Internet of Things
Networks - Part 2
Standards and Protocols

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Overview

- Revisit layering and encapsulation

- IoT Standards
  - What is a standard and Why is it required?
  - Challenges in standardizing the IoT ecosystem?

- IoT protocols and standards
  - Two views of IoT standards - “Thing” and “Network”
  - M2M protocols - IEEE 802.15.4
    - Zigbee, 6LoWPAN, Z-Wave
  - Non-RF Communications - Powerline Communication, Li-Fi (VLC)
  - Smart Grids and Electric Vehicles
Layering and Encapsulation
Network functions

- Billions of connected computing devices
  - Workstations, servers
  - Smartphones
  - Machine-to-machine (M2M), e.g., toasters, meters

- Communication links
  - Fiber, copper, radio, satellite
  - Transmission rate = bits/sec

- Shared media and access control

- Routers: forward packets (chunks of data)

- Networking is all about “end-to-end” reliable communication
<table>
<thead>
<tr>
<th>Layer #</th>
<th>OSI Name</th>
<th>TCP/IP Name</th>
<th>Encapsulation Units</th>
<th>Devices or Components</th>
<th>Keywords/Description</th>
<th>Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
<td>Application</td>
<td>data</td>
<td>PC / Phone/Tablet/ “Things”</td>
<td>Network services for application processes, such as file, print, messaging, database services, mobile APPs</td>
<td>FTP, HTTP, POP3, IMAP, telnet, SMTP, DNS</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
<td>Application</td>
<td>data</td>
<td></td>
<td>Standard interface to data for the application layer. data encryption, conversion, formatting, compression</td>
<td>TCP / UDP</td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
<td></td>
<td>data</td>
<td></td>
<td>Interhost communication. Establishes, manages and terminates connection between applications</td>
<td>ICMP, OSPF, RIP, BGP</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
<td>Transport</td>
<td>segments</td>
<td></td>
<td>End-to-end connections and reliability. Segmentation/desegmentation of data in proper sequence. Flow control, Congestion control</td>
<td>AM/FM, PSK, OFDM, CDMA, Modulation, Coding, Spectral Efficiency (b/s/Hz)</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
<td>Internet</td>
<td>packets</td>
<td>router</td>
<td>Logical addressing and path determination. Routing. Reporting delivery errors</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Data Link</td>
<td>Network Access</td>
<td>frames</td>
<td>bridge, switch, NIC</td>
<td>Physical addressing and access to media. Two sublayers: Logical Link Control (LLC) and Media Access Control (MAC)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
<td></td>
<td>bits</td>
<td>repeater, hub, transceiver</td>
<td>Binary transmission signals and encoding. Layout of pins, voltages, cable specifications, modulation</td>
<td></td>
</tr>
</tbody>
</table>
Why Layering

- Explicit structure allows identification, relationship of complex system’s pieces
  - Layered reference model for discussion
- Modularization eases maintenance, updating of system
  - Change of implementation of layer’s service transparent to rest of system
  - e.g., changing the network card does not change your connectivity (or redesign the app)
- Is layering considered harmful?
  - Crosslayer optimization
Encapsulation

source

destination

"Each header field specify how to decode the rest of the packet"
Encapsulation - Example

TCP Header contains source & destination port numbers

IP Header contains source and destination IP addresses; transport protocol type

Ethernet Header contains source & destination MAC addresses; network protocol type

HTTP Request

TCP header

IP header

Ethernet header

TCP header

IP header

TCP header

HTTP Request

FCS
TCP Segment

- **URG**: urgent data (generally not used)
- **ACK**: ACK # valid
- **PSH**: push data now (generally not used)
- **RST, SYN, FIN**: connection estab (setup, teardown commands)
- **Internet checksum** (as in UDP)

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>source port #</td>
<td>32 bits of source host port number</td>
</tr>
<tr>
<td>dest port #</td>
<td>32 bits of destination host port number</td>
</tr>
<tr>
<td>sequence number</td>
<td>32 bits of sequence number</td>
</tr>
<tr>
<td>acknowledgement number</td>
<td>32 bits of acknowledgement number</td>
</tr>
<tr>
<td>head len</td>
<td>16 bits of header length</td>
</tr>
<tr>
<td>not used</td>
<td></td>
</tr>
<tr>
<td>UAP</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td></td>
</tr>
<tr>
<td>Receive window</td>
<td>32 bits of receive window</td>
</tr>
<tr>
<td>checksum</td>
<td>32 bits of checksum</td>
</tr>
<tr>
<td>Urg data pnter</td>
<td>32 bits of urgent data pointer</td>
</tr>
<tr>
<td>Options (variable length)</td>
<td></td>
</tr>
<tr>
<td>application data</td>
<td>variable length of application data</td>
</tr>
<tr>
<td>(variable length)</td>
<td></td>
</tr>
</tbody>
</table>
Layering leads to “Protocol Stack” with “Abstractions”

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)
IoT Standards
Why Standards

- Enable interoperability of equipment/software from different vendors
- With open systems customers are not locked into one vendor’s solution
- Facilitate the building of a large market to reduce prices
- Standards lead to "Open Systems"
- Open systems lead to a "seamless" user environment
Problems with Standards

- Freezes technology
- Multiple standards evolve for the same system
- Standards take a long time to be established
- Difficult to evolve to meet rapidly changing needs
- Often standards are complex
- De-facto standards often emerge
Organizations

- American National Standards Institute (ANSI)
  - Manufacturers, Organizations, Government, Users
- Electronic Industries Association (EIA)
  - Electronic manufacturers
- Internet Engineering Task Force (IETF)
  - Request for Comment (RFC)
- International Telecommunications Union (ITU)
- Institute of Electrical and Electronics Engineers (IEEE)
- The 3rd Generation Partnership Project (3GPP)
Why new standard for IoT

- Too many humans, speaking too many languages
  - Should we use a translator or invent a new language and train everyone?
- Isn’t it all IP? The core is still the Internet.
  - IoT can be thought of as a lightweight Internet
- Fundamental challenges in IoT
  - More processing need more power
  - Trust and Authentication
- Isn’t WiFi ubiquitous? Is it over-provisioning for IoT?
  - Low-throughput, energy efficient waveform and RF circuits
- Are there fundamental differences with broadband communications?
Four broad areas

From AT&T foundry

● The Application layer
  o Protocols for developing IoT applications

● The Service layer
  o Being developed by oneM2M, OIC, and AllSeen

● The Network
  o IPv6, interoperability with IPv4, Scalability

● Access technologies
  o Optimize with IoT services and access networks
  o Being developed by 3GPP, IEEE 802.11 and 802.15, Bluetooth SIG, Weightless SIG, and others.
Another View

- Infrastructure (ex: 6LowPAN, IPv4/IPv6, RPL, CCN/ICN)
- Identification (ex: EPC, uCode, IPv6, URIs)
- Comms / Transport (ex: Wifi, Bluetooth, LPWAN)
- Discovery (ex: Physical Web, mDNS, DNS-SD)
- Data Protocols (ex: MQTT, CoAP, Websocket, Node)
- Device Management (ex: TR-069, OMA-DM)
- Semantic (ex: JSON-LD, Web Thing Model)
- Multi-layer Frameworks (ex: Alljoyn, IoTivity, Weave, Homekit)

A good summary of protocols (click here)
Areas need attention

- IoT Ecosystem Study
- IoT Standard Survey
- Adapting existing standards and systems

So, what is the current status of all these standards and protocols.........
IoT Protocols
“Thing” view of standards

● Representation (device manifest)
  ○ Who am I?
  ○ What can I do?
  ○ What language do I speak?
  ○ Attributes, definitions, parameters, etc

● Communication (MAC/PHY)
  ○ How to communicate with me?
    ■ protocols, headers, frame structure, etc
  ○ Radio - spectrum, roll-off, transmit power, etc

● Addressing (IP)
  ○ How to reach me?
“Network” view of standards

- Application-aware
  - Identify communication requirement based on information flow, latency, frequency, energy efficiency requirements (QoS)

- Context-aware
  - Situational, proactive, use the optimum parameters when and where it’s needed

- Network or channel-aware
  - Identify and advertise network capabilities to provide awareness of available transport options
  - Interoperability - policy-based, distributed

- Topologies and Hierarchy
  - Translators or Gateways (CoAP, HTTP other RESTful protocols)?
  - Important for network management and cost optimization
Quadruple Trust

- Protection, Security, Privacy and Safety
- Key principle - “security in depth”
- Four pillars of security
  - Secrecy, Authentication, Integrity and Availability
- Threat analysis approach for IoT entities and their interactions
  - Threat models
802.15.4

- Maintained by IEEE 802.15 working group for WPAN
  - MAC/PHY for Bluetooth is IEEE 802.15.1 standard (frozen in 2005)
- Low-Rate PAN - Specifications for PHY and MAC
- 902–928 MHz (North America) or 2400–2483.5 MHz (ISM)
- Many PHY modes
  - Modulation and coding determine data rate (20 kbps - 250 kbps)
  - Supports dynamic ad-hoc and infrastructure mode
- Range: 10 - 100 m
  - Key concept - What does it depend on and why?
- Uses spread-spectrum waveform
  - Direct-Sequence Spread Spectrum (DSSS)

<table>
<thead>
<tr>
<th>FCC band</th>
<th>Maximum transmit power</th>
<th>Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>&lt;1W</td>
<td>902 MHz–928 MHz</td>
</tr>
<tr>
<td>Scientific</td>
<td>&lt;1W</td>
<td>2.4 GHz–2.48 GHz</td>
</tr>
<tr>
<td>Medical</td>
<td>&lt;1W</td>
<td>5.725 GHz–5.85 GHz</td>
</tr>
<tr>
<td>U-NII</td>
<td>&lt;40 mW</td>
<td>5.15 GHz–5.25 GHz</td>
</tr>
<tr>
<td></td>
<td>&lt;200 mW</td>
<td>5.25 GHz–5.35 GHz</td>
</tr>
<tr>
<td></td>
<td>&lt;800 mW</td>
<td>5.725 GHz–5.82 GHz</td>
</tr>
</tbody>
</table>
Spread Spectrum (aka CDMA)

As the pulses in time get shorter, the frequency bandwidth gets larger

Time-frequency duality of Fourier transform

“Spreading” is the widening of the bandwidth of the transmitted signal

Also called “chipping code”

- Major Benefits
  - The chipping codes for every user is unique (or orthogonal)
  - Multiple devices can coexist in the same time, frequency and space (code is also known as the fourth dimension of orthogonality, hence CDMA
Media Access Control (MAC)

- **Beacon-enabled CSMA/CA**
  - Nodes wait for Beacon frame from AP
  - Extract parameters
  - Use one of the 11 slots
    - Contend using CSMA/CA
  - Or use 7 Contention free slots
  - Multiple APs coordinate to stagger Beacons

- **Non-beacon enabled CSMA/CA**
  - Used by ZigBee and 6LoWPAN
  - Devices do not “listen” permanently
Application of 802.15.4

- Various proprietary UPPER layer protocols run over 802.15.4
  - IEEE 802.15.5 - Mesh standard, routing, (dis)association,
  - 802.15.6 - Body area network, physiological sensors, implants
  - Others - ZigBee, 6LoWPAN, Bluetooth low energy for homes and others

- Does not support fragmentation and reassembly
  - Maximum MAC layer length 127 bytes (77 bytes of data)

- Security
  - Uses CCM mode - Counter with CBC-MAC
  - Authenticate using hash and secure using encryption
  - “Counter” mode is a form of block cipher
ZigBee

- Suite of high-level communication protocols with small, low-power digital radios
- **Connected Home** with ZigBee
- Application Support Sublayer (APS)
  - Multiplexing, De-multiplexing, ACK, keys
- Zigbee Device Object (ZDO)
  - Manage the role of the device, discovery
- Application Framework
  - API environment of ZigBee application developers
- Types - End Device, Router, Coordinator
- Routing - **AODV**
- **Toys** (Enter your favorite toy in the list)
ZigBee Cluster Library

- ZCL supports communication between applications (Details)
  - A cluster is a set of related commands and attribute
  - Has a client side and server side
  - Functional Domain -> Cluster ID -> Commands
  - Commands that allow devices to manipulate and report attributes

<table>
<thead>
<tr>
<th>Functional Domain</th>
<th>Cluster ID Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>0x0000 – 0x00ff</td>
</tr>
<tr>
<td>Closures</td>
<td>0x0100 – 0x01ff</td>
</tr>
<tr>
<td>HVAC</td>
<td>0x0200 – 0x02ff</td>
</tr>
<tr>
<td>Lighting</td>
<td>0x0300 – 0x03ff</td>
</tr>
<tr>
<td>Measurement and sensing</td>
<td>0x0400 – 0x04ff</td>
</tr>
<tr>
<td>Security and safety</td>
<td>0x0500 – 0x05ff</td>
</tr>
<tr>
<td>Protocol interfaces</td>
<td>0x0600 – 0x06ff</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Cluster</th>
<th>Cluster ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>0x0000</td>
</tr>
<tr>
<td>Power Configuration</td>
<td>0x0001</td>
</tr>
<tr>
<td>Identify</td>
<td>0x0003</td>
</tr>
<tr>
<td>Groups</td>
<td>0x0004</td>
</tr>
<tr>
<td>Scenes</td>
<td>0x0005</td>
</tr>
<tr>
<td>On/Off</td>
<td>0x0006</td>
</tr>
<tr>
<td>On/Off Switch Configuration</td>
<td>0x0007</td>
</tr>
<tr>
<td>Level Control</td>
<td>0x0008</td>
</tr>
<tr>
<td>Alarms</td>
<td>0x0009</td>
</tr>
<tr>
<td>Time</td>
<td>0x000A</td>
</tr>
<tr>
<td>Binary Input (Basic)</td>
<td>0x000F</td>
</tr>
<tr>
<td>Commissioning</td>
<td>0x0015</td>
</tr>
<tr>
<td>Door Lock</td>
<td>0x0101</td>
</tr>
<tr>
<td>Thermostat</td>
<td>0x0201</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Command Identifier</th>
<th>Field Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td></td>
<td>Read attributes</td>
</tr>
<tr>
<td>0x01</td>
<td></td>
<td>Read attributes response</td>
</tr>
<tr>
<td>0x02</td>
<td></td>
<td>Write attributes</td>
</tr>
<tr>
<td>0x03</td>
<td></td>
<td>Write attributes undivided</td>
</tr>
<tr>
<td>0x04</td>
<td></td>
<td>Write attributes response</td>
</tr>
<tr>
<td>0x05</td>
<td></td>
<td>Write attributes no response</td>
</tr>
</tbody>
</table>
ZigBee Application Profile

- Defines a set of messages and attributes for use in a particular context
- Profile lists mandatory and optional clusters specific to each device type

<table>
<thead>
<tr>
<th>Public Application Profile</th>
<th>Profile ID</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Automation</td>
<td>HA 0x0104</td>
<td>Security, HVAC, LIGHTING CONTROL, ACCESS CONTROL, IRRIGATION...</td>
</tr>
<tr>
<td>Commercial Building Automation</td>
<td>CBA 0x0105</td>
<td>Security, HVAC, AMR, lighting control, access control</td>
</tr>
<tr>
<td>Industrial Plant Monitoring</td>
<td>IPM 0x0101</td>
<td>Asset management, process control, environmental control, energy management</td>
</tr>
<tr>
<td>Telecommunications Applications</td>
<td>TA 0x0107</td>
<td>Information delivery in hot zones, public information enquiry, location-based services, remote control (TV, DVD), cell phone</td>
</tr>
<tr>
<td>Automatic (Advanced) Metering Initiative or Smart Energy 1</td>
<td>AMI 0x0109</td>
<td></td>
</tr>
<tr>
<td>ZSE 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal Home and Hospital (Health) Care</td>
<td>PHHC 0x0108</td>
<td>Patient monitoring, Fitness monitoring.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Device name</th>
<th>Device ID</th>
<th>Supported clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic</td>
<td>0x0103</td>
<td>Ms: OnOff (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Os: OnOffSwitchConfig (0x0007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Groups (0x0004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Identify (0x0003)</td>
</tr>
<tr>
<td>Range Extender</td>
<td>0x0008</td>
<td>Only common clusters</td>
</tr>
<tr>
<td>Mains Power Outlet</td>
<td>0x0009</td>
<td>Ms: OnOff (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Groups (0x0004)</td>
</tr>
<tr>
<td>Lighting</td>
<td>0x0100</td>
<td>Ms: OnOff (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Groups (0x0004)</td>
</tr>
<tr>
<td>DimmableLight</td>
<td>0x0101</td>
<td>Ms: OnOff (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Groups (0x0004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Occupancy sensing (0x0406)</td>
</tr>
<tr>
<td>Light Sensor</td>
<td>0x0106</td>
<td>Ms: Illuminance measurement (0x0400)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Groups (0x0004)</td>
</tr>
<tr>
<td>DimmerSwitch</td>
<td>0x0104</td>
<td>Ms: OnOff (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: OnOff switch configuration (0x0007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Groups (0x0004)</td>
</tr>
<tr>
<td>Closures</td>
<td>Shade</td>
<td>Ms: OnOff (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: OnOff switch configuration (0x0007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: Groups (0x0004)</td>
</tr>
<tr>
<td>Shade Controller</td>
<td>0x0201</td>
<td>Ms: OnOff (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ms: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Shade configuration (0x0100)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Groups (0x0004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: Identify (0x0003)</td>
</tr>
</tbody>
</table>
ZigBee Smart Energy 2.0 and 6LoWPAN

- **ZigBee Smart Energy 2.0**
  - Joint work between ZigBee and HomePlug
  - Key addition - IP based and RESTful design

- **6LoWPAN** is the adaptation layer for IPv6 over 802.15.4 MAC-PHY
  - Neighbor discovery, encapsulation and header compression mechanisms

- **IETF ROLL RPL Routing** - Routing Over Low power and Lossy networks

Multiple Subnet *(v6ops)*
RESTful service (API)

- REST == REpresentational State Transfer
- Resource based vs Action based
  - Anything can be a resource and can be addressed using a URL
- Constraints
  - Uniform Interface, Stateless, Cacheable
  - Client-Server, Layered System, Code on Demand (optional)
- REST asks developers to use HTTP methods - GET, PUT, POST DELETE
- Good overview [Tutorial](#), [Data Models](#)
- More [resources](#)
REST Examples

Listings One: JSON representation of a resource.
{
  "ID": "1",
  "Name": "M Vaqqas",
  "Email": "m.vaqqas@gmail.com",
  "Country": "India"
}

Listings Two: XML representation of a resource.
<Person>
  <ID>1</ID>
  <Name>M Vaqqas</Name>
  <Email>m.vaqqas@gmail.com</Email>
  <Country>India</Country>
</Person>

Representation that can accessed by an URI “http://MyService/Persons/1”

A stateless design looks like so:
Request1: GET http://MyService/Persons/1 HTTP/1.1
Request2: GET http://MyService/Persons/2 HTTP/1.1
Each of these requests can be treated separately.

A stateful design, on the other hand, looks like so:
Request1: GET http://MyService/Persons/1 HTTP/1.1
Request2: GET http://MyService/NextPerson HTTP/1.1

Stateless: Each request is independant and self contained
CoAP

● Constrained Application Protocol
  ○ Based on the REST architecture

● Request/response interaction model between application endpoints
  ○ Servers make resources available under a URL, and clients access these resources using methods such as GET, PUT, POST, and DELETE.

● Many tools and resources are here

● Good tutorials - [1], [2]
Bluetooth Low Energy (ZigBee Competitor)

- Best suited for “short range wireless” communication
  - Which are state based - low Bandwidth, low latency
- Energy is lost in
  - Maintaining connection (TCP retransmissions)
  - Peak current is 25mA
- New feature - Asynchronous connection-less MAC
- For Bluetooth low energy, data throughput is not a meaningful parameter
  - It does not support streaming. It has a data rate of 1Mbps, but is not optimised for file transfer
Z-Wave Alliance

- Operates in the sub-1 GHz band
  - Impervious to interference from Wi-Fi and other wireless technologies in the 2.4-GHz range (Bluetooth, ZigBee, etc.)
- Data rates of up to 100kbps, with AES 128 encryption, IPV6, and multi-channel operation
- Dev-kits
- ZigBee and ZWave Comparison
LoRA Alliance

- Physical layer (waveform specs) for Low Power and Long Range
- Uses spread spectrum techniques to enable low power communication
- Covers hundreds of sq. miles with one base stations

![Comparison Chart]

- Whitepaper with more details [Link]
Energy Harvesting
PowerLine Communication

- Utilize power cables to send information
  - Narrow band PLC (3-500 KHz, upto 100 kbps) - utility metering, inter-grid communication
  - Broadband PLC (1.8-250 MHz, 100s Mbps) - last mile, home networking, etc.

- Can be used to communicate between any electrical devices, even grids
- Standard baseband modulation techniques applied to a carrier signal
- Need coupling transformer and filters

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>Low Data Rate</th>
<th>Medium Data Rate</th>
<th>High Data Rate</th>
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<tr>
<td></td>
<td>0-10kbps</td>
<td>10kbps-1Mbps</td>
<td>&gt;1Mbps</td>
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<td>Modulation</td>
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<td>PSK+OFDM</td>
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<td>Upto 500kHz frequency</td>
<td>Upto 500kHz</td>
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<td>Applications</td>
<td>Control and Command</td>
<td>Control and command, Voice</td>
<td>Broadband over powerline, home networking</td>
</tr>
</tbody>
</table>
Visible Light Communication (Li-Fi)

- Visible spectrum - 400 and 800 THz
- Visible light is the carrier (equivalent to 2.4GHz ISM band for WiFi)
- Challenge is in modulating the super high frequency carrier
  - How do you modulate (and detect) visible light?

- Disney Research VLC page
- It’s more about the PHY than the MAC.