Internet of Things
IO 4041

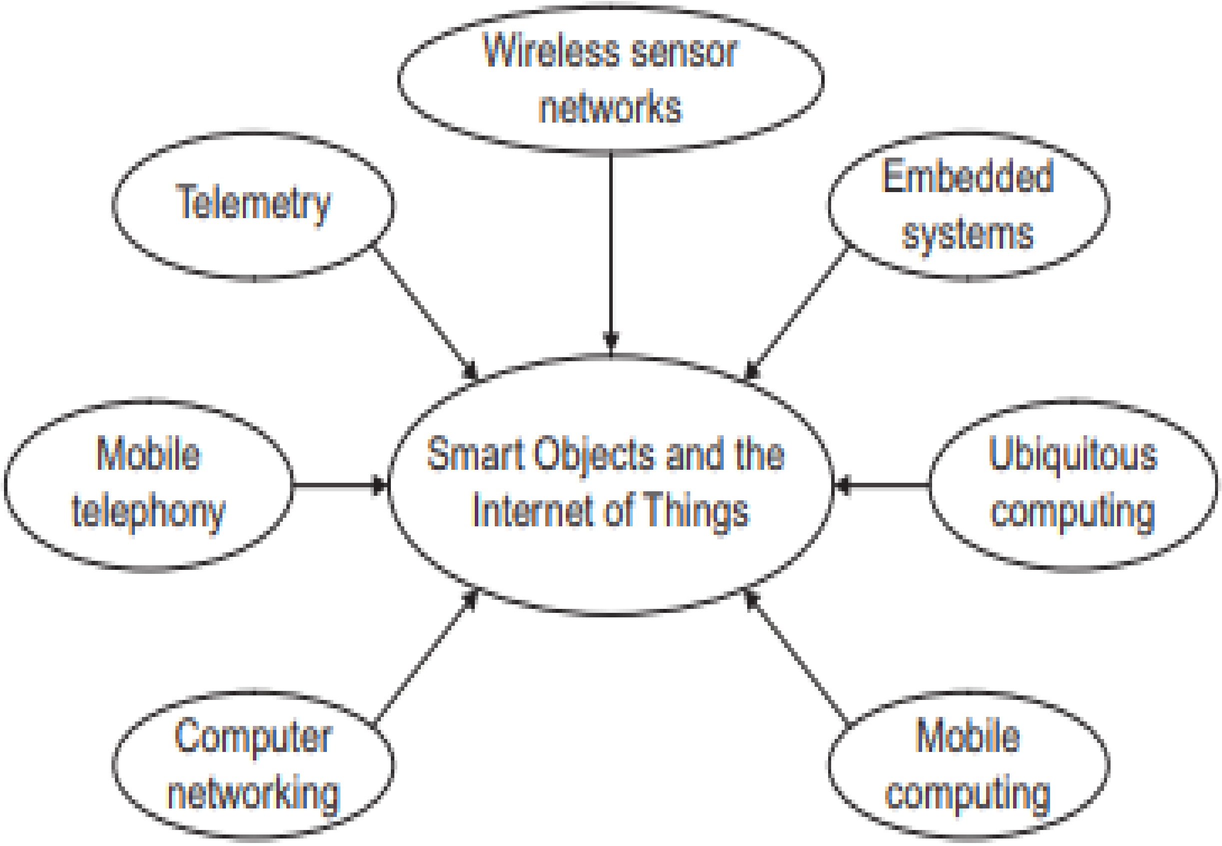
Week 3

Origin of IoT

IoT Roots

- **Computing and Telephony**
  - Led to the development of smart objects/IoT
  - Both have different culture and technical history
- Smart objects borrow from both (**middle ground**)
  - Culture of Engineering evolvable systems (from computing)
  - applied the principles from connecting disparate systems that may be managed by different companies and organizations (from telephony).
- Smart object technology needs to be evolvable and standardized

Related Areas/Terminology



Related Areas/Terminology

- **Embedded systems**: not necessarily connected
- **Wireless sensor networks**: collection of sensor devices connected through wireless channels
- **Pervasive/ubiquitous computing**: focus on anytime/anywhere computing
- **Mobile computing**: field of wireless communication and carry-around computers, such as laptop computers
- **Computer networking**: connecting computers to allow them to communicate with each other

Related Areas/Terminology

- **Mobile Telephony**: promises to provide ubiquitous access to telephony (not only telephony everywhere but also internet access)
- **Telemetry and M2M communication**:
  - **Telemetry** is about performing remote measurements
  - **M2M** communication implies autonomic communication between non-human operated machines (central to the concept of telemetry)
- **Real-time systems**: focus on time constraints
  - always respond to external input, or a timer, in a pre-specified amount of time

IoT Enablers

Enablers: Portability

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

Enablers: Miniaturization

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

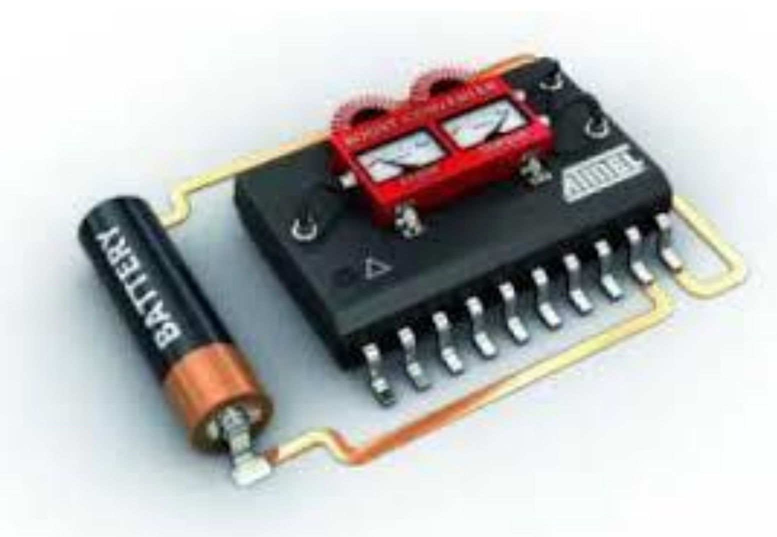
50mm x 50mm

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

Wi Fi

Bluetooth®

4G LTE

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: 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

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 …

Challenges for Smart Objects/IoT

- **Node Level Challenges (internal to each)**
  - Physical size, cost and power consumption
- **Network Level Challenges**
  - Scale of nodes in network
  - Power and memory constraints of nodes
- **Non-technical challenges:** spreading technology and awareness about the technology
- **Standardization:** major advantage in terms of acceptance
- **Interoperability:** ability of equipment and systems from different vendors to operate together

Node Level Challenges

Physical size, cost and power consumption

- **Power consumption**: a critical factor (either battery-powered or use of external low power energy source
- **Physical size:** size and form factor determines the potential applications for a given smart system (objects must be small)
- **Cost:** large scale deployments

Node level challenges deal with small scale of available resources

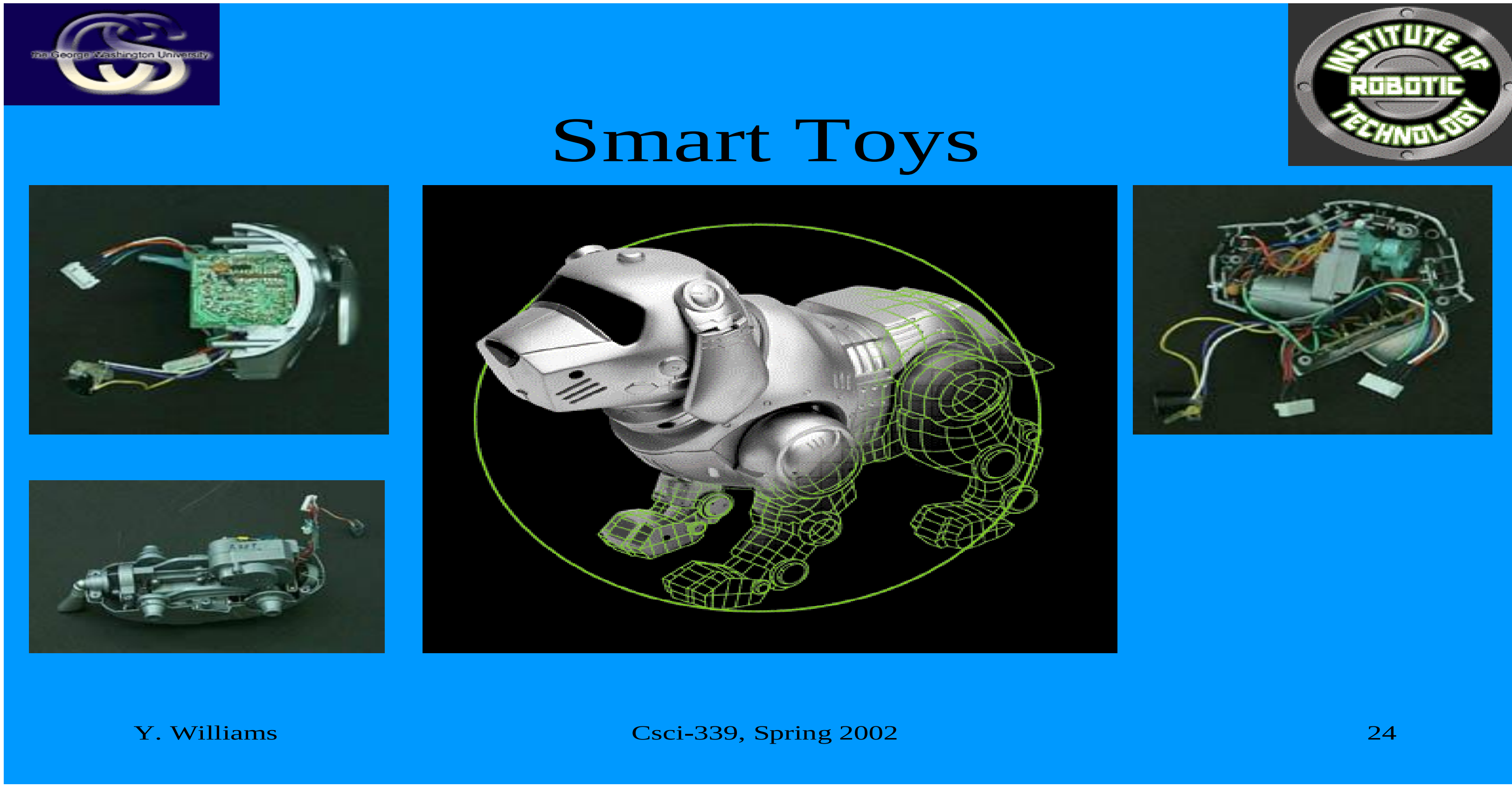
Network Level Challenges

- Deal with large scale of nodes in network
- Large amount of data generated by each node (i.e., temperature sensor)
- Power and memory constraints of nodes
- Routing aspects of the network
  - nodes that communicate often drain their energy faster than those that are silent.
  - routing protocol must make well-informed choices when planning how messages are transported through the network
  - Unreliable media
  - Lossy nature of IoT objects

Embedded System

- "Any sort of device which includes a programmable computer but itself is not intended to be a general-purpose computer"

- Computing systems embedded within electronic devices are known as embedded computing systems



Slide credit Y Williams, GWU

Embedded Systems

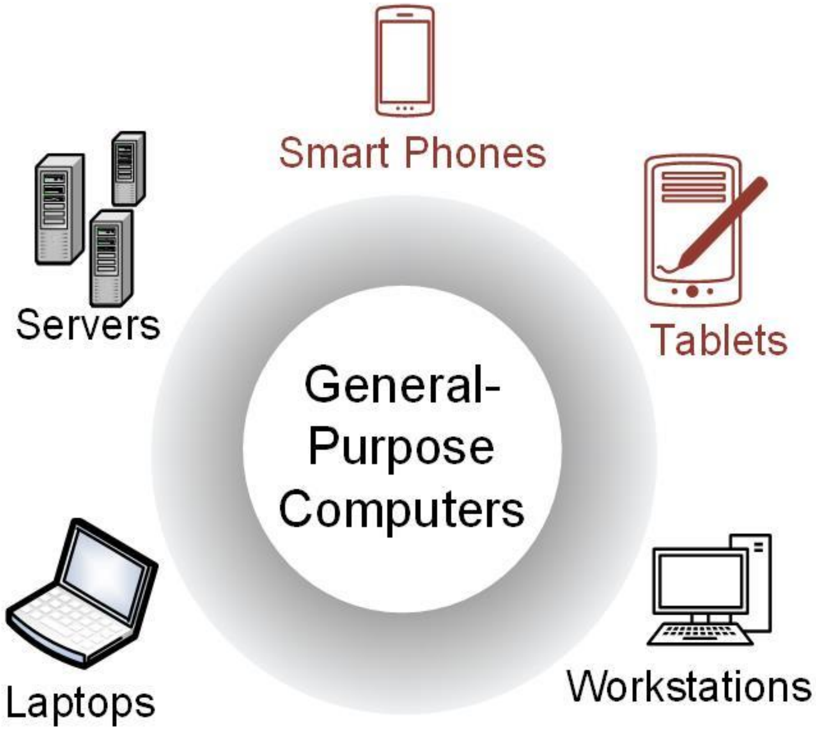
- From Wikipedia:

  An embedded system is a special-purpose computer system designed to perform one or a few dedicated functions, often with real-time computing constraints. It is usually embedded as part of a complete device including hardware and mechanical parts.

  In contrast, a general-purpose computer, such as a personal computer, can do many different tasks depending on programming. Embedded systems control many of the common devices in use today.

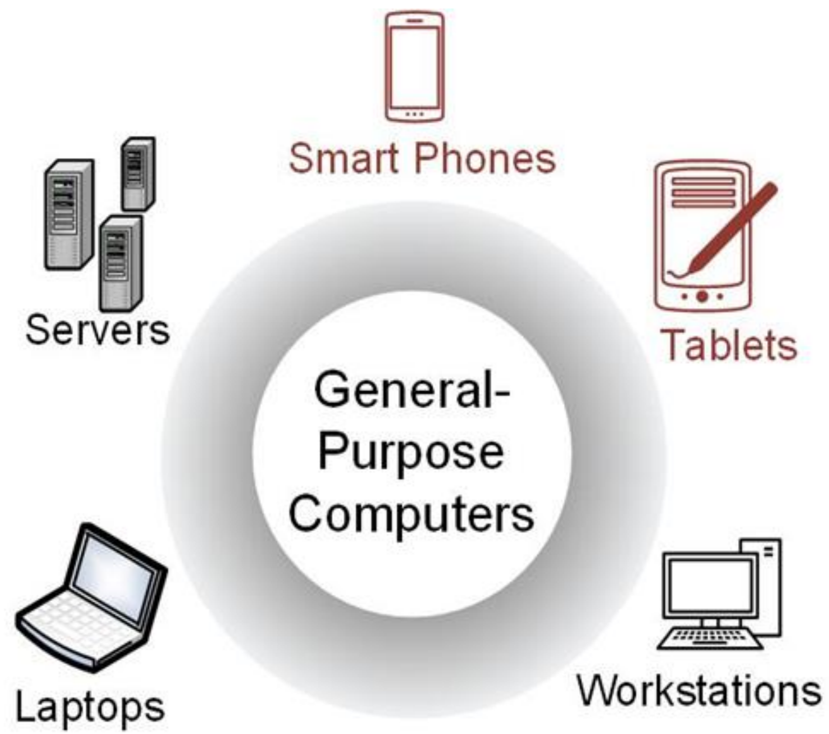
GENERAL-PURPOSE COMPUTERS

- Able to run a variety of software.
- Contain relatively high-performance hardware components (fast processors, data & program storage).
- Require an operating system (OS).



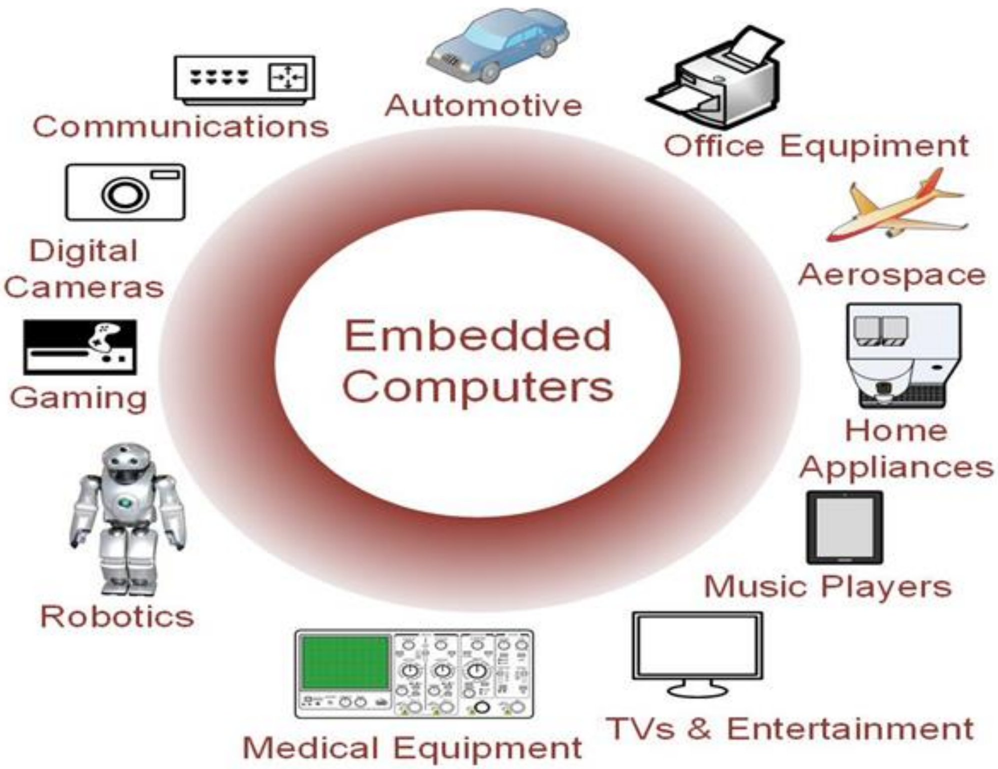
GENERAL-PURPOSE COMPUTERS

- Designed for heavy user interaction.
- Uses a variety of peripherals (displays, keyboards, mice, internet connections, wireless communication capability).
- Expensive ($100s - $1000s).
- Use a group of integrated circuits or chips (ICs).
    - One implements the central processing unit (CPU).
- Several implement data memory and program storage.



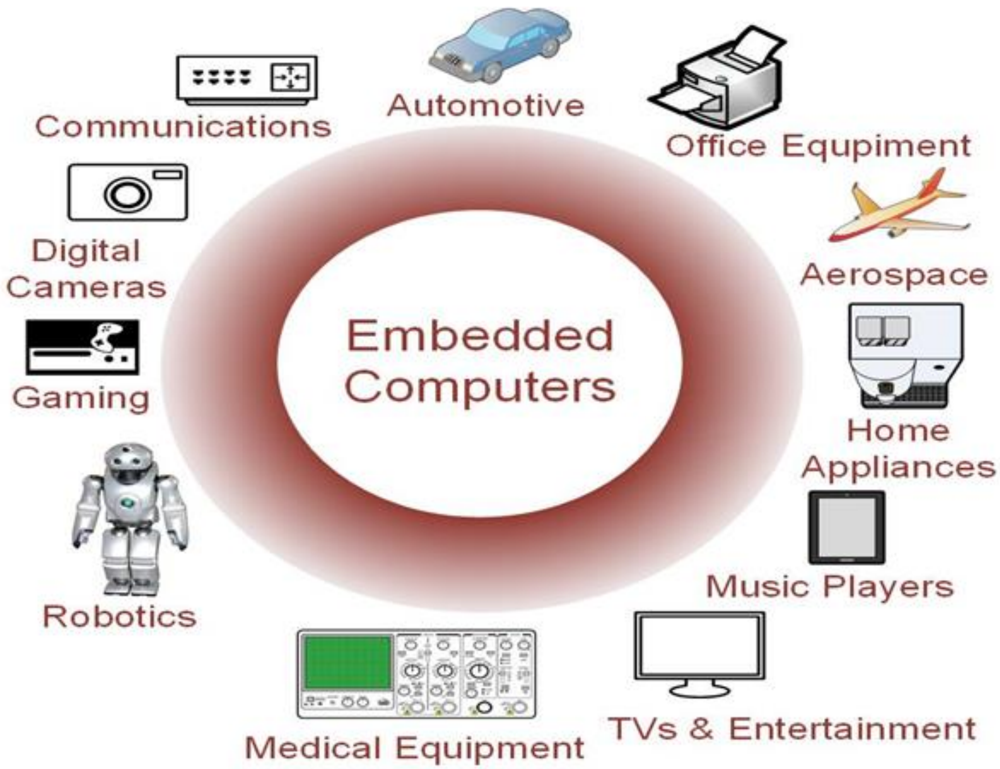
EMBEDDED COMPUTERS

- Resources can be implemented on a single IC.
- Include a variety of peripherals (timers, analog-to-digital converters, digital-to-analog converters, serial interfaces).
- Small size makes them very versatile.



EMBEDDED COMPUTERS

- Contains firmware (only the *needed* software which is not intended to be changed frequently).
- May contain Real Time Operating Systems (RTOS) which are used as a task scheduler.
- Low cost (10s of cents to a few dollars).



Microprocessor vs Microcontroller

Microprocessor

- A chip that contains only the processor
- Need other chips to make a working system
- More flexible
- Can have very few I/O or many I/O
- Devices using the same processor chip
- General purpose

Microcontroller

- A chip that contains all the components of a computer – processor, memory and input/output
- fix amount of on-chip ROM, RAM, I/O ports
- Less flexibility
- Less component count in system
- Less powerful
- Single purpose

Application Areas of Embedded Systems

- Consumer Electronics
  - Used in daily life by general public
  - Digital Camera, Digital Diary, DVD player, Electronic Toys
  - Microwave Oven, Remote control for TV, Air conditioner
  - VCD Player
  - Video Gaming Console
  - Video Recorder (like Irecord for IPhone)
- High tech Cars
  - Have more than 50+ embedded systems
  - Like automatic door lock, Engine spark control, air conditioning, Navigation, Security System and locks

Application Areas of Embedded Systems

- Office Automation
  - Copying Machine
  - Printer
  - Fax Machine
  - Scanner
  - Key Telephone
- Industrial Automation
  - Process Control
  - Monitoring Systems
    - Temperature, pressure, humidity, voltage etc
    - Industrial Robots
      - Specially for Hardware Assembling
      - In hazardous industrial environments

Application Areas of Embedded Systems

- Instrumentation
  - Measuring equipment used in Laboratories
    - Voltage, Current, Temperature etc.
  - Test equipment used in Laboratories
    - Oscilloscope, Spectrum Analyzer, Logic analyzer etc.
- Security
  - Authentication and verification
  - Fingerprinting and face recognition systems
  - Monitoring Systems
- Finance
  - ATM (Automatic Teller Machine)
  - Smart Card etc

- And so on (Self Study)

Design Principles of Internet / IoT Architecture

From NCP to TCP/IP

ARPANET: a project of ARPA

- Network Control Protocol (1970s)
  - To interconnect computers with Interface Message Processor (IMP) between various sits
  - Interconnecting leased lines of a few Kbps
  - IMPs are routers (today) --- called
- TCP to replace NCP
  - (designed by Robert Kahn and Vint Cerf)
- IPv4 (Version 4 of TCP), was designed in 1981 and the Internet migrated to it
- IPv6 does not change TCP/IP architecture

FUNDAMENTAL TCP/IP ARCHITECTURAL DESIGN PRINCIPLES

Original goals of TCP/IP

- Internet communication must continue despite loss of networks or gateways (in presence of link or node failures - in today's terms)
  - Design a single protocol (not realistic)
- The Internet must support multiple types of communication services.
  - characterized by different requirements such as delay, bandwidth, and jitter
  - File transfer service: can tolerate delay but requires high bandwidth
  - Packetized voice traffic: short delay and jitter but low bandwidths
  - Layering and then UPD

FUNDAMENTAL TCP/IP ARCHITECTURAL DESIGN PRINCIPLES

One of the key reasons for the impressive success of TCP/IP is its open, non-proprietary nature:

No intellectual property claims

It was an open standard

Challenges of IoT in the light of IP Architecture

Evolvability:

- Mechanisms for IoT should not be constrained by today's ideas but must allow for the next generation of applications

- IP is proven as evolvable architecture due to
  - the way applications, protocols, and mechanisms running on top of the architecture have evolved, and
  - the way that protocols within the architecture have evolved.
- Ability to evolve and versatility is due to end-to-end principle (basic of IP architecture)
- The network does not contain any application-level intelligence (solely at network end points) and only transports data between the end point

Challenges of IoT in the light of IP Architecture

Interoperability:

- need interoperability between IoT devices and also between IoTs and existing network infrastructures.
- As with the large base of existing systems that IoTs enhance,
    - an IoT architecture that makes interoperability and interconnection difficult will not prevail.
- IP is interoperable as it runs over link layers with very different characteristics, providing interoperability among them
- Operating over a variety of media has always been the prime objective of the IP architecture
- IP-based IoT devices are able to communicate with any given device without any additional hardware or software.

Challenges of IoT in the light of IP Architecture

Scale:

- IoT networks have a large number of nodes per system
- Existing IoT systems have thousands of nodes,
- And they are likely to develop into systems composed of hundreds of thousands or even millions of nodes.
- Thus, IoT architecture must support an increasing number of nodes through its addressing, routing, and management mechanisms.

Challenges of IoT in the light of IP Architecture

Diversity of Applications:

- The number of IoT applications is huge, and so is the number of differences in each application
- A home automation application does not share all of the properties of an industrial automation application.
- IoT technology tailored to one specific application therefore may not work for other applications.

Challenges of IoT in the light of IP Architecture

Diversity of Communication Technologies:

- IoTs can use a wide range of communication technologies
  - Depending on the application and the environment in which the system is deployed,
- Wireless communication is appropriate in many situations because of its deployment convenience, whereas
- Wired communication is more suitable in other places.
- Many IoT systems use combinations of disparate technologies in the same deployment.

Challenges of IoT in the light of IP Architecture

Standardization:

- Mechanisms and protocols defining the operation of IoT must be standardized
    - using open standards through well-established standardization practices.
- Any patents covering the standardized technology must be disclosed and made available to be used by third parties.
- Open standards make the entry barrier low for manufacturers, and allow them to freely choose between different vendors.
- Open standards was a key to the success of IP.

Challenges of IoT in the light of IP Architecture

Potentially lossy communication technology:

- Many of the communication technologies used for IoTs are inherently lossy
- IoT protocols and mechanisms need to take this into account when
  - determining where and how to send data as well as
  - determining when and how often

Challenges of IoT in the light of IP Architecture

Lifetime:

- Due to large-scale installations and demanding applications
  - IoT networks are meant to remain functional for many years
- So, they must be power-efficient, and
  - must remain operational over the lifetime of the system

Challenges of IoT in the light of IP Architecture

Low power consumption:

- IoTs have severe power constraints.
  - Many are powered by batteries that cannot easily be replaced or recharged.
  - Other draw their energy from their surroundings, such as vibration or electromagnetic energy.
  - In either case, power consumption must be low for the system to achieve its optimal lifetime.
- The power requirement affects both the network protocols and the construction of nodes.
- The memory size and computational complexity of the nodes are limited by the power consumption constraints.

Challenges of IoT in the light of IP Architecture

Low cost :

- As IoTs are deployed in large numbers;
  - a small reduction in per-device costs quickly translates into large savings in the cost of the entire system.
  - Just as the power consumption constraints affect the memory size and computational complexity of the nodes, so do cost constraints.
  - Because of constrained resources such as memory, power, and computation, any IoT architecture must be lightweight.