Chapter 1

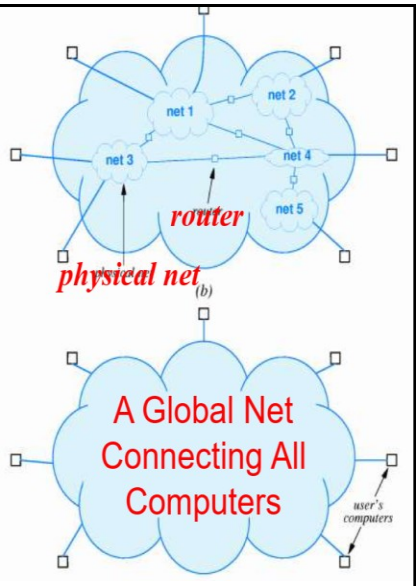
INTRODUCTION to IoT

Introduction

- The Internet of Things refers to the ever-growing network of physical objects that feature an IP address for internet connectivity, and the communication that occurs between these objects and other Internet-enabled devices and systems.
- IoT extends Internet connectivity beyond traditional devices like desktop, laptop, smart phones, tablets, etc
- IoT has evolved from the convergence of wireless technologies, micro electro mechanical systems (MEMS) and the Internet.

What are the Internet?

- The **Internet** … a **Network** of **Networks** that consists of millions of private, public, academic, business, and government networks, of local to global scope. - *From Wikipedia*
- Originated from the ARPANET around 1970
  Available from 1980, got popular from 1990.
- Key components
  - Hardware: Routers connecting networks
  - Software: TCP/IP protocol suite, IPv4 → IPv6
  - Addressing: 2**32 (IPv4) →2**128 (IPv6)
  - Naming: DNS → symbolic names



The Internet → Internet of Computers (IoC)

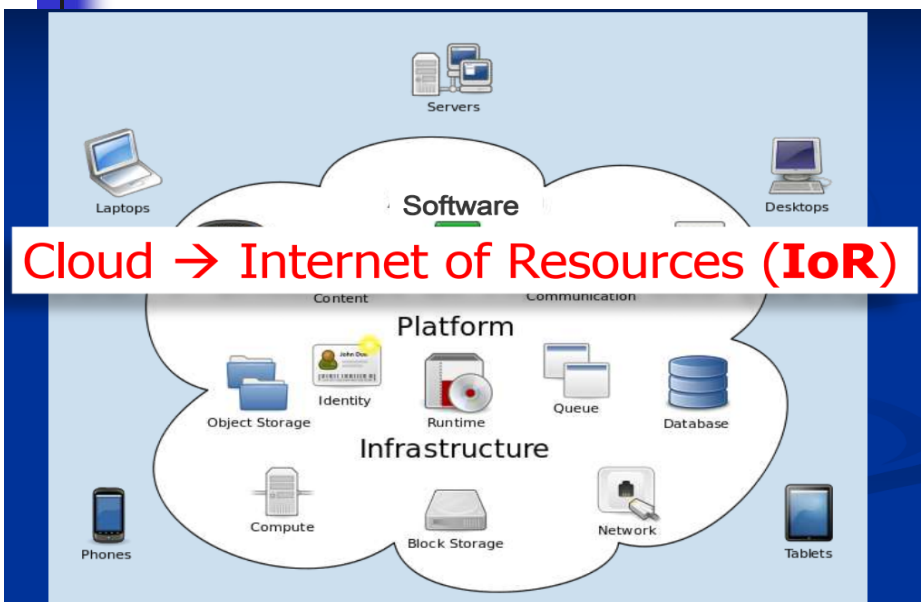
What are the Web?

- The World Wide Web, abbreviated as WWW or the Web, is a system of interlinked documents accessed via the Internet. - *From Wikipedia*
- The Web was originated from ***Tim Berners-Lee*** around 1990.
- The Web, like Email, is one of the services that runs on the Internet.
- Key components
  - Uniform Resource Locator (URL) & Uniform Resource Identifier (URI)
  - HyperText Markup Language (HTML)
  - Hypertext Transfer Protocol (HTTP)
  - Web server and web browser (client)

The Web → Internet of Documents (IoD)

How about Social Media/Web2.0?

How about Cloud Computing?

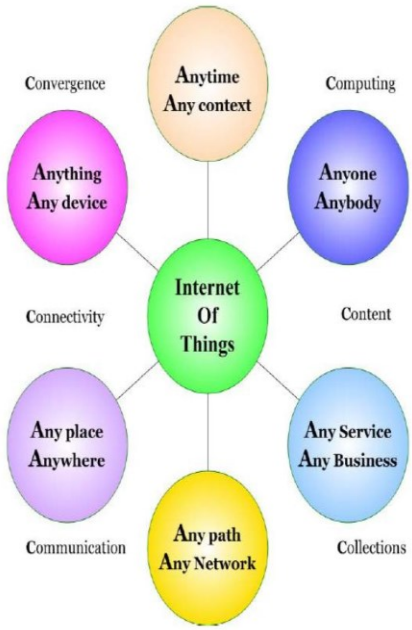


What are Things?

- **Thing** - An **object**, an entity, an idea, or a quality perceived, known, or thought to have its own existence, … *(dictionary)*
- **Object** – A tangible/visible **thing**; a person or thing seen as a focus or target for feelings, thought, etc.; a purpose/objective; ... *(dictionary)*
- Everyday Things/Objects – used in human daily lives
- Inner Things – mind, directly insensible things, ...
- Physical things, digital things, real/virtual things

Introductions-IoT

- The Internet of Things (IoT) allows people and things to be CONNECTED
- The IoT allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service
- This implies context where there is seamless interconnection between people and things and/or between things

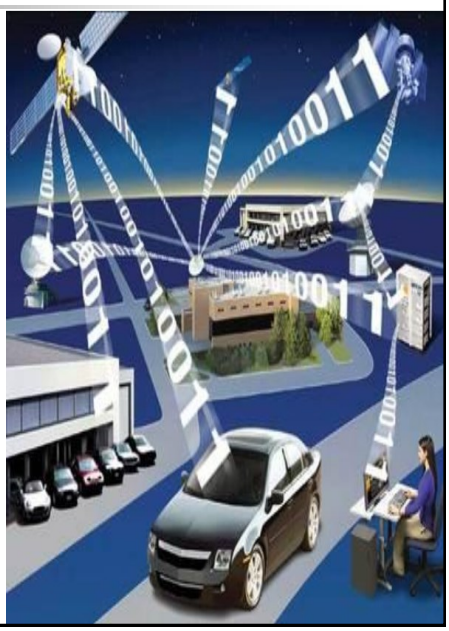


Internet of Things

IoT is an integrated part of Future Internet

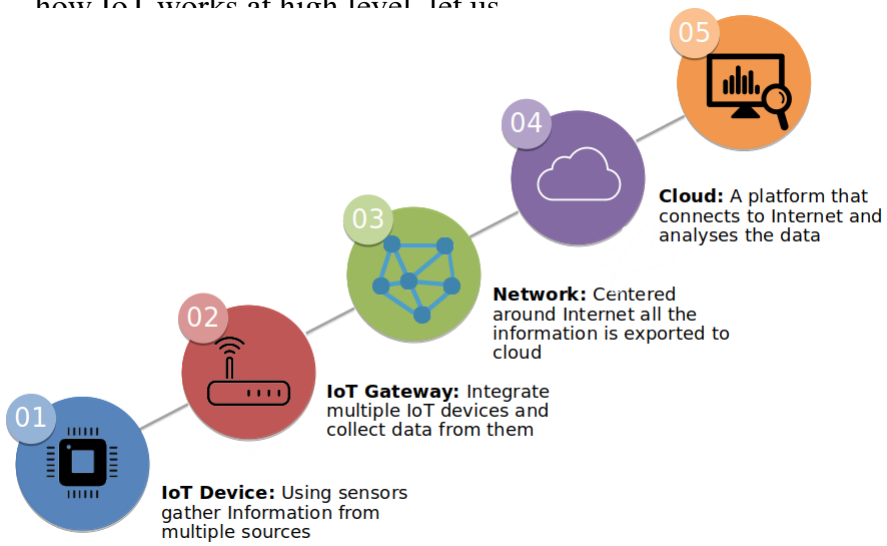
- IoT is a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols
- In the IoT, physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces
- The physical and virtual "things" are seamlessly integrated into the information network

- In the IoT, things are expected to become active participants in business, information and social processes
- In IoT, things are enabled to interact and communicate among themselves and with the environment by exchanging data and information "sensed" about the environment
- Things should react autonomously to the "real/physical world" events with or without direct human intervention

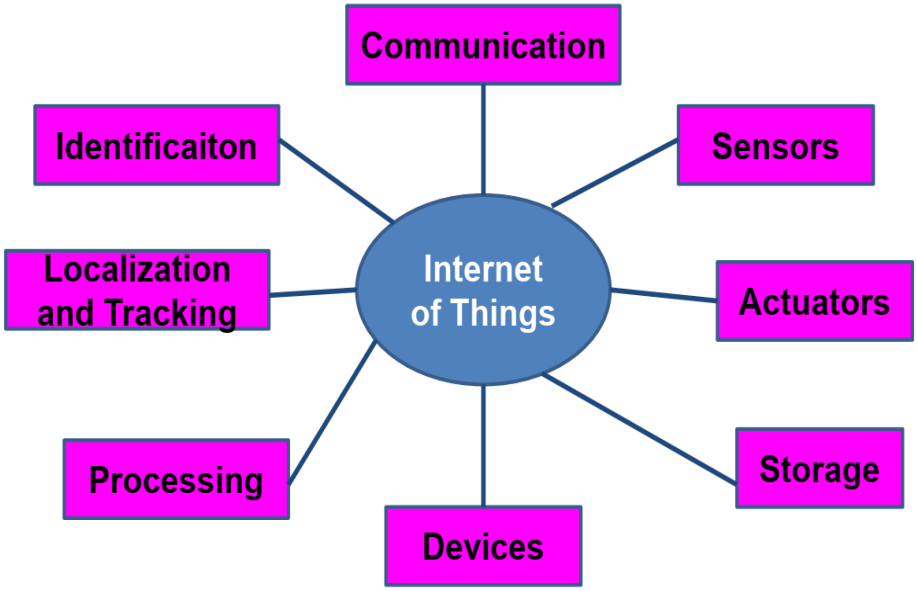


Components of IoT:

- Now that you have a brief idea about how IoT works at high level, let us

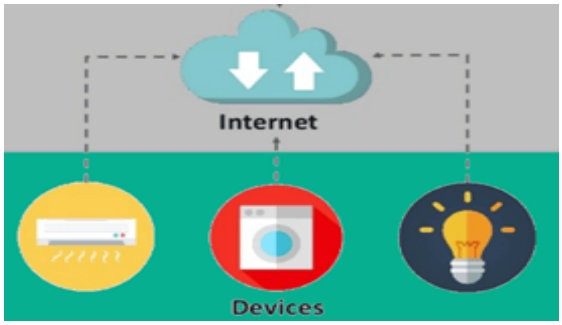


IoT is consists of the following components



How IoT works?

- The entire IoT process starts with the devices themselves like smartphones, smartwatches, electronic appliances like TV, Washing Machine which helps you to communicate with the IoT platform.

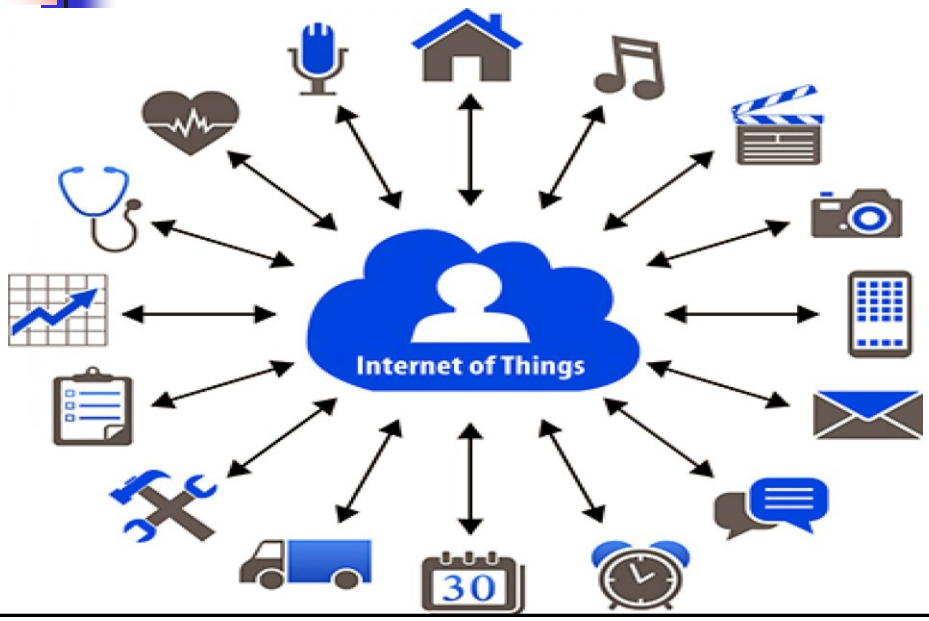


1. IoT device:

- IoT device can be wireless sensors, software, actuators and computer devices. They are fixed to a specific object that runs through internet. These devices **enable the transfer of data** among objects or people automatically without any interference of human resources. For example, **Fit bit** is an IoT device which communicates with an app via internet and provides us so many insights about our health condition.

- IoT devices can:
  - Exchange data with other connected devices and applications (directly or indirectly), or
  - Collect data from other devices and process the data locally or
  - Send the data to centralized servers or cloud-based application back-ends for processing the data, or
  - Perform some tasks locally and other tasks within the IoT infrastructure, based on temporal and space constraints

IoT Components – Sensors/Devices

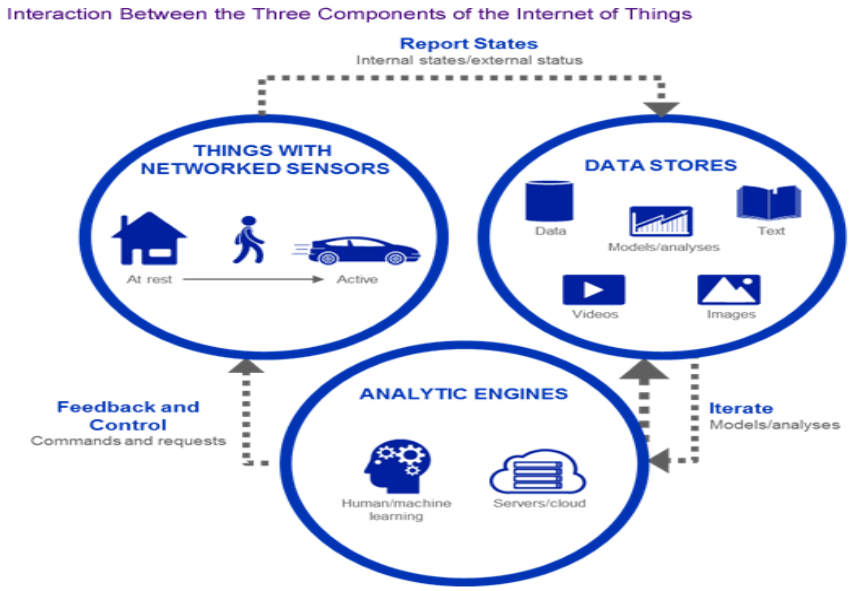


2. IoT Gateway:

- IoT gateway is a device or a software program that serves as a connection point between cloud and multiple IoT devices. All the information moving to cloud or vice versa has to pass through IoT gateway. IoT gateway provides extra security for the IoT network and the data that is being transported.
- An array of IoT devices connect with IoT gateway via **low-range protocols** (ex: Bluetooth Low Energy or **BLE**). The gateway in turn uses **web-scale protocols** (ex: Message Queue Telemetry Transport or **MQTT**) to access the internet.

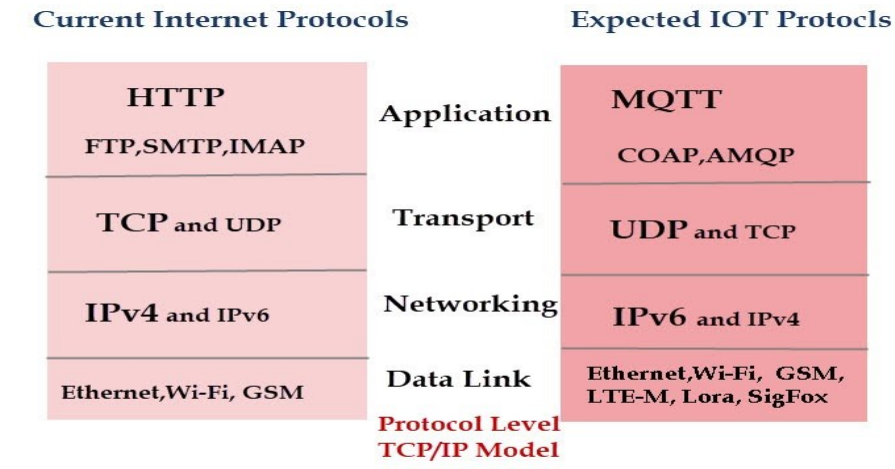
IoT Components – Connectivity

IoT Components – Data Processing



3. Network:

- Network is the bridging element that connect an array of IoT gateways to the Cloud platform by traditional **TCP/IP network**. It is been existing over years connected with a bunch of protocols. Now the same network has additional meaning of "glue" that bridges everything. The network has a series of protocols (some of them are given below) which makes the communication happen in a seamless way. Overall IoT protocols can be summarized as mentioned in the image below.



IOT and Internet Protocols

4. Cloud:

- **Cloud is a platform** which takes massive volumes of data generated. They receive them via IoT gateways which in turn has tons of by devices behind them. Since the amount of data handling is very significant it will have following characteristics.
  - Web services – Ability to handle incoming client request and response
  - Salability – Ability to scale-up or scale-down depending on the data / network traffic
  - Distributed – Inherently support distributed computing to handle resources

4. Cloud:

- Business Intelligence / Analytics – By analyzing big data and derive analysis
- Cost optimization – Provide facilities to customer to achieve results in optimized way

- Today almost all the major giants like **Google**, **Amazon**, **Microsoft**, **IBM** are offering their own IoT platforms. All of them provide key features mentioned above and much more.

5. Applications:

- The synthesized data for the end user to derive meaningful insights. The application typically provides an **User Interface (UI)** which the user can get the final insights (ex: Home devices status) or even trigger some action (ex: Switch ON / OFF). Again this interface can be anything ranging from a **mobile application, custom dashboards on panels or simply a web interface.**

What is Internet of Things bring for us ?

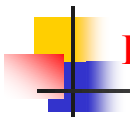
- A leading path to smart world with ubiquitous computing and networking
- Aims to make different tasks easier for users
- In IoT, environmental & daily life items (things, objects or machines) are enhanced with computing and communication technology
- Communication framework already provide communication capabilities and interactions

What is Internet of Things bring for us ?

- Different services based on person-to-person, person-to-machine, machine-to-person, machine-to-machine interactions and so on
- These connected machines/objects/things will be new Internet or network users
- And will generate data traffic in current or emerging Internet
- Connecting objects might be wireless, RFID or sensor radio technologies

What is Internet of Things bring for us ?

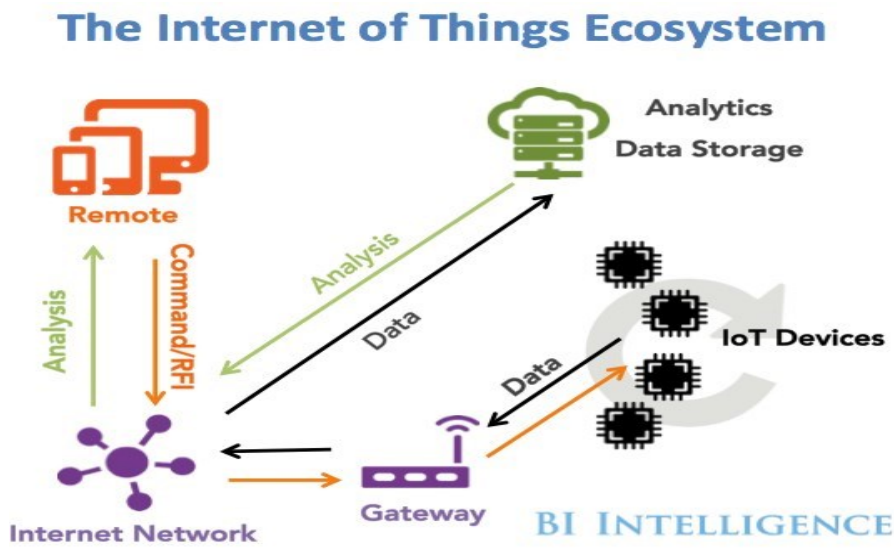
- They offers identification of items and sensing of the environment
- Connection may be wired or wireless
- IoT services will provide more automation around people & connected objects
- In IoT, identifying, sensing, automatically deciding & actuating will be new functionalities
- So sensor & RFID will be increasingly deployed



IoT

- IoT enables the embedded devices communicate with other devices through network infrastructure (e.g. Internet, Wi-Fi, BT)
- Innumerous smart sensors and actuators help devices capture data and transfer them to central decision maker
- Applications based on this technology will play an ever increasing role and are supposed to change both, industry and social life dramatically in the close future

Internet-of-Things (IoT)



Terminology

- **Internet:** Interconnected computer networks, based on a standard communication protocol (TCP/IP)
- **Things:** any unique object in the world
- **Internet of Things:** connected objects uniquely addressable, based on standard communication protocol

IoT → Big Data → Extract knowledge (offering value-added services)

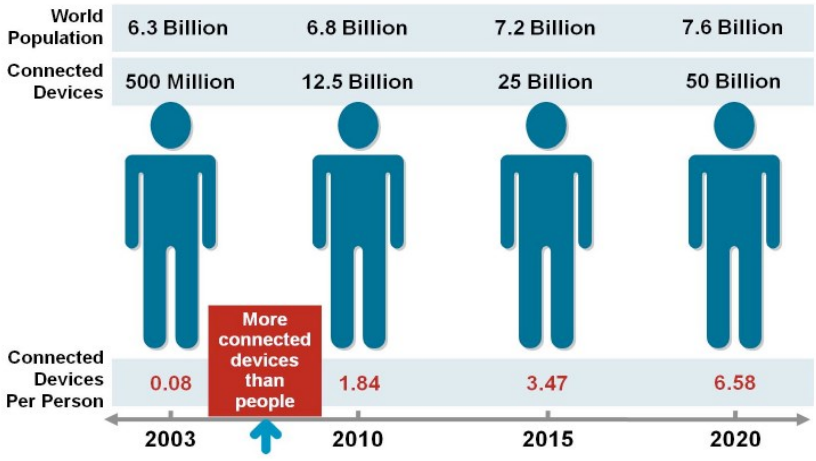
- **Example of IoT**: Imagine when you enter your house, your car send signals to open garage door, turn on air condition/ heat system, lights, TV, Stove, etc. to find everything ready for you, making your life easier and save your money buy saving energy

Related Areas/Terminology

- **Embedded systems**: not necessarily connected
- **Sensor networks**: collection of sensor devices connected through wireless channels
- **Cyber-physical systems**: focus on interaction between physical and cyber systems
- **Real-time systems**: focus on time constraints
- **Pervasive/ubiquitous computing**: focus on anytime/anywhere computing

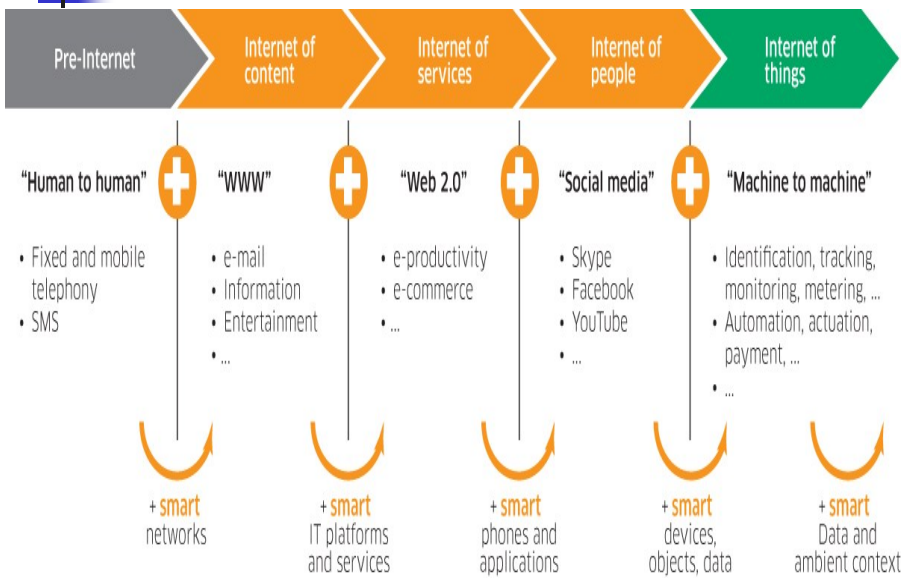
Internet-of-Things Vision & Growth

Figure 1. The Internet of Things Was "Born" Between 2008 and 2009



Source: Cisco IBSG, April 2011

Internet-of-Things Vision & Growth



One Vision of the Internet of Things

- The goal of the Internet of Things is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/ network and any service.
- Developing the technology in Europe right now demonstrating, testing and deploying products

Why Internet of Things

- Dynamic control of industry and daily life
- Improve the resource utilization ratio
- Better relationship between human and nature
- Forming an intellectual entity by integrating human society and physical systems
- Flexible configuration, P&P…
- Universal transport & internetworking
- Accessibility & Usability?
- Acts as technologies integrator

History of IoT

- IoT was originally introduced by the Auto-ID research center at MIT (Massachusetts Institute)in 1999
- Founded by Kevin Ashton, David Brock and Sanjay Sarma to develop the Electronic Product Code or EPC to uniquely identify products

A Few IoT Facts

- The phrase 'Internet of Things' was first used in 1999.
- First Article about IoT in 2004 from MIT researchers called I0 (Internet 0).
- Why it is important to our future? Optimistic prediction: 7 trillion wireless devices for 7 billion people by 2020
- Does it exist now? Some say – Yes !!

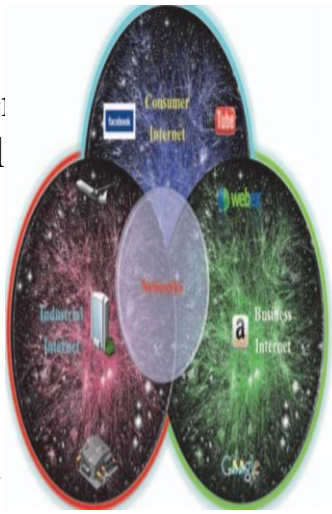
History

- 1997, "The Internet of Things" is the seventh in the series of ITU Internet Reports originally launched in 1997 under the title "Challenges to the Network"
- 1999, Auto-ID Center founded in MIT
- 2003, EPC Global founded in MIT
- 2005, Four important technologies of the internet of things was proposed in WSIS conference
- 2008, First international conference of internet of things: The IOT 2008 was held at Zurich.

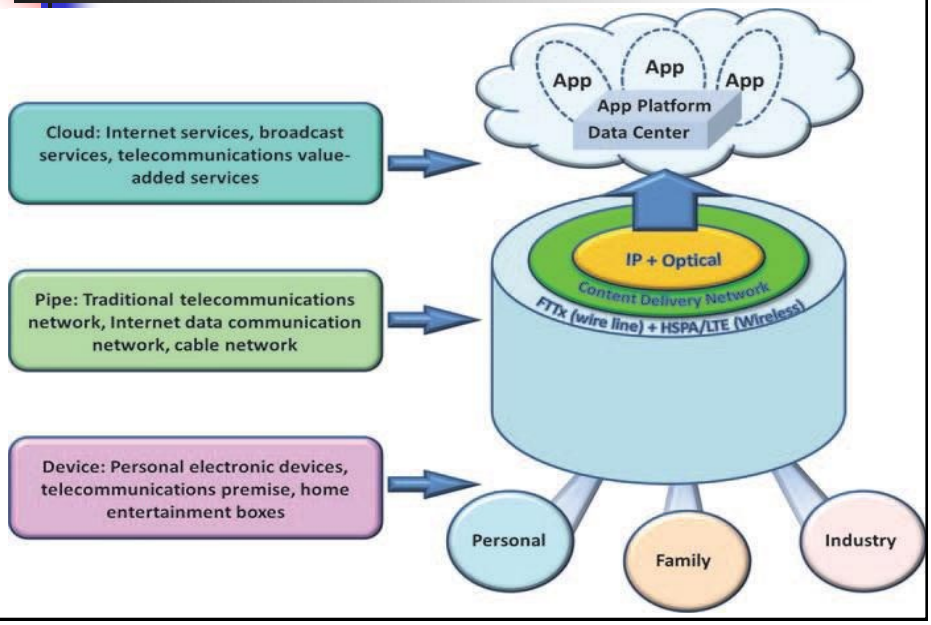
IoT Ecosystem

Convergence

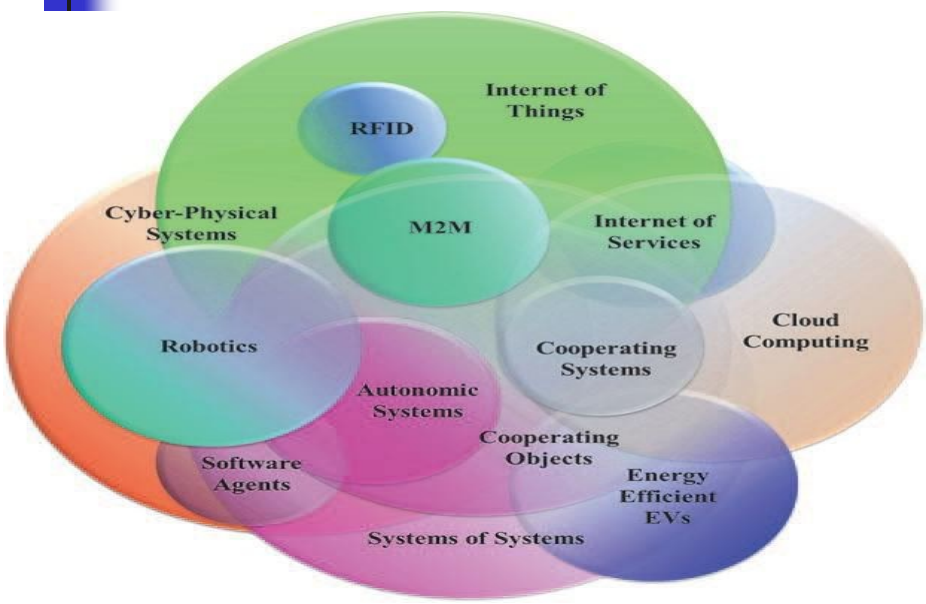
- Convergence of consumer, business and Industrial internet
- The convergence creates the ope global network connecting peopl data, and things
- Convergence leverages used to connect intelligent things that sense and transmit a broad array of data
- Platforms also rely on the power of network effects



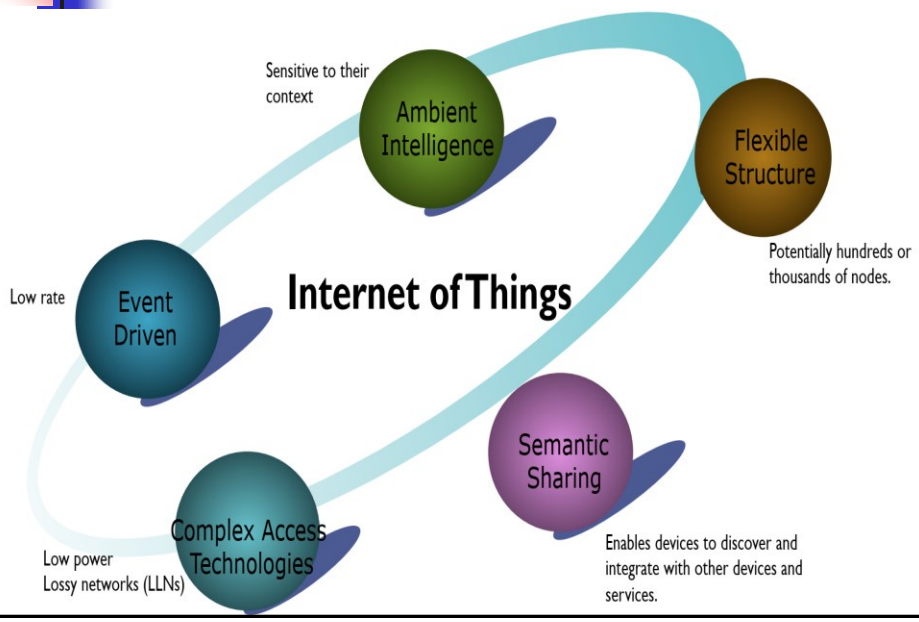
Factors Driving Convergence



Technology convergence



Characteristics of IoT



Characteristics of IoT (Cont)

- 1. Intelligence
  - Knowledge extrac1on 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

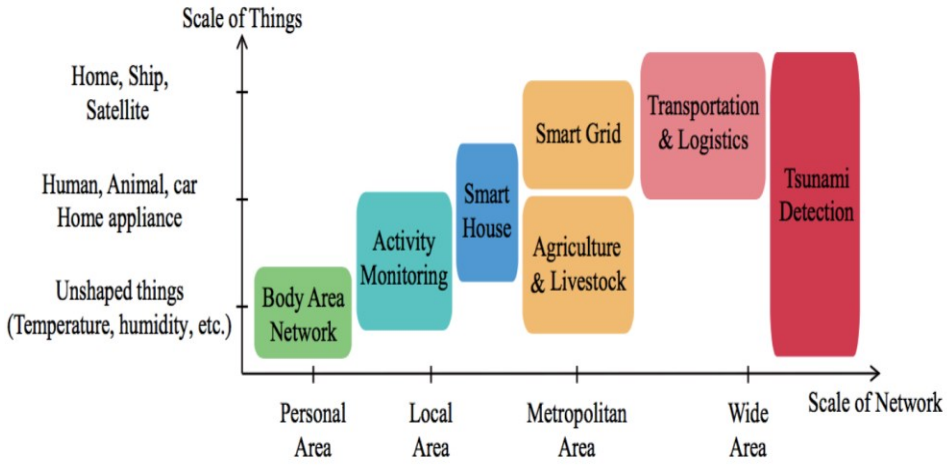
Properties of IoT

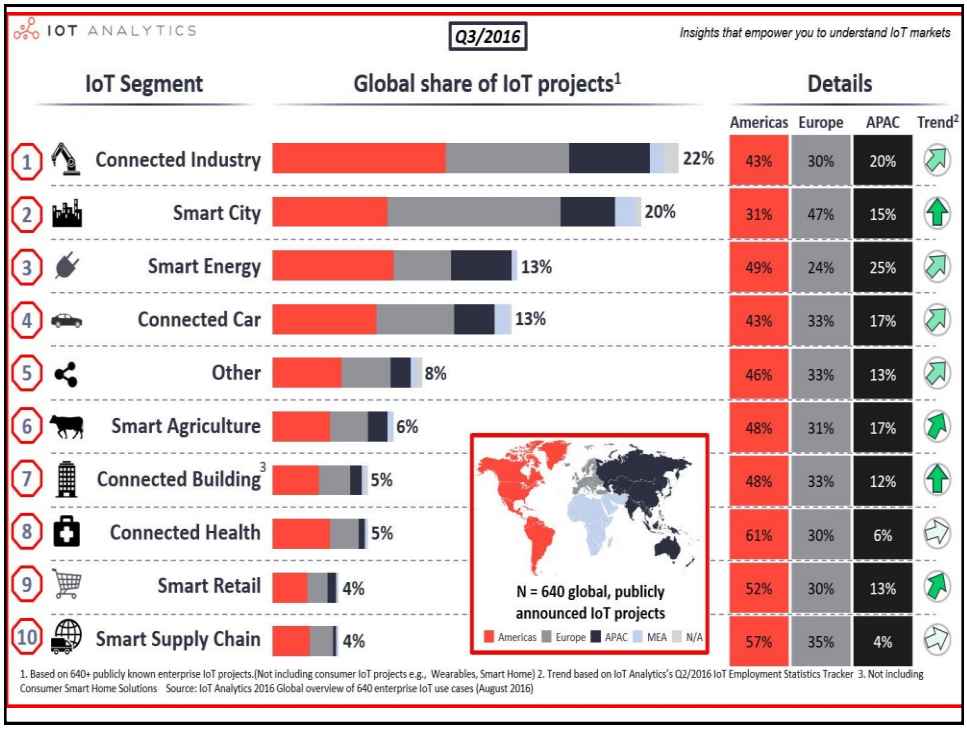
- Self-adaptation
- Self-organization
- Self-optimization
- Self-configuration
- Self-protection
- Self-healing
- Self-description
- Self-discovery
- Self-matchmaking
- Self-energy supplying

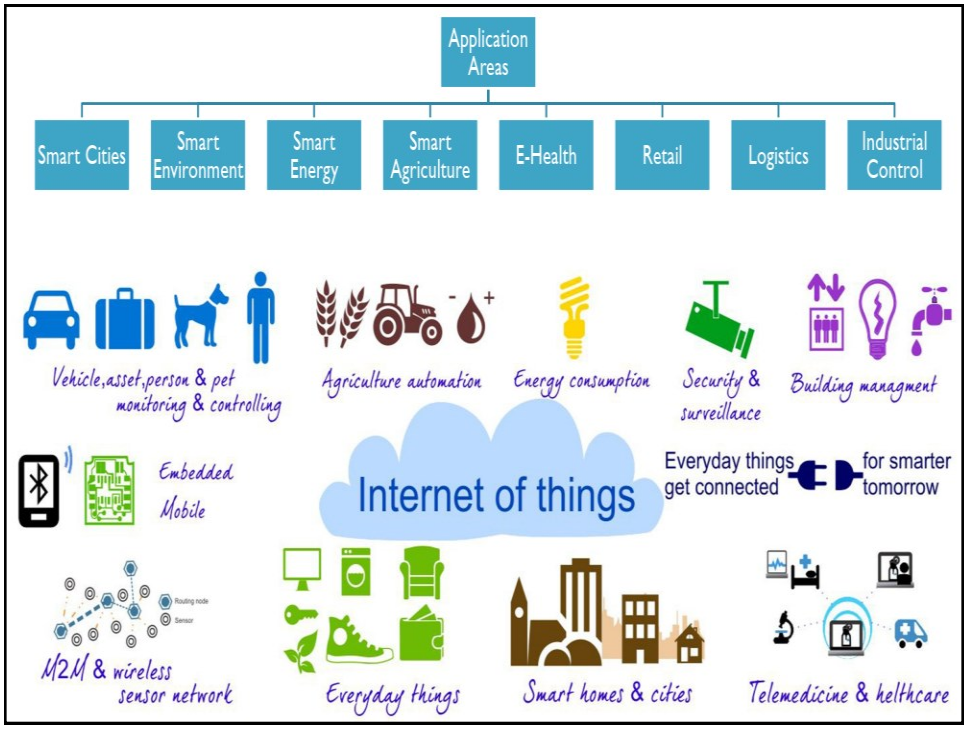
Application domains

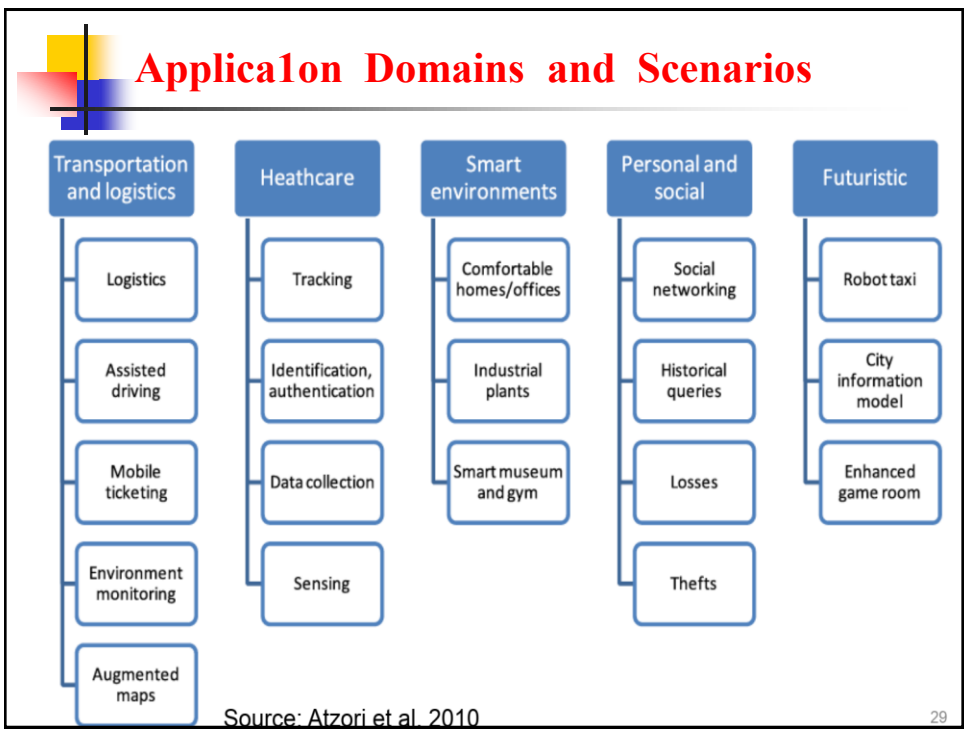
- Industry (manufacturing, transportation, agriculture)
- Consumer (smart homes, appliances, assisted living)
- Wearables (healthcare, fitness, productivity)

Classifications and Examples of IoT Systems






Application Areas
Smart Cities
Smart Environment
Smart Energy
Smart Agriculture
E-Health
Retail
Logistics
Industrial Control
Vehicle,asset,person & pet monitoring & controlling
Agriculture automation
Energy consumption
Security & surveillance
Building managment
Embedded
Mobile
Internet of things
Everyday things get connected
for smarter tomorrow
M2M & wireless sensor network
Everyday things
Smart homes & cities
Telemedicine & helthcare


Applica1on Domains and Scenarios
Transportation and logistics
Logistics
Assisted driving
Mobile ticketing
Environment monitoring
Augmented maps
Heathcare
Tracking
Identification, authentication
Data collection
Sensing
Smart environments
Comfortable homes/offices
Industrial plants
Smart museum and gym
Personal and social
Social networking
Historical queries
Losses
Thefts
Futuristic
Robot taxi
City information model
Enhanced game room
Source: Atzori et al. 2010
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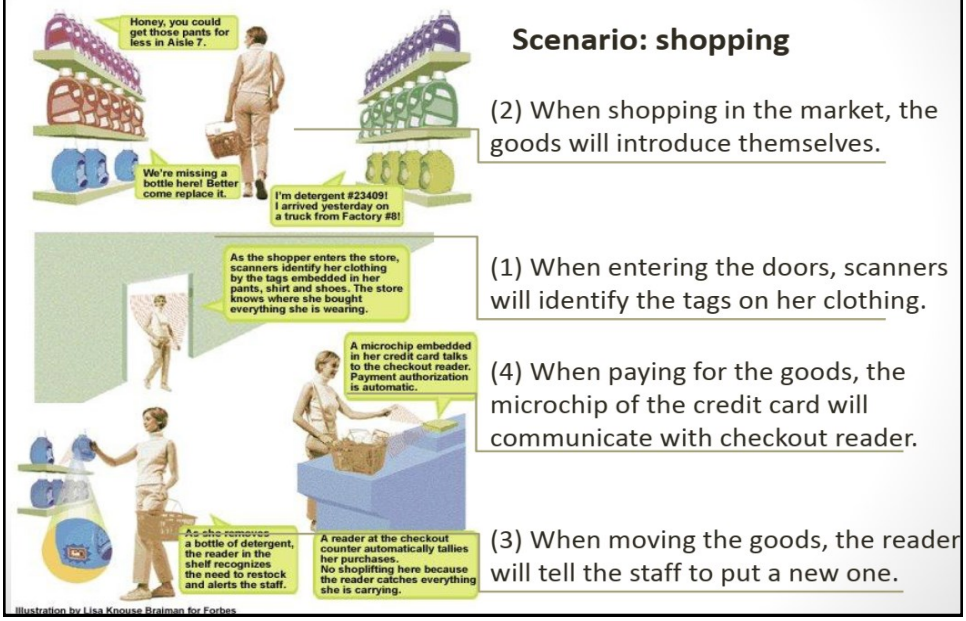
Application type	Description
Smart Thermostats	Helps you to save resource on heating bills by knowing your usage patterns.
Connected Cars	IoT helps automobile companies handle billing, parking, insurance, and other related stuff automatically.
Activity Trackers	Helps you to capture heart rate pattern, calorie expenditure, activity levels, and skin temperature on your wrist.
Smart Outlets	Remotely turn any device on or off. It also allows you to track a device's energy level and get custom notifications directly into your smartphone.
Parking Sensors	IoT technology helps users to identify the real-time availability of parking spaces on their phone.
Connect Health	The concept of a connected health care system facilitates real-time health monitoring and patient care. It helps in improved medical decision-making based on patient data.
Smart City	Smart city offers all types of use cases which include traffic management to water distribution, waste management, etc.
Smart home	Smart home encapsulates the connectivity inside your homes. It includes smoke detectors, home appliances, light bulbs, windows, door locks, etc.
Smart supply chain	Helps you in real time tracking of goods while they are on the road, or getting suppliers to exchange inventory information.

Smart shopping



Scenario: shopping

(2) When shopping in the market, the goods will introduce themselves.

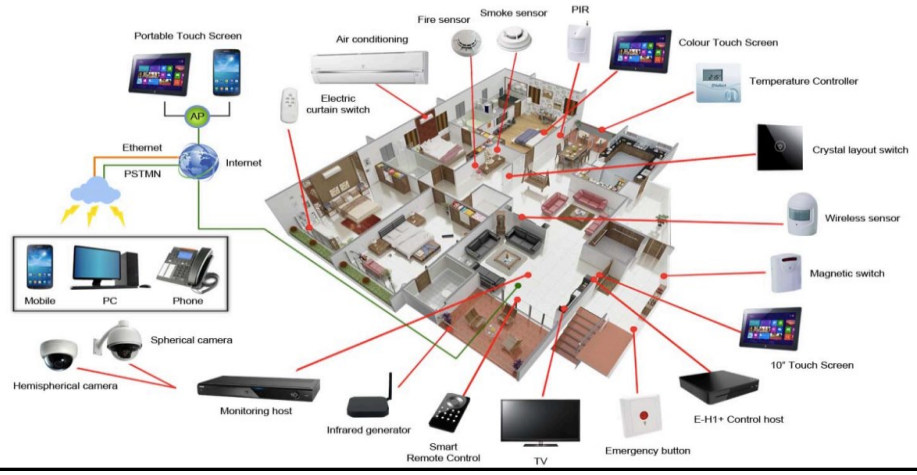
(1) When entering the doors, scanners will identify the tags on her clothing.

(4) When paying for the goods, the microchip of the credit card will communicate with checkout reader.

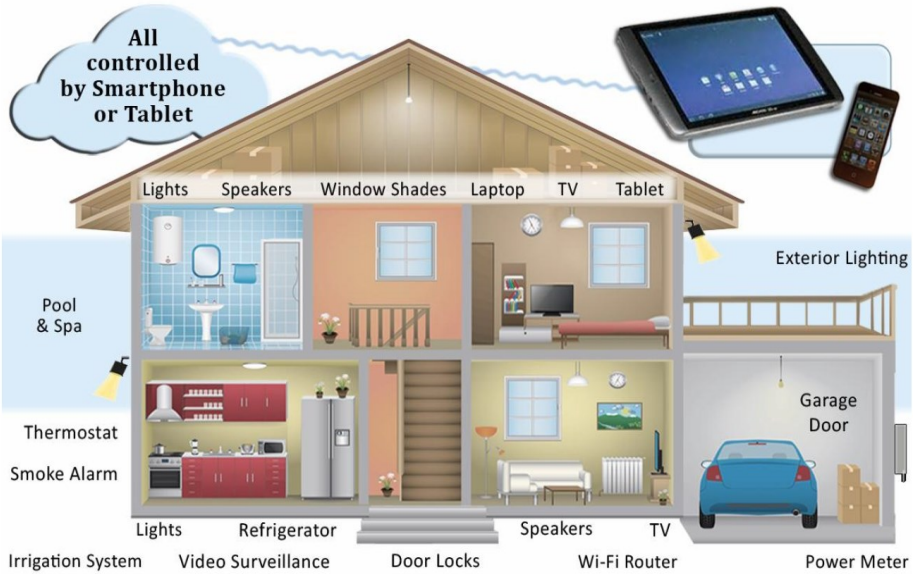
(3) When moving the goods, the reader will tell the staff to put a new one.

Smart Home Applications

- Smart meters, heating/cooling, motion/temperature/lighting sensors, smart appliances, security,



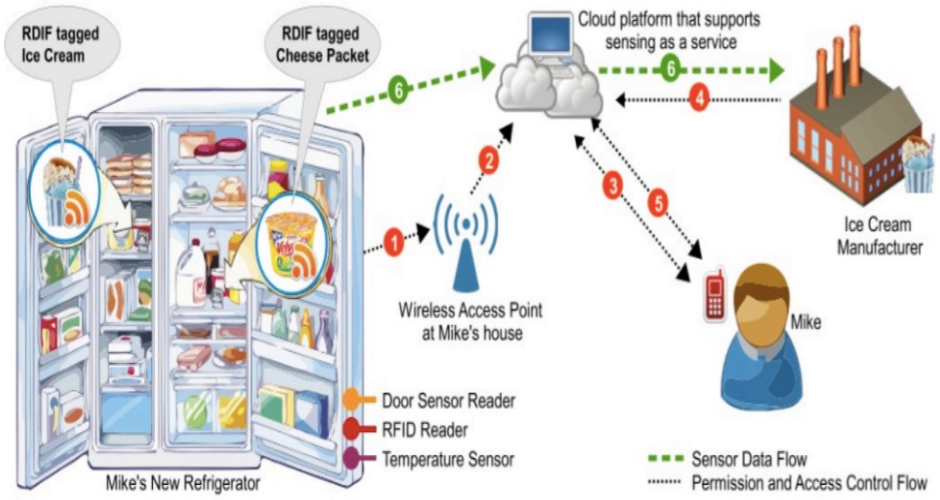
Smart Home



Working of Smart Home

- Many devices or sensors **(1 → IoT device)** connects to a main processor which is the gateway **(2 → IoT gateway)**. The gateways perform many important functions such as device connectivity, security, protocol translation, data filtering, management and many more. The network or router **(3 → Network)** connects the gateway to the cloud using various protocols. The data of the lighting's in the house is saved in a cloud **(4 → cloud)**. With the help of an application in a smartphone **(5 → Application)** one can see the data present on the cloud and keep a check on the home.

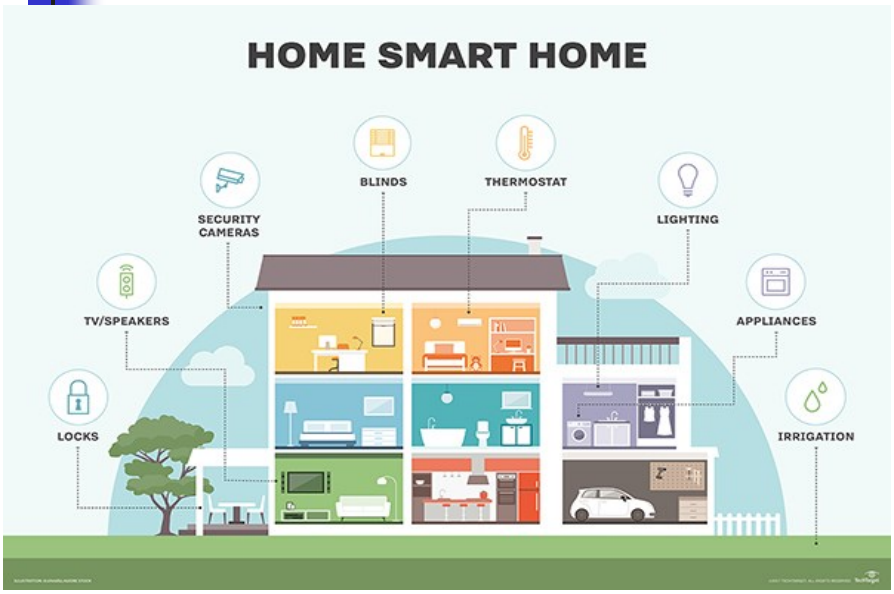
Smart Home Scenario



Example: Smart homes

- A range of appliances controllable via a mobile app

Example: Smart Homes



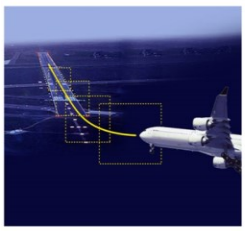
Example: Smart Lighting

- Tunable light, 16 million colors
- Activated by smartphone or over Zigbee wireless
- Can serve as alarm clock
- Can synch colors to movies or possibly music

Philips never anticipated the demand - sold out in 3 months at Apple stores!

Transportation Applications

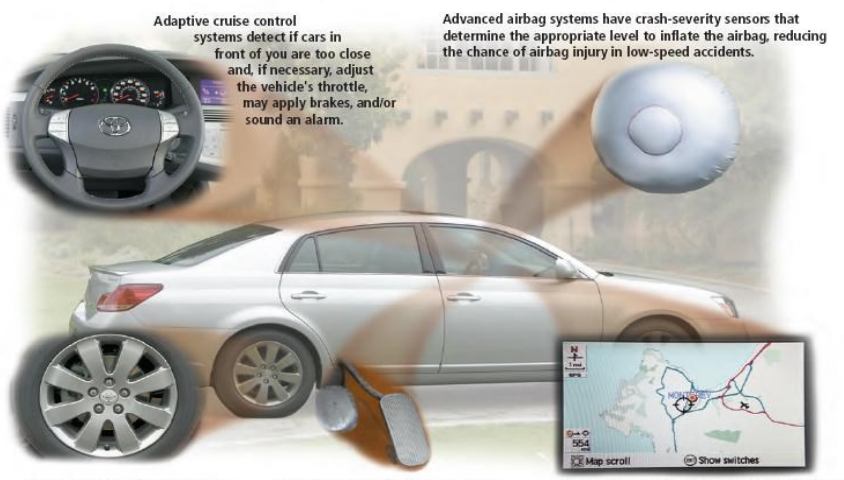
- **Vehicle control:** Airplanes, automobiles, autonomous vehicles
  - All kinds of sensors to provide accurate, redundant view of the world
  - Several processors in cars (Engine control, break system, airbag deployment system, windshield wiper, door locks, entertainment sy stem, etc.)
  - Actua1on is maintaining control of the vehicle
  - Very tight timing constraints and requirements enforced by the platform



Example Transportation Scenarios

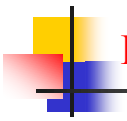
- 1. A network of sensors in a vehicle can interact with its surroundings to provide information
  - Local roads, weather and traffic condi1ons to the car driver
  - Adap1ve drive systems to respond accordingly
- 2. Automatic activation of braking systems or speed control via fuel management systems.
  - Condition and event detection sensors can ac1vate systems to mainta in driver and passenger comfort and safety through the use of airbag s and seatbelt pre--tensioning
- 3. Sensors for fa1gue and mood monitoring based on driving condi1ons, driver behavior and facial indicators
  - Ensuring safe driving by ac1va1ng warning systems or directly controlling the vehicle

Automotive Embedded Systems



Automotive Embedded Systems

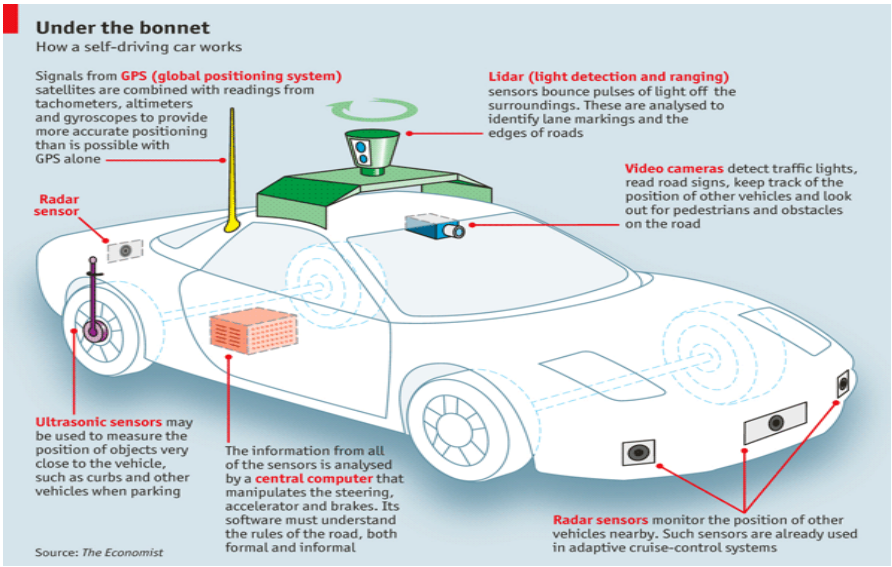
- Today's high-end automobile may have 100+ microprocessors:
  - Seat belt; dashboard devices; engine control; ABS; automatic stability control; navigation system; infotainment system; collision avoidance system; tire pressure monitoring; lane warning; adaptive cruise control; climate control; airbag control unit; electric window and central locking; parking aid; automatic wiper control; alarm and immobilizer; power seat; electric power steering; electronic transmission; active suspension



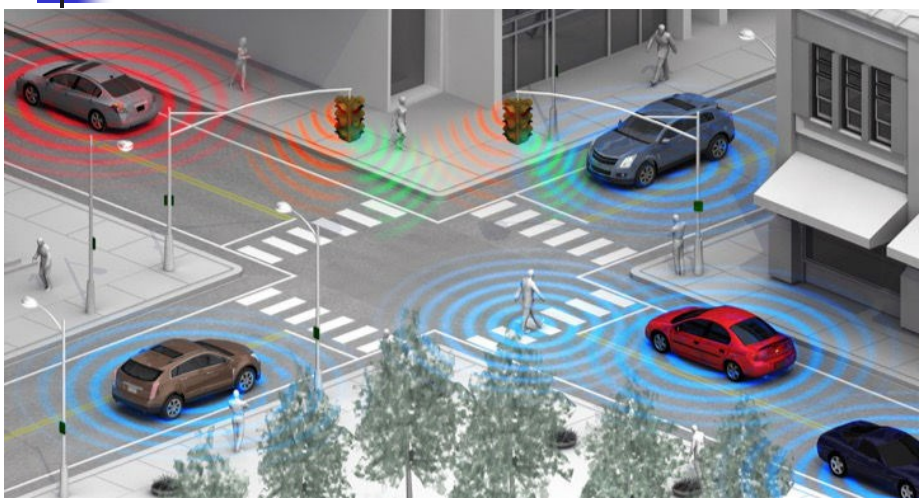
Example: Connected Roadways

- US DoT Statistics for 2012:
  - 5.6million crashes
  - About 31,o00 fatalities (26,500 in EU)
  - Over 1.6M injuries
- 1trillion USD in economic loss
- 5.5billion hours of travel delays per year
- CO2 emissions

Example: Connected Roadways

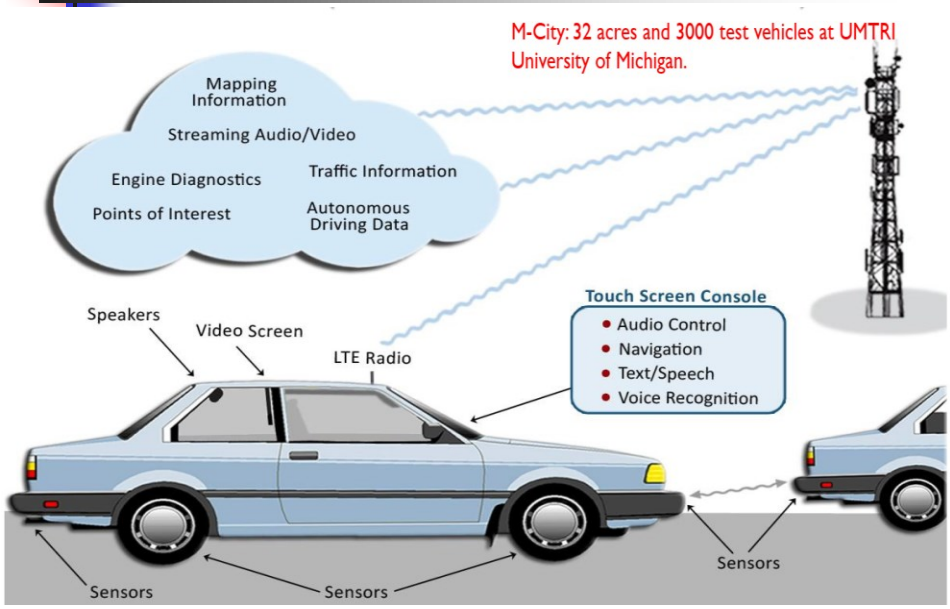


Example: Connected Roadways



State of Self-Driving Car

Smart Cars (aka the Internet of Vehicles)



Smart Parking

Ingredients:

- Asphalt sensors and/or cameras
- Communication technologies
- "Intelligence" to manage the parking information
- End user Apps

Ex: SFPark *http://sfpark.org*
-8200 park meters + 12500 spots
-Dynamic pricing to incentivize virtuous users behavior

Example: Connected Factory

Example: Connected Factory

- New product and service introductions faster
- Increasing production, quality, uptime
- Mitigating unplanned downtime
- Protecting from cyber threats
- Worker productivity and safety

Healthcare Applications

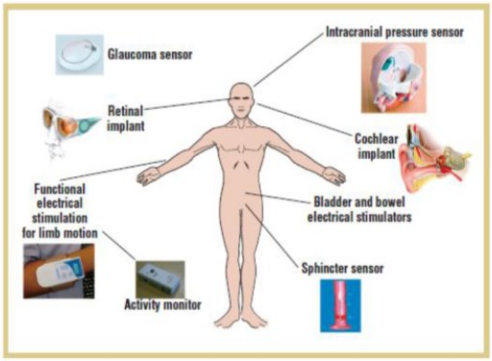


Figure 6. Fully implantable wireless sensor for the intracranial pressure monitoring system.

Source: Qian Zhang. Lecture notes. 2013

- Various sensors for various conditions
- Example ICP sensor: Short or long term monitoring of pressure in the brain cavity
- Implanted in the brain cavity and senses the increase of pressure
- Sensor and associated electronics encapsulated in safe and biodegradable material
- External RF reader powers the unit and receives the signal
- Stability over 30 days so far

30

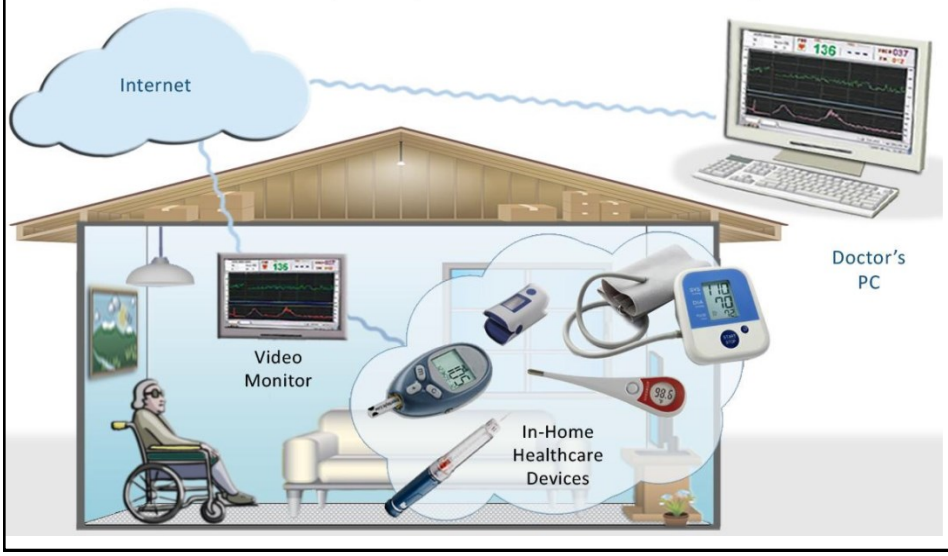
Healthcare Applications

- Other applications:
  - National Health Information Network
  - Electronic Patient Record
  - Home monitoring and control
    - Pulse oximeters, blood glucose monitors, infusion pumps, accelerometers
  - Bioinformatics
    - Gene/protein expression
    - Systems biology
    - Disease dynamics

Source: Qian Zhang. Lecture notes. 2013

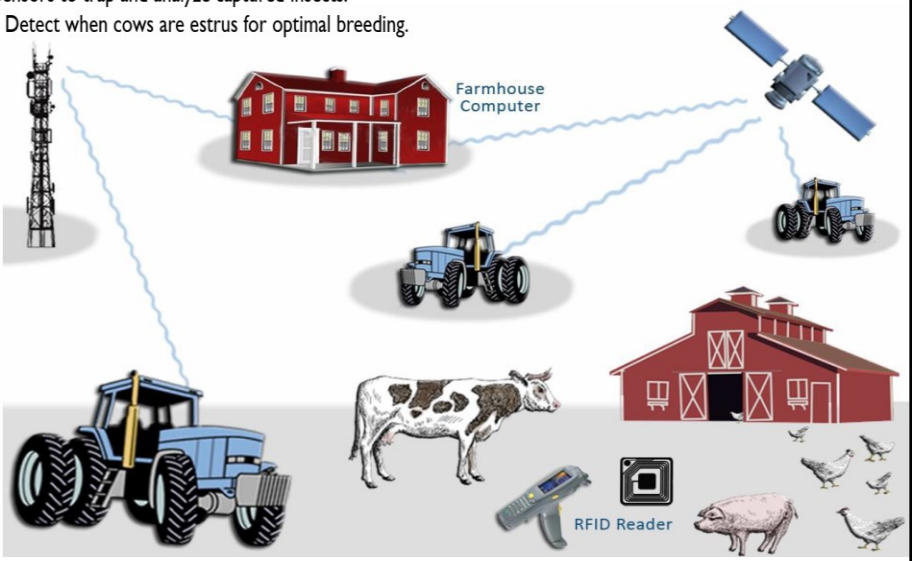
E-Healthcare

Offer remote health services for baby boomers.
Help them to live independently at their homes instead of nursing homes.

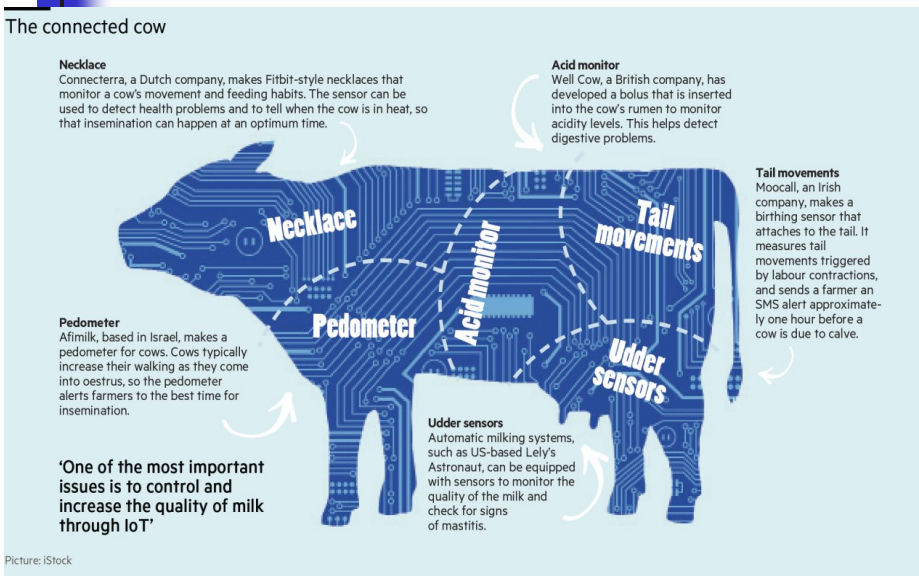


Smart Farms

- Temperature sensors, moisture sensors, etc.
- Sensors to trap and analyze captured insects.
- - Detect when cows are estrus for optimal breeding.



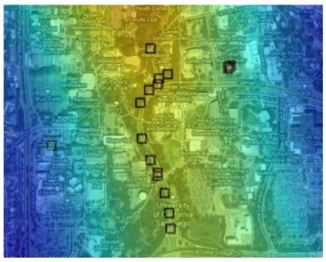
Example: Smart Creatures



Environmental Application: CitiSense

- Air quality monitoring project in UCSD CSE

- Environmental application
- Electrochemical **sensors**, **microcontroller** for data collection and transmission to an **Android** app
- **Actuation**: air quality is immediately reported, as well as retransmitted to a backend for larger-scale analysis



Environment

Gestione rifiuti

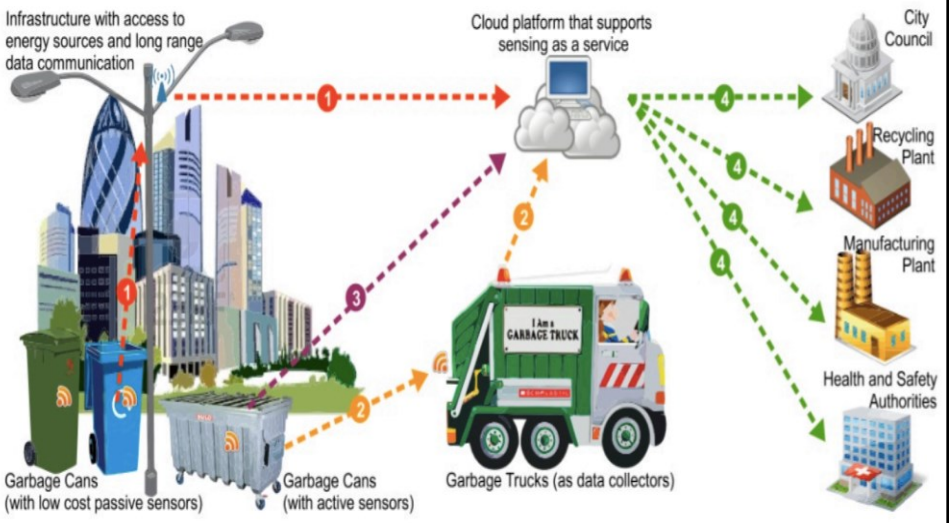
Energy efficiency

Pollution

75% of GHG emissions due to cities
Cities cover 2% of Earth surface[1]

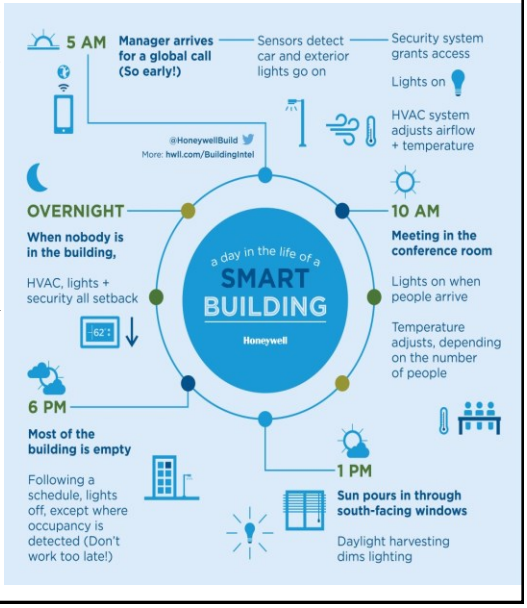
Source:
[1]http://www.ghgprotocol.org/city-accounting

Efficient Waste Management in Smart Cities

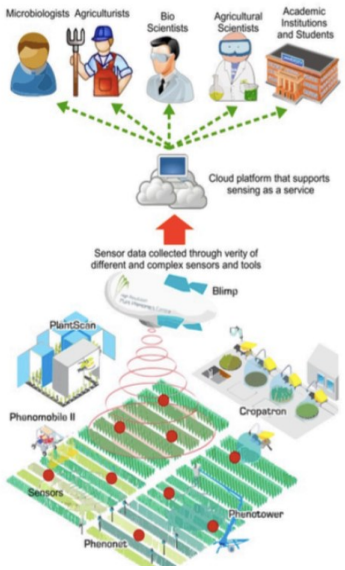


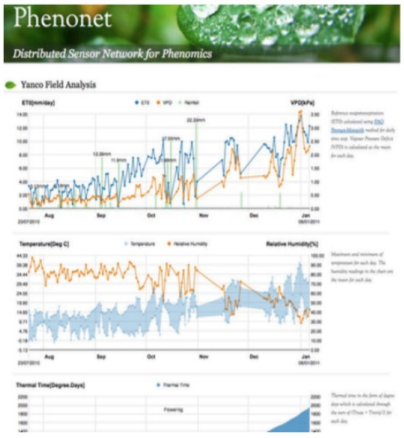
Example: Smart & Connected Buildings

- Energy management
- Lighting
- Safety
- HVAC
- Building automation
- Smart spaces



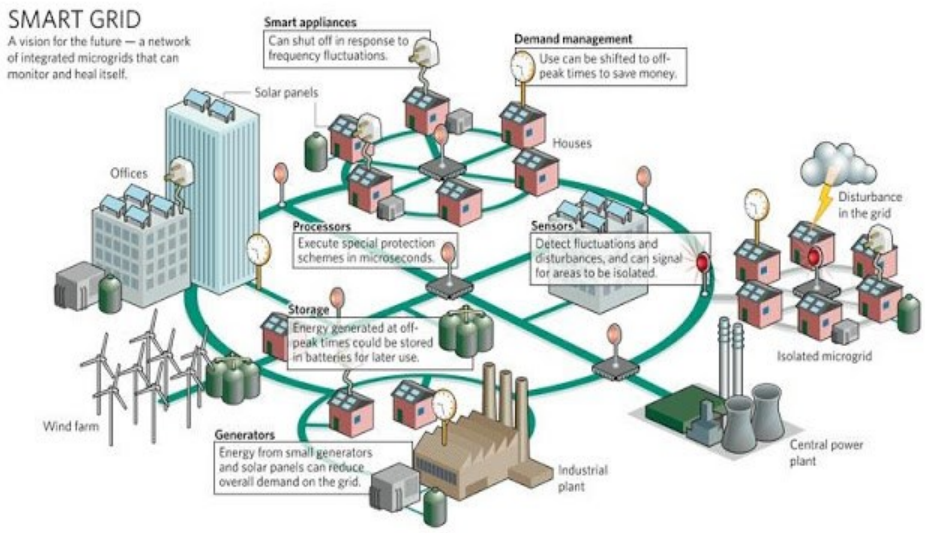
Efficient Collaborative Research





The sensing-as-a-service model allows researchers to share resources across borders and understand phenomenon which are not available in their own countries

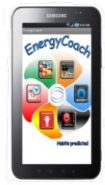
Example: Smart Grid

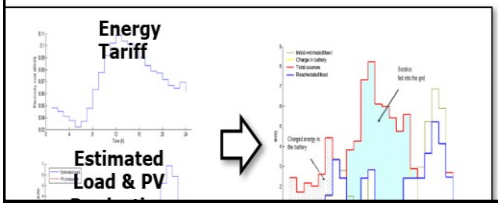


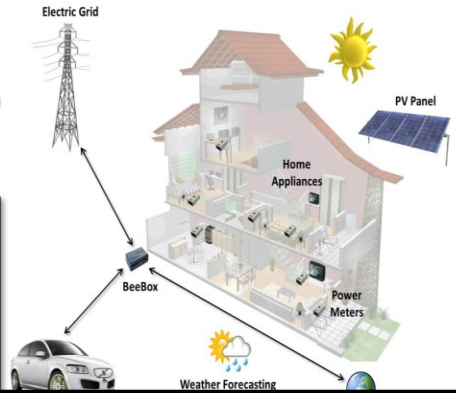
Smart Energy

Ingredients:

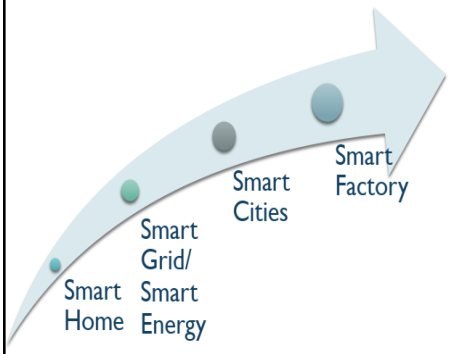
- WSN to monitor power consumption and user "profiles"
- Algorithms to optimally schedule appliances
- Communication channel with the power supplier to get energy prices
- Communication channel with the Internet to get context data (meteo)
- End user App

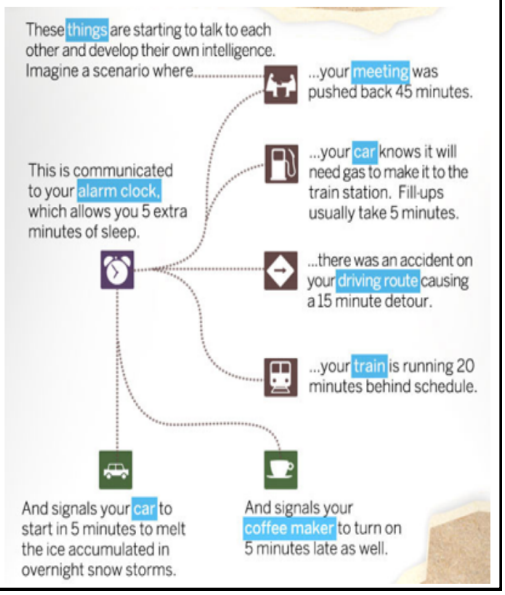






Future Scenario





More Smarts

- Smart bathroom cabinet for medicine
- Smart refrigerator
- Smart toilet
- Smart history (in museums)
- Smart health (sensors in running shoes)
- Smart buying (beacons)
- Smart shirt (seal wounds)
- Smart helmet (detect concussion)
- …

Benefits of IoT:

- **1. Automation**
- **2. Improved customer engagement**
- **3. Efficient**
- **4. Derive meaningful insights & prediction**
- **5. IoT used in various domains**

1. Automation:

- In today's context, automation is the key to everything we do – be it home or office or industry. Automation, in the past few years has evolved as the primary factor to efficient mass production and mitigate human errors as well as saving time and reducing cost factors. Automation helps us to manage everything from a place. We don't have to go to the location. It keeps all the devices connected through a single interface which is massive. Automation gives us the comfort and convenience to perform everything from a one place.

2. Improved customer engagement

- Customer experience is very important for any company or product. IoT helps us to get the maximum customer engagement. It helps us to provide better customer experience. For example IoT can improve customer satisfaction by monitoring equipment. The customers can stay connected to their products and devices from anywhere.

3. Efficient:

- The Internet of things has taken the world by a storm. It has gained momentum in the business world and successfully managed to do what technology aims to do such as automate process and drive efficiency remotely. Moreover, sensors can be deployed almost anywhere to track about anything that provides useful data. IoT is very efficient in many fields such as home automation, smart industry, automobiles, retail, agriculture and many more.

4. Derive meaningful insights & prediction

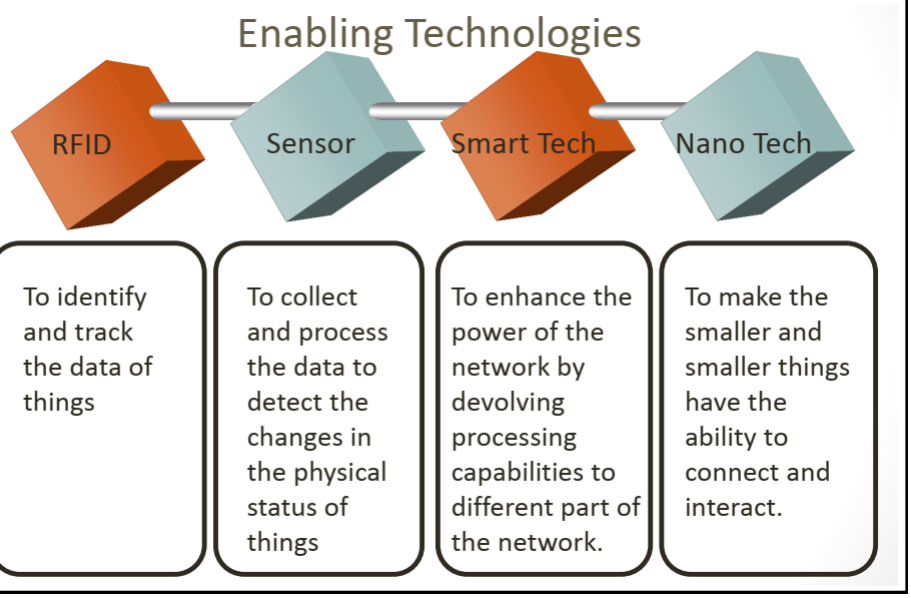
- The Internet of things helps us to make better decisions about everything even about the way we trade goods and health care to building smart cities. The internet has connected millions of people across the globe. No one had anticipated this a decade ago. There are a countless interactions between humans and machines that occur over these networks are producing data about almost everything that we do. It's not just people that are being connected but a vast network of electronic devices and sensors are constantly transmitting huge amount of data concerning everything we do.

5. IoT used in various domains:

- Certainly, it's needless to say that the hype for IoT has been increasing immensely. IoT is a very huge domain. It is implemented is various Here are a few applications of the various IoT verticals

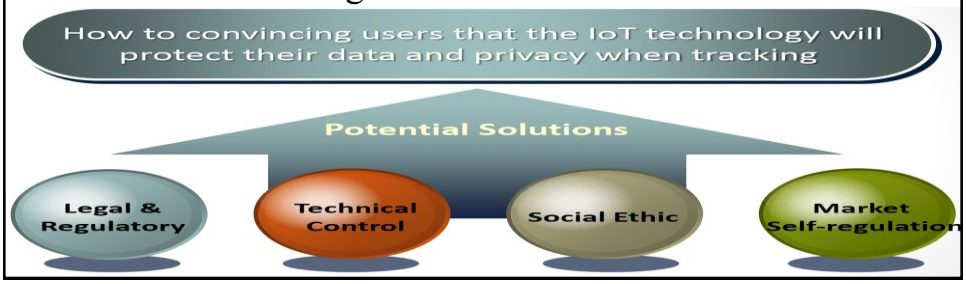
IoT Verticals	Applications
Industrial	Energy networks, Aerospace, Futuristic Farming, Drones, Smart Dust, Smart Robotics, Smart Logistics Management, Power Management, etc.
Automotive	In vehicle infotainment, predictive maintenance, security, surveillance, safety, data analytics and dashboard reporting, real time monitoring, etc.
Smart Home	Remote monitoring, energy saving, communication, automation, data analytics, etc.
Health Care	Tracking and alerts, remote medical assistance, data assortment and analysis, end to end connectivity, simultaneous reporting and monitoring,etc.
Retail	Predictive equipment maintenance, smart transportation, demand aware warehouse, connected consumer, smart store, etc.
Logistics	Location management systems, inventory tracking and warehousing, IoT technology and predictive analytics, blockchain for supply chain management, etc.
Agriculture	Precision farming, agricultural drones, livestock monitoring, smart greenhouses, etc.
Education	Attendance monitoring system, smart boards, superior safety features, learning at anytime anywhere, poster boards into IoT enabled boards, etc.
Smart City	Smart parking, road traffic, public transport, utilities, street lighting, waste management, environment, public safety, etc.
Environment	Environmental sensors, smart farming, energy efficiency, energy requirements, etc.

State of the Art of IoT

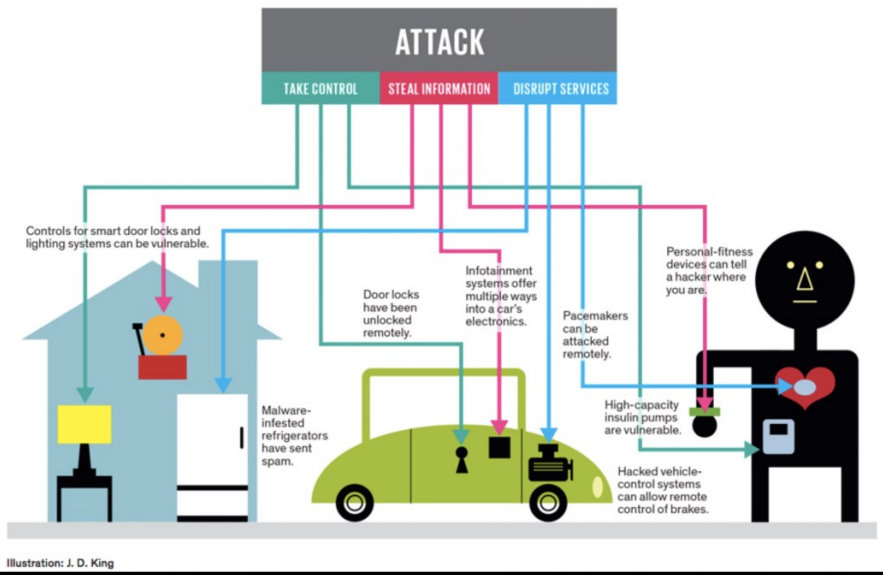


The Challenges of IoT

- Total challenge of IoT
  - 1. Technological Standardization in most areas are still remain fragmented.
  - 2. managing and fostering rapid innovation is a challenge for governments
  - 3. privacy and security
  - 4. Absence of governance



IoT Issues & Challenges



- Things that connect
  - Homes; devices and more
- Network expanding
  - More connections; more nodes; ipv6
- Sensors and data
- Heterogeneous devices; languages; protocols, processors and systems
- Power constraints
- Anytime Anyplace Anything
- Context aware systems – data centric – Service oriented

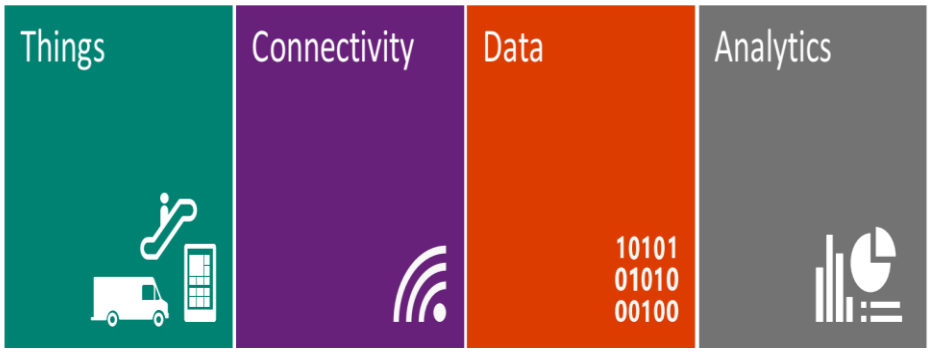
More on Challenges and requirements

- Scalable
- Cloud support
- Security at all levels
- Reliability
- Trust
- Privacy
- Opportunities at every

Challenges

SECURITY

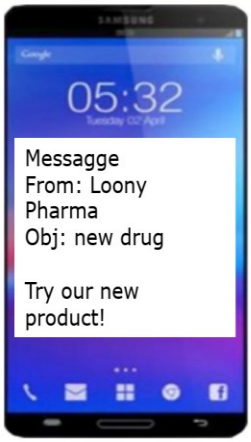
RELIABILITY/ROBUSTNESS

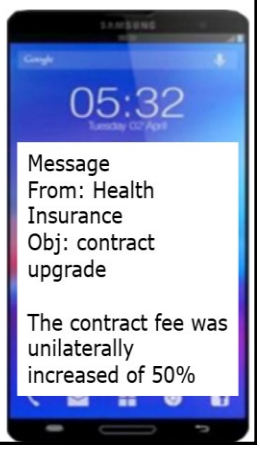


IoT Challenges: Security

SECURITY

- Scenario[1]:
  - Bio-sensor detects heart attack and calls 911
  - while waiting…



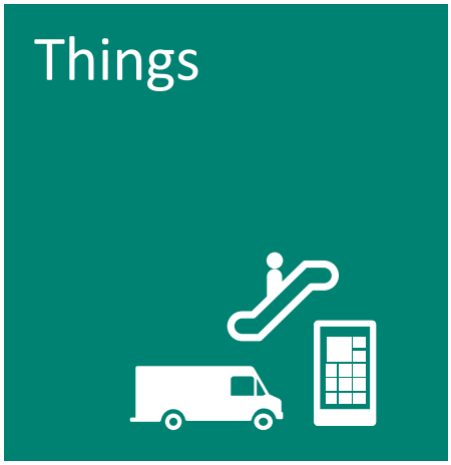


RELIABILITY/ROBUSTNESS

- Hardware level:
  - Data collected must be reliable/consistent
  - Device must live in harsh environment
- Software level
  - Communication protocols must be robust to failures, changing topologies, interferences, etc.
  - Self healing, self configuration functionalities needed

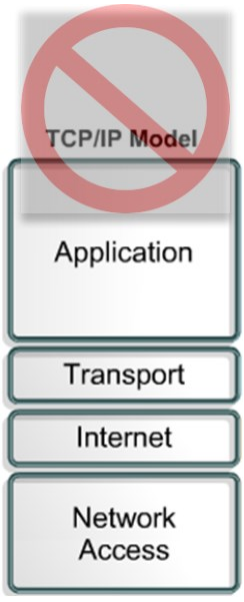
IoT Challenges: Things

- Cost reduction
- Miniaturization
- Energy Efficiency
- Resiliency
- Design, H&M interfaces



IoT Challenges : Connectivity

- What communication technologies?
  - Energy efficiency is a "must
  - Single-hop vs Multi-hop
- What communication protocols?
  - "Classical protocols" not suited
  - The "integration issue"



IoT challenges

- Interconnecting many devices that exchange (big) data is challenging

Developing code that runs on embedded devices and ensure energy efficient operation.

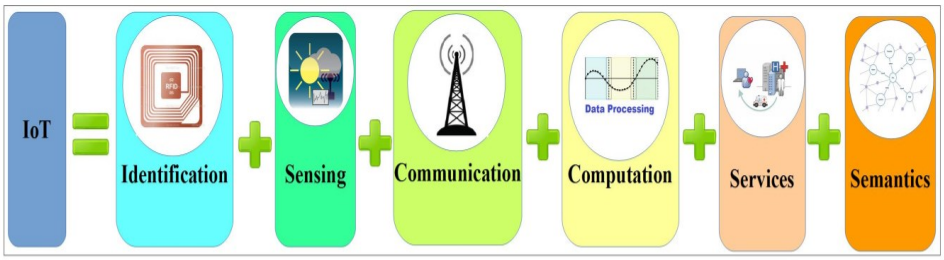
Ensuring reliable connectivity, optimal infrastructure sharing, scalability.

Guaranteeing secure operation, ease of use, and not compromising user privacy for some utility.

Aggregating large data sets and exploiting only context specific information in real-time.

Big Data

IoT Enabling Technologies



To identify and track the data of things	To collect and process the data to detect the changes in the physical status of things	To enhance the power of the network by devolving processing capabilities to different part of the network.	To enhance integration and interoperation between devices and services.

IoT Enabling Technologies

IoT Enabling Technologies

IoT Elements		Samples
Identification	Naming	EPC, uCode
	Addressing	IPv4, IPv6
Sensing		Smart Sensors, Wearable sensing devices, Embedded sensors, Actuators, RFID tag
Communication		RFID, NFC, UWB, Bluetooth, BLE, IEEE 802.15.4, Z-Wave, WiFi, WiFiDirect, , LTE-A
Computation	Hardware	SmartThings, Arduino, Phidgets, Intel Galileo, Raspberry Pi, Gadgeteer, BeagleBone, Cubieboard, Smart Phones
	Software	OS (Contiki, TinyOS, LiteOS, Riot OS, Android); Cloud (Nimbits, Hadoop, etc.)
Service		Identity-related (shipping), Information Aggregation (smart grid), Collaborative-Aware (smart home), Ubiquitous (smart city)
Semantic		RDF, OWL, EXI

Enablers of the IoT

- **Cheap sensors** – Sensor prices have dropped to an average 60 cents from $1.30 in the past 10 years.
- **Cheap bandwidth** – The cost of bandwidth has also declined precipitously, by a factor of nearly 40X over the past 10 years.
- **Cheap processing** – Similarly, processing costs have declined by nearly 60X over the past 10 years, enabling more devices to be not just connected, but smart enough to know what to do with all the new data they are generating or receiving.
- **Smartphones** – Smartphones are now becoming the personal gateway to the IoT, serving as a remote control or hub for the connected home, connected car, or the health and fitness devices consumers are increasingly starting to wear.

Enablers of the IoT

- **Ubiquitous wireless coverage** – With Wi-Fi coverage now ubiquitous, wireless connectivity is available for free or at a very low cost, given Wi-Fi utilizes unlicensed spectrum and thus does not require monthly access fees to a carrier.
- **Big data** – As the IoT will by definition generate voluminous amounts of unstructured data, the availability of big data analytics is a key enabler.
- **IPv6** – Most networking equipment now supports IPv6, the newest version of the Internet Protocol (IP) standard that is intended to replace IPv4.

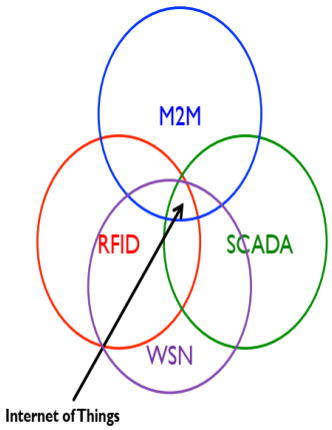
Enabling Technologies

- Technologies needed:
  - RFID
  - Power for Sensors*
  - Mobile and Smart phones
  - Nanoscience and Miniaturization
  - Smart Objects (intelligence) and Robotics
  - M2M (Machine-to- Machine) communication
  - Standardization* of communication, protocols, security
  - IPv6*, 6LoWPAN, Zigbee
- Others
  - Big Data
  - The Cloud

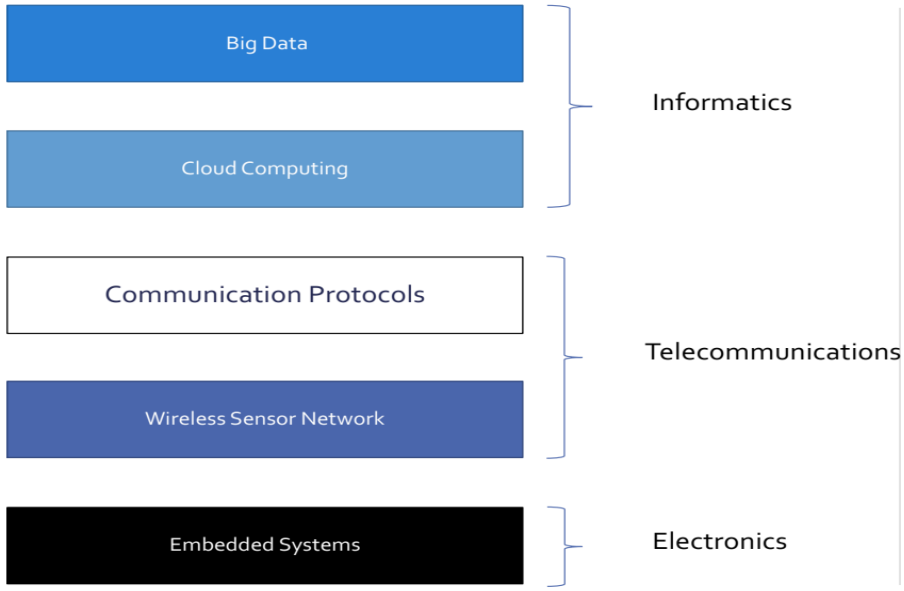
IoT Enabling Technologies

- RFID Technology
- Sensor Technology (nano-technology)
- Wireless Communication (low power, lossy networks)
- Energy Harvesting Technologies
- Cloud Computing
- Advanced Internet Protocol (IPv6)

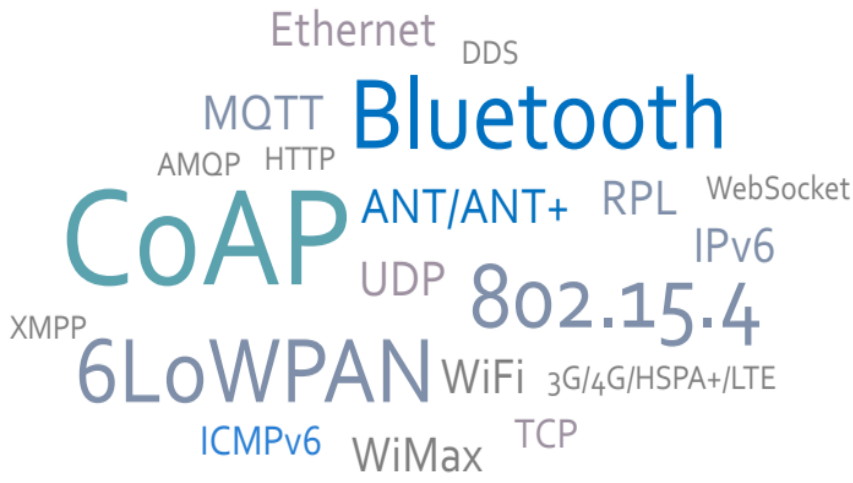
Essential Technologies Involved in IoT



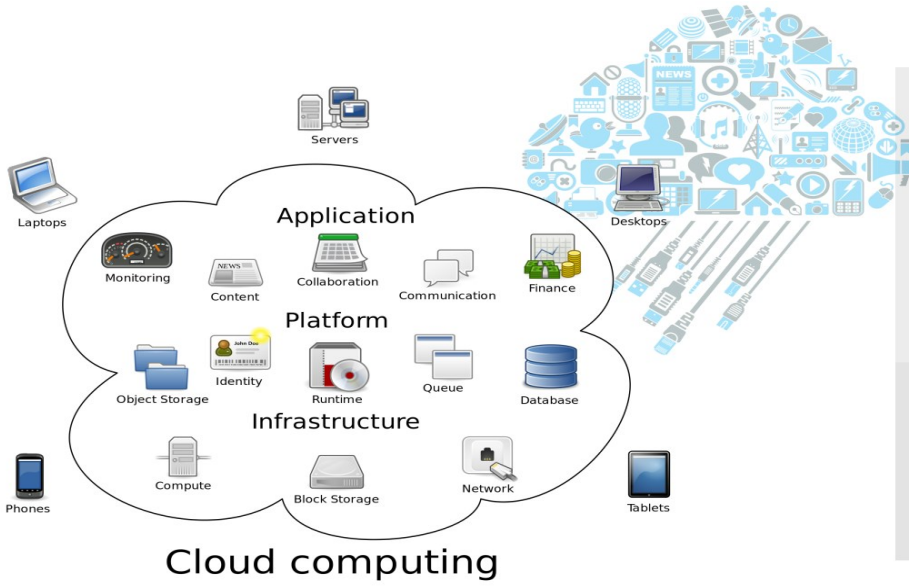
Supporting Technologies of IoT



Communication Protocols



Cloud Computing

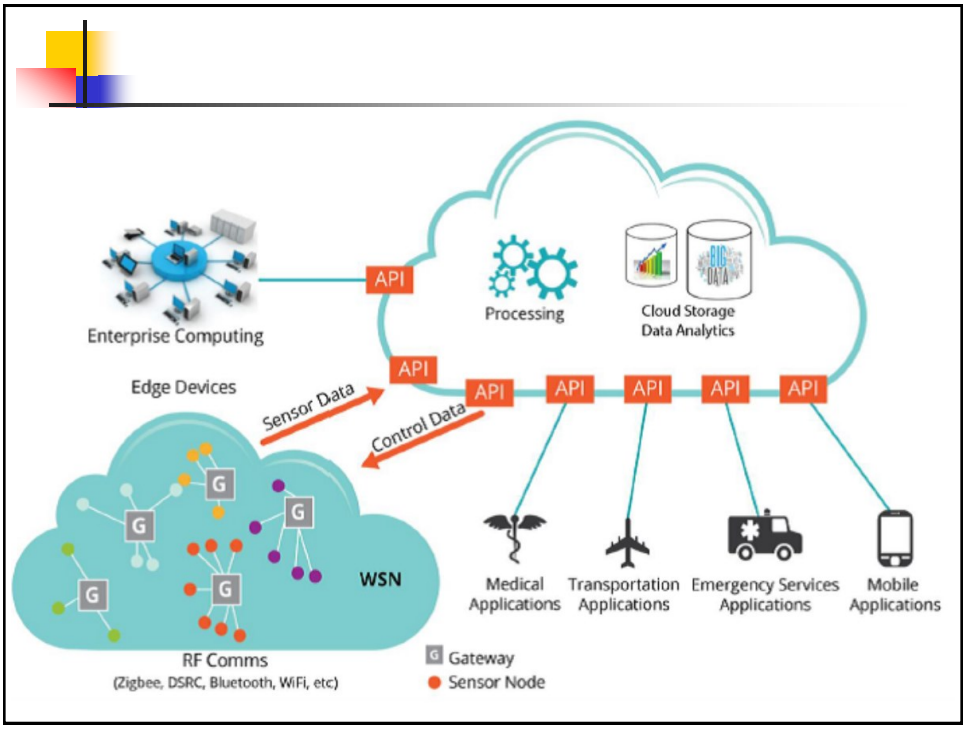


Enablers: Portability

- Reducing the size of hardware to enable the creation of computers that could be physically moved around relatively easily

Big Data


BIG
DATA
ANALYTICS
STORAGE
ALSO
TOOLS
DISK
TARGET
EXAMPLES
APPLIED
SENSOR
SHARED
DEFINITION
MAY
MOVING
WITHIN
EVERY
SET
RELATIONAL
SOCIAL
LARGER
CONTINUES
COMPLEX
CITATION
TENS
INTERNET
PRACTITIONERS
CAPTURE
BUSINESS
SETS
GENOMICS
DISTRIBUTED
MANAGEMENT
TERABYTES
PETABYTES
INCLUDE
SYSTEMS
TOLERABLE
ABILITY
SIZE
CAPACITY
BIOLOGICAL
PROCESSING
HUNDREDS
NETWORKS
DATABASES
RECORDS
SEARCH
GARTNER
WORKING
PARALLEL
MASSIVELY
GROW
SAN
DIFFICULTY


Enterprise Computing
API
Processing
Cloud Storage
Data Analytics
Edge Devices
Sensor Data
Control Data
API
API
API
API
API
API
G
WSN
RF Comms
(Zigbee, DSRC, Bluetooth, WiFi, etc)
Medical Applications
Transportation Applications
Emergency Services Applications
Mobile Applications
Gateway
Sensor Node

Enablers: Miniaturization

- Creating new and significantly smaller mobile form factors that allowed the use of personal mobile devices while on the move

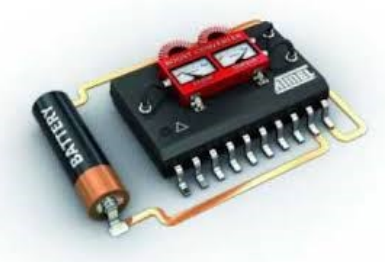
50mm x 50mm

35mm x 35mm

15mm x 15mm

Enablers: Low Power and Low Heat

- Low power architectures
- Low power radios
- Sleep modes
- Energy harvesting



Enablers: Connectivity

- Developing devices and applications that allowed users to be online and communicate via wireless data networks while on the move

Enablers: Convergence

- Integrating emerging types of digital mobile devices, such as Personal Digital Assistants (PDAs), mobile phones, music players, cameras, games, etc., into hybrid devices

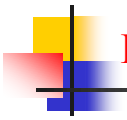
Enablers: Divergence

- Opposite approach to interaction design by promoting information appliances with specialized functionality rather than generalized ones




Enablers: Ecosystems

- The emerging wave of *digital ecosystems* is about the larger wholes of pervasive and interrelated technologies that interactive mobile systems are increasingly becoming a part of



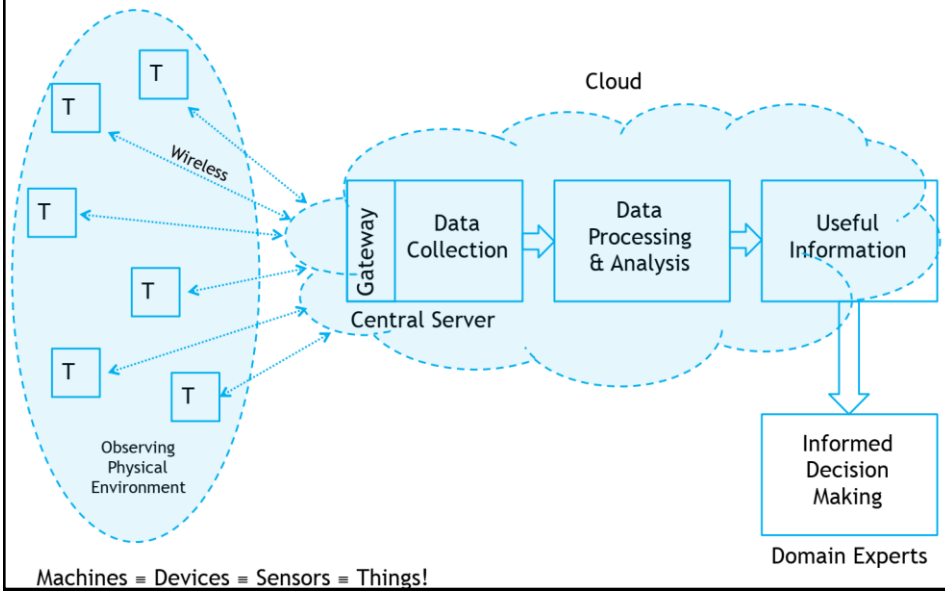
Example: Smartphone

- Portability: carry it anywhere you want
- Miniaturization: make it possible to build device to fit in your pocket
- Connectivity: Wi-Fi, LTE/4G, cellular, Bluetooth
- Convergence: phone, camera, gaming device, movie streaming, music player, …
- Digital Ecosystem: cloud, social networks, software development kits, app stores, big data, standardization …

IoT and Cloud

- Sensors talk to each other
- Only a few sensors are connected to the internet through gateway/router.
- The data generated by sensors can grow huge.
  - For example, GBs or TBs of data from video surveillance
  - “Big Data” issues - This is where scalability of clouds come in handy

An IoT System



Challenges of Internet of Things (IoT)

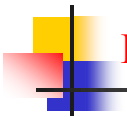
- At present IoT is faced with many challenges, such as:
- Insufficient testing and updating
- Concern regarding data security and privacy
- Software complexity
- Data volumes and interpretation
- Integration with AI and automation
- Devices require a constant power supply which is difficult
- Interaction and short-range communication

Advantages of IoT

- **Technical Optimization:** IoT technology helps a lot in improving technologies and making them better. Example, with IoT, a manufacturer is able to collect data from various car sensors. The manufacturer analyzes them to improve its design and make them more efficient.
- **Improved Data Collection:** Traditional data collection has its limitations and its design for passive use. IoT facilitates immediate action on data.
- **Reduced Waste:** IoT offers real-time information leading to effective decision making & management of resources. For example, if a manufacturer finds an issue in multiple car engines, he can track the manufacturing plan of those engines and solves this issue with the manufacturing belt.
- **Improved Customer Engagement:** IoT allows you to improve customer experience by detecting problems and improving the process.

Disadvantages IoT

- **Security:** IoT technology creates an ecosystem of connected devices. However, during this process, the system may offer little authentication control despite sufficient security measures.
- **Privacy:** The use of IoT, exposes a substantial amount of personal data, in extreme detail, without the user's active participation. This creates lots of privacy issues.
- **Flexibility:** There is a huge concern regarding the flexibility of an IoT system. It is mainly regarding integrating with another system as there are many diverse systems involved in the process.
- **Complexity:** The design of the IoT system is also quite complicated. Moreover, it's deployment and maintenance also not very easy.
- **Compliance:** IoT has its own set of rules and regulations. However, because of its complexity, the task of compliance is quite challenging.



Future Internet Technologies

- Cloud Computing
- IoT and Semantic Technologies
- Autonomy

Infrastructure

- The current Internet typically connects full-scale computers, the Internet of Things will connect everyday objects with a strong integration into the physical world
  - Plug and Play Integration
  - Infrastructure Functionality
  - Semantic Modelling of Things
  - Physical Location and Position
  - Security and Privacy