IoT Architectural Reference Model

Internet of Things

Rahul Shandilya

IoT A Reference Model

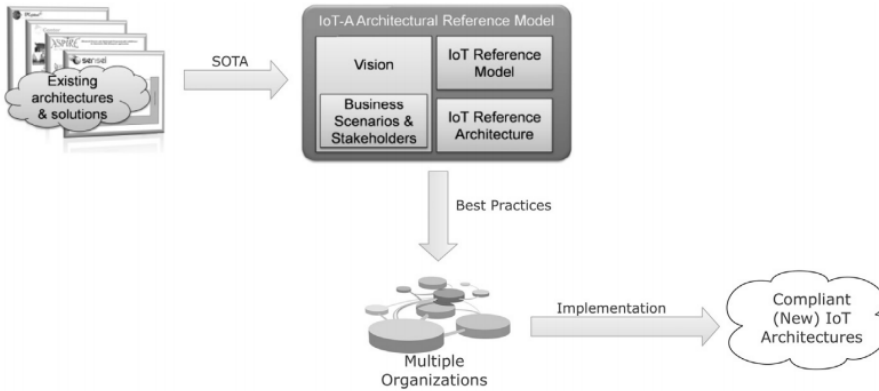
In the IoT domain, anyone can propose an own architecture and an own communication protocol, due to a wide variety of requirements to which each architecture should be compliant.
A common reference model for the IoT domain and the identification of reference architectures can help to a faster, more focused development and an exponential increase of IoT-related solutions.
The European Lighthouse Integrated Project has addressed for three years the Internet-of-Things Architecture (IoT-A) and created an architectural reference model together with the definition of an initial set of key building blocks. It wants to promote a common ground between architectures so that they can interoperate even a more levels. IoT-A has achieved that thanks to two steps:

- Establishing a Reference Model
- Providing a Reference Architecture

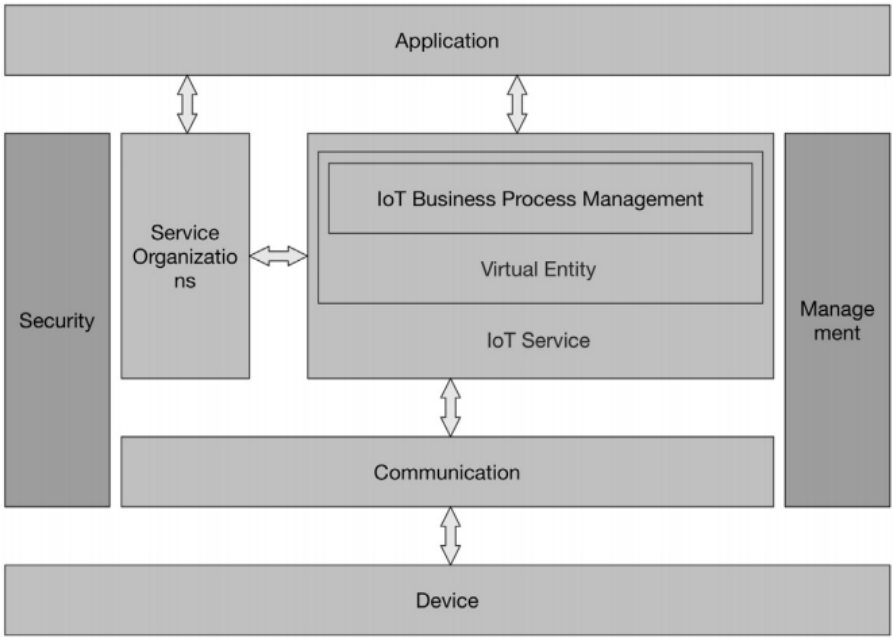
IoT-A ARM

The IoT-A ARM (Architecture Reference Model) consists of four parts:

- **Vision**: summarizes the rationale for providing an architectural reference model for the IoT;
- **Business scenarios**: define requirements provided by stakeholders that are the drivers of the architecture. They allow the architecture to be validated;
- **The IoT Reference Model**, which provides the highest abstraction level for the definition of the IoT-A Architectural Reference Model. It promotes a common understanding of the IoT domain. It includes the description of domain, communication and information model;
- **The IoT Reference Architecture**, which is the reference for building compliant IoT architectures. It provides views and perspectives on different architectural aspects that are of concern to stakeholders of the IoT.


Existing architectures & solutions
SOTA
IoT-A Architectural Reference Model
Vision
IoT Reference Model
Business Scenarios & Stakeholders
IoT Reference Architecture
Best Practices
Multiple Organizations
Implementation
Compliant (New) IoT Architectures

IoT-Information Model



Uses of IoT ARM

Cognitive Aid

When it comes to product development and other activities, an architectural reference model is of fourfold use.

- Firstly, it helps to guide discussions, since it provides a language everyone involved can use, and which is intimately linked to the architecture, the system, the usage domain
- Secondly, the high-level view provided in such a model is of high educational value, since it provides an abstract but also rich view of the domain. Such a view can help people new to the field to "find their way" and to understand the special features and intricacies of IoT.
- Thirdly, the IoT ARM can assist IoT project leaders in planning the work at hand and the teams needed.
- Fourthly, the IoT ARM helps to identify independent building blocks for IoT systems. This constitutes very valuable information when dealing with questions such as system modularity, processor architectures, third-vendor options, re-use of components already developed, etc.

Reference Model as a Common Ground

Establishing the common ground for the IoT encompasses defining IoT entities and describing their basic interactions and relationships with each other. The IoT ARM provides exactly such a common ground for the IoT field.

Generating Architectures

One of the main benefits is the use of the IoT ARM for generating compliant architectures for specific systems. This is done by providing best practices and guidance for translating the IoT ARM into concrete architectures. The benefit of this type of generation scheme for IoT architectures is not only a certain degree of automation in this process, and thus lower R&D efforts, but also that the decisions made follow a clear, documented pattern.

Identifying Differences in Derived Architectures

the IoT ARM defines a set of tactics and design choices for meeting qualitative system requirements. All of these facts can be used to predict whether two derived architectures will differ and where they will do so. The IoT ARM can also be used for reverse mapping. System architectures can be cast in the "IoT ARM" language and the resulting "translation" of the system architectures is then stripped of incompatible language and system partitions and mappings. The differences that remain are then true differences in architecture.

Achieving Interoperability

By comparing the design choices made when deriving two architectures, one can readily identify where in the architecture measures are necessary to achieve interoperability. Interoperability may be achieved a posteriori by integrating one IoT system as subsystem in another system, or by building a bridge through which key functionalities of the respective other IoT system can be used.

System Roadmaps and Product Life Cycles

the IoT ARM can be used to devise system roadmaps that lead to minimum changes between two product generations while still guaranteeing a noticeable enhancement in system capability and features. This approach also helps the designer to formulate clear and standardised, requirements-based rationales for the system roadmap chosen and the product life cycles that result from the system roadmap.

Benchmarking

While the reference model prescribed the language to be used in the systems/architectures to be assessed, the reference architecture stated the minimum (functional) requirements for the systems/ architectures. By standardising the description and also the ordering and delineation of system components and aspects, this approach also provided the benchmarking process with a high level of transparency and inherent comparability

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- IoT system contain communicating entities, and therefore the corresponding *communication model* needs to capture the communication interactions of these entities.

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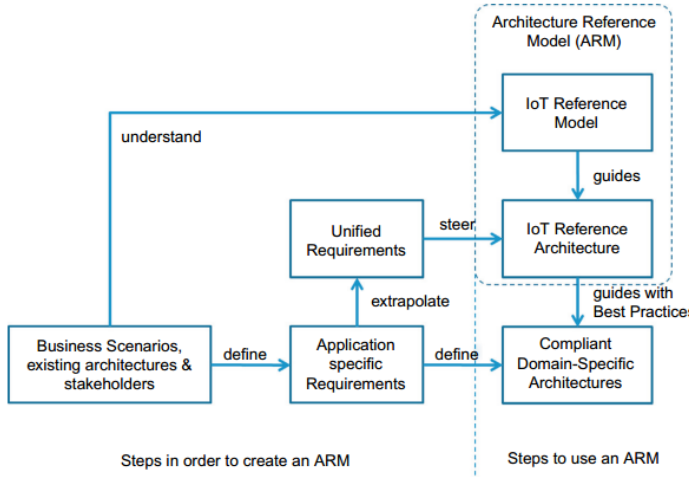
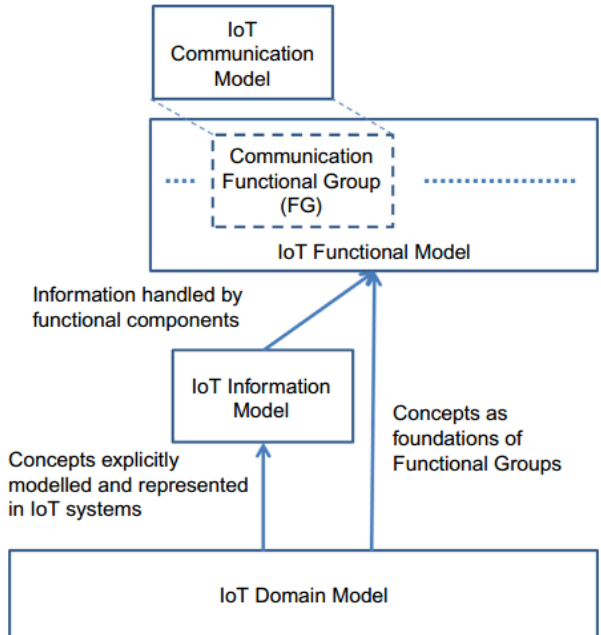
- A concrete architecture can be further elaborated and mapped into real world components by designing, building, engineering, and testing the different components of the actual system.
- The whole process is iterative, which means that the actual deployed system in the field provides invaluable feedback with respect to the design and engineering choices, current constraints of the system, and potential future opportunities that are fed back to the concrete architectures. The general essentials out of multiple concrete architectures can then be aggregated, and contribute to the evolution of the Reference Architecture.


Architecture Reference Model (ARM)
IoT Reference Model
understand
guides
Unified Requirements
steer
IoT Reference Architecture
extrapolate
guides with Best Practices
Business Scenarios, existing architectures & stakeholders
define
Application specific Requirements
define
Compliant Domain-Specific Architectures
Steps in order to create an ARM
Steps to use an ARM

IoT reference model



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- *User and Physical Entity*: As interaction with the physical world is the key for the IoT. The first most fundamental interaction is between a human or an application with the physical world object or place. The physical interaction is the result of the intention of the human to achieve a certain goal (e.g. park the car).A Physical Entity, as the model shows, can potentially contain other physical entities (e.g building).

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- *Virtual Entity*: A Physical Entity is represented in the digital world as a Virtual Entity. A Virtual Entity can be a database entry, a geographical model (mainly for places), an image or avatar, or any other *Digital Artifact*. Each Virtual Entity also has a unique identifier for making it addressable among other Digital Artifacts.

- A Virtual Entity representation contains several attributes that correspond to the Physical Entity current state (e.g. the parking spot availability). The Virtual Entity representation and the Physical Entity actual state should be synchronized whenever a User operates on one or the other, if of course that is physically possible. There are cases that state synchronization can occur only one way.

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- *Physical Artifact*:In order to monitor and interact with the Physical Entities through their corresponding virtual entities, the Physical Entities or their surrounding environment needs to be instrumented with certain kinds of Devices, or certain Devices need to be embedded/attached to the environment. The Devices are physical artifacts with which the physical and virtual worlds interact. For the IoT Domain Model, three kinds of Device types are the most important - Sensors, actuators and Tags.

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- An on-Device Resource is typically hosted on the Device itself and provides information, or is the control point for the Physical Entities that the Device itself is attached to. The Network Resources are software components hosted somewhere in the network or cloud.

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- IoT Services can be classified into three main classes according to their level of abstraction: (i)Resource-Level Services (ii) Virtual Entity-Level Services (iii) Integrated Services .

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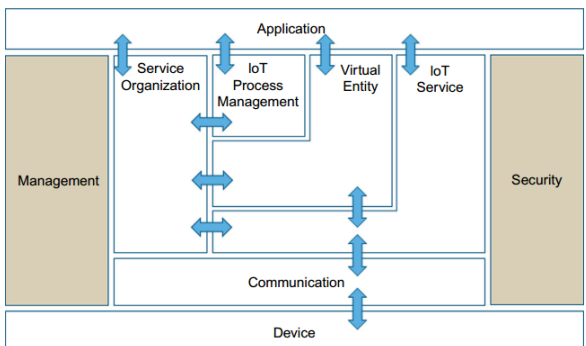
- A Virtual Entity object contains simple attributes/properties: (a) entityType to denote the type of entity, such as a human, car, or room (the entity type can be a reference to concepts of a domain ontology, e.g. a car ontology); (b) a unique identifier; and (c) zero or more complex attributes of the class Attributes.

Functional model

In the IoT-ARM project, *Functional Decomposition* (FD) refers to the process by which the different *Functional Components* (FC) that make up the IoT ARM are identified and related to one another. The main purpose of Functional Decomposition is, on the one hand, to break up the complexity of a system compliant to the IoT ARM in smaller and more manageable parts, and to understand and illustrate their relationship on the other hand.



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- *Virtual Entity functional group* The Virtual Entity FG corresponds to the Virtual Entity class in the IoT Domain Model, and contains the necessary functionality to manage associations between Virtual Entities with themselves as well as associations between Virtual Entities and related IoT Services, i.e. the Association objects for the IoT Information Model.

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- *Security functional group* The SecurityFG contains components for Authentication of Users (Applications,Humans), Authorization of access to Services by Users, secure communication (ensuring integrity and confidentiality of messages) between entities of the system such as Devices, Services, Applications, and last but not least,assurance of privacy of sensitive information relating to Human Users

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- *Service / Resource / Device Interactions*: The complexity of this interaction is due to variety of different properties that a Device can have; in particular, a Device can be as simple and limited as a Tag and as complex and powerful as a server.

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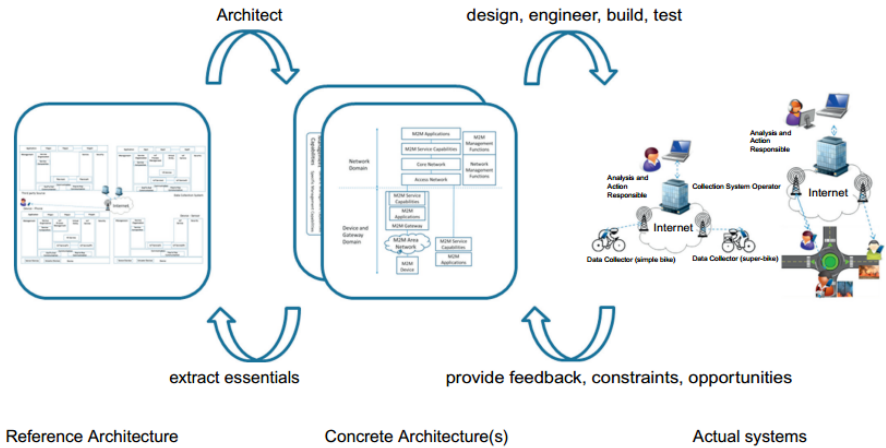
- **Security** The Security Model for IoT consists of communication security that focuses mostly on the confidentiality and integrity protection of interacting entities and functional components such as Identity Management, Authentication, Authorization, and Trust & Reputation.

IoT Reference Architecture

The Reference Architecture is a starting point for generating concrete architectures and actual systems. A Reference Architecture, serves as a guide for one or more concrete system architects.



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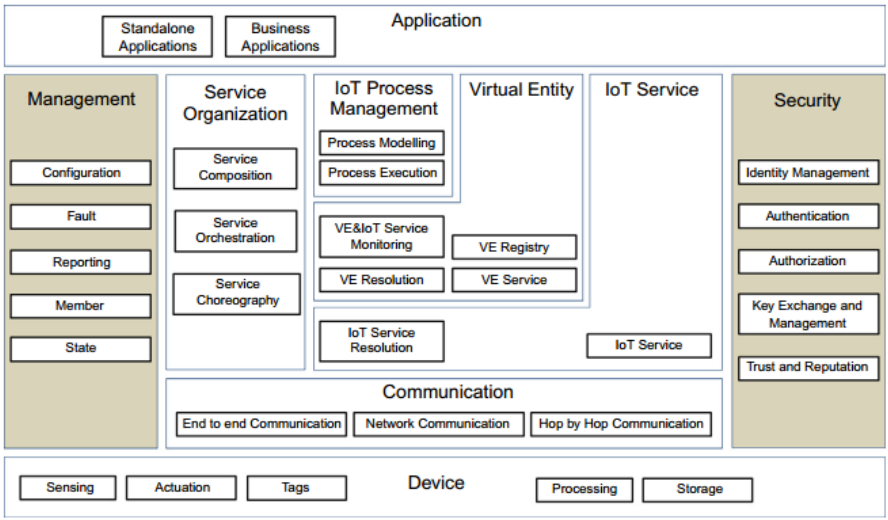
- **Functional View**: Description of what the system does, and its main functions.
- **Information View**: Description of the data and information that the system handles.
- **Deployment and Operational View**: Description of the main real world components of the system such as devices, network routers, servers, etc.

Functional View

It consists of the Functional Groups (FGs) presented earlier in the IoT Functional Model, each of which includes a set of Functional Components (FCs).



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- Management information such as state information from operational FCs used for fault/performance purposes, configuration snapshots, reports, membership information, etc.

Information Handling

The presentation of information handling in an IoT system assumes that FCs exchange and process information. The exchange of information between FCs follows the interaction patterns below

- **Push:** An FC A pushes the information to another FC B provided that the contact information of the component B is already configured in component A, and component B listens for such information pushes.

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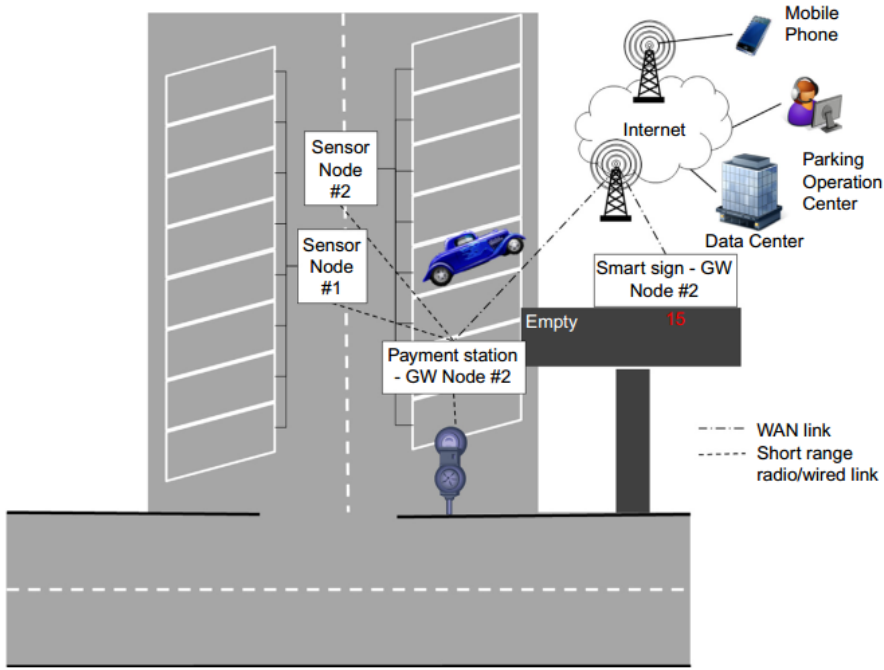
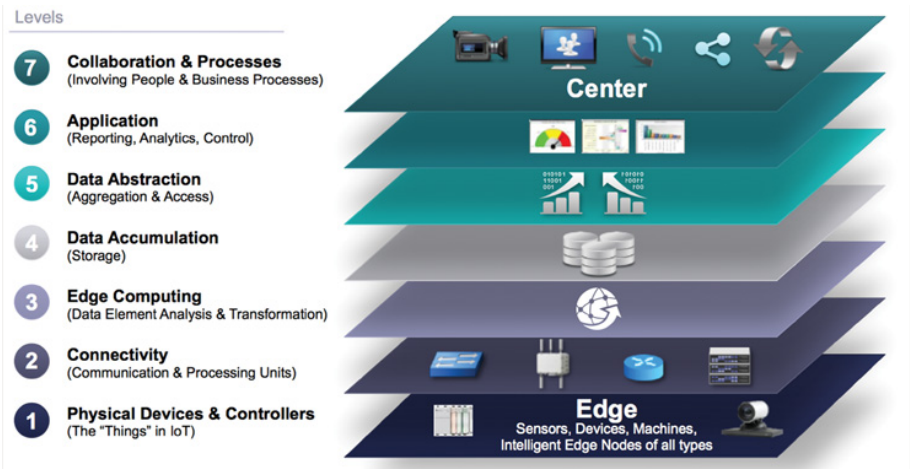
- **Publish/Subscribe**: In the Publish/Subscribe (also known as a Pub/Sub pattern), there is a third component called the broker B, which mediates subscription and publications between subscribers (information consumers) and publishers (or information producers)

Deployment and Operational View



The IoT World Forum (IoTWF) Standardized Architecture

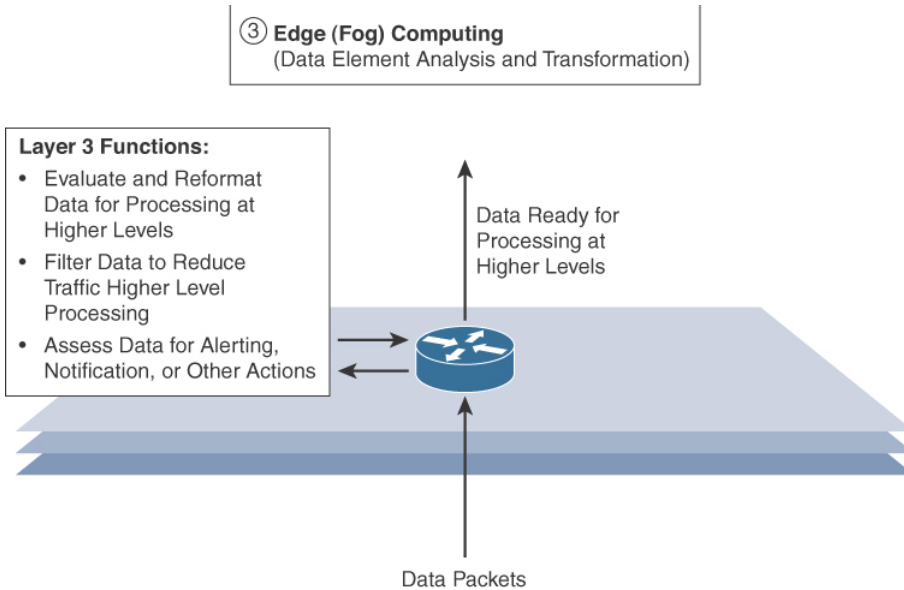
In 2014 the IoTWF architectural committee (led by Cisco, IBM, Rockwell Automation, and others) published a seven-layer IoT architectural reference model. While various IoT reference models exist, the one put forth by the IoT World Forum offers a clean, simplified perspective on IoT and includes edge computing, data storage, and access.



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


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

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.