Internet of Things Networks - Part 1
Networking Basics and IoT Taxonomy

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Background

- Part 0 - Fundamentals of Communication Networks (EECS 563 review)
  - Layering as a form of abstraction - Application, Transport, Routing, MAC, Physical
  - Protocols - Rules that every node in a network must follow
  - TCP / IP - This is what makes the Internet work, IPv6
  - Topology is important - Star, Mesh, Ring, etc.
  - Communication medium - Fiber, coax, Ethernet, WiFi, Cellular, etc
  - Networking is about “efficiently” sharing “resources” among large number of nodes
  - In IoT, nodes could potentially be any object in the physical world, hence Cyber-Physical systems

Always click on the links for hidden treasures
The Internet - nuts and bolts

- It is a distributed system (no central control)
- Millions (soon to be Billions) of connected devices
  - hosts = end systems that run network applications (protocols)
- Communication links
  - Fiber, copper, radio, satellite
  - Bandwidth matters the most. Delay, jitter etc are also important
- Routers forward packets (well defined chunks of data)
  - IP is the glue that connects all these devices
  - Analogous to sending mail using the postal service
The Internet - nuts and bolts

- Protocols control sending, receiving of msgs
  - TCP, IP, HTTP, Skype, Ethernet

- Internet: “network of networks”
  - Loosely hierarchical. Public Internet versus private intranet

- Internet standards - very important for interoperability
  - RFC: Request for comments, IETF: Internet Engineering Task Force

- Communication infrastructure enables distributed applications
  - Web, VoIP, email, games, e-commerce, file sharing

- Communication services provided to apps:
  - Reliable data delivery from source to destination
  - “Best effort” (unreliable) data delivery
What’s a protocol

Humans

Hi

Hi

Got Time?

2.00 pm

Machines

TCP connection request

TCP connection response

get www.gmail.com

<files>

Language, Semantics, Grammar, Loudness, Noise, Reliability (repetition)

Protocols, Interface, Sockets, Signal Strength, Noise, Error Recovery (Re-transmission)
Mobility -> Wireless -> Trouble

- Communication: Chat over coffee with Hertz, Maxwell, Friis, Shannon, Paulraj

  ![Antenna Theory](image)

  ![Transmission in free space](image)

  ![Channel capacity](image)

- Networks - chat with Cerf, Metcalfe, Lamport, Dijkstra, Erlang

  ![Shortest path routing](image)

  ![Multiplexing](image)

  ![Medium Access Control (CSMA-CA)](image)
Leads to cool Internet appliances

Source: http://www.macleans.ca/authors/scott-feschuk/the-kitchen-at-the-end-of-the-universe/
Protocol Layering

- Networks are complex! Too many pieces
  - Hosts, Routers
  - Links of various media
  - Applications
  - Protocols
  - Hardware, software

- Layers Implement service abstractions
  - Each relying on services provided by layer below

Internet Protocol Stack

- **Application**: supporting network applications
  - FTP, SMTP, HTTP

- **Transport**: process-process data transfer
  - TCP, UDP

- **Network**: routing of datagrams from source to destination
  - IP, routing protocols

- **Link**: data transfer between neighboring network elements
  - PPP, Ethernet

- **Physical**: bits “on the wire”

Network Security

- Network security is the study of ([Whitepaper, Discussion Panel](#))
  - How bad guys can attack networks
  - How to defend against such attacks
  - How to design systems that are immune to attacks
- Internet was not designed with security in mind
  - The protocols and system works best under mutual trust
  - Security is embedded in every layer
- Review materials from EECS 563 on network security
- Blockchain is a superb example of asserting trust in an untrustworthy system
So, what’s next ....
The term “IoT” was added to the 2011 annual Gartner Hype Cycle that tracks technology life-cycles from "technology trigger" to "plateau of productivity" and has hit the Hype Cycle's "Peak of Inflated Expectations" in 2014.
Application driven architecture

- Use cases that leverage the power of the Internet
- Observe (Measure) -> Learn (Intelligence) -> Adapt (Infer Actions)

Source: http://www.opinno.com/en/content/internet-things-0
Challenge is in Heterogeneity

Locations

Networks

Devices

Applications
User-centric Solutions

Connectivity

Computing

Content / Applications
The Things (Everything) - Why now

- Anything with an interface to communicate with another entity
  - Hardware and software define capability, range, application
- Power is king
  - Battery, Line voltage supply (limited mobility), Solar, Backscatter (Energy Harvesting)
  - Low power solutions - hardware or software
- Open source revolution for hardware
- Cost of manufacturing, prototype
- Build intelligence in dumb systems
IoT Taxonomy
IoT Domain

- Individual
  - Smart Living
  - Personal electronics, wearables, smart homes, connected cars

- Industrial
  - Improves business efficiency
  - Smart factory, buildings, machines, retail

- Infrastructure
  - Smart communities, cities
  - Intelligent transportation systems
  - Public safety
  - Smart education
  - Healthcare

- Some applications span multiple domains

- Technology driving business decision
  - Break down barriers of vertical markets
4A’s and 4S’s

- **The 4A’s**
  - Automated Remote Provisioning and Management - Sensing and Control
  - Augmented Reality
  - Awareness of Context and Location - aka Cognition
  - Analyze and Take Action - aka Big Data

- **The 4S’s**
  - Simplicity - as in the Internet protocols
  - Security
  - Smart - Intelligent actionable items
  - Scalable

- **The current version of the Internet provides some of these but not all**

- **Our goal - how to incorporate these new attributes to the Internet**
IoT Landscape

- IoT is not new, goes back to early 1990s
- Migrate fixed function systems to generic architecture
- Key enabler are abstractions
  - Sensing (Plethora of systems - RFID, ZigBee, Z-Wave, NFC, etc)
  - Gateway / Aggregation (Ubiquitous wireless infrastructure)
  - Services (Cloud based processing and storage)
Building Blocks - Sensing

- Can’t *control* a variable if you can’t measure it (sense)
  - Static, Mobile, Wearable
  - Mostly converges to the sensitivity of the transducers
- RFID tags, MEMS, iBeacon, Bluetooth, Arduino, Android, OpenBCI (cost)
  - Greater reliability at much lower cost of opportunity
- ZigBee, Z-wave, WiFi - key differences in waveform/RF (throughput)
  - Data transport, infrastructure, adhoc, mesh, overlay
- 6LoWPAN - IPv6 over Low-Power Wireless Personal Area Network (power)
  - Energy Harvesting
- Frequency of data generation (application)
Building Blocks - Gateway

- Migrate IPv4 to IPv6 to address large number of devices
- Heterogeneity of connection - Wireless, PLC
  - Smart grid and smart meters
- Topology - Infrastructure-based, mesh, other.
  - Depends on application
  - Small cells, V2X (X = Infrastructure, vehicles, anything)
- Host-centric network to Information-centric based networks (ICN)
- Network virtualization - resource sharing
- Spectrum (FCC spectrum database)
  - Dynamic spectrum access - 802.22, 802.11af
    - Whitespaces - unused or low utilization bands - atmospheric radar, tv band - [Television Spectrum Database](#)
Building Blocks - Service

- From Cloud to Fog or cloudlets
  - Personal cloud
  - Challenge is in maintaining consistency of data and services, SAN
  - Virtualization and resource sharing
  - Software Defined Networking and Network function Virtualization

- Datacenter scale networking

- Infrastructure as a Service (IaaS)
  - Anything as a service (XaaS)
  - Amazon EC2
  - Google fi, OTT services

- Distributed algorithms
  - Map-Reduce

Graphic: http://dusil.com/2015/05/12/ott-multiscreen-digital-video-series-10-turning-piratez-into-consumers-iii/
Application Requirements
Use cases and application requirements

- Health and Fitness
- Video surveillance, Drone, Machine Vision
- Smart Home and Building
- Smart cities, Intelligent Transportation System
- Smart Energy, Smart Grid
- Smart Materials
Health and Fitness

● Today’s healthcare silos:
  ○ Individual
    ■ Lack of availability of information when and where it is required - Doctor on demand
    ■ Ridiculous healthcare costs (Lab on a chip)
  ○ Industry - Physicians, hospitals, clinics, etc.
    ■ Bottleneck: Patient records, alternate medicine
  ○ Infrastructure
    ■ Long approval process Government and FDA !!!!

● Solutions
  ○ Connect devices to Internet, Mobile health (wearables), iTriage (10K or more apps)
  ○ Healthcare analytics - Statistics and Math behind the curtains, IFTTT
Video Surveillance

- 60 intersection in 0.5 Km radius
- Will generate 4.64 Gbps @ 1080p res

**Fundamental challenge is to transport data to a central aggregation point - Why?**

- Other challenges
  - Video Compression (MPEG H.264)
  - Real-time vs delayed video (time budget)
  - Bottleneck links, buffers, storage

- Image processing - facial recognition?
- Can it be crowdsourced? **May be!**
Smart Home and Building

- Isolated sensors - easy, well understood
- More challenging - intelligent actions based on events
  - Rule based - IFTTT, Adaptive - Learning algorithms
  - Local or cloud-based solutions
- Fault tolerance
  - Triggering the wrong event
- Applications that are proactive, intuitive, contextual
- Security and authentication
- Architecture and topology
  - Usually “Star”. Can it be different?
  - Avoid single point of failure - the Smart Hub
Smart Cities and Intelligent Transportation

- **Primary application** - Safety, Safety and Safety
- **But also other things**
  - SPaT
  - Broadband communication (not just for video)
- **Broad term** - V2X
  - ‘X’ stands for Vehicle or Infrastructure
- **Other tech**
  - Radar, for proximity detection
  - Heads up display
  - Vehicular analytics
  - Firmware upgrade on the fly
- **Not just automobiles**
Smart Energy and Grid

- Good stuff, but not enough
- Not just measure but manage energy
- Two-way comms
- Renewables and storage
- Why not make money - energy market

- Grid is more complex
- Powerline Comms. [Article]
- Security vulnerabilities [Article]