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

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Background

- Part 0 - Fundamentals of Communication Networks (ICEN/ICSI 416)
  - 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

Time

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

\[ P_r = P_t \left( \frac{\lambda}{4\pi R} \right)^2 G_t G_r \]

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

Antenna Theory

Transmission in free space

Channel capacity

Shortest path routing

Multiplexing

Medium Access Control (CSMA-CA)
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 ICEN/ICSI 416 on network security
- Blockchain is a superb example of asserting trust in an untrustworthy system
So, what’s next ....
A Brief History of IoT

- Click here for details

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.
Fast forward to 2017

Gartner Hype Cycle for Emerging Technologies, 2017

As of July 2017

gartner.com/SmarterWithGartner

Source: Gartner (July 2017)
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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](https://www.fcc.gov/spectrumdatabase))
  - Dynamic spectrum access - 802.22, 802.11af
    - Whitespaces - unused or low utilization bands - atmospheric radar, tv [Television Spectrum Database](https://tvtelevision.com/spectrumdatabase)
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)
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]