Internet of Things Networks - Part 2

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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
## Layering

<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></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></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>TCP / UDP</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>ICMP, OSPF, RIP, BGP</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>CSMA/CA, Ethernet, Token Ring</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>AM/FM, PSK, OFDM, CDMA, Modulation, Coding, Spectral Efficiency (b/s/Hz)</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 application)

● Is layering considered harmful?
  ○ Crosslayer optimization
Each header field specifies 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

HTTP Request

IP header

TCP header

HTTP Request

Ethernet header

IP header

TCP header

HTTP Request

FCS
TCP Segment

- **source port #**
- **dest port #**
- **sequence number**
- **acknowledgement number**
- **Receive window**
- **checksum**
- **Urg data ptr**
- **Options (variable length)**
- **application data (variable length)**

**Fields and Flags:**
- **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)**
- **# bytes rcvr willing to accept**
- **counting by bytes of data (not segments!)**
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?
- 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

Steve Deering IP hourglass model
Four broad areas

From AT&T foundry

- The Application layer
  - Protocols for developing IoT applications
- The Service layer
  - Being developed by oneM2M, OIC, and AllSeen
- The Network
  - IPv6, interoperability with IPv4, Scalability
- Access technologies
  - Optimize with IoT services and access networks
  - Being developed by 3GPP, IEEE 802.11 and 802.15, Bluetooth SIG, Weightless SIG, and others.
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
It’s a Fan!

It’s a Wall!

It’s a Spear!

It’s a Snake!

It’s a Tree!

It’s a Rope!
“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)**

- **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)

**Time-frequency duality of Fourier transform**

"Spreading" is the widening of the bandwidth of the transmitted signal

Also called "chipping code"
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

CBC-MAC
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</td>
<td>AMI 0x0109</td>
<td>Patient monitoring, Fitness monitoring.</td>
</tr>
<tr>
<td>Smart Energy 1</td>
<td>ZSE 1</td>
<td>Patient monitoring, Fitness monitoring.</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>Supported clusters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo/Ms: mandatory on client or server side</td>
<td></td>
</tr>
<tr>
<td>Oc/Os: optional on client or server side</td>
<td></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>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: On/OffSwitch Config (0x0007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Groups (0x0004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Identify (0x0003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Only common clusters</td>
</tr>
<tr>
<td>Range Extender</td>
<td>0x0008</td>
<td>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td>Mains Power Outlet</td>
<td>0x0009</td>
<td>Mo: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Groups (0x0004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Identify (0x0003)</td>
</tr>
<tr>
<td>Lighting</td>
<td>0x0100</td>
<td>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Groups (0x0004)</td>
</tr>
<tr>
<td>DimmableLight</td>
<td>0x0101</td>
<td>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: 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>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: On/Off 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>DimmerSwitch</td>
<td>0x0104</td>
<td>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oc: On/Off 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></td>
<td></td>
<td>Oc: Identify (0x0003)</td>
</tr>
<tr>
<td>Closures</td>
<td>0x0200</td>
<td>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: LevelControl (0x0008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: On/Off switch configuration (0x0007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Scenes (0x0005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: Groups (0x0004)</td>
</tr>
<tr>
<td>Shade</td>
<td>0x0201</td>
<td>Mo: On/Off (0x0006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo: 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>Shade Controller</td>
<td>0x0201</td>
<td>Mo: On/Off (0x0006)</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

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

HTTP Request / Response using verbs

Example POST request
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

Click here for more details
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
Energy Harvesting

- Lightning talk by Preston
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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-10kbps</td>
<td>10kbps-1Mbps</td>
<td>&gt;1Mbps</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK, FSK, SFSK, QAM</td>
<td>PSK+OFDM</td>
<td>PSK+OFDM</td>
</tr>
<tr>
<td>Standards</td>
<td>IEC 61334, ANSI/EIA 709.1, 2, UPB</td>
<td>PRIME, G3, P1901.2</td>
<td>G.hn, IEEE 1901</td>
</tr>
<tr>
<td>Frequency range</td>
<td>Upto 500kHz frequency</td>
<td>Upto 500kHz frequency</td>
<td>In MHz</td>
</tr>
<tr>
<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.

Source - Disney Research publication - Linux Light Bulbs: Enabling Internet Protocol Connectivity for Light Bulb Networks