAN** The IPv6 Low Power Wireless Personal Area Network (6LoWPAN) standard allows IPv6 to be used over 802.15.4 wireless networks. 6LoWPAN is often used for wireless sensor networks, and the Thread protocol for home automation devices also runs over 6LoWPAN.

– The Internet Layer also covers routing. IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) is designed for routing IPv6 traffic over low-power networks like those networks implemented over 6LoWPAN. RPL (pronounced “ripple”) is designed for routing packets within constrained networks such as wireless sensor networks, where not all devices are reachable at all times and there are high or unpredictable amounts of packet loss. RPL can compute the optimal path by building up a graph of the nodes in the network based on dynamic metrics and constraints like minimizing energy consumption or latency.

APPLICATION LAYER IOT NETWORK TECHNOLOGIES

HTTP and HTTPS are ubiquitous across internet applications, which is true also within IoT, with RESTful HTTP and HTTPS interfaces widely deployed. CoAP (Constrained Application Protocol) is like a lightweight HTTP that is often used in combination with 6LoWPAN over UDP. Messaging protocols like MQTT, AMQP, and XMPP are also frequently used within IoT applications:

- **MQTT** Message Queue Telemetry Transport (MQTT) is a publish/subscribe-based messaging protocol that was designed for use in low bandwidth situations, particularly for sensors and mobile devices on unreliable networks.
- **AMQP** Advanced Message Queuing Protocol (AMQP) is an open standard messaging protocol that is used for message-oriented middleware. Most notably, AMQP is implemented by RabbitMQ.
- **XMPP** The Extensible Messaging and Presence Protocol (XMPP) was originally designed for real-time human-to-human communication including instant messaging. This protocol has been adapted for machine-to-machine (M2M) communication to implement lightweight middleware and for routing XML data. XMPP is primarily used with smart appliances.

Your choice of technologies at this layer will depend on the specific application requirements of your IoT project. For example, for a budget home automation system that involves several sensors, MQTT would be a good choice as it is great for implementing messaging on devices without much storage or processing power because the protocol is simple and lightweight to implement.

IOT NETWORKING CONSIDERATIONS AND CHALLENGES

When you consider which networking technologies to adopt within your IoT application, be mindful of the following constraints:

⍰ Range

⍰ Bandwidth

⍰ Power usage

⍰ Intermittent connectivity

⍰ Interoperability

⍰ Security

Range

Networks can be described in terms of the distances over which data is typically transmitted by the IoT devices attached to the network:

- **PAN(PersonalAreaNetwork)** PAN is short-range, where distances can be measured in meters, such as a wearable fitness tracker device that communicates with an app on a cell phone over BLE.
- **LAN(LocalAreaNetwork)** LAN is short- to medium-range, where distances can be up to hundreds of meters, such as home automation or sensors that are installed within a factory production line that communicate over wifi with a gateway device that is installed within the same building.
-**MAN (Metropolitan Area Network)** MAN is long-range (city wide), where distances are measured up to a few kilometers, such as smart parking sensors installed throughout a city that are connected in a mesh network topology.
- **WAN (Wide Area Network)** WAN is long-range, where distances can be measured in kilometers, such as agricultural sensors that are installed across a large farm or ranch that are used to monitor micro-climate environmental conditions across the property.

Your network should retrieve data from the IoT devices and transmit to its intended destination. Select a network protocol that matches the range is required. For example, do not choose BLE for a WAN application to operate over a range of several kilometers. If transmitting data over the required range presents a challenge, consider edge computing. Edge computing analyzes data directly from the devices rather than from a distant data center or elsewhere.

Bandwidth

Bandwidth is the amount of data that can be transmitted per unit of time. It limits the rate at which data can be collected from IoT devices and transmitted upstream. Bandwidth is affected by many factors, which include:

- The volume of data each device gathers and transmits
- The number of devices deployed
-Whether data is being sent as a constant stream or in intermittent bursts, and if any peak periods are notable

The packet size of the networking protocol should match up with the volume of data typically transmitted. It is inefficient to send packets padded with empty data. In contrast, there are overheads in splitting larger chunks of data up across too many small packets. Data transmission rates are not always symmetrical (that is, upload rates might be slower than download rates). So, if there is two-way communication between devices, data transmission needs to be factored in. Wireless and cellular networks are traditionally low bandwidth, so consider whether a wireless technology is the right choice for high-volume applications.

Consider whether all raw data must be transmitted. A possible solution is to capture less data by sampling less frequently. Thus, you'll capture fewer variables and may filter data from the device to drop insignificant data. If you aggregate the data before you transmit it, you reduce the volume of data transmitted. But this process affects flexibility and granularity in the upstream analysis. Aggregation and bursting are not always suitable for time-sensitive or latency-sensitive data. All of these techniques increase the data processing and storage requirements for the IoT device.

Power usage

Transmitting data from a device consumes power. Transmitting data over long ranges requires more power than over a short range. You must consider the power source – such as a battery, solar cell, or capacitor – of a device and its total lifecycle. A long and enduring lifecycle will not only provide greater reliability but reduce operating cost. Steps may be taken to help achieve longer power supply lifecycles. For example, to prolong the battery life, you can put the device into sleep mode whenever it is idle. Another best practice is to model the energy consumption of the device under different loads and different network conditions to ensure that the device's power supply and storage capacity matches with the power that is required to transmit the necessary data by using the networking technologies that you adopted.

Intermittent connectivity

IoT devices aren't always connected. In some cases, devices are designed to connect periodically. However, sometimes an unreliable network might cause devices to drop off due to connectivity issues. Sometimes quality of service issues, such as dealing with interference or channel contention on a wireless network using a shared spectrum. Designs should incorporate intermittent connectivity and seek any available solutions to provide uninterrupted service, should that be a critical factor for IoT landscape design.

Interoperability

Devices work with other devices, equipment, systems, and technology; they are interoperable. With so many different devices connecting to the IoT, interoperability can be a challenge. Adopting standard protocols has been a traditional approach for maintaining interoperability on the Internet. Standards are agreed upon by industry participants and avoid multiple different designs and directions. With proper standards, and participants who agree to them, incompatibility issues, hence interoperability issues may be avoided.

However, for the IoT, standardization processes sometimes struggle to keep up with innovation and change. They are written and released based on upcoming versions of standards that are still subject to change. Consider the ecosystem around the technologies: Are they widely adopted? Are they open versus proprietary? How many implementations are available?

Using these questions to plan your IoT networks help plan better interoperability for a more robust IoT network.

Security

Security is a priority. Selection of networking technologies that implement end-to-end security, including authentication, encryption, and open port protection is crucial. IEEE 802.15.4 includes a security model that provides security features that include access control, message integrity, message confidentiality, and replay protection, which are implemented by technologies based on this standard such as ZigBee.

Consider the following factors in shaping a secure and safe IoT network:

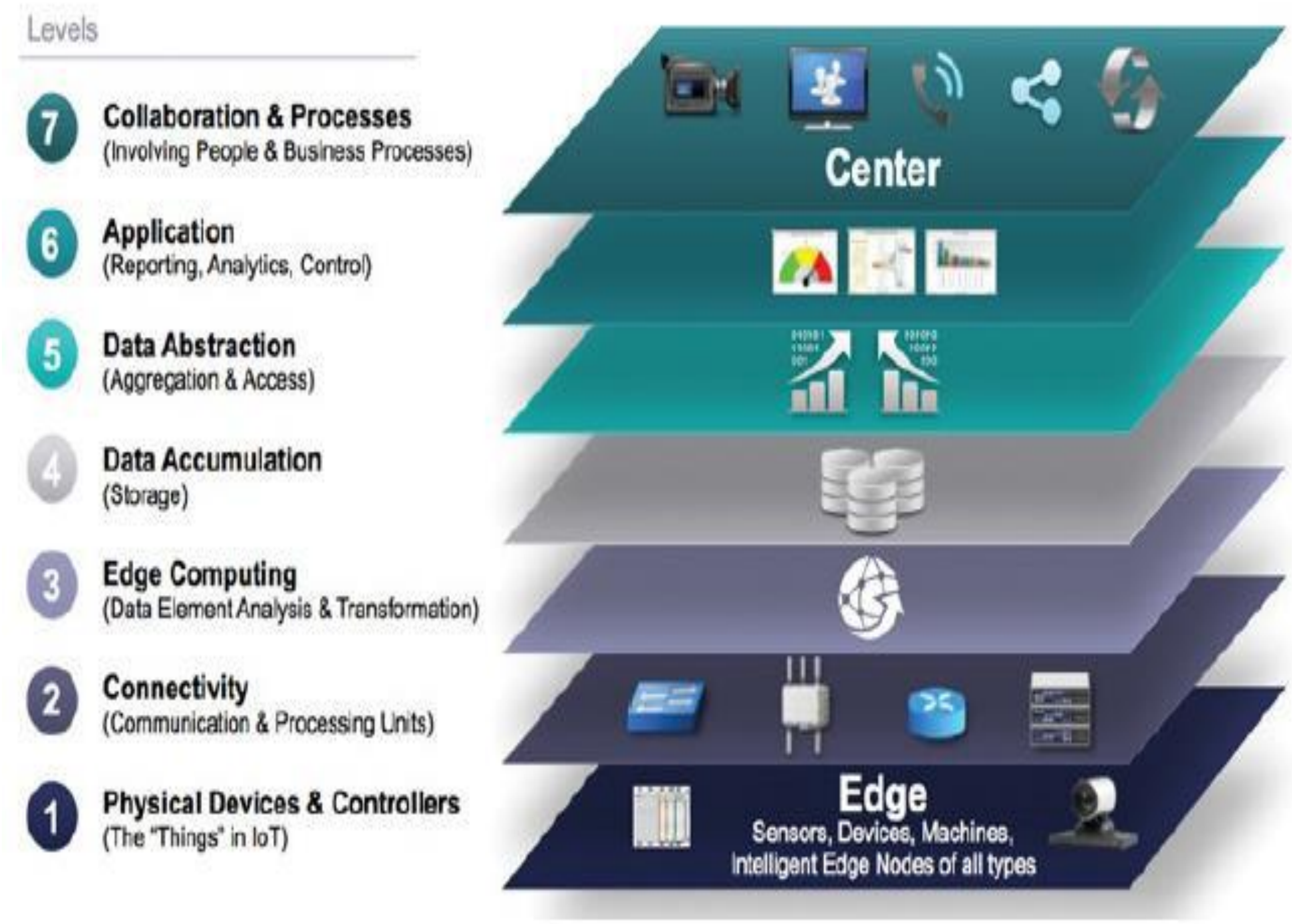
- **Authentication** Adopt secure protocols to support authentication for devices, gateways, users, services, and applications. Consider using adopting the X.509 standard for device authentication.

- **Encryption** If you are using wifi, use Wireless Protected Access 2 (WPA2) for wireless network encryption. You may also adopt a Private Pre-Shared Key (PPSK) approach. To ensure privacy and data integrity for communication between applications, be sure to adopt TLS or Datagram Transport-Layer Security (DTLS), which is based on TLS, but adapted for unreliable connections that run over UDP. TLS encrypts application data and ensures its integrity.

- **Port protection** Port protection ensures that only the ports required for communication with the gateway or upstream applications or services remain open to external connections. All other ports should be disabled or protected by firewalls. Device ports might be exposed when exploiting Universal Plug and Play (UPnP) vulnerabilities. Thus, UPnP should be disabled on the router.

The IoT World Forum (IoTWF) Standardized Architecture

In 2014 the IoTWF architectural committee (led by Cisco, IBM, Rockwell Automation, and others)published a seven-layer IoT architectural reference model. While various IoT reference models exist, theone put forth by the IoT World Forum offers a clean, simplified perspective on IoT and includes edgecomputing, data storage, and access. It provides a succinct way of visualizing IoT from a technicalperspective. Each of the seven layers is broken down into specific functions, and security encompassesthe entire model. Figure belowdetails the IoT Reference Model published by the IoTWF.



Levels
7 Collaboration & Processes
(Involving People & Business Processes)
6 Application
(Reporting, Analytics, Control)
5 Data Abstraction
(Aggregation & Access)
4 Data Accumulation
(Storage)
3 Edge Computing
(Data Element Analysis & Transformation)
2 Connectivity
(Communication & Processing Units)
1 Physical Devices & Controllers
(The "Things" in IoT)
Center
Edge
Sensors, Devices, Machines,
Intelligent Edge Nodes of all types

As shown in Figure , the IoT Reference Model defines a set of levels with control flowing from thecenter (this could be either a cloud service or a dedicated data center), to the edge which includessensors, devices, machines, and other types of intelligent end nodes. In general, data travels up the stack,originating from the edge, and goes northbound to the center. Using this reference model, we are able to achieve the following:

 Decompose the IoT problem into smaller parts

 Identify different technologies at each layer and how they relate to one another

 Define a system in which different parts can be provided by different vendors

 Have a process of defining interfaces that leads to interoperability

 Define a tiered security model that is enforced at the transition points between levels

The following sections look more closely at each of the seven layers of the IoT Reference Model.

Layer 1: Physical Devices and Controllers Layer

The first layer of the IoT Reference Model is the physical devices and controllers layer. This layer is hometo the "things" in the Internet of Things, including the various endpoint devices and sensors that send andreceive information. The size of these "things" can range from almost microscopic sensors to giantmachines in a factory. Their primary function is generating data and being capable of being queriedand/or controlled over a network.

Layer 2: Connectivity Layer

In the second layer of the IoT Reference Model, the focus is on connectivity. The most important functionof this IoT layer is the reliable and timely transmission of data. More specifically, this includestransmissions between Layer 1 devices and the network and between the network and informationprocessing that occurs at Layer 3 (the edge computing layer).As you may notice, the connectivity layer encompasses all networking elements of IoT and doesn't reallydistinguish between the last-mile network (the network between the sensor/endpoint and the IoT gateway,discussed later in this chapter), gateway, and backhaul networks. Functions of the connectivity layer aredetailed in Figure .

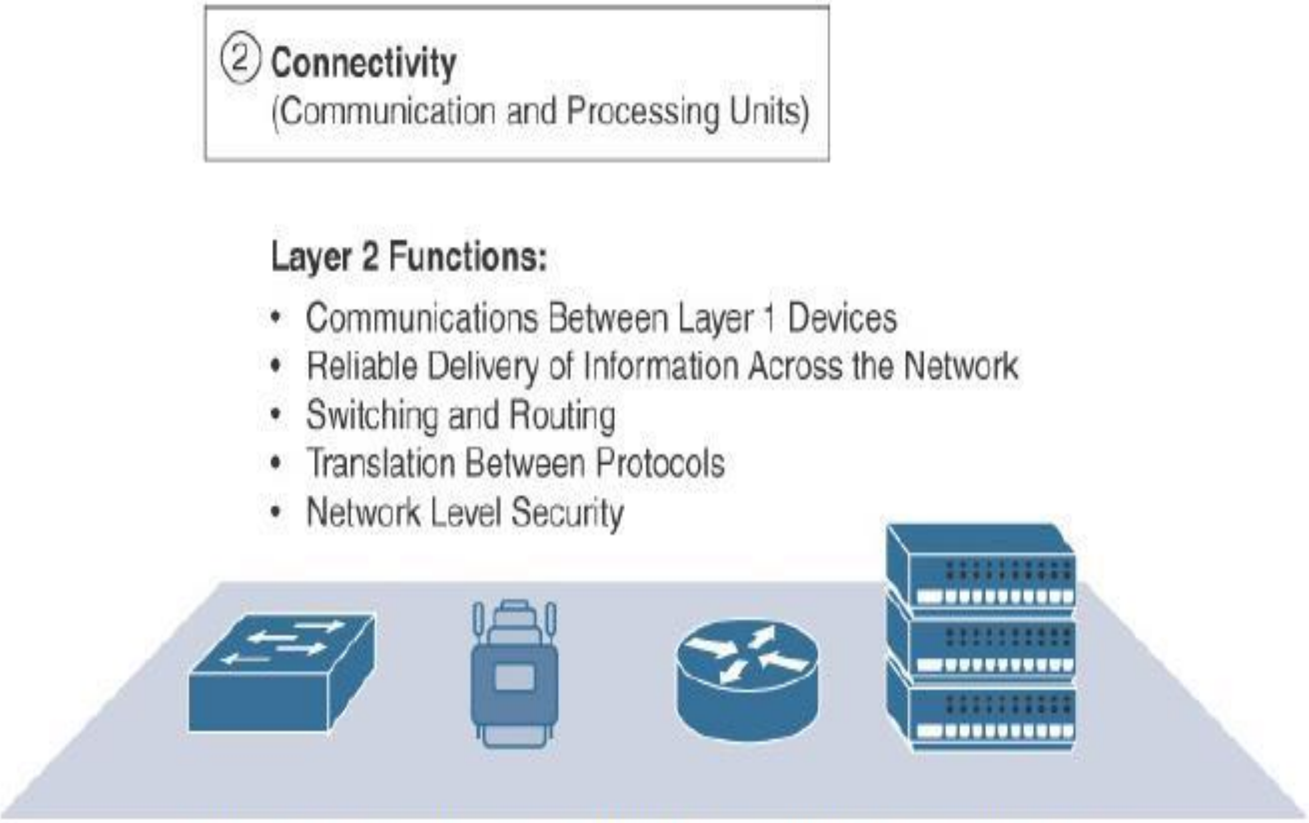

② Connectivity
(Communication and Processing Units)
Layer 2 Functions:
• Communications Between Layer 1 Devices
• Reliable Delivery of Information Across the Network
• Switching and Routing
• Translation Between Protocols
• Network Level Security

Figure 2-3 *IoT Reference Model Connectivity Layer Functions*

Layer 3: Edge Computing Layer

Edge computing is the role of Layer 3. Edge computing is often referred to as the “fog” layer and isdiscussed in the section “Fog Computing,” later in this chapter. At this layer, the emphasis is on datareduction and converting network data flows into information that is ready for storage and processing byhigher layers. One of the basic principles of this reference model is that information processing is initiated as early and as close to the edge of the network as possible. Figure 2-4 highlights the functions handledby Layer 3 of the IoT Reference Model.

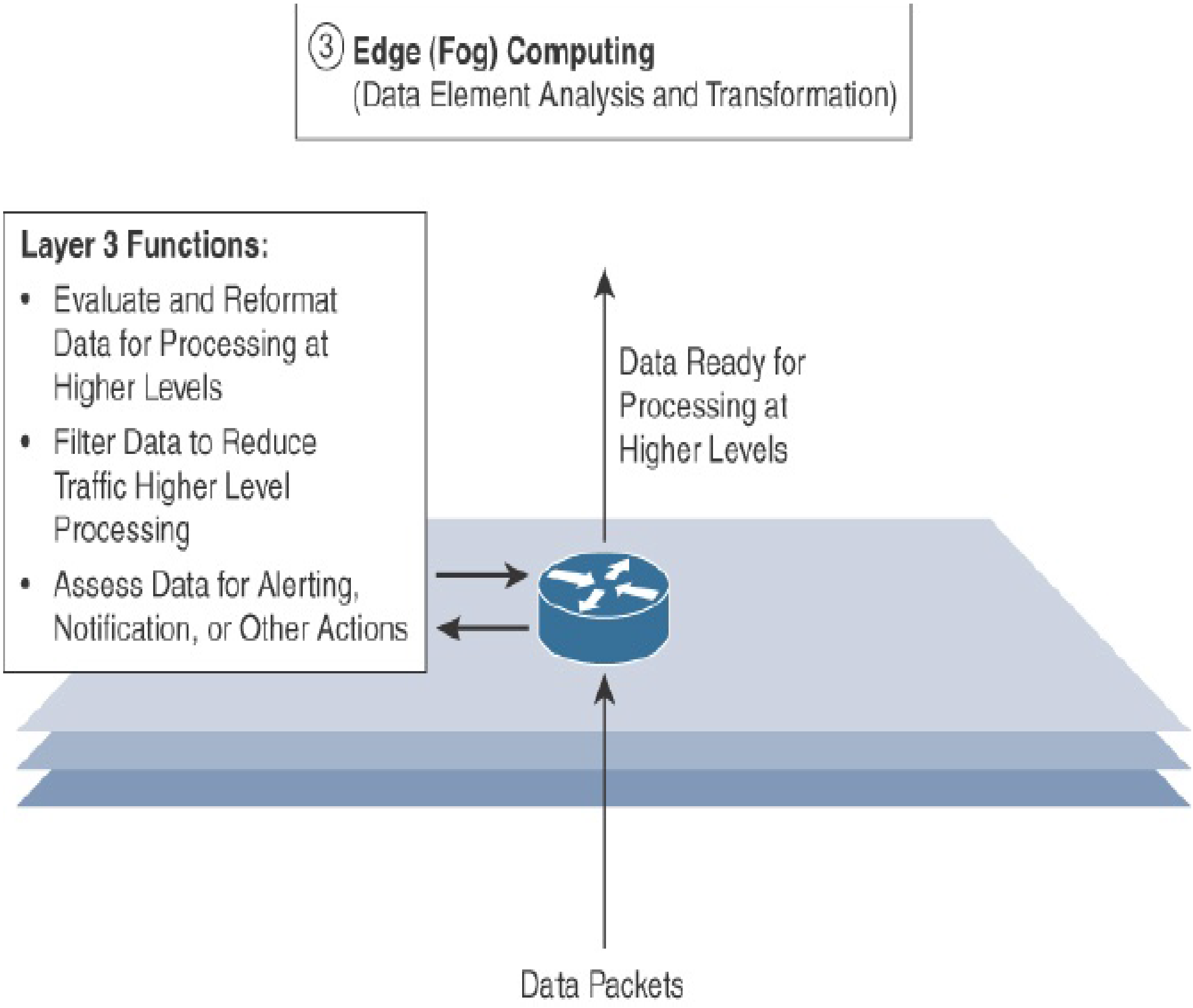
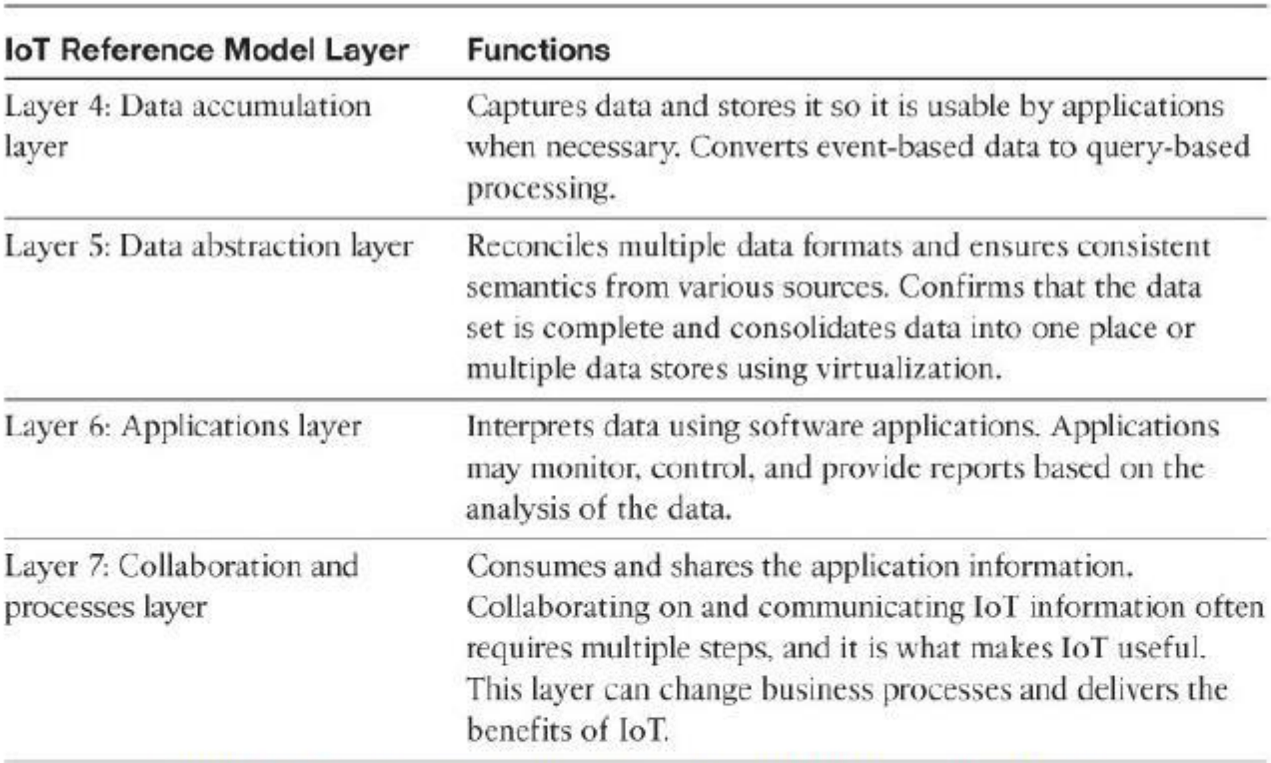

③ Edge (Fog) Computing
(Data Element Analysis and Transformation)
Layer 3 Functions:
• Evaluate and Reformat Data for Processing at Higher Levels
• Filter Data to Reduce Traffic Higher Level Processing
• Assess Data for Alerting, Notification, or Other Actions
Data Ready for Processing at Higher Levels
Data Packets

Figure 2-4 *IoT Reference Model Layer 3 Functions*

Another important function that occurs at Layer 3 is the evaluation of data to see if it can be filtered oraggregated before being sent to a higher layer. This also allows for data to be reformatted or decoded,making additional processing by other systems easier. Thus, a critical function is assessing the data to seeif predefined thresholds are crossed and any action or alerts need to be sent.

Upper Layers: Layers 4–7

The upper layers deal with handling and processing the IoT data generated by the bottom layer. For thesake of completeness, Layers 4–7 of the IoT Reference Model are summarized in Table 2-2.



IoT Reference Model Layer	Functions
Layer 4: Data accumulation layer	Captures data and stores it so it is usable by applications when necessary. Converts event-based data to query-based processing.
Layer 5: Data abstraction layer	Reconciles multiple data formats and ensures consistent semantics from various sources. Confirms that the data set is complete and consolidates data into one place or multiple data stores using virtualization.
Layer 6: Applications layer	Interprets data using software applications. Applications may monitor, control, and provide reports based on the analysis of the data.
Layer 7: Collaboration and processes layer	Consumes and shares the application information. Collaborating on and communicating IoT information often requires multiple steps, and it is what makes IoT useful. This layer can change business processes and delivers the benefits of IoT.

Table 2-2 *Summary of Layers 4–7 of the IoTWF Reference Model*

M2M Communication

Machine-to-machine communication, or M2M, is exactly as it sounds: two machines “communicating,” or exchanging data, without human interfacing or interaction. This includes serial connection, powerline connection (PLC), or wireless communications in the industrial Internet of Things (IoT). Switching over to wireless has made M2M communication much easier and enabled more applications to be connected.

In general, when someone says M2M communication, they often are referring to cellular communication for embedded devices. Examples of M2M communication in this case would be vending machines sending out inventory information or ATM machines getting authorization to despense cash.

As businesses have realized the value of M2M, it has taken on a new name: the Internet of Things (IoT). IoT and M2M have similar promises: to fundamentally change the way the world operates. Just like IoT, M2M allows virtually any sensor to communicate, which opens up the possibility of systems monitoring themselves and automatically responding to changes in the environment, with a much reduced need for human involvement. M2M and IoT are almost synonymous—the exception is IoT (the newer term) typically refers to wireless communications, whereas M2M can refer to any two machines—wired or wireless—communicating with one another.

Traditionally, M2M focused on “industrial telematics,” which is a fancy way of explaining data transfer for some commercial benefit. But many original uses of M2M still stand today, like smart meters. Wireless M2M has been dominated by cellular since it came out in the mid-2000’s with 2G cell networks. Because of this, the cellular market has tried to brand M2M as an inherently cellular thing by offering M2M data plans. But cellular M2M is only one subsection of the market, and it shouldn’t be thought of as a cellular-only area.

How M2M Works

As previously stated, machine-to-machine communication makes the Internet of Things possible. According to Forbes, M2M is among the fastest-growing types of connected device technologies in the market right now, largely because M2M technologies can connect millions of devices within a single network. The range of connected devices includes anything from vending machines to medical equipment to vehicles to buildings. Virtually anything that houses sensor or control technology can be connected to some sort of wireless network. This sounds complex, but the driving thought behind the idea is quite simple. Essentially, M2M networks are very similar to LAN or WAN networks, but are exclusively used to allow machines, sensors, and controls, to communicate. These devices feed information they collect back to other devices in the network. This process allows a human (or an intelligent control unit) to assess what is going on across the whole network and issue appropriate instructions to member devices.

M2M Applications

The possibilities in the realm of M2M can be seen in four major use cases, which we've detailed below:

1. MANUFACTURING

Every manufacturing environment—whether it's food processing or general product manufacturing—relies on technology to ensure costs are managed properly and processes are executed efficiently. Automating manufacturing processes within such a fast-paced environment is expected to improve processes even more. In the manufacturing world, this could involve highly automated equipment maintenance and safety procedures. For example, M2M tools allow business owners to be alerted on their smartphones when an important piece of equipment needs servicing, so they can address issues as quickly as they arise. Sophisticated networks of sensors connected to the Internet could even order replacement parts automatically.

2. HOME APPLIANCES

IoT already affects home appliance connectivity through platforms like Nest. However, M2M is expected to take home-based IoT to the next level. Manufacturers like LG and Samsung are already slowly unveiling smart home appliances to help ensure a higher quality of life for occupants.

For example, an M2M-capable washing machine could send alerts to the owners' smart devices once it finishes washing or drying, and a smart refrigerator could automatically order groceries from Amazon once its inventory is depleted. There are many more examples of home automation that can potentially improve quality of life for residents, including systems that allow members of the household to remotely control HVAC systems using their mobile devices. In situations where a homeowner decides to leave work early, he or she could contact the home heating system before leaving work to make sure the temperature at home will be comfortable upon arrival.

3. HEALTHCARE DEVICE MANAGEMENT

One of the biggest opportunities for M2M technology is in the realm of health care. With M2M technology, hospitals can automate processes to ensure the highest levels of treatment. Using devices that can react faster than a human healthcare professional in an emergency situation make this possible. For instance, when a patient's vital signs drop below normal, an M2M-connected life support device could automatically administer oxygen and additional care until a healthcare professional arrives on the scene. M2M also allows patients to be monitored in their own homes instead of in hospitals or care centers. For example, devices that track a frail or elderly person's normal movements can detect when he or she has had a fall and alert a healthcare worker to the situation.

4. SMART UTILITY MANAGEMENT

In the new age of energy efficiency, automation will quickly become the new normal. As energy companies look for new ways to automate the metering process, M2M comes to the rescue, helping energy companies automatically gather energy consumption data, so they can accurately bill customers. Smart meters can track how much energy a household or business uses and automatically alert the energy company, which supplants sending out an employee to read the meter or requiring the customer to provide a reading. This is even more important as utilities move toward more dynamic pricing models, charging consumers more for energy usage during peak times.

A few key analysts predict that soon, every object or device will need to be able to connect to the cloud. This is a bold but seemingly accurate statement. As more consumers, users, and business owners demand deeper connectivity, technology will need to be continually equipped to meet the needs and challenges of tomorrow. This will empower a wide range of highly automated processes, from equipment repairs and firmware upgrades to system diagnostics, data retrieval, and analysis. Information will be delivered to users, engineers, data scientists, and key decision-makers in real time, and it will eliminate the need for guesswork.

The Value Of M2M

Growth in the M2M and IoT markets has been growing rapidly, and according to many reports, growth will continue. Strategy Analytics believes that low power, wide-area network (LPWAN) connections will grow from 11 million in 2014 to 5 billion in 2022. And IDC says the market for worldwide IoT solutions will go from $1.9 trillion in 2013 to $7.1 trillion in 2020.

Many big cell operators, like AT&T and Verizon, see this potential and are rolling out their own M2M platforms. Intel, PTC, and Wipro are are all marketing heavily in M2M and working to take advantage of this major industry growth spurt. But there is still a great opportunity for new technology companies to engage in highly automated solutions to help streamline processes in nearly any type of industry. We're certain we'll see a huge influx of companies who begin to innovate in this area in the next five years.

However, as the cost of M2M communication continues to decrease, companies must determine how they will create value for businesses and customers. In our mind, the opportunity and value for M2M doesn't lie in the more traditional layers of the communication world. Cell carriers and hardware manufacturers, for example, are beginning to look into full-stack offerings that enable M2M and IoT product development. We strongly believe value lies in the application side of things, and the growth in this industry will be driven by smart applications from this point forward.

Companies shouldn't think about IoT or M2M for the sake of IoT or M2M. Instead, they should focus on optimizing their business models or providing new value for their customers. For example, if you're a logistics company like FedEx or UPS, you have obvious choices for automated logistics decisions made by machines. But if you're a retailer, the transition to automation may not be as obvious. It's one thing to think of a "cool" automated process—say, creating advertising that is automatically tied to a specific customer through the use of M2M technology—but before you move forward with the process, you have to consider the value you're getting out of it. How much does it cost to implement? Will any company considering a move into the IoT space needs to understand what its business model is, how it will make money, and how it will provide value for customers or internal processes.

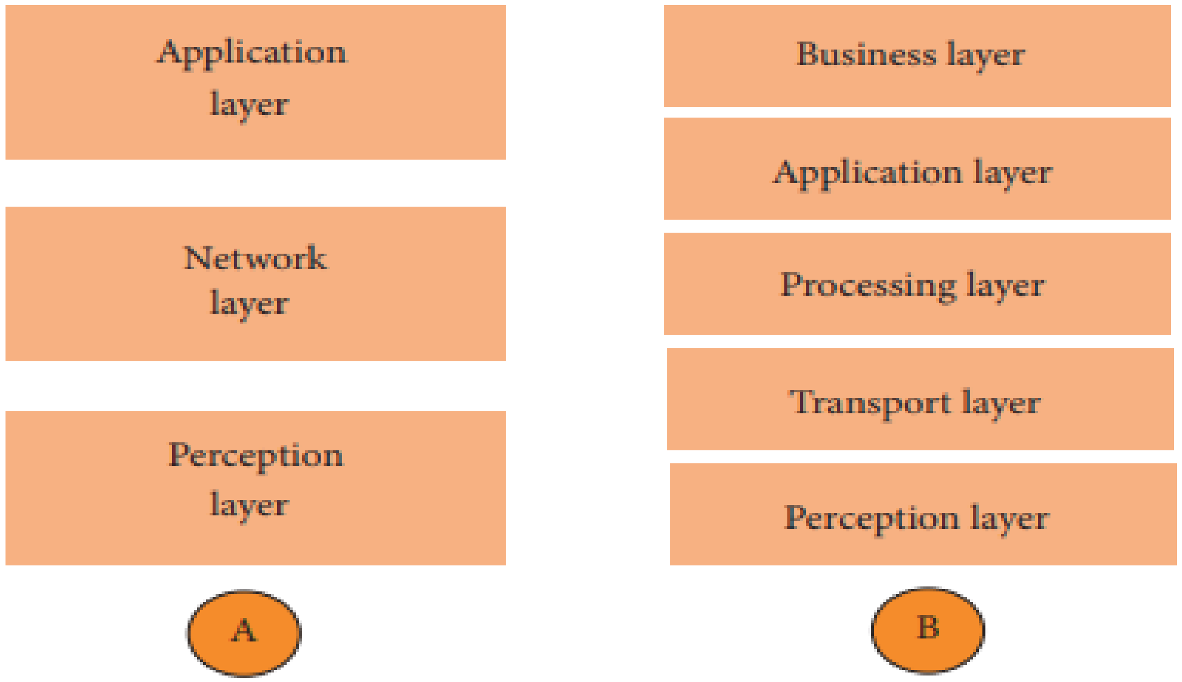
Architecture of IoT

Figure below has three layers, namely, the perception, network, and application layers.

(i) The perception layer is the physical layer, which has sensors for sensing and gathering information about the environment. It senses some physical parameters or identifies other smart objects in the environment.

(ii) The network layer is responsible for connecting to other smart things, network devices, and servers. Its features are also used for transmitting and processing sensor data.

(iii) The application layer is responsible for delivering application specific services to the user. It defines various applications in which the Internet of Things can be deployed, for example, smart homes, smart cities, and smart health.



The three-layer architecture defines the main idea of the Internet of Things, but it is not sufficient for research on IoT because research often focuses on finer aspects of the Internet of Things. That is why, we have many more layered architectures proposed in the literature. One is the fivelayer architecture, which additionally includes the processing and business layers [3–6]. The five layers are perception, transport, processing, application, and business layers (see Figure 1). The role of the perception and application layers is the same as the architecture with three layers. We outline the function of the remaining three layers.

(i) The transport layer transfers the sensor data from the perception layer to the processing layer and vice versa through networks such as wireless, 3G, LAN, Bluetooth, RFID, and NFC.

(ii) The processing layer is also known as the middleware layer. It stores, analyzes, and processes huge amounts of data that comes from the transport layer. It can manage and provide a diverse set of services to the lower layers. It employs many technologies such as databases, cloud computing, and big data processing modules.

(iii) The business layer manages the whole IoT system, including applications, business and profit models, and users' privacy. The business layer is out of the scope of this paper. Hence, we do not discuss it further.