CE/CZ4171
Internet of Things: Communications and Networking

Module 2
General Network Architecture for IoT

Part I Outline

- Module 1: Introduction to IoT
  - A Motivating Example
  - IoT Concept
  - IoT Trend
  - IoT Applications
  - IoT Application Enablers
  - IoT Challenges
- Module 2: General Network Architecture for IoT
  - **IoT Network Architecture**
  - 3-Layer Model: Functional Stack, Compute Stack
  - Cloud Computing
  - Communications with Cloud: HTTP, REST, CoAP, MQTT
- Module 3: IoT Devices
  - Sensors and Actuators
  - Connected Smart Objects
  - IP as the IoT Network Layer
  - Information Acquisition

Network Architecture for IoT

Drivers Behind New Network Architectures

- Scale
- Security (physically exposed)
- Network and device constrained (power, CPU, memory, bandwidth, etc.)
- Massive volume of data generated
- Support for legacy devices
- Real-time data analysis

Network Architecture for IoT

- Machine to Machine (M2M) IoT Architecture

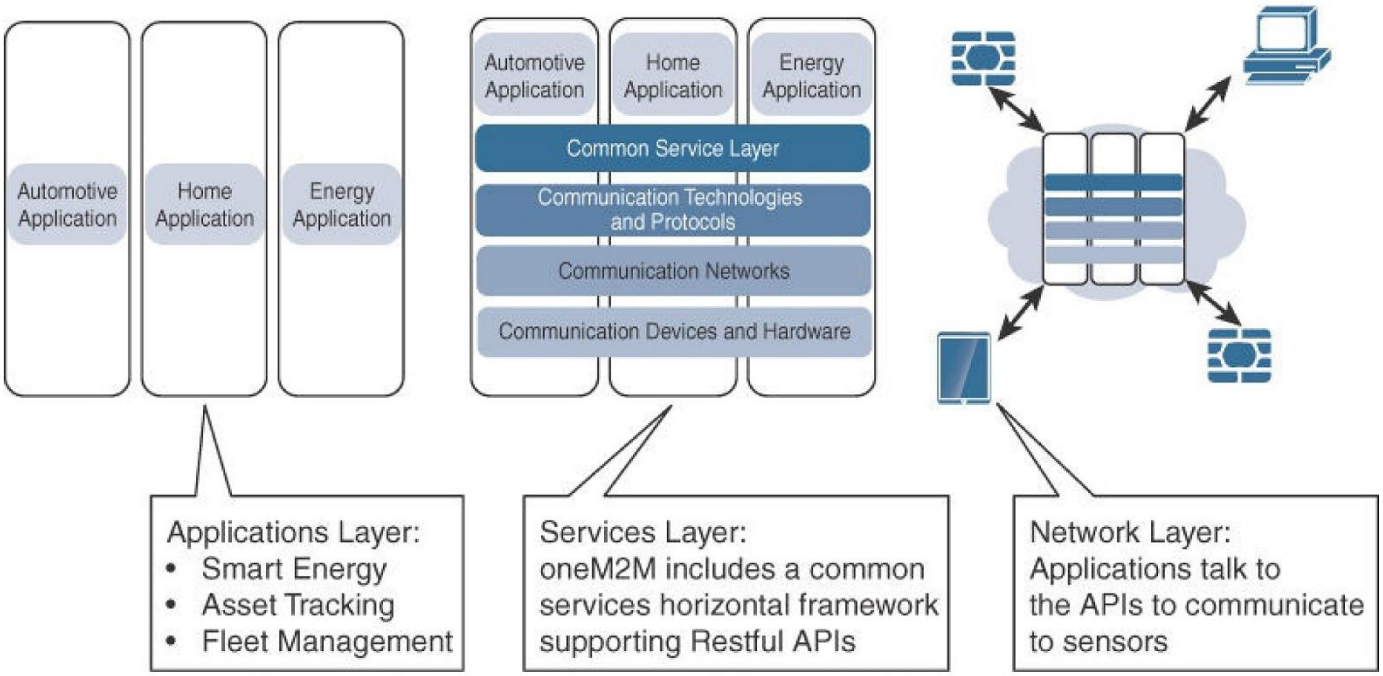
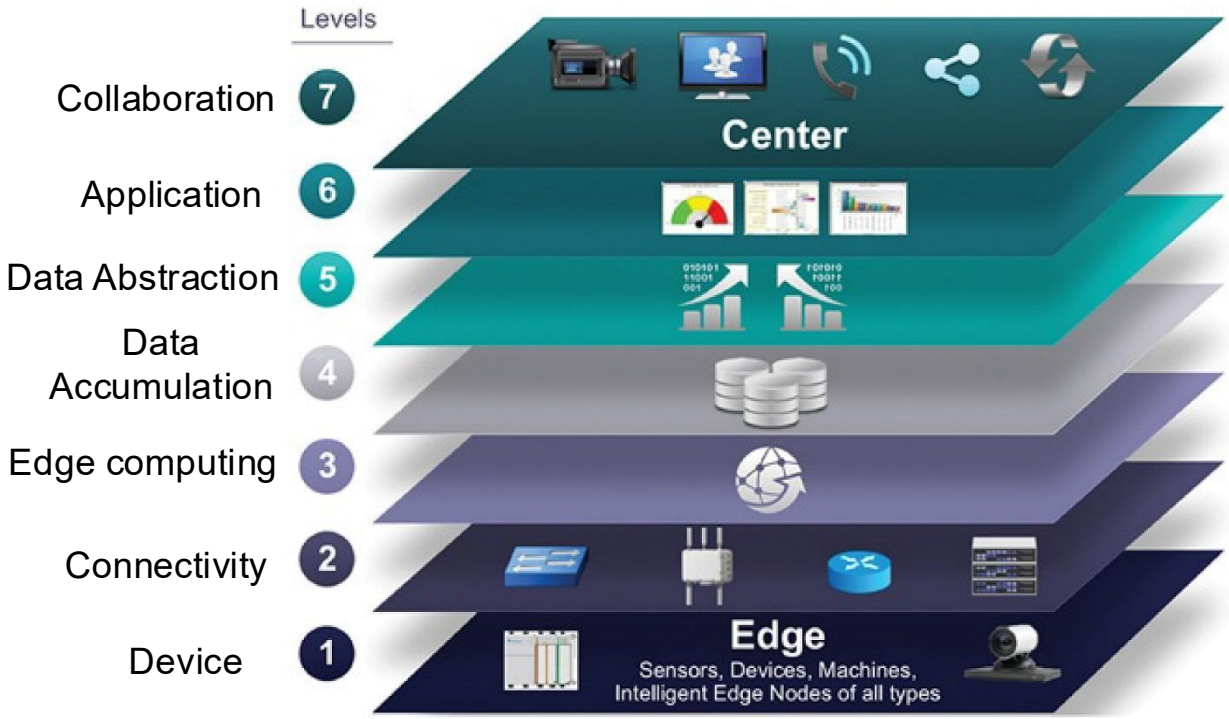
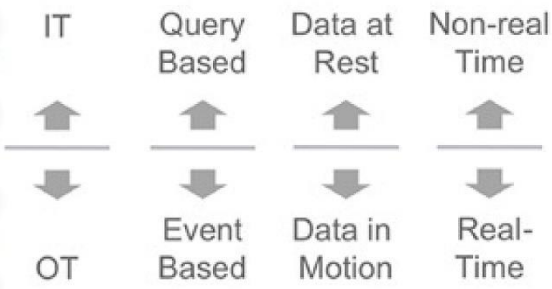


Figure 2-1 *The Main Elements of the oneM2M IoT Architecture*

IoTWF Standardized Architecture

- IoTWF: IoT World Forum





IT: Information Technology

OT: Operational Technology

Figure 2-5 *IoT Reference Model Separation of IT and OT*

IoTWF Standardized Architecture

- Layer 1: Physical Devices and Controllers Layer
- Layer 2: Connectivity Layer

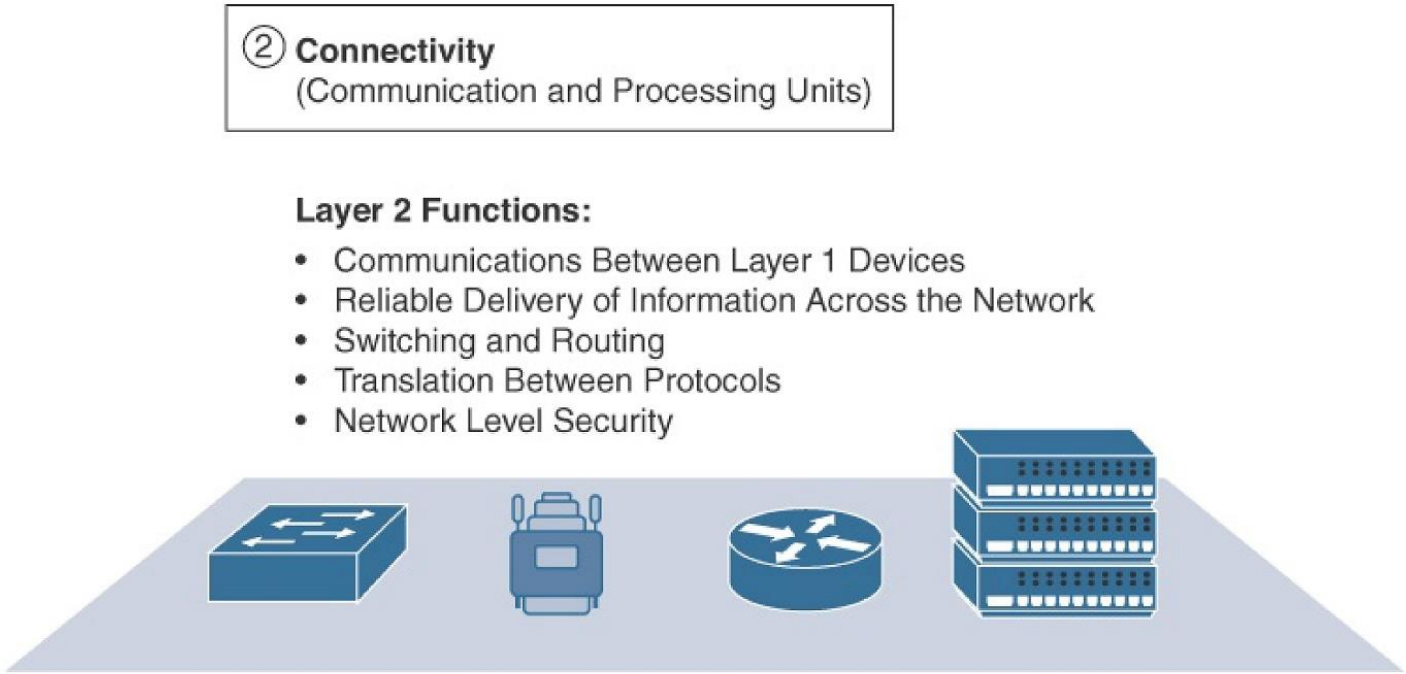


Figure 2-3 *IoT Reference Model Connectivity Layer Functions*

IoTWF Standardized Architecture

- Layer 3: Edge Computing Layer

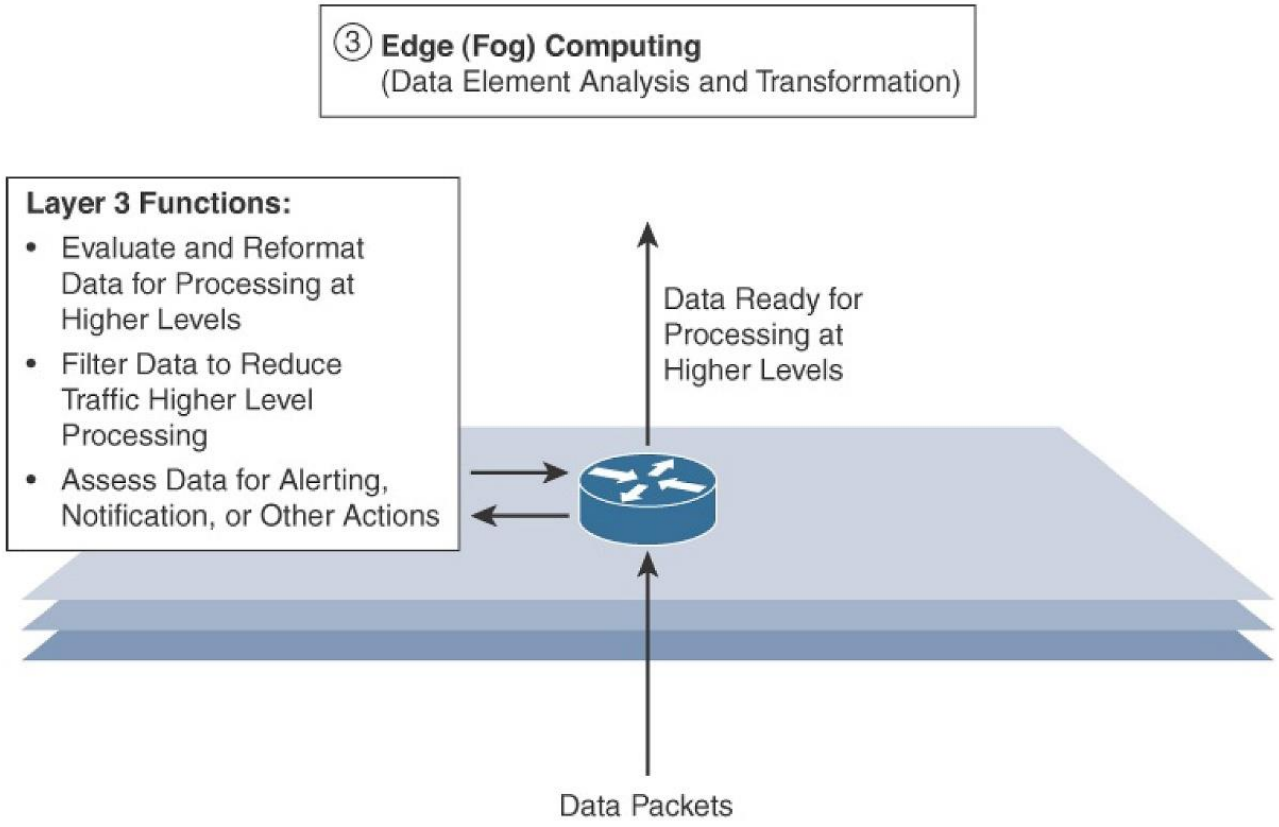


Figure 2-4 *IoT Reference Model Layer 3 Functions*

IoTWF Standardized Architecture

- Layers 4 to 7

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*

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3-Layer Model

- Functional stack & compute stack

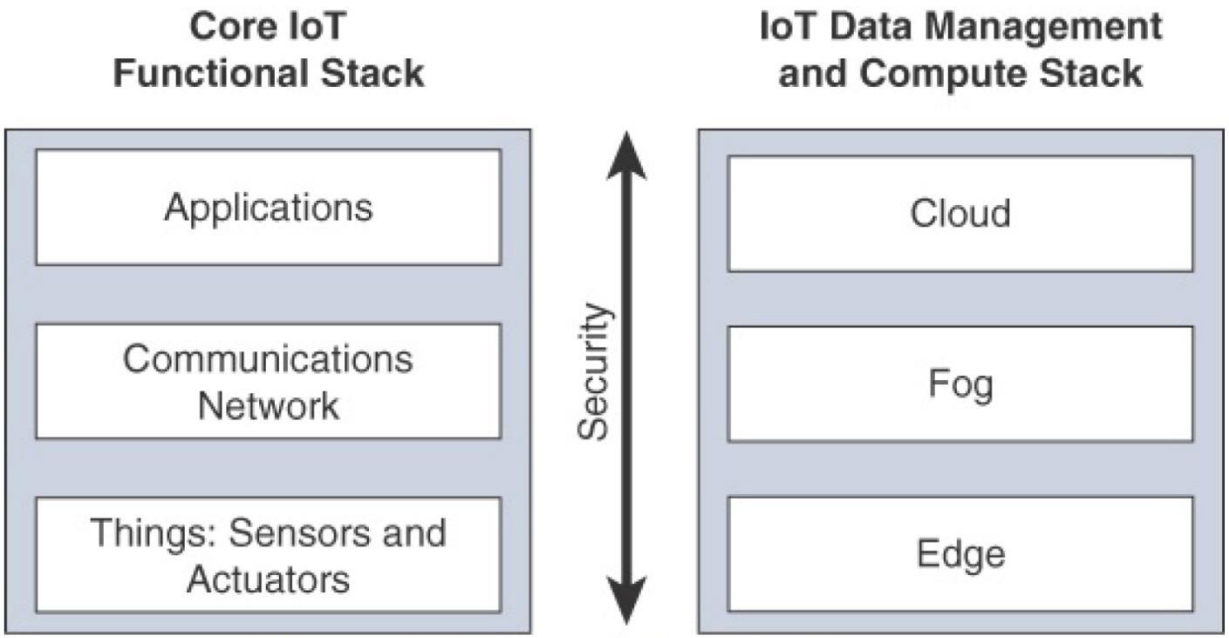
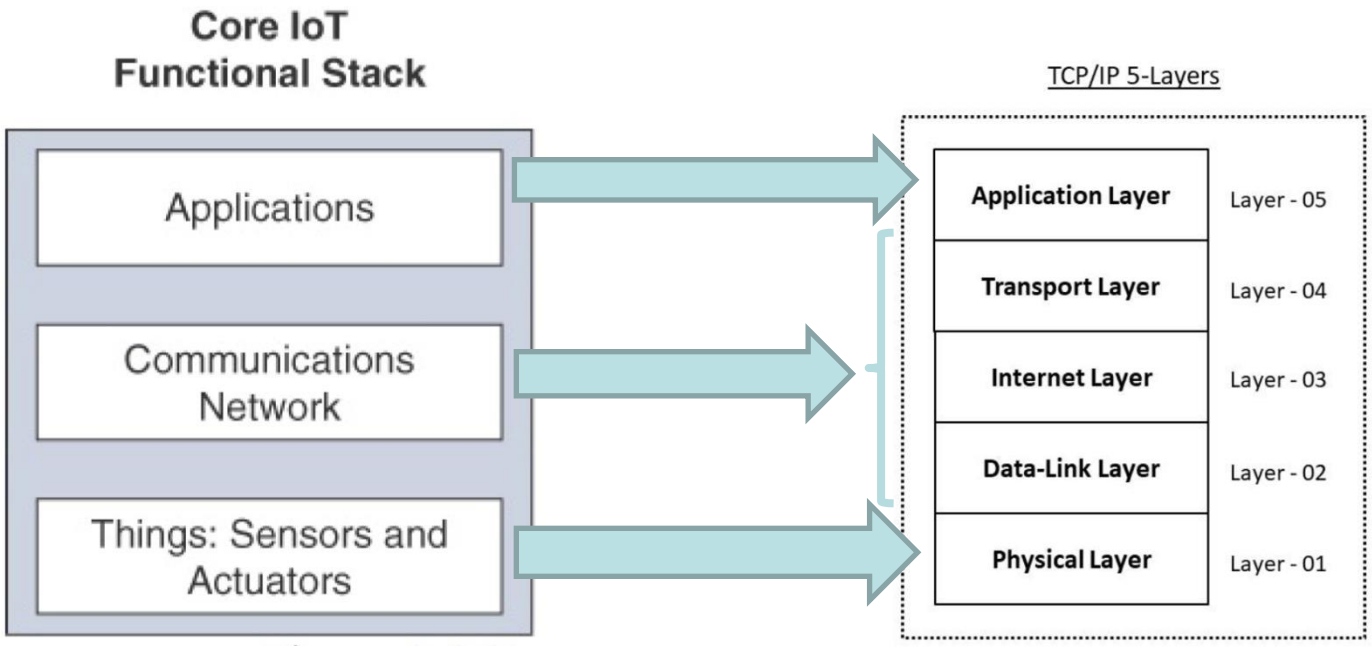


Figure 2-6 *Simplified IoT Architecture*

IoT Functional Stack vs. TCP/IP Model



Layer 1: Things: Sensors and Actuators Layer

Core IoT Functional Stack

- Battery-powered or power-connected
- Mobile or static
- Low or high reporting frequency
- Complexity of data
- Object density per cell

Layer 1: Things: Sensors and Actuators Layer

Core IoT Functional Stack

- Determine which technology should be used to allow smart objects to communicate
- Depend on the way the "things" are classified

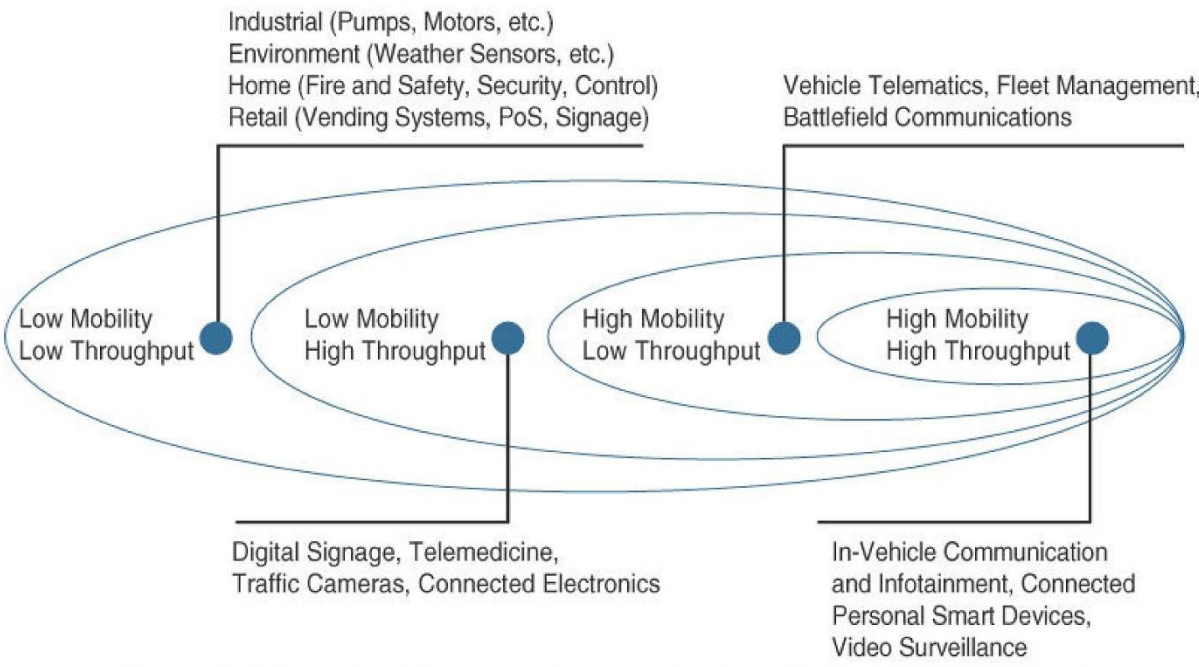


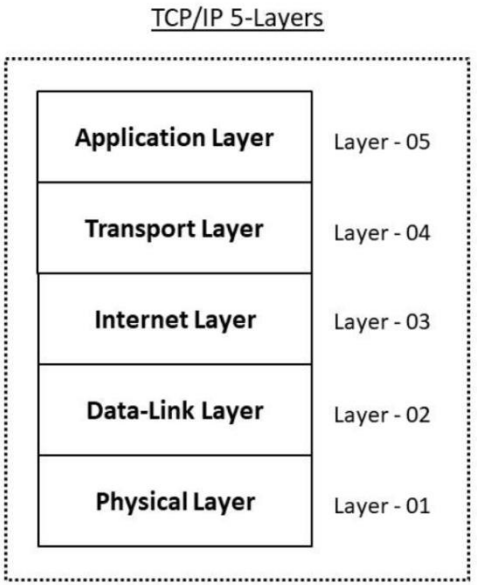
Figure 2-8 *Example of Sensor Applications Based on Mobility and Throughput*

First step in designing an IoT network is to examine the requirements in terms of mobility and data transmission (how much data, how often).

Layer 2: Communications Network Layer

Core IoT Functional Stack

- Access Network Sublayer
  - *Layer 2 of TCP/IP reference model*
- Gateways and Backhaul Sublayer
  - *Layer 3 of TCP/IP reference model*
- Network Transport Sublayer
  - *Layers 3 & 4 of TCP/IP reference model*
- IoT Network Management Sublayer
  - *Layer 3 of TCP/IP reference model*



Layer 2: Communications Network Layer

Core IoT Functional Stack

- Access Network Sublayer
  - Choice of access technology is the range between the smart object and the information collector

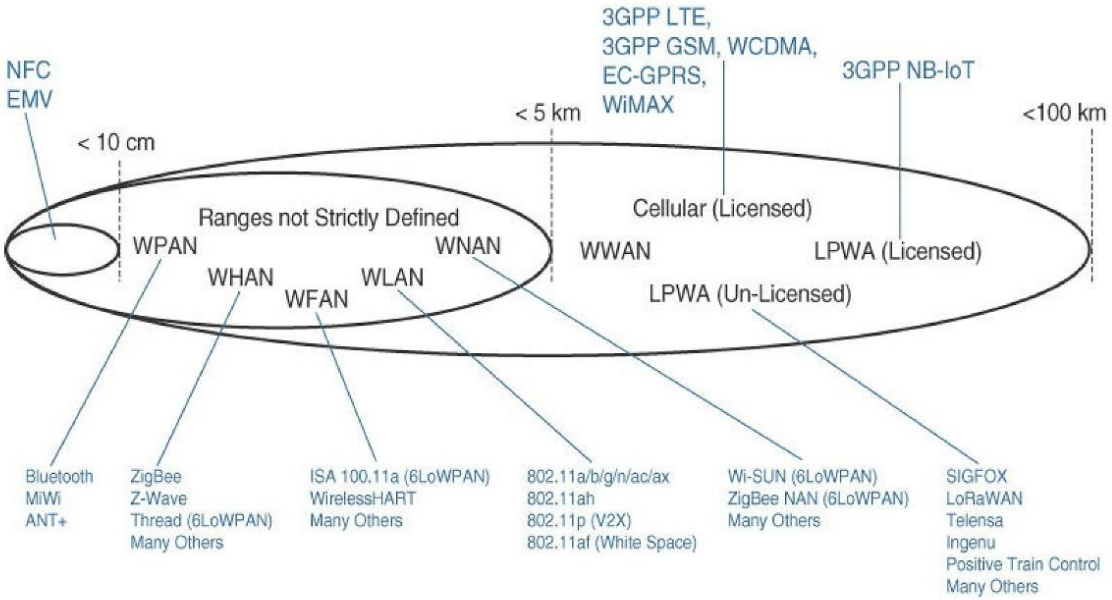


Figure 2-9 *Access Technologies and Distances*

Layer 2: Communications Network Layer

Core IoT Functional Stack

Access network categories

- **PAN** (personal area network): a few meters, Bluetooth
- **HAN** (home area network): a few tens of meters, ZigBee and Bluetooth Low Energy (BLE)
- **NAN** (neighborhood area network): a few hundreds of meters, WiFi
- **FAN** (field area network): several tens of meters to several hundred meters “outdoor”
- **LAN** (local area network): Scale of up to 100 m, WiFi

Layer 2: Communications Network Layer

Core IoT Functional Stack

Characteristics of different access networks

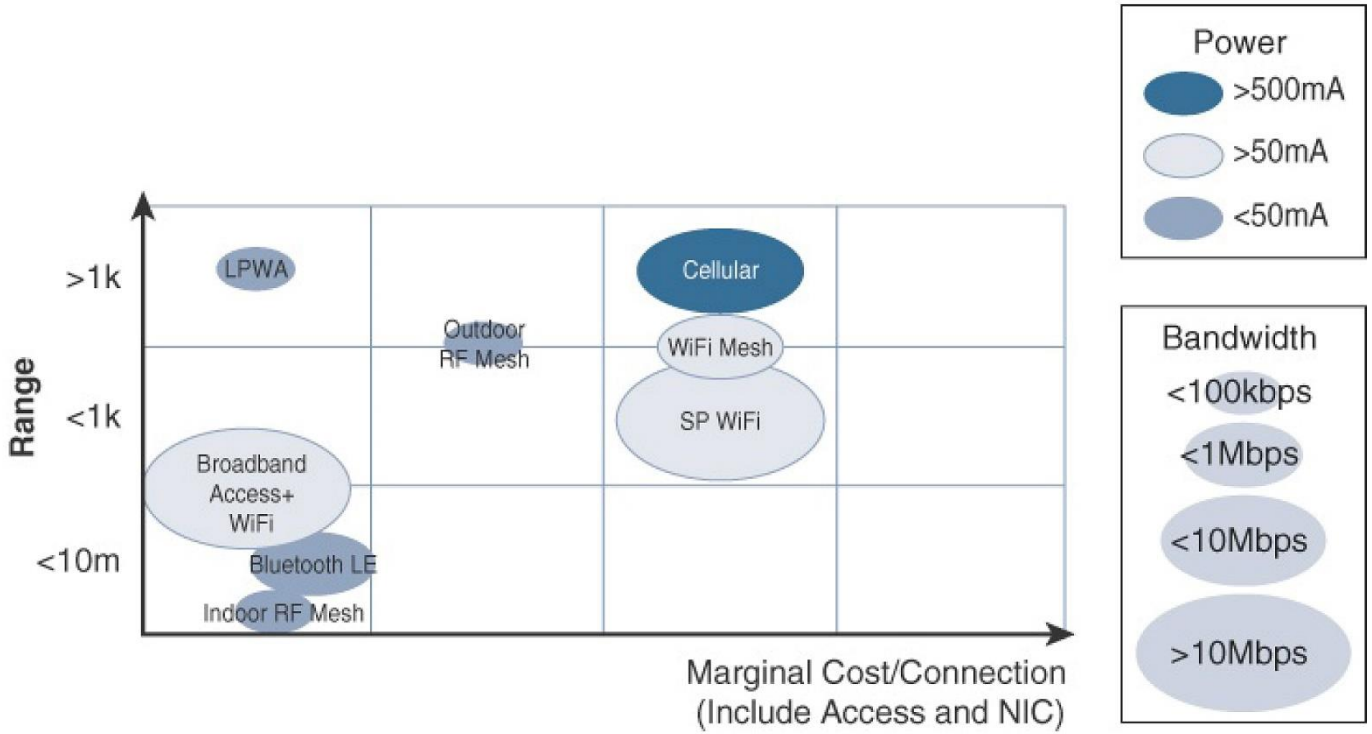


Figure 2-11 *Comparison Between Common Last-Mile Technologies in Terms of Range Versus Cost, Power, and Bandwidth*

Layer 2: Communications Network Layer

Core IoT Functional Stack

Network topologies of access networks

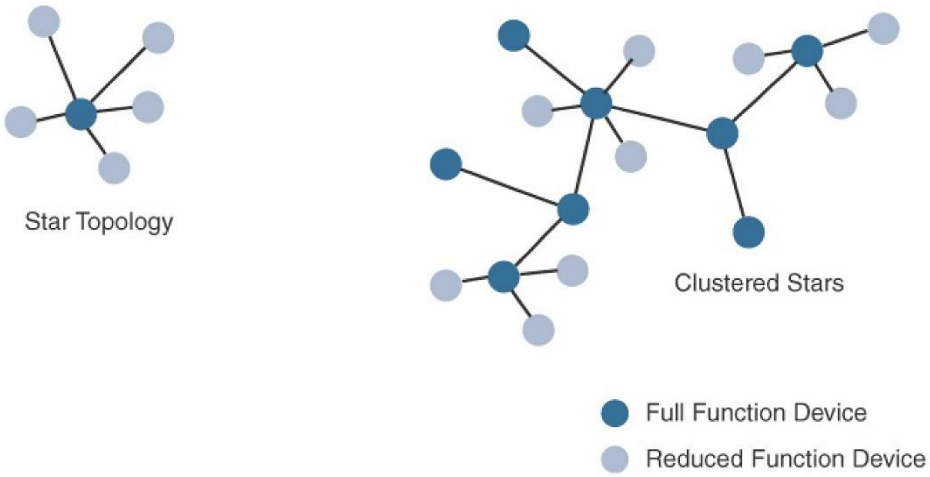


Figure 2-12 *Star and Clustered Star Topologies*

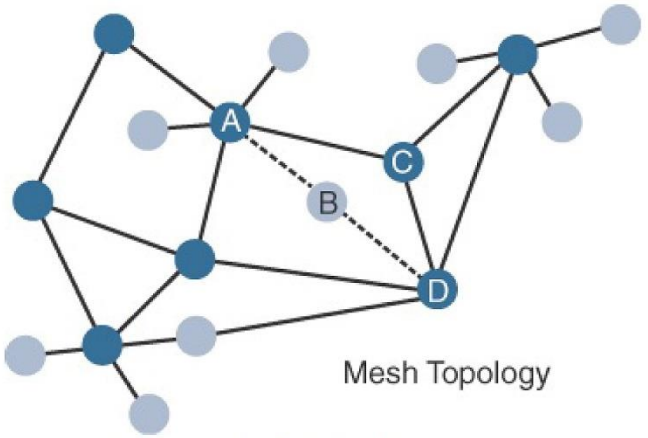


Figure 2-13 *Mesh Topology*

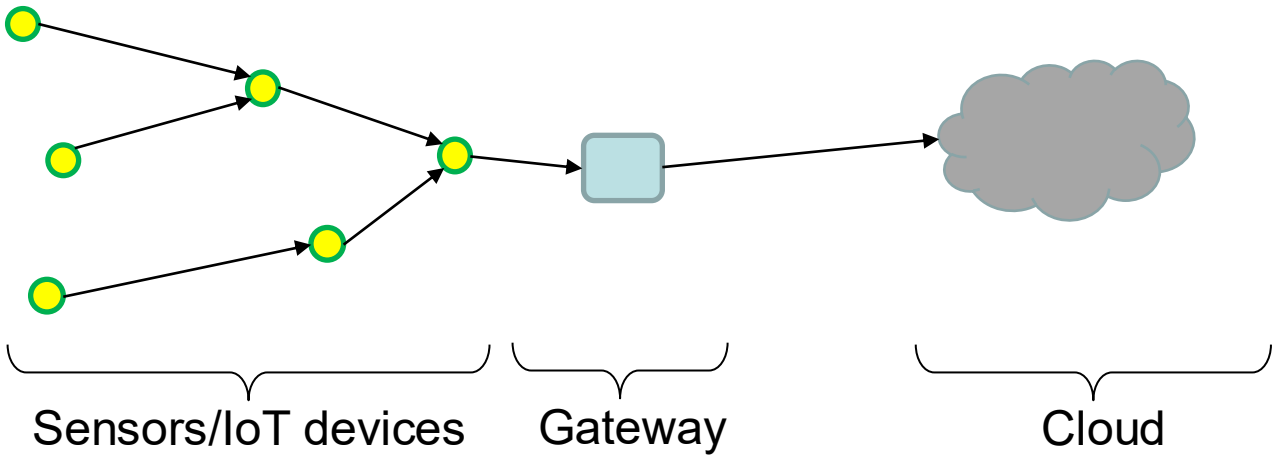
Have redundancy

Layer 2: Communications Network Layer

Core IoT Functional Stack

Gateways and Backhaul Sublayer

- Data collected from a smart object may need to be forwarded to a central station where data is processed
- Gateway is in charge of this intermedium communication



Layer 2: Communications Network Layer

Core IoT Functional Stack

Network Transport Sublayer

- IP
  - Flexibility of IP allows this protocol to be embedded in objects of very different natures, exchanging information over very different media, including low-power, lossy, and low-bandwidth networks
- UDP and TCP
  - UDP is a much lighter and faster protocol than TCP
  - However, it does not guarantee packet delivery

Layer 2: Communications Network Layer

Core IoT Functional Stack

IoT Network Management Sublayer

- Push model
  - Sensor reports at a regular interval or based on a local trigger or certain events happen
- Pull model
  - Application queries the sensor over the network

Layer 2: Communications Network Layer

Core IoT Functional Stack

IoT Network Management Sublayer

- Some IoT applications use HTTP for the data transfer
  - HTTP is fat protocol and was not designed to operate in constrained environments with low memory, low power, low bandwidth, and a high rate of packet failure

- Alternatives
  - WebSocket
  - Extensible Messaging and Presence Protocol (XMPP)
  - Constrained Application Protocol (CoAP)
  - Message Queue Telemetry Transport (MQTT)

Layer 3: Applications and Analytics Layer

Core IoT Functional Stack

Analytics Applications versus Control Applications

- Collect, process, and visualize data
  - Historical reports
  - Statistics
  - Trends to individual system states
- The important aspect that cannot be obtained from solely looking at the information displayed by a single smart object

Layer 3: Applications and Analytics Layer

Core IoT Functional Stack

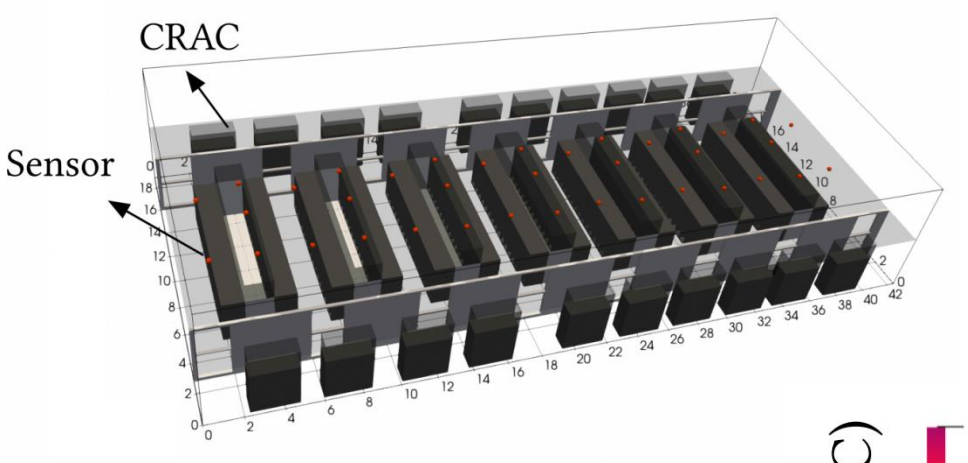
Analytics Applications versus **Control Applications**

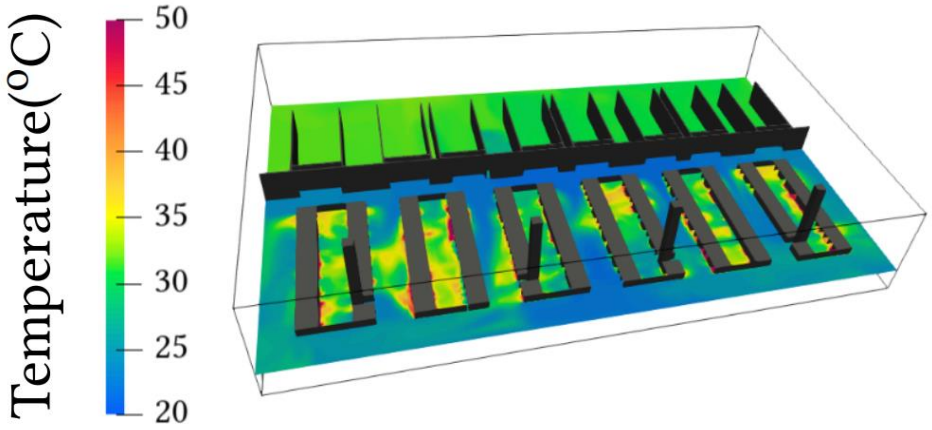
- Controls the behavior of the smart object or the behavior of an object related to the smart object
- Useful for controlling complex aspects of IoT network with a logic that cannot be programmed inside a single IoT object
  - because the configured changes are too complex to fit into the local system
  - because the configured changes rely on parameters that include elements outside the IoT object

Layer 3: Applications and Analytics Layer

Core IoT Functional Stack

Analytics Applications (example)

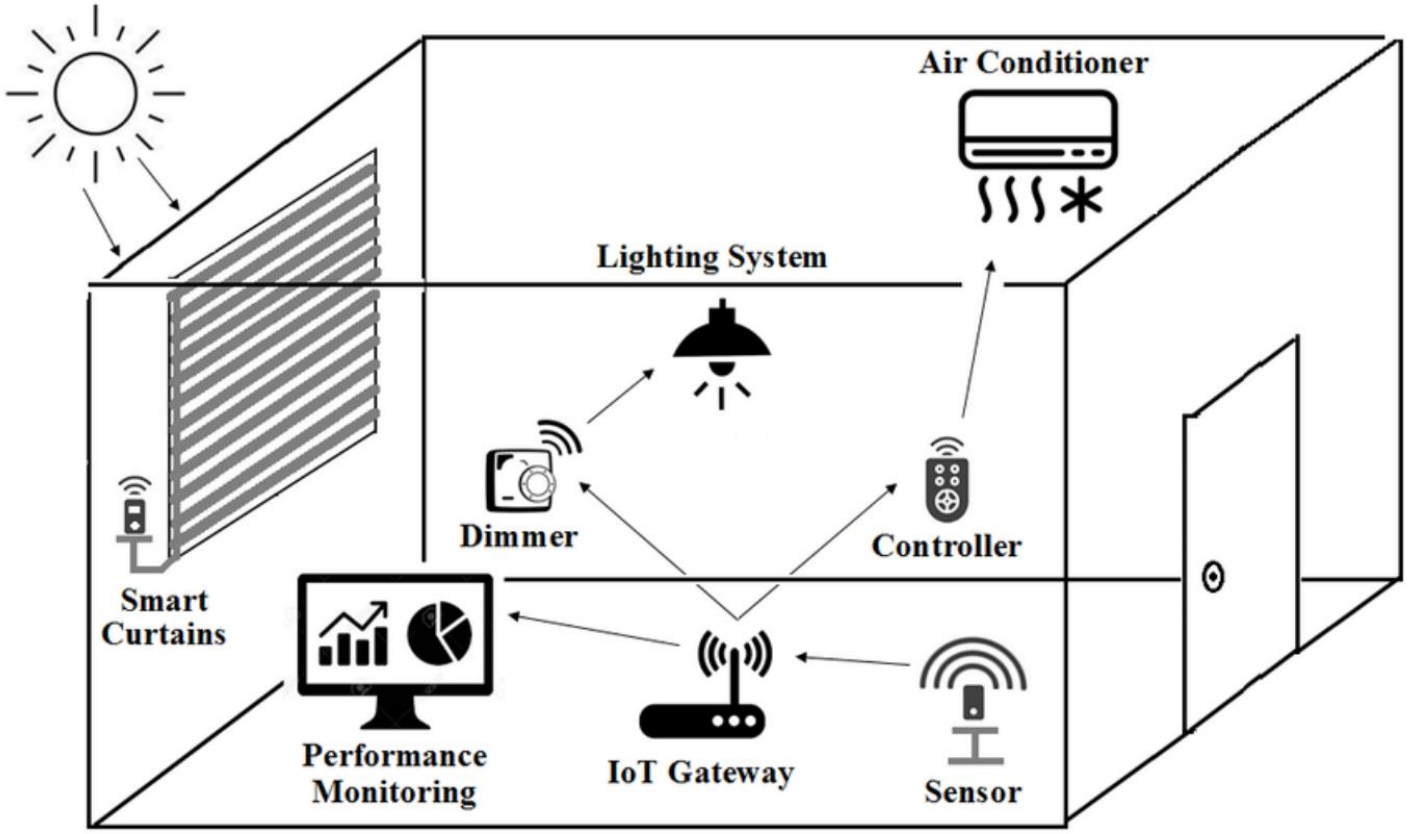




Layer 3: Applications and Analytics Layer

Core IoT Functional Stack

Control Applications (example)



Layer 3: Applications and Analytics Layer

Core IoT Functional Stack

Data Analytics versus **Network Analytics**

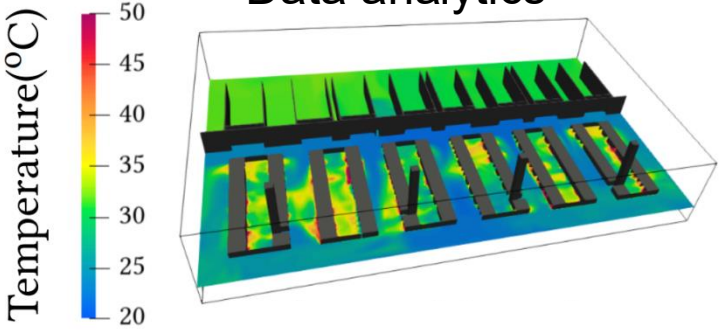
- Data Analytics: Process the data collected by smart objects and combine to provide intelligent view related to IoT system
  - Temperature, pressure, wind, humidity, and light levels collected from thousands of sensors may be combined and then processed to determine likelihood of storm and its possible path
- Network Analytics: Provide critical view of "network" status
  - Open mines use wireless networks to automatically pilot dump trucks
  - Loss of connectivity may result in an accident or degradation of operations efficiency (automated dump trucks typically stop upon connectivity loss)

Layer 3: Applications and Analytics Layer

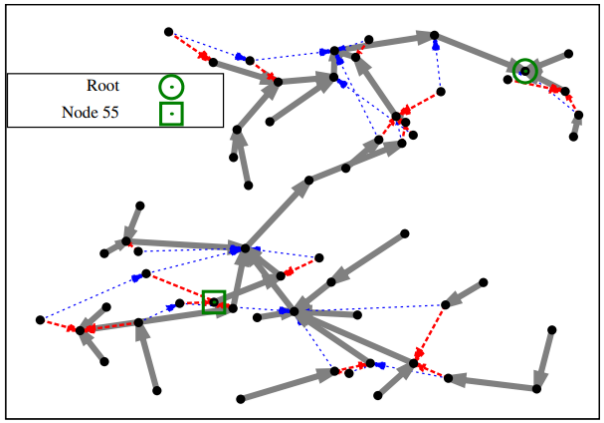
Core IoT Functional Stack

Data Analytics versus **Network Analytics** (examples)

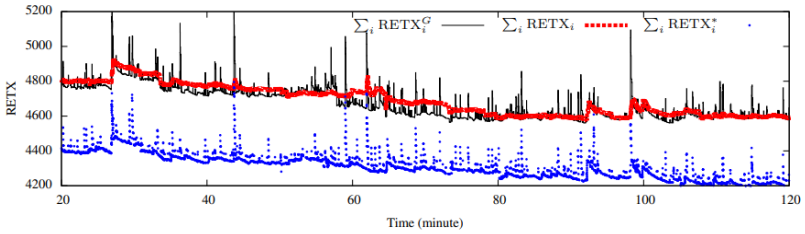
Data analytics



Network analytics



A Zigbee Wireless ad-hoc network



Link quality statistics over time

Layer 3: Applications and Analytics Layer

Core IoT Functional Stack

Smart Services

- Ability to use IoT to improve operations is often termed "smart services."
  - Smart services can be integrated into an IoT system
  - For example, sensors can be integrated in a light bulb
  - A sensor can turn a light on or off based on the presence of a human in the room
  - An even smarter system can communicate with other systems in the house, learn the human movement pattern, and anticipate the presence of a human, turning on the light just before the person enters the room
  - Results: Saving energy and providing better light user perception