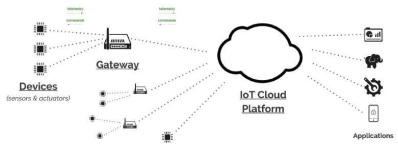
Internet of Things: IoT Reference Model

Dr. E.SURESH BABU
Assistant Professor
Computer Science and Engineering Department
National Institute of Technology, Warangal.
Warangal, TS, India.

Session Outline

1. IoT Architecture
2. IoT World Forum Reference Model
3. Physical Devices and Controllers Level
4. Connectivity Level
5. Edge Computing Level
6. Data Accumulation Level
7. Data Abstraction Level
8. Application Level

IoT Architecture Devices, Gateways, and IoT Platforms



Need of IoT Architecture

- **Internet of Things** is a **very complex systems** with **many "things"**
- Various **Sensors, Networking Technologies, Cloud Technology Applications, Protocols, Hardware, Software** etc. which needs a **overall plan**
- IoT requires an **Architecture**

IoT Architecture

- **Architecture** is all about the **protocol stack** that provides
  - ✓ The relationship between the **physical layer technologies** and the **applications.**
- The essence of **IoT Architectures** involves how the **data is transported, collected, analysed**, and **ultimately acted upon.**

IoT Architecture Standard

- **Architectures** will define the **standards and techniques** for designing and **building IoT Ecosystem**
- **Architectural standards** and **frameworks** have emerged **to address the challenge** of **designing massive-scale IoT networks.**

Benefits of IoT Architecture

- It provides the **IT or network manager** with a **useful checklist** for evaluating the **functionality and completeness of vendor offerings.**
- It provides **guidance to developers** as to which **functions are needed** in an IoT and how these **functions work together.**
- It can serve as a **framework** for **standardization, promoting interoperability and cost reduction.**

Design Principles

- **Design principles** that need to consider for an **Ideal IoT Architecture.**
- A **Layering Approach** in need to be considered
  - ✓ To reduce the **design complexity** and to **flexible implementation**, the **concept of layering** is introduced
- IoT are organized as a **Stack of Different Layers**
  - ✓ **Stack for Constrained Devices, Stack for Gateways, Stack for IoT Cloud Platforms**

IoT World Forum (IWF) Reference Model

The IoT World Forum (IWF) Reference Model

- The **IoT World Forum (IWF)** is an **Industry-sponsored Annual event**
  - ✓ **Business, Government, and Academia** will be part to promote the **market adoption of IoT.**
  - ✓ Industry leaders including **Cisco, IBM and Intel** are part of this event.
- This model serves as a **common framework** to help the **industry accelerate IoT deployments.**

IWF Reference Model

- The **IWF model** is mainly concerned to solve the broader issue
  - ✓ **Developing The Applications,**
  - ✓ **Middleware, And**
  - ✓ **Support Functions** for an **Enterprise-based IoT.**

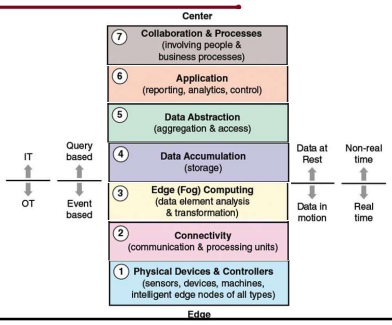
Characteristics of IWF Model

- The **IWF reference model** is designed to have the following **Characteristics.**
  1. **Simplifies:** It helps **break down complex systems** and each part is understandable.
  2. **Clarifies:** It provides **additional information** to identify **levels of the IoT** and to **establish common terminology.**

Characteristics of IWF Model

3. **Identifies:** It identifies where **specific types of processing** is optimized across **different parts of the system.**
4. **Standardizes:** It provides a first step in **enabling vendors to create IoT products** that work with each other.
5. **Organizes:** It makes the **IoT real and approachable**, instead of simply conceptual

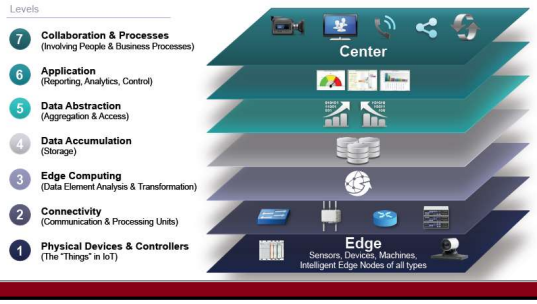
IoT World Forum Reference Model



IWF Reference Model

- **IoT World Forum (IWF)** is a **seven-layer IoT architectural reference model.**
  - ✓ Each of the **seven layers** is **broken down** into **specific functions**, and **security encompasses** the entire model.
- It provides a **concise way** of **visualizing IoT** from a **technical perspective.**

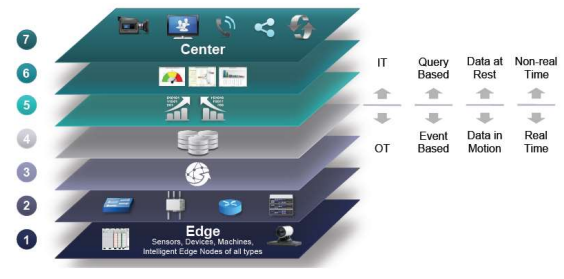
IoT World Forum Reference Model



Set of Levels

- The **IoT Reference Model** defines a **set of levels** with **control flowing** from the **Centre** to the **Edge**
  - ✓ **Centre - Cloud Service Or A Dedicated Data Centre**
  - ✓ **Edge**- includes **Sensors, Devices, Machines,** and **other types** of **Intelligent End Nodes.**
- **Data travels** up the stack, **originating from the edge**, and **goes northbound to the centre.**

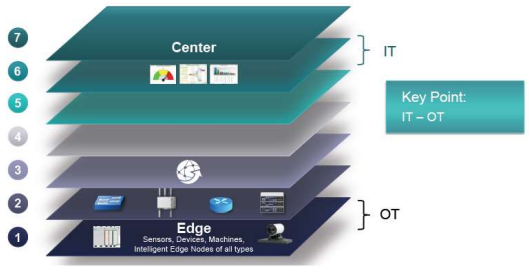
IoT World Forum Reference Model



IT and OT

- The **key difference** between **IT and IoT** is the **data.**
  - ✓ The **IT systems** are mostly concerned with **reliable and continuous support** of **business applications** such as **email, web, databases.**
  - ✓ The **IoT** is all about the **data generated** by **sensors** and how that **data is used.**

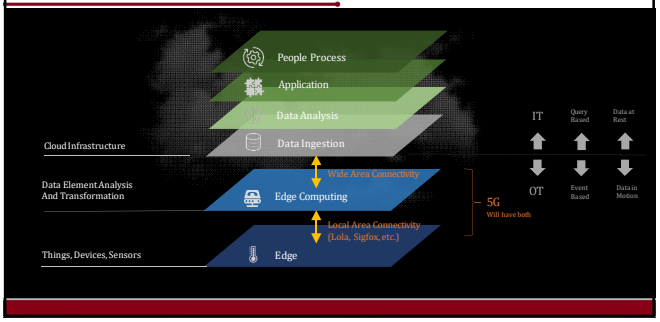
Bridging IT and OT



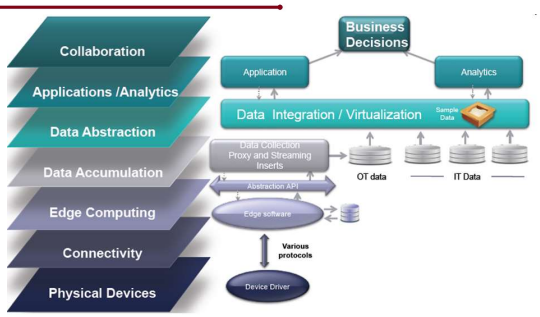
IT and OT Role

- The **bottom of the stack** is generally in the **domain of OT.**
  - ✓ **Sensors and Devices, Networking, Fog Computing** and so on.
- The **top of the stack** is in the **IT area** that includes
  - ✓ **Things** like the **servers, databases, and applications**, all of which run on a part of the **network controlled by IT.**
- **OT and IT** have generally been **very independent** and **had little need to even talk** to each other.

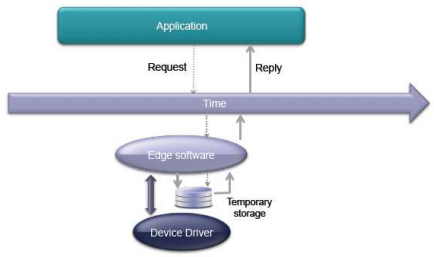
IoT in Process Layers



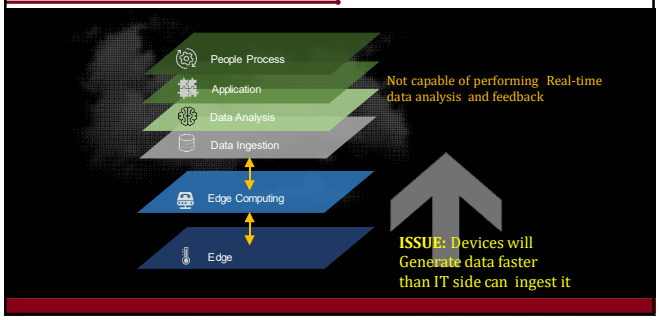
Open IoT Framework



Data Captured from Devices and Send to Application as requested



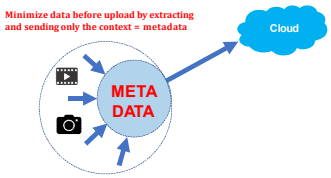
Challenging Issue in IoT



IT and OT Challenge

- In bottom, **OT layers**, the **devices generate real-time data** at their **own rate.**
  - ✓ **Huge amount of data transiting the IoT** network
- **Large volume** of **data available** to the **applications** at the **top layer (IT Layer)**
  - ✓ Need to **ingest that much data** at the **rate required.**
- The **IT and OT organizations** need to **work together** for **overall data management**

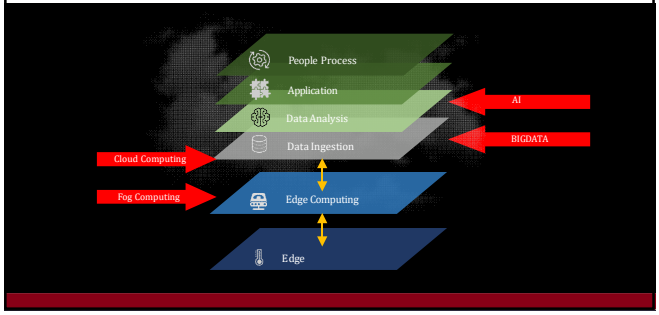
Challenge: Minimizing IoT Data



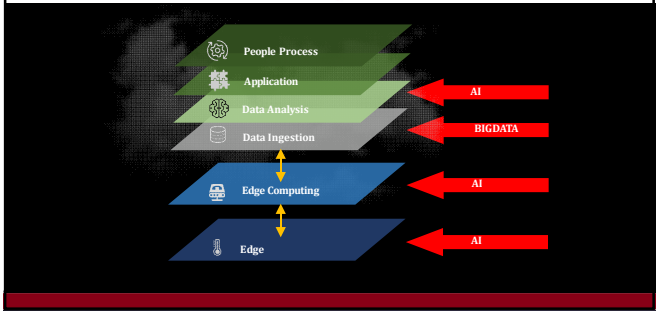
IT and OT Solution

- To meet this challenge
  - ✓ **Data has to be buffered or stored** at **certain points** within the **IoT stack**.
- **Layering data management** of **IoT stack helps** the **top four layers handle data** at their **own speed.**
  - ✓ The **real-time "data in motion" close to the edge** has to be **organized and stored** so that it becomes "**data at rest" for the applications in the IT tiers.**

Roll of BIG DATA and AI in IoT

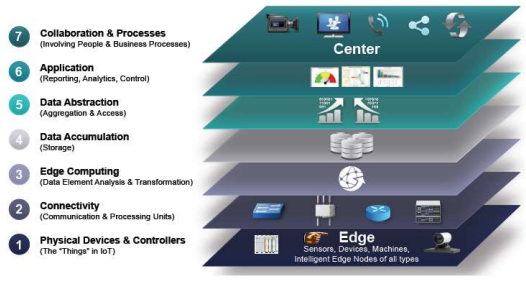


Solution



Physical Devices and Controller Layer

Physical Devices



Physical Devices and Controllers Level

- The **first layer** of the **IoT Reference Model** is
  - ✓ The **physical devices** and **controllers layer.**
    - **Devices** interact with **physical things, such as sensors and actuators** that **send and receive** information.
  - ✓ This Level-1 also **control** the **multiple devices.**

Physical Devices & Device Controllers

- **IoT "devices" are capable** of:
  - ✓ **Analog to digital conversion, as required**
  - ✓ **Generating data**
  - ✓ **Being queried / controlled over-the-network**

Capabilities of the Physical Devices

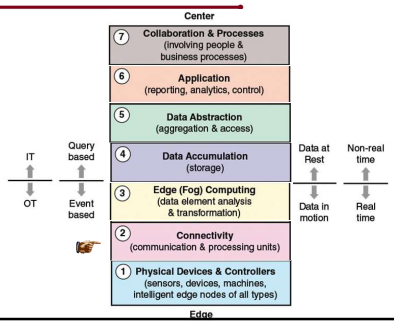
- The **capabilities of the devices** may have
  - ✓ **Analog-to-digital and Digital-to-analog conversion,**
  - ✓ **Data generation, and**
  - ✓ **The ability to be queried/controlled remotely.**
- The **IoT Reference Model** generally describes the **level of processing needed** from **Level 1 devices**

Role and Size of the Physical Devices

- The **primary function** of these **devices** is **generating data** and being **capable of being queried** and/or **controlled over a network.**
- The size of the **"things"**
  - ✓ **Range** from almost **microscopic sensors** to **giant machines** in a factory.

Level-2 : Connectivity Level

Level-2 : Connectivity Level



Connectivity : (Communication & Processing Units)

❖ **Connectivity** is in Level 2

✓ The **functionality** of this connectivity focuses on **communications**

Functions of Connectivity Level : (Communication & Processing Units)

❖ **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**

Connectivity Level View

❖ **Logical Point of View**

✓ This level enables **communication between**

- **Physical devices (Level-1)** and **network (Level-2)**
- Across **networks (east-west)**
- **Network (Level-2)** and the **Edge Computing Level (Level-3)** for **low-level information processing.**

Connectivity Level View

❖ **Physical Point of View,**

✓ This level consists of **networking devices**

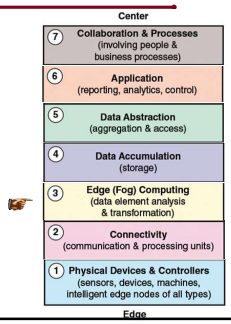
- **Routers, Switches, Gateways,** and **Firewalls** that are used to construct **local and wide-area networks** and **provide Internet connectivity.**

Role of Connectivity

- The **most important function** of this **IoT layer** is the **reliable and timely transmission** of **data.**
  - It provides **communications** and **processing** to be executed with **new and existing networks.**
  - It enables **devices** to **communicate with one another**
  - **To communicate, via the upper logical levels**, with **application platforms** such as computers, remote control devices, and smartphones.

Level-3 : Edge Computing Level

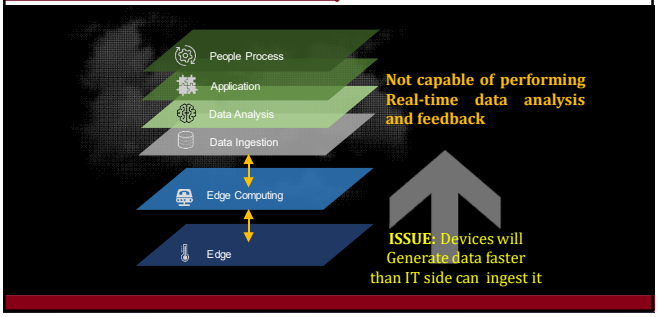
Level-3 : Edge Computing Level



Layer 3: Edge Computing Layer

- **Edge computing** is the **role of Layer 3.**
- **Edge computing** is often referred to as the **"fog" layer.**
- **Many IoT Deployments,**
  - ✓ **Massive amounts of data** may be generated by a **distributed network of sensors.**

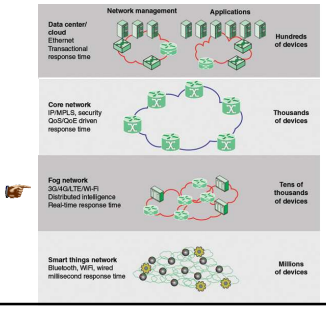
Massive Amounts of Data



Issue with Traditional IT

- **For Instance**
  - ✓ An **Airplane** can create **multiple terabytes of data** per hour.
  - ✓ **Storing all of the data permanently** in **central storage accessible(Cloud)** in **big problem** and send to the **IoT applications**

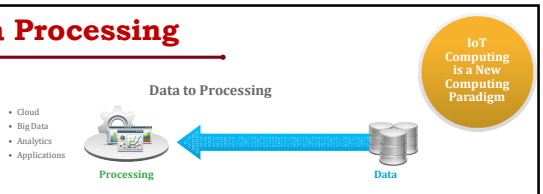
Need of Fog Computing



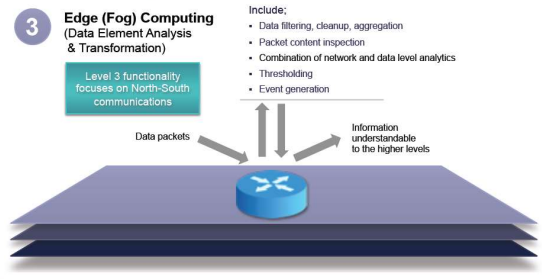
Layer 3: Edge Computing Layer

- **Level 1 devices** do not include **computing capabilities** themselves.
- **Some computational activities** could occur at Level 2, such as **protocol translation** or **application of network security policy.**

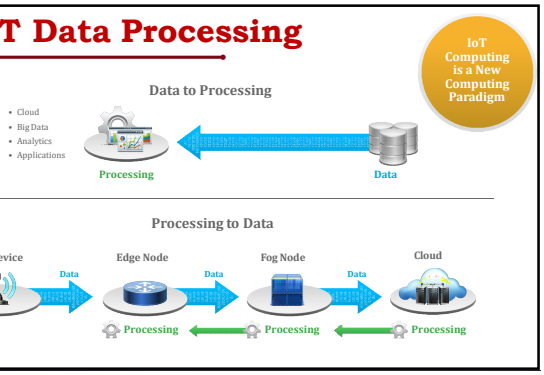
IT Data Processing



Edge Computing Level



The IoT Data Processing



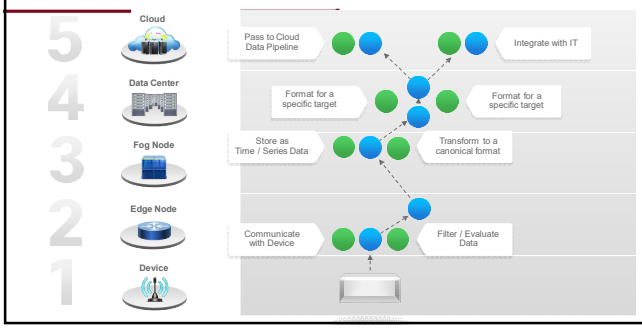
Edge Computing Solutions

- it is often desirable to do as **much data processing close to the sensors** as possible.
- This Layer is to **evaluate of data** to see
  - ✓ If it can be **filtered or aggregated before** being sent to a **higher layer.**
- It also **allows for data** to be **reformatted or decoded**, making **additional processing** by **other systems easier**.

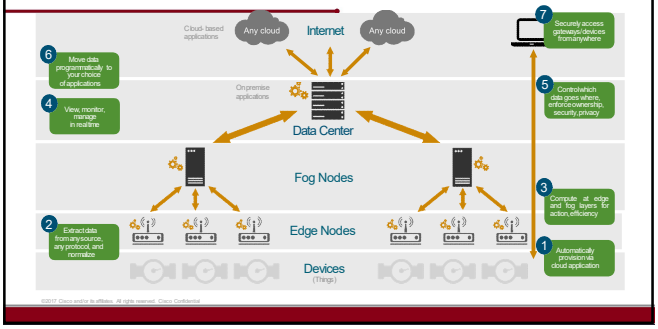
Fog Computing

- **Fog Computing** and **Fog Services** are expected to be a **distinguishing characteristic of the IoT.**
  - ✓ It handles **massive numbers of individual smart objects** that are **interconnected with fog networking** and
  - ✓ Facilities for **processing and storage resources** close to the edge devices in an IoT.

Solution : The IoT Data Processing



How can you use the IoT Data Via Fog



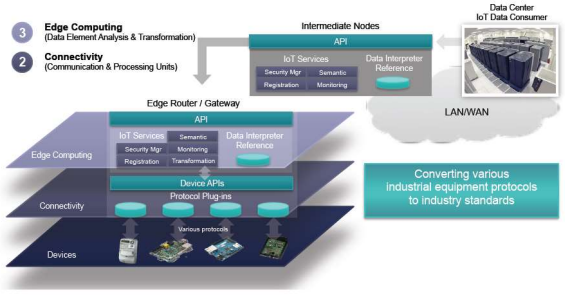
Edge (Fog) Computing

- Mainly used to provide the **Information understandable** to the higher levels Data packets
- Include
  - ✓ **Data filtering, Clean-up, Aggregation**
  - ✓ **Packet content inspection**
  - ✓ **Combination of network and data level Analytics**
  - ✓ **Event Generation**

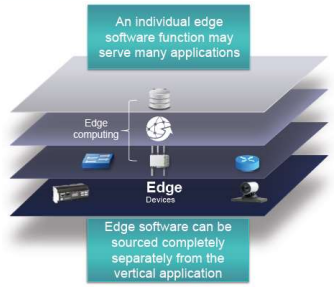
Edge (Fog) Computing

- **Heterogeneous systems distributed** across **multiple management domains** represents an example of **fog computing.**
- **Level 3 processing** is performed on a **packet-by-packet basis.**
  - ✓ **Compute tasks** such as **packet inspection.**
- The **processing is limited**, because there is **only awareness of data units—not "sessions" or "transactions."**

Connectivity and Data Element Analysis



Introducing IoT "Edgeware"



Role of Edge Computing

- The purpose of the **edge computing level** is
  - ✓ To convert **network data flows** into **information** that is suitable for **storage and higher level processing.**
- **Processing Elements** at this level may deal with
  - ✓ **High Volumes of Data** and
  - ✓ Perform **Data Transformation Operations**,
  - ✓ **Storage** of much **lower volumes of data.**

Edge Computing Operations

- **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)

Edge Computing Operations

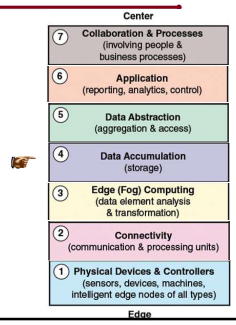
- **Distillation/Reduction: Reducing/summarizing data to minimize** the impact of **data and traffic on the network** and **higher-level processing systems**
- **Assessment:** Determining whether **data represents** a threshold or alert; this could include **redirecting data to additional destinations**

Solutions to IoT Challenges

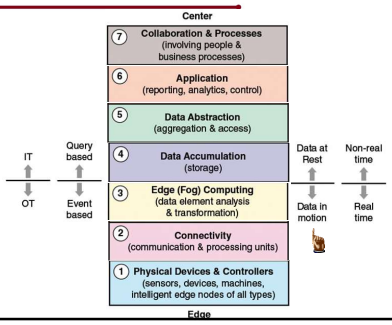
- It addresses various **challenges** raised by
  - ✓ The **activity of thousand or millions of smart devices,** including **security, privacy, network capacity constraints,** and **latency requirements.**
- The term **fog computing is inspired** by the fact that fog tends to **low to the ground**, whereas **clouds are high in the sky.**

Level-4 : Data Accumulation Level

Level-4 :Data Accumulation (Storage)



Data in Motion



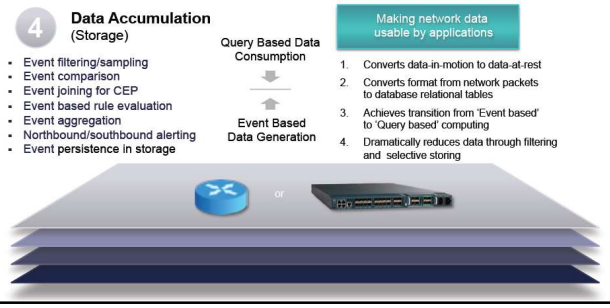
Data in Motion

- **Data moving through a network** is referred to as **Data In Motion.**
- The **rate and organization of the data in motion** is determined by the **devices generating the data.**

Level-4 : Data Accumulation Level

- **Networking systems** are built **to reliably move data. The data is "in motion."**
  - ✓ **Data is moving** through the **network at the rate** and determined by the **devices generating the data.** The model is **event driven.**

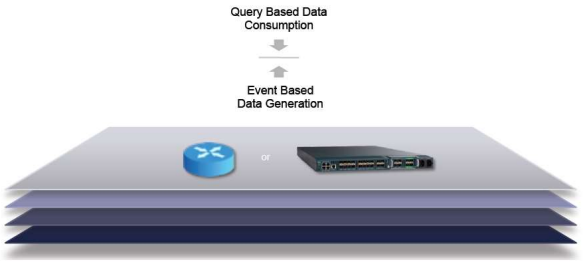
Level-4 : Data Accumulation Level



Separation of Data

- This level marks a **clear distinction**
  - ✓ The **Requirements and Design Issues,**
  - ✓ **Method of processing** between **lower-level (fog) computing** and **upper-level (cloud computing.)**

Data Accumulation (Storage)



Level-4 : Data Accumulation Level

- **Applications** typically assume that **data is "at rest" or unchanging** in memory or on disk.
- As **Level 4 captures data** and **puts it at rest**, it is now **usable by applications** on a **non-real-time basis.**
  - ✓ **Applications access the data** when necessary.
- This is a **crucial step** in **bridging** the **differences** between the **real-time networking world** and the **non-real-time application** world.

Level-4 : Data Accumulation Level

- At Level 4, **Data Accumulation, data in motion** is converted to **data at rest.**
- **Filtered and Processed** that are coming from the **numerous devices** at edge computing level
  - ✓ **stored in this level** that will be **accessible by higher levels.**

Operations Performed On Data Accumulation Level:

- **Converts data-in-motion to data-at-rest**
- **Converts** format from **network packets to database relational tables.**
- Achieves **transition** from **event based** to **query based computing**
- Dramatically **reduces data** through **filtering and selective storing**

Data Accumulation Level

- Provides **data is of interest to higher levels.**
- **Maintains Persisted data.**
- **Type of storage is Needed.**
- **Verifies the data is organized properly**
- **Checks the data must be recombined or recomputed**

Determines

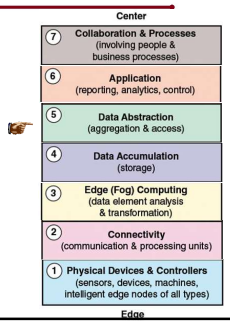
- **If data is of interest to higher levels: configured to serve** the specific **needs of a higher level.**
- **If data must be persisted:** Should **data be kept on disk** in a **non-volatile state** or **accumulated in memory**.
- **Type of storage needed:** Does **persistency require** a **file system, big data system, or relational database?**

Determines

- **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** may have come from **non-IoT sources.**

Level-5 : Data Abstraction Level

IoT World Forum Reference Model



Role of Data Accumulation Level

- The **Data Accumulation Level**
  - ✓ **absorbs large quantities of data** and **places them in storage, with little or no modifying** to specific applications or groups of applications.
  - ✓ A **number of different types of data** in **varying formats** and from **heterogeneous processors** may be coming up from the **edge computing level for storage.**

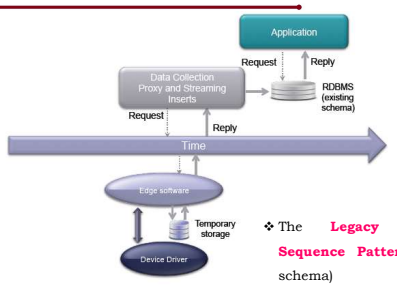
Problems of Generating Data By Multiple Devices

- **Data may not land** in the **Same Data Storage.**
  - ✓ **Too much data** to put in **one place.**
  - ✓ **Moving data** into a **database** might consume **too much processing power**

Solutions Provided by Data Abstraction

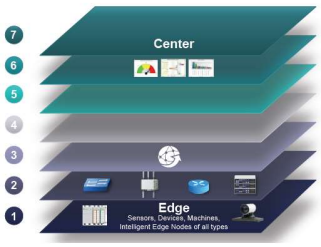
- Different kinds of **data processing might be required**.
  - ✓ **Data storage** for **streaming data** may be a **big data system**, such **as Hadoop**.
  - ✓ **Storage** for **event data** may be a **relational database management system (RDBMS)** with **faster query times.**

The Legacy Application Compatibility



❖ The **Legacy Application Compatibility Sequence Pattern** (use the existing DB and schema)

Handling the Volume of Data

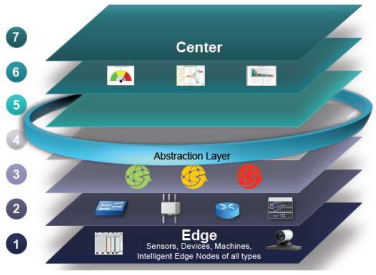


Role of Data Accumulation Level

❖ **Levels 3 and 4** might **separate "continuous streams of raw data"** from **"data that represents an event."**

✓ **Devices** might be **geographically separated**, and **processing is optimized locally.**

Data Abstraction Level



1. **Scalability**
2. **Interoperability:** Enable Edgeware and Applications from Different Vendors

Data Abstraction (Aggregation & Access)

❖ **Information Integration**

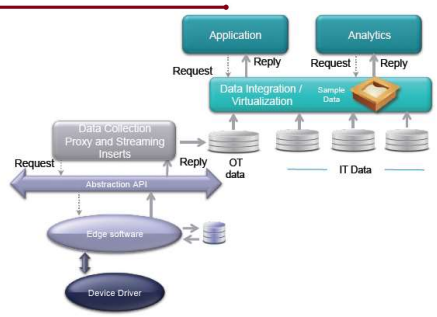
1. Creates **schemas and views of data** in the manner that applications want
2. **Combines data** from multiple sources, simplifying the application
3. **Filtering, selecting, projecting, and reformatting** the data to serve the client applications
4. Reconciles differences in data shape, format, semantics,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

Level-5 : Data Abstraction Level

❖ The **data abstraction level** can **aggregate and format this data** in ways that **make access by applications** more.

❖ The **data abstraction functions** are focused on **interpretation data** that enable developing **simpler, performance-enhanced applications.**

Abstraction API between Data and Application



Operation/Task on Data Abstraction Level

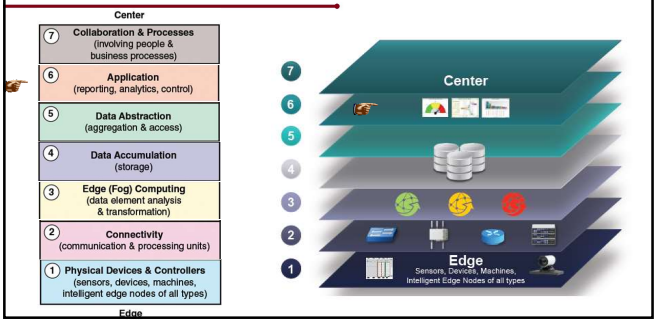
- **Combining multiple data formats** from different sources. This includes **integration multiple data formats.**
- Perform **necessary conversions** to provide **consistent semantics of data** across sources.
- **Place formatted data** in **appropriate database.**
  - ✓ High-volume repetitive data may go into a **big data system**.
  - ✓ Event data would be steered to a relational **database management system**

Operation/Task on Data Abstraction Level

- **Alerting higher-level applications** that **data is complete or had accumulated** to a defined threshold.
- Consolidating **data into one place** 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.**

Level-6 : Application Level

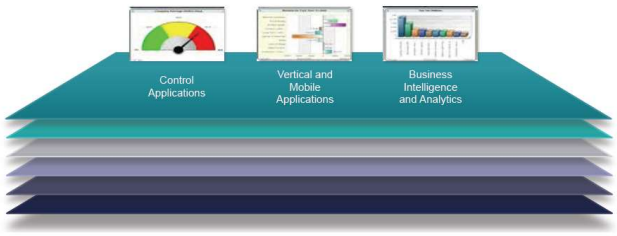
Level-6 : Application Level



Level-6 : Application Level

- In the **application level**,
  - ✓ where **information interpretation occurs.**
  - ✓ **Software** at this **level interacts** with **Level 5** and **data at rest.**

Application (Reporting, Analytics, Control)



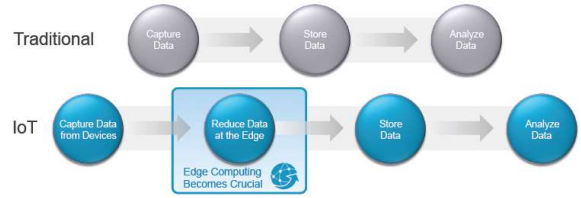
Types of Applications

- **Applications** vary based on **vertical markets**, the **nature of device data**, and **business needs**.
  - ✓ **Some applications** will focus on **monitoring device data.**
  - ✓ Some will **focus on controlling devices**.
  - ✓ Some will combine **device and non-device data.**
  - ✓ **Mobile applications** that **handle simple interactions**

Types of Applications

- **Analytic applications** that **interpret data** for business decisions
- **Business intelligence reports**, where the application is the **BI server**

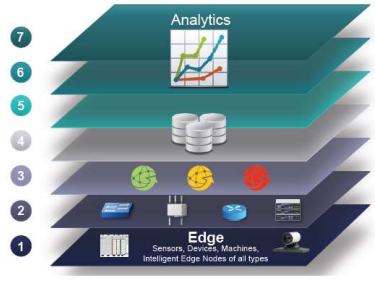
IoT Analytics Introduces New Complexities to Analytics



Key Issues:

- ✓ The velocity and volume of data may be huge
- ✓ In some cases, most of the data is unimportant

The Internet of Things and Analytics

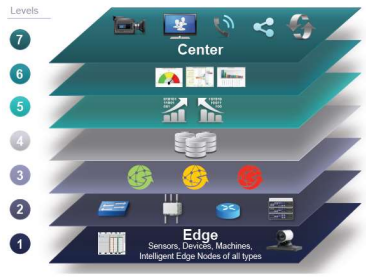


Key Point:
- Enabling IoT Analytics

Key Points: IT – OT

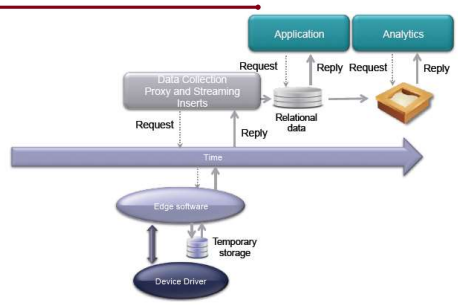
- Interoperability
- Legacy
- Compatibility

Analytics Using Both OT and IT Data



Key Point:
- Integration with the Enterprise

Analytics Sequence Pattern



Controls the IoT Devices

- This level contains **any type of application** that uses **IoT input or controls IoT devices.**
- **System management/control centre** applications that **control the IoT system itself** and **don't act on the data** produced by it

Application Level

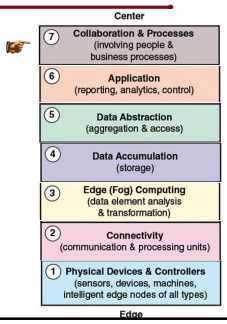
- This level contains **any type of application** that uses IoT input or controls IoT devices.
- Provision should be available for streamlined operation that allows **applications to bypass intermediate layers** and **interact directly** with **Edge Computing Level or even Connectivity Level**

Observation

- If **Levels 1-5** are architected properly, the **amount of work** required by **Level 6 will be reduced**.
- If **Level 6 is designed properly**, users will be able to do their **jobs better.**
- Provision should be available for streamlined operation that allows **applications to bypass intermediate layers** and **interact directly** with **Edge Computing Level or even Connectivity Level**

Collaboration and Processes Level

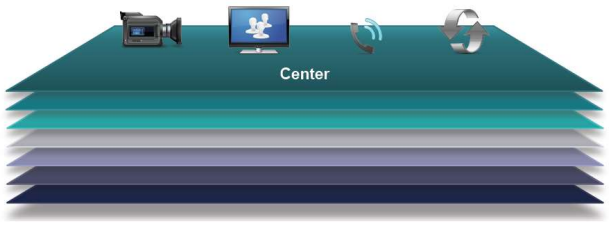
IoT World Forum Reference Model



Communication and Collaboration

- **Communication and collaboration** often
  - ✓ Requires **multiple steps.** And it
  - ✓ Usually **transcends multiple applications**.
- ✓ **Level 7** represents a **higher level than a single application.**

Collaboration and Processes Level



Level-7 Collaboration and Processes Level

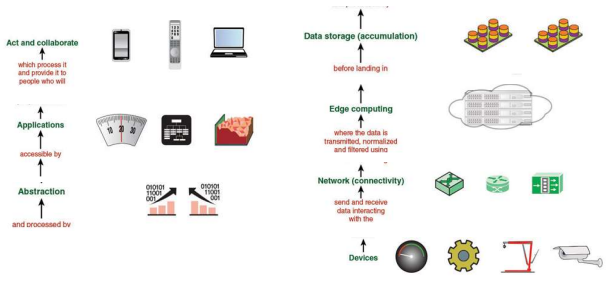
- **IoT** need to include **people and processes.**
  - ✓ **IoT creates the information**, is of **little value** unless it **yields action**, which often requires **people and processes.**
  - ✓ **People must be able to communicate** and **collaborate** to **make an IoT useful.**
  - ✓ **People** use **applications** and **associated data** for their **specific needs.**

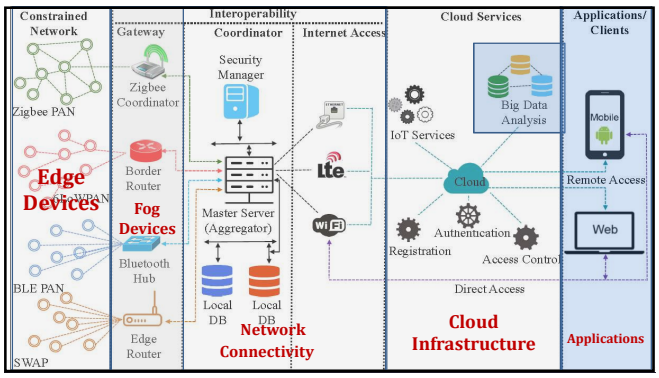
Collaboration and Processes Level

- This may involve **multiple applications** and **exchange of data and control information** across the **Internet or an enterprise network.**
- **Applications** execute **business logic** to **empower people.**
- **Multiple people** use the **same application** for a range of **different purposes.**

Example of IWF Reference Model

Example of IWF Reference Model



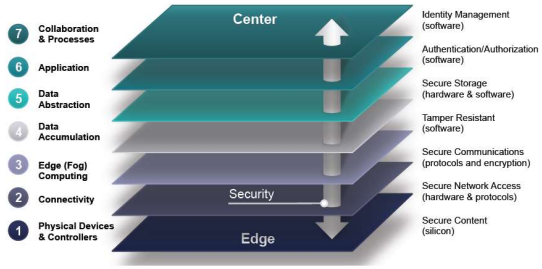


Summary of the IoT Reference Model

- The IWF views the IoT reference model as an **industry-accepted framework** aimed at **standardizing the concepts and terminology** associated with IoT
- The IWF model sets out the **functionalities required** and **concerns that must be addressed** before the **industry can realize the value of the IoT**
- This model is useful both for **suppliers who develop functional elements** within the model and **customers for developing their requirements** and evaluating **vendor offerings.**

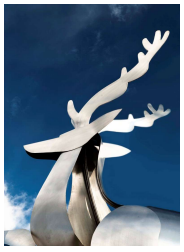
Security in the IoT

Internet of Things Reference Model: Security



Internet of Things Reference Model: Security

- 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**



Thank U