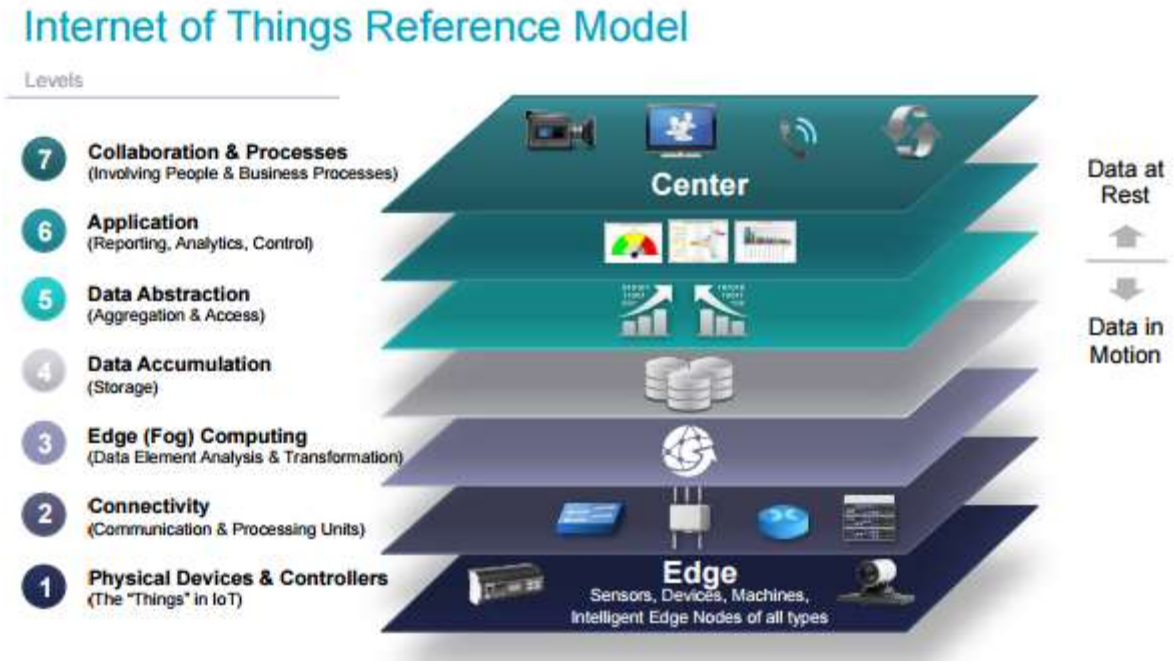
IoT Reference Model

The Seven Layers of IoT



Physical Devices and Controllers

- The IoT Reference Model starts with Level 1: physical devices and controllers that might control multiple devices.
- These are the “things” in the IoT, and they include a wide range of endpoint devices that send and receive information.
- Today, the list of devices is already extensive and myraid. It will become almost unlimited as more equipment is added to the IoT over time.
- Devices are diverse, and there are no rules about size, location, form factor, or origin. Some devices will be the size of a silicon chip. Some will be as large as vehicles.
- The IoT must support the entire range. Dozens or hundreds of equipment manufacturers will produce IoT devices. To simplify compatibility and support manufacturability, the IoT Reference Model generally describes the level of processing needed from Level 1 devices.

IoT Reference Model

Figure 2. Level 1 Physical Devices and Controllers

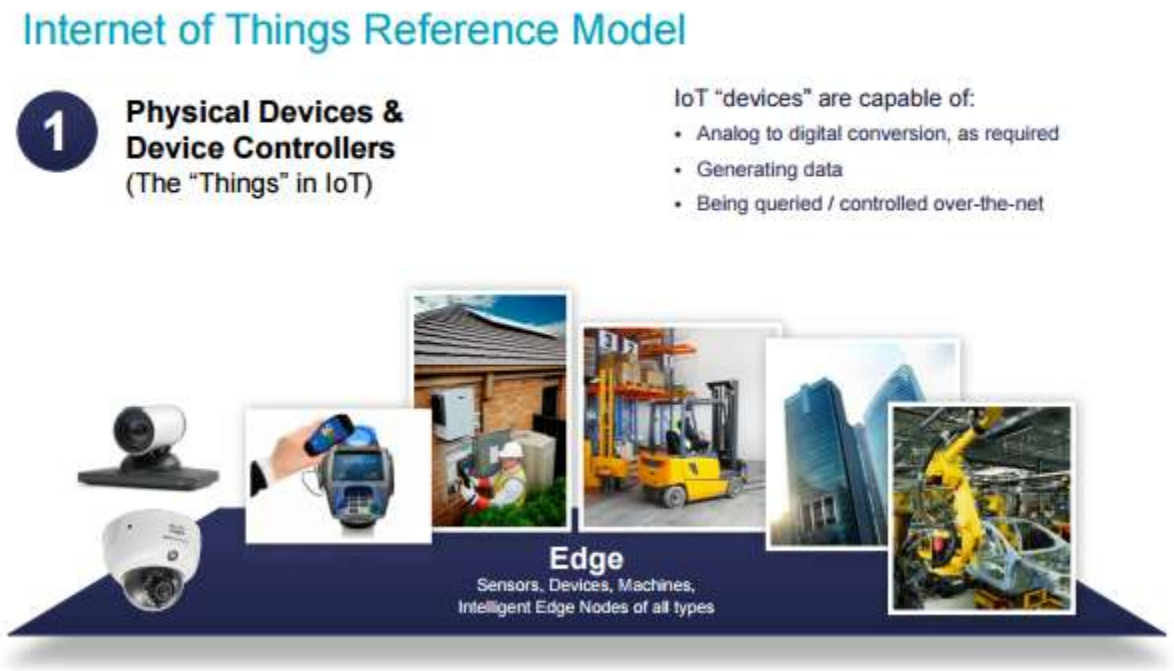


Figure 2 describes basic capabilities for a device

Connectivity

- Level 2: Connectivity Communications and connectivity are concentrated in one level—Level 2.
  The most important function of Level 2 is reliable, timely information transmission.
  This includes transmissions:
  - Between devices (Level 1) and the network
  - Across networks (east-west)
  - Between the network (Level 2) and low-level information processing occurring at Level 3

  Traditional data communication networks have multiple functions, as evidenced by the International Organization for Standardization (ISO) 7-layer reference model.
  However, a complete IoT system contains many levels in addition to the communications network.

Connectivity

- One objective of the IoT Reference Model is for communications and processing to be executed by existing networks.
- The IoT Reference Model does not require or indicate creation of a different network—it relies on existing networks.
- However, some legacy devices aren't IP-enabled, which will require introducing communication gateways.
- Other devices will require proprietary controllers to serve the communication function.
- However, over time, standardization will increase. As Level 1 devices proliferate, the ways in which they interact with Level 2 connectivity equipment may change.
- Regardless of the details, Level 1 devices communicate through the IoT system by interacting with Level 2 connectivity equipment, as shown in Figure 3.

Connectivity

2 **Connectivity**
(Communication & Processing Units)

Level 2 functionality focuses on East-West communications

Connectivity includes:

- Communicating with and between the Level 1 devices
- Reliable delivery across the network(s)
- Implementation of various protocols
- Switching and routing
- Translation between protocols
- Security at the network level
- (Self Learning) Networking Analytics

Edge (Fog) Computing

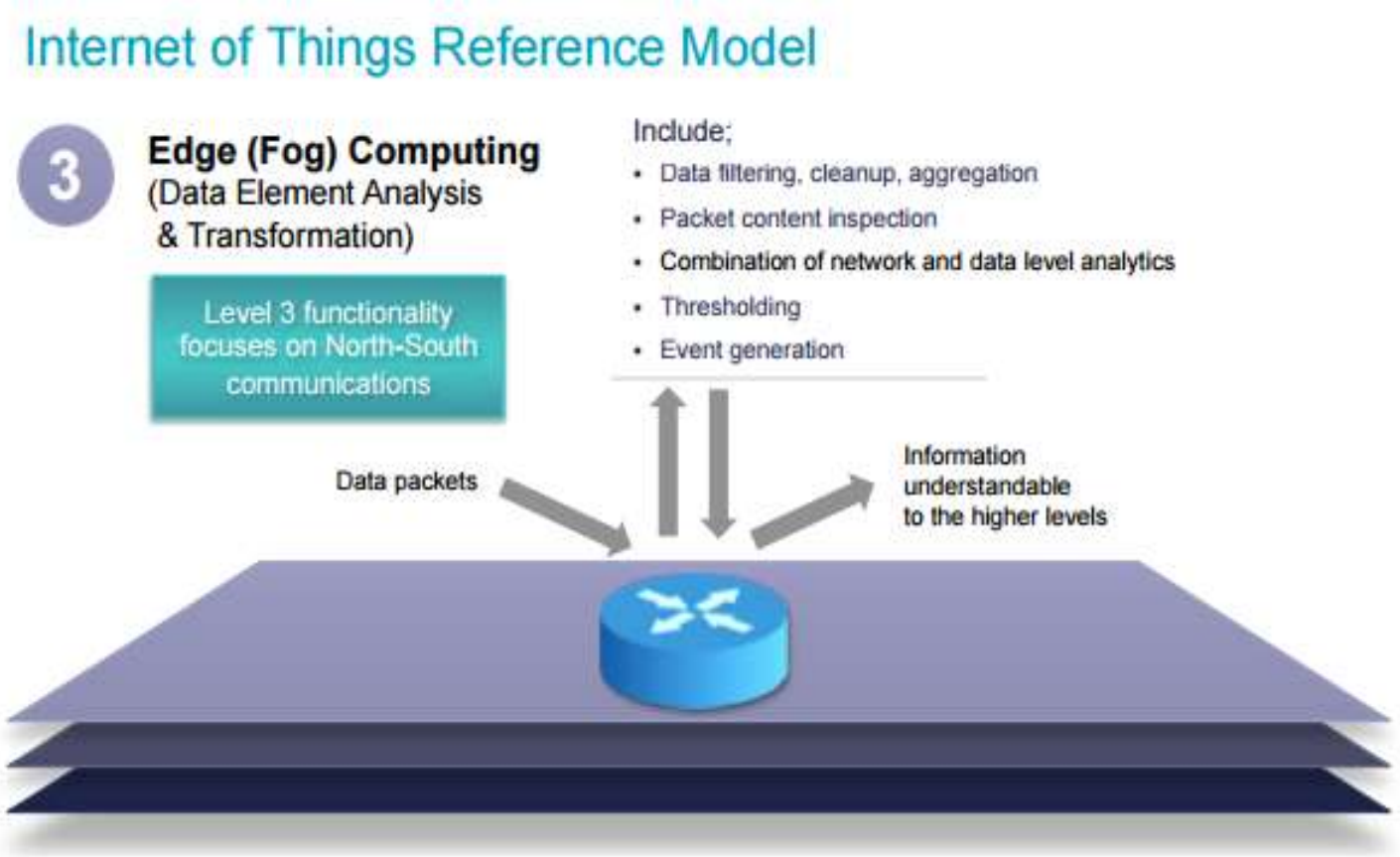
- The functions of Level 3 are driven by the need to convert network data flows into information that is suitable for storage and higher level processing at Level 4 (data accumulation).
- This means that Level 3 activities focus on high-volume data analysis and transformation. For example, a Level 1 sensor device might generate data samples multiple times per second, 24 hours a day, 365 days a year.
- A basic tenet of the IoT Reference Model is that the most intelligent system initiates information processing as early and as close to the edge of the network as possible.
- This is sometimes referred to as fog computing. Level 3 is where this occurs.
- Given that data is usually submitted to the connectivity level (Level 2) networking equipment by devices in small units, Level 3 processing is performed on a packet-by-packet basis

Edge (Fog) Computing

- This processing is limited, because there is only awareness of data units—not “sessions” or “transactions.” Level 3 processing can encompass many examples, such as:
- Evaluation: Evaluating data for criteria as to whether it should be processed at a higher level
- Formatting: Reformatting data for consistent higher-level processing
- Expanding/decoding: Handling cryptic data with additional context (such as the origin)
- Distillation/reduction: Reducing and/or summarizing data to minimize the impact of data and traffic on the network and higher-level processing systems
- Assessment: Determining whether data represents a threshold or alert; this could include redirecting data to additional destinations

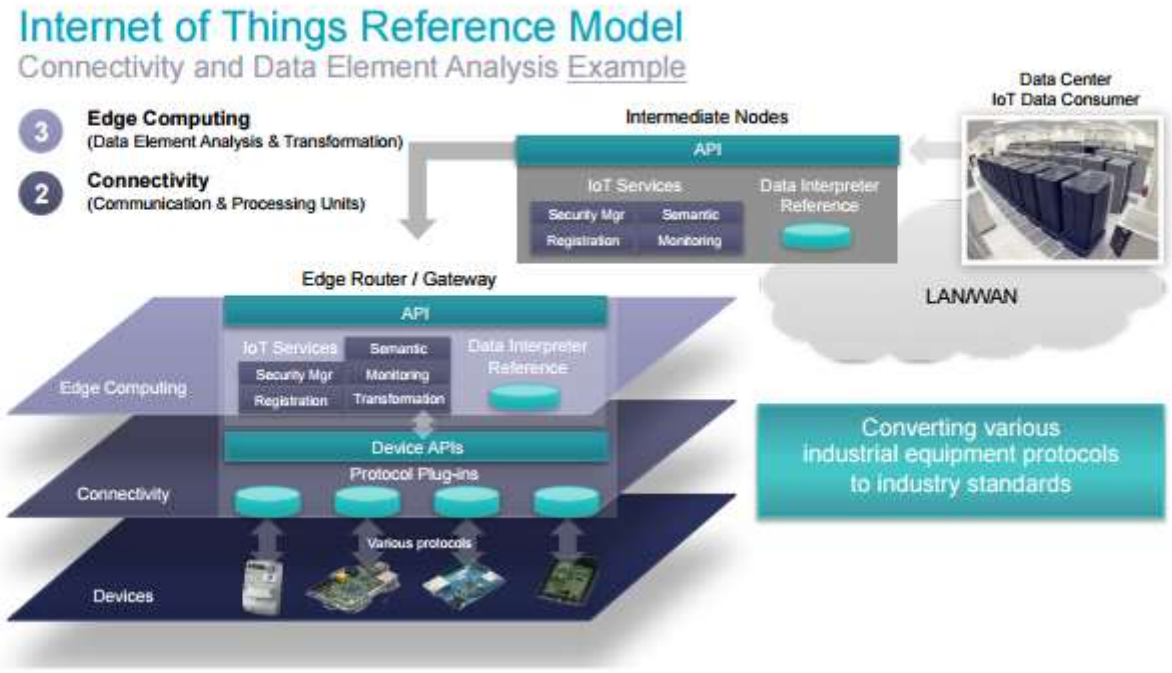
Edge (Fog) Computing

Figure 4. Level 3 Edge (Fog) Computing



Edge (Fog) Computing

Figure 5. Level 2 and 3 Connectivity and Data Element Analysis Example



Data Accumulation

- Data Accumulation Networking systems are built to reliably move data. The data is “in motion.”
- Prior to Level 4, data is moving through the network at the rate and organization determined by the devices generating the data. The model is event driven.
- As defined earlier, Level 1 devices do not include computing capabilities themselves. However, some computational activities could occur at Level 2, such as protocol translation or application of network security policy.
- Additional compute tasks can be performed at Level 3, such as packet inspection.
- Driving computational tasks as close to the edge of the IoT as possible, with heterogeneous systems distributed across multiple management domains represents an example of fog computing.
- Fog computing and fog services will be a distinguishing characteristic of the IoT

Data Accumulation

- Most applications cannot, or do not need to, process data at network wire speed.
- Applications typically assume that data is “at rest”—or unchanging—in memory or on disk.
- At Level 4, Data Accumulation, data in motion is converted to data at rest.
- Level 4 determines:

● If data is of interest to higher levels: If so, Level 4 processing is the first level that is configured to serve the specific needs of a higher level.

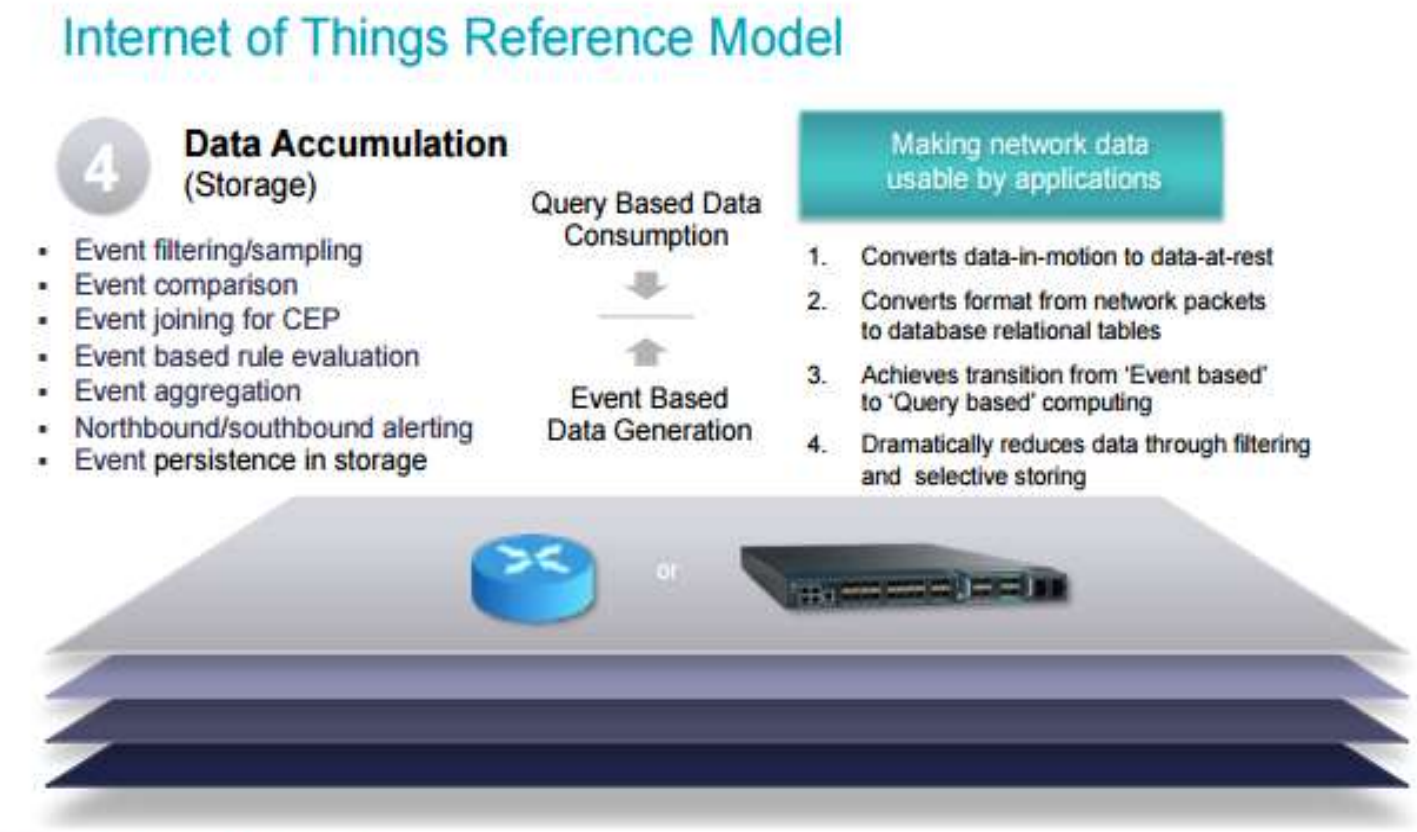
● If data must be persisted: Should data be kept on disk in a non-volatile state or accumulated in memory for short-term use?

● The type of storage needed: Does persistency require a file system, big data system, or relational database?

● If data is organized properly: Is the data appropriately organized for the required storage system?

● If data must be recombined or recomputed: Data might be combined, recomputed, or aggregated with previously stored information, some of which may have come from non-IoT sources

Data Accumulation



Level 5: Data Abstraction

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Data Abstraction

- Level 5: Data Abstraction IoT systems will need to scale to a corporate—or even global—level and will require multiple storage systems to accommodate IoT device data and data from traditional enterprise ERP, HRMS, CRM, and other systems.
- The data abstraction functions of Level 5 are focused on rendering data and its storage in ways that enable developing simpler, performance-enhanced applications.
- With multiple devices generating data, there are many reasons why this data may not land in the same data storage:

● There might be too much data to put in one place.

● Moving data into a database might consume too much processing power, so that retrieving it must be separated from the data generation process. This is done today with online transaction processing (OLTP) databases and data warehouses.

Data Abstraction

- Devices might be geographically separated, and processing is optimized locally.
- Levels 3 and 4 might separate “continuous streams of raw data” from “data that represents an event.”Data storage for streaming data may be a big data system, such as Hadoop. Storage for event data may be a relational database management system (RDBMS) with faster query times.
- Different kinds of data processing might be required. For example, in-store processing will focus on different things than across-all-stores summary processing.

Data Abstraction

- For these reasons, the data abstraction level must process many different things. These include:
- Reconciling multiple data formats from different sources
- Assuring consistent semantics of data across sources
- Confirming that data is complete to the higher-level application
- Consolidating data into one place (with ETL, ELT, or data replication) or providing access to multiple data stores through data virtualization
- Protecting data with appropriate authentication and authorization
- Normalizing or denormalizing and indexing data to provide fast application access

Data Abstraction

Internet of Things Reference Model

5 **Data Abstraction**
(Aggregation & Access)

Abstracting the data interface for applications

Information Integration

1. Creates schemas and views of data in the manner that applications want
2. Combines data from multiple sources, simplifying the application
3. Filtering, selecting, projecting, and reformatting the data to serve the client applications
4. Reconciles differences in data shape, format, semantics, access protocol, and security

Level 6: Application

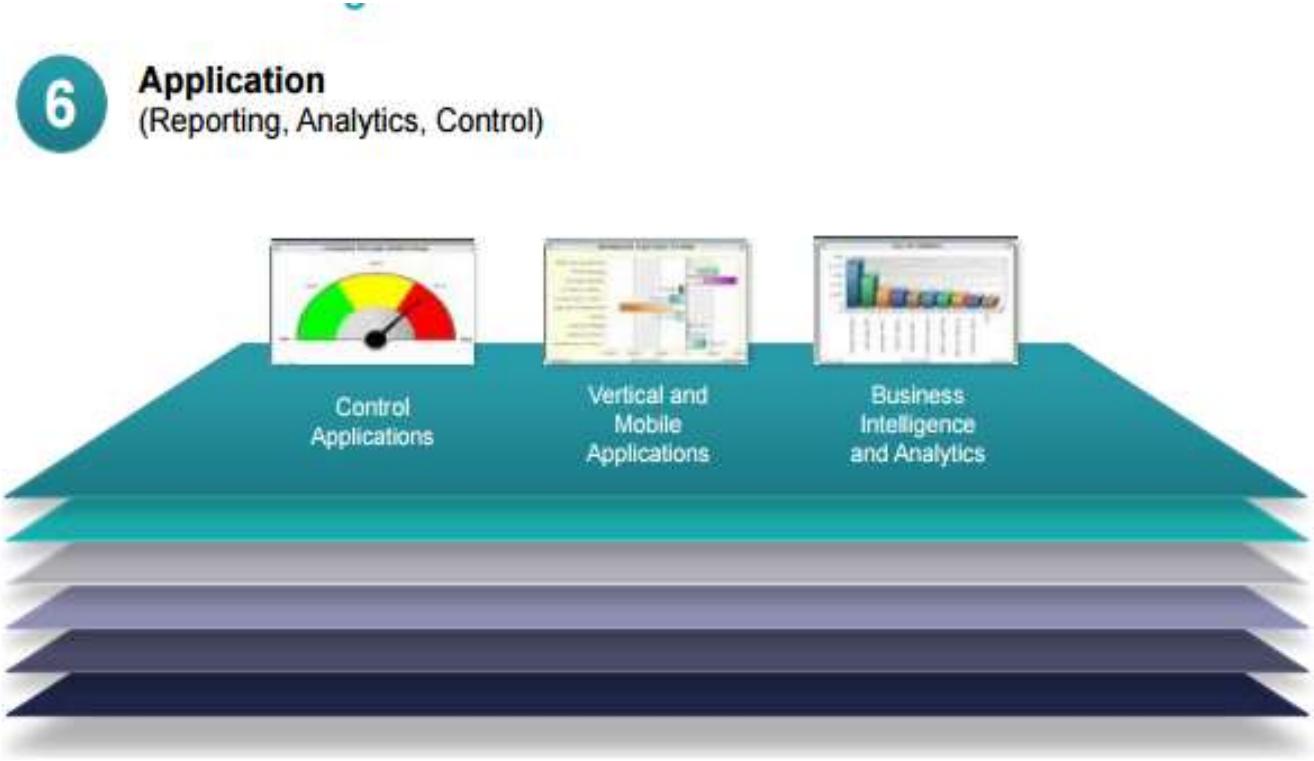
Application Level

- Level 6 is the application level, where information interpretation occurs.
- Software at this level interacts with Level 5 and data at rest, so it does not have to operate at network speeds.
- he IoT Reference Model does not strictly define an application. Applications vary based on vertical markets, the nature of device data, and business needs.
- For example, some applications will focus on monitoring device data.
- Some will focus on controlling devices.
- Some will combine device and non-device data.
- Monitoring and control applications represent many different application models, programming patterns, and software stacks, leading to discussions of operating systems, mobility, application servers, hypervisors, multi-threading, multi-tenancy, etc.
- These topics are beyond the scope of the IoT Reference Model discussion. Suffice it to say that application complexity will vary widely.

Application Level

- Examples include:
- Mission-critical business applications, such as generalized ERP or specialized industry solutions
- Mobile applications that handle simple interactions
- Business intelligence reports, where the application is the BI server
- Analytic applications that interpret data for business decisions.
- System management/control center applications that control the IoT system itself and don’t act on the data produced by it

Application Level



Collaboration Processes

- Level 7: Collaboration and Processes One of the main distinctions between the Internet of Things (IoT) and IoT is that IoT includes people and processes.
- This difference becomes particularly clear at Level 7: Collaboration and Processes. The IoT system, and the information it creates, is of little value unless it yields action, which often requires people and processes.
- Applications execute business logic to empower people. People use applications and associated data for their specific needs. Often, multiple people use the same application for a range of different purposes.
- So the objective is not the application—it is to empower people to do their work better. Applications (Level 6) give business people the right data, at the right time, so they can do the right thing.
- But frequently, the action needed requires more than one person. People must be able to communicate and collaborate, sometimes using the traditional Internet, to make the IoT useful.
- Communication and collaboration often requires multiple steps. And it usually transcends multiple applications. This is why Level 7, as shown in Figure 9, represents a higher level than a single application.

Collaboration Processes

Collaboration Processes

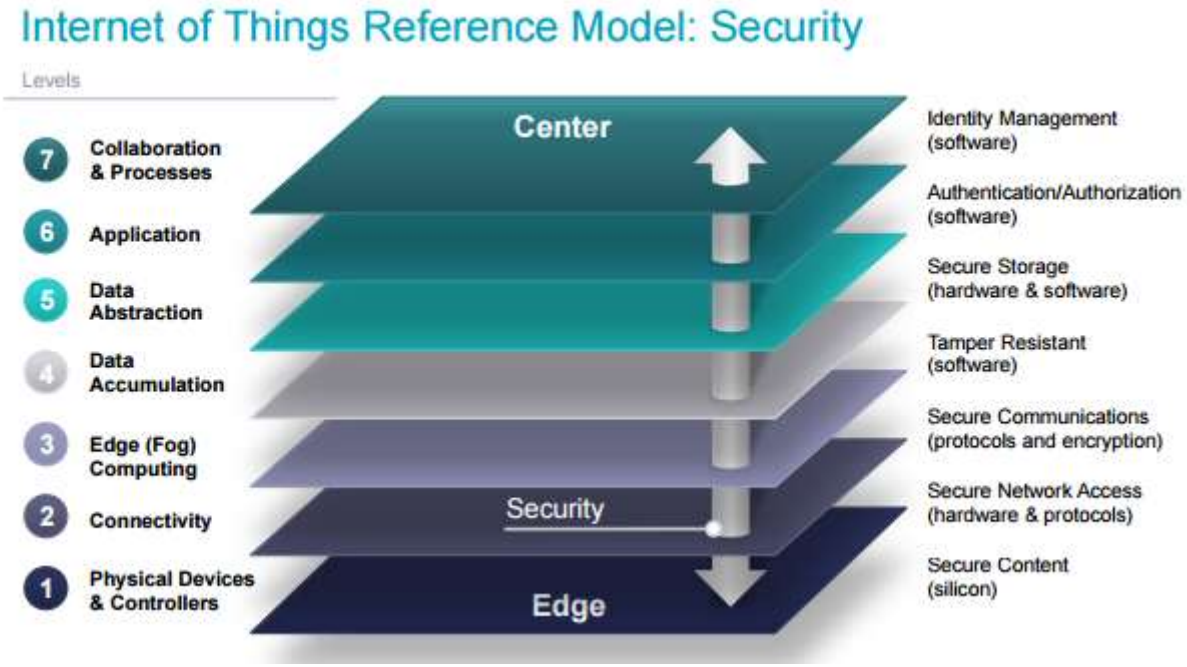
- Security in the IoT Discussions of security for each level and for the movement of data between levels could fill a multitude of papers.
- For the purpose of the IoT Reference Model, security measures must:

● Secure each device or system

● Provide security for all processes at each level

● Secure movement and communication between each level, whether north- or south-bound As shown in Figure 10, security must pervade the entire model.

Summary


Internet of Things Reference Model: Security
Levels
7 Collaboration & Processes
6 Application
5 Data Abstraction
4 Data Accumulation
3 Edge (Fog) Computing
2 Connectivity
1 Physical Devices & Controllers
Center
Security
Edge
Identity Management (software)
Authentication/Authorization (software)
Secure Storage (hardware & software)
Tamper Resistant (software)
Secure Communications (protocols and encryption)
Secure Network Access (hardware & protocols)
Secure Content (silicon)

Summary

- Summary The Internet of Everything (IoT) Reference Model is a decisive first step toward standardizing the concept and terminology surrounding the IoT.
- From physical devices and controllers at Level 1 to the collaboration and processes at Level 7, the IoT Reference Model sets out the functionalities required and concerns that must be addressed before the industry can realize the value of the IoT. With the goal of enabling the IoT, this reference model provides a baseline for understanding its requirements and its potential.