Data-Link Layer and Management Protocols for IoT

Raj Jain
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

These slides and audio/video recordings of this class lecture are at:
http://www.cse.wustl.edu/~jain/cse570-18/

Overview

- Recent Protocols for IoT
- Power Line Communication (PLC)
- HomePlug, HomePlug AV, HomePlug AV2, BPL, Netricity
- IEEE 1905.1 Management, Security, and Configuration
- Smart Cards

Note: This is part 2 of a series of class lectures on IoT.
Wireless datalink protocols are covered in CSE 574 Wireless Network Class. More protocols are covered in other parts of this series.

Recent Protocols for IoT

		Security	Management
Session	MQTT, SMQTT, CoRE, DDS, AMQP , XMPP, CoAP, IEC, IEEE 1888, …	IEEE 1888.3, TCG, Oath 2.0, SMACK, SASL, EDSA, ace, DTLS, Dice, …	IEEE 1905, IEEE 1451, IEEE 1377, IEEE P1828, IEEE P1856
Network	Encapsulation 6LowPAN, 6TiSCH, 6Lo, Thread… Routing RPL, CORPL, CARP		
Datalink	WiFi, Bluetooth Low Energy, Z-Wave, ZigBee Smart, DECT/ULE, 3G/LTE, NFC, Weightless, HomePlug GP, 802.11ah, 802.15.4e, G.9959, WirelessHART, DASH7, ANT+, LTE-A, LoRaWAN, ISA100.11a, DigiMesh, WiMAX, …		

Ref: Tara Salman, Raj Jain, "A Survey of Protocols and Standards for Internet of Things," Advanced Computing and Communications, Vol. 1, No. 1, March 2017, http://www.cse.wustl.edu/~jain/papers/iot_accs.htm

L2 Protocols for IoT

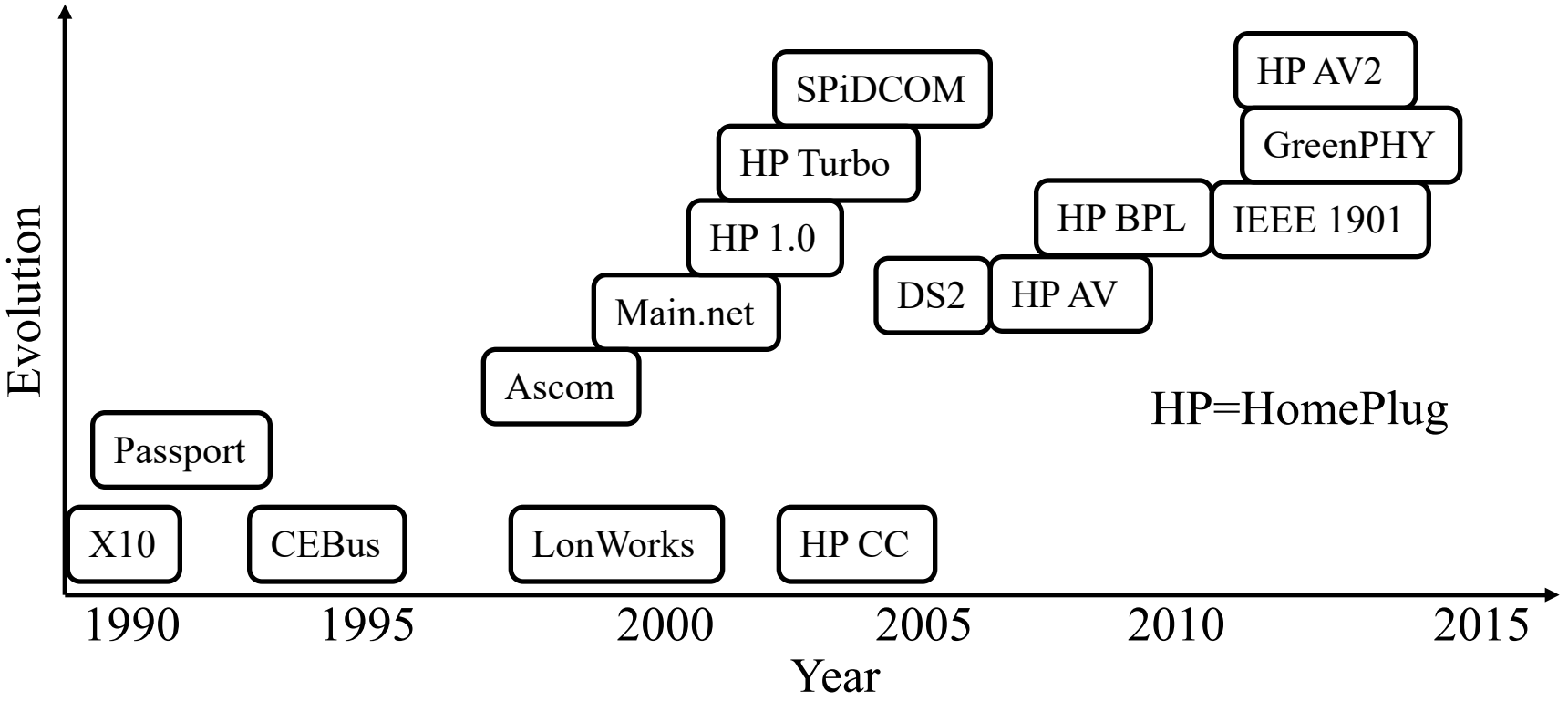
Most of the L2 IoT protocols are wireless.

- **Wireless Protocols**: WiFi, Bluetooth Low Energy, Z-Wave, ZigBee Smart, DECT/ULE, 3G/LTE, NFC, Weightless, IEEE 802.11ah, IEEE 802.15.4, G9959, WirelessHart, DASH7, ANT+, LTE-A, LoraWAN, ISA 100.11a, DigiMesh, etc. These are covered in CSE 574 Wireless and Mobile Networking class.
- **Wired Protocols**: In this lecture, we cover Powerline Communications (HomePlug GP) and associated management protocols

Ref: Raj Jain, "CSE574S: Wireless and Mobile Networking (Spring 2016)," http://www.cse.wustl.edu/~jain/cse574-16/index.html

Power Line Communication (PLC)

- Started in 1950 for remote ignition and lighting of street lights. 100 Hz and 1 kHz signals over electrical wires
- Two way systems using 3-148.5 kHz for reading electric meters, and home automation, alarms etc.



Ref: H. Chaouchi, "The Internet of Things: Connecting Objects," Wiley, Jun 2010, 288 pp., ISBN: 9781848211407 (Safari Book)

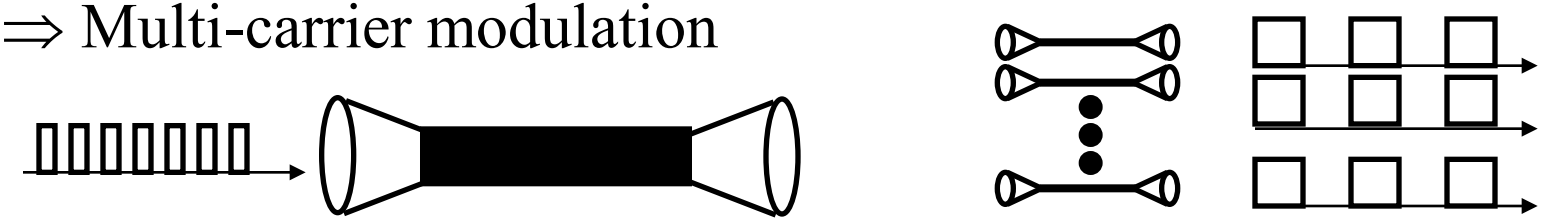
Broadband Over Power Lines (BPL)

- High-speed internet connection using power lines (like DSL)
- Also known as HomePlug-BPL. Incorporated in IEEE 1901-2010
- Not cost competitive with optical fiber or DSL
  ⇒ Suitable only for remote locations
- High-frequency signal cannot pass through transformers and so the signal has to be bypassed using a repeater
- In US, 1 transformer per house ⇒ Very expensive
  In Europe: 1 transformer per 10-100 houses
  ⇒ More cost effective
- Radio frequency interference with existing wireless services is avoided using OFDM

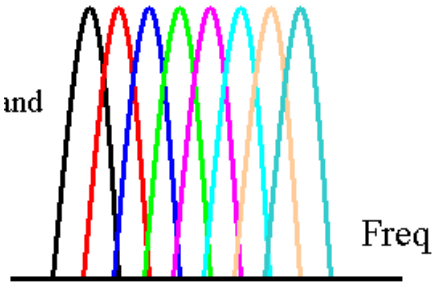
Ref: http://en.wikipedia.org/wiki/Broadband_over_power_lines

OFDM

- Orthogonal Frequency Division Multiplexing
- Ten 100 kHz channels are better than one 1 MHz Channel
  ⇒ Multi-carrier modulation



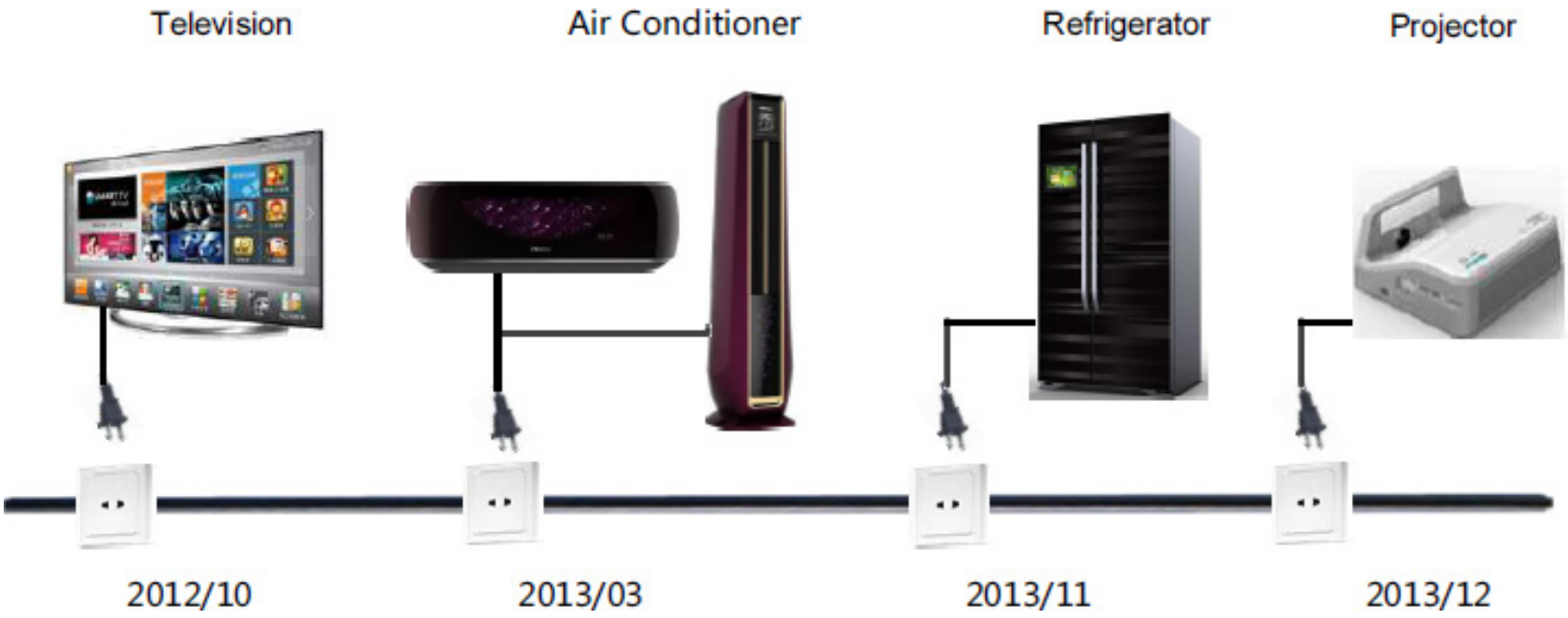
- Frequency band is divided into 256 or more sub-bands.
  Orthogonal ⇒ Peak of one at null of others
- Each carrier is modulated with a **BPSK** (2bps/Hz), **QPSK** (4 bps/Hz), **16-QAM** (8bps/Hz), **64-QAM** (16 bps/Hz) etc depending on the noise (Frequency selective fading)
- Used in 802.11a/g, 802.16,
  Digital Video Broadcast handheld (DVB-H)
- Easy to implement using FFT/IFFT



HomePlug

- HomePlug 1.0
- HomePlug AV
- HomePlug AV2
- HomePlug GP
- HomePlug BPL

Connected Home

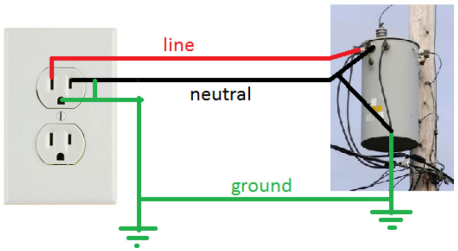


HomePlug AV

- HomePlug Alliance: Industry consortium for power line communications Disbanded in October 2016.
- 90% of PLC devices use HomePlug
- 1.8 MHz to 30 MHz spectrum = 28 MHz ⇒ 20 to 200 Mbps
- Multipath distortion
- **Orthogonal Frequency Division Multiplexing (OFDM):** Using 1155 carriers at 24.414 kHz spacing of which 917 are used for signal. Rest as pilots.
- **Adaptive bit loading**: Each carrier is modulated based on the noise level and multipath at that frequency.
  2-bits/symbol to 10 bits/symbol.
- **Tone Maps**: Each receiver keeps a table of signal strengths from each of the other receivers ⇒ n-1 tone maps in a n-device system

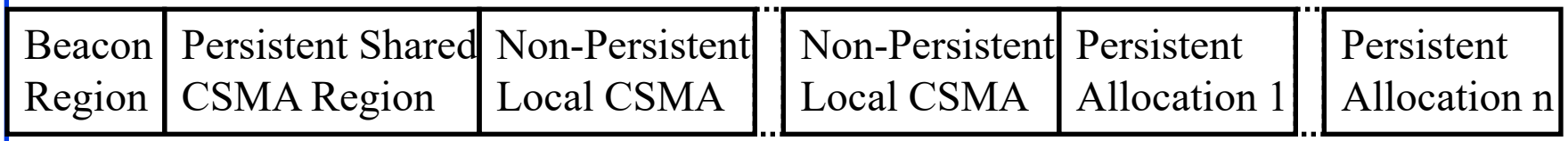
HomePlug AV (Cont)

- **Robust OFDM** (ROBO) mode for highly reliable transmission. The same information is transmitted on 2-5 subcarriers using a low-bit rate modulation
- Use only Line-neutral pair (ground is not used)
- Four channel access priorities
- MAC is similar to that of WiFi
  ⇒ **Carrier Sense Multiple Access (CSMA).**
- All devices part of the same trust domain form a "**AV Logical Network** (AVLN)."
- All members of the AVLN share a Network Membership Key 128-bit AES.
- Each AVLN has a **central coordinator (CCo)**



HomePlug AV (Cont)

- CCo transmits beacons containing schedule
- Long best effort transmissions declare their queues to CCo and use a pre-allocated **persistent shared CSMA** region
- Short best effort transmissions use **non-persistent CSMA** region.
- Real-time traffic uses periodic time division multiple access (TDMA) allocation in the **contention-free** period
- Before video transmission, the transmitter tests the channel for achievable throughput. Helps determine the required transmission interval per beacon period



HomePlug AV Security

- A station can participate in a AVLN if it has the **Network membership key (NMK)**.
  A station with multiple keys can participate in multiple AVLNs.
- All devices have a default NMK and so can form the network. Users should program the devices to use specific NMK.
- Once a devices has a NMK, it will be given the **network encryption key** which is used to encrypt the data.
- If there are multiple networks on the same wire, CCos coordinate their transmission schedules

HomePlug AV2

- Gigabit networking using home powerline wiring. Peak PHY rate of 1.256 Gbps. 600 Mbps net throughput.
- Can transmit multiple HD video streams
- Compatible with HomePlug AV devices on the same wires

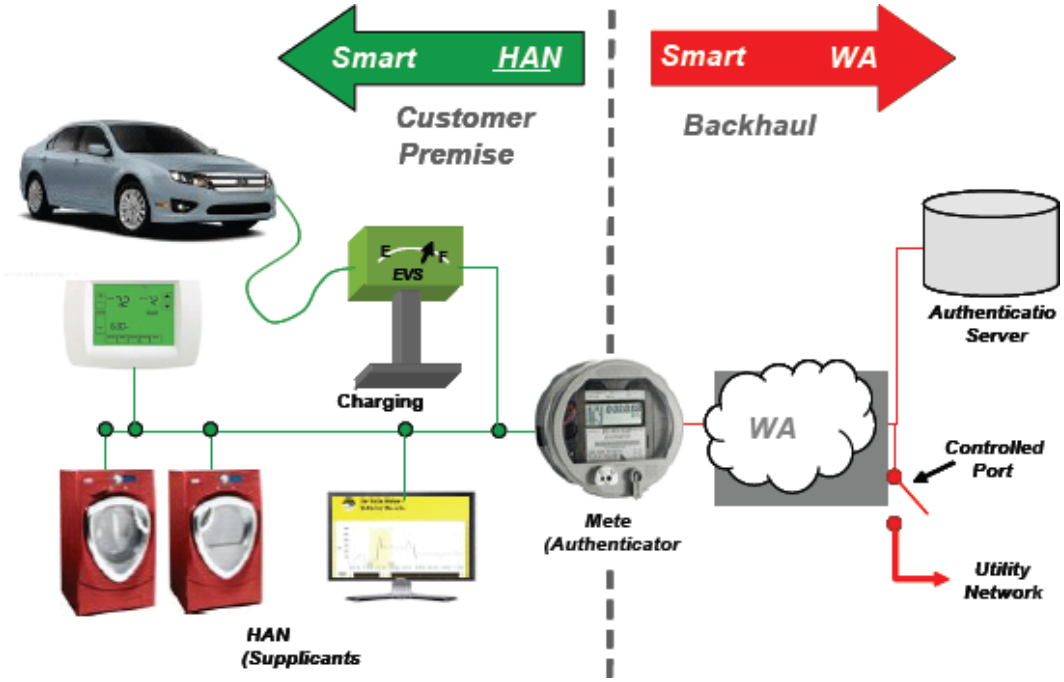
1. **Additional Spectrum**: 2MHz-86MHz (84 MHz)
2. **Multiple-input Multiple-output (MIMO)**: transmissions using two wires with three-wire configuration (Line-Neutral, Line-Ground, Neutral-Ground)
3. **Beam forming**: Bit loading for each transmitter
4. **Lower overhead**: Shorter packet delimiter and delay acks.
5. **Efficient notching**: Of noisy carriers

HomePlug AV2 (Cont)

6. **Repeating**: Signal is demodulated and re-modulated at intermediate devices
7. **Better coding**: 12 bps/Hz and aggressive code rates (8/9)
8. **Power Control**: Manage transmission power to enhance coverage and throughput
9. **Power Save**: Stations can declare sleep periods. Other transmit only when the destination is awake.

HomePlug GreenPHY

- Designed for **home area network (HAN)** for monitoring and control of energy consuming/controlling devices including electric vehicle charging.
- Low cost. Low power. Low data rate version of HomePlug AV.

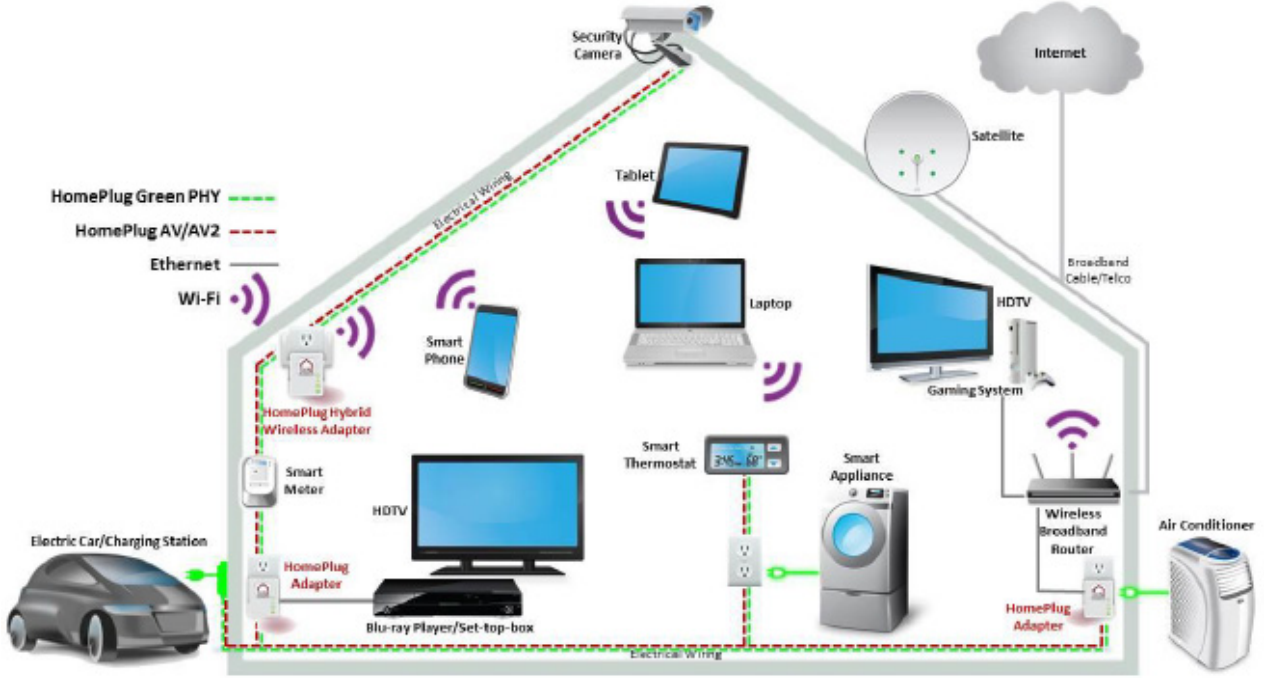


HomePlug GP (Cont)

- HomePlug GP is a profile of **IEEE 1901-2010** standard for Powerline Networks and is compatible with HomePlug AV and HomePlug AV2.
- 28 MHz ⇒ 256 kbps to 10 Mbps using only one modulation
  No tone maps.
- Use 75% less power than HomePlug AV.
  75% less bill of materials
- Devices coordinate their sleep cycle and may sleep for 2^n beacon intervals, n=1,..,10
- HomePlug GP 1.1 adds new power management and features for electric vehicles. Secure billing is possible at a public charging station.

Convergent Digital Home Network

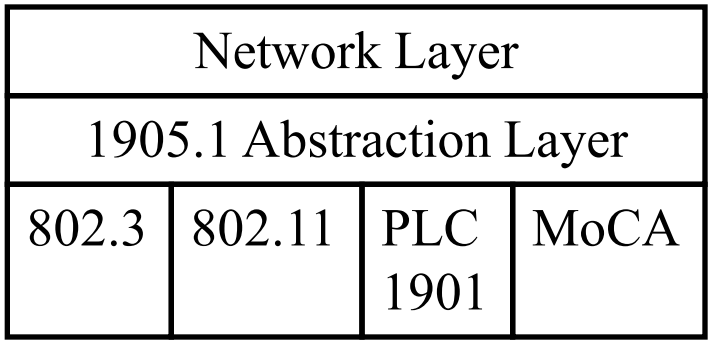
- IEEE 1905.1-2013 Convergent Digital Home Network for Heterogeneous Technologies
- Combined use of WiFi, HomePlug, Ethernet, Multimedia over Coax (MoCA) in a home



Ref: http://en.wikipedia.org/wiki/IEEE_1905

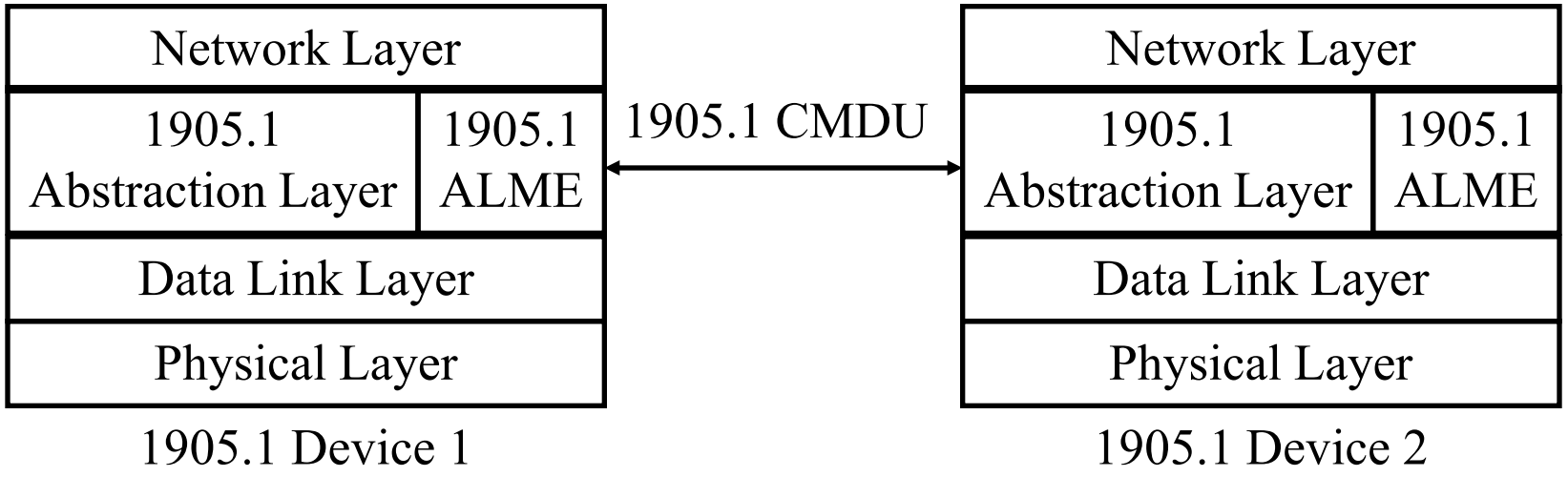
Convergent Digital Home (Cont)

- Entire home looks like a single network with automated provisioning, management, and operation
- Allows a device to aggregate throughput from multiple interfaces
- A link can be used fallback when another link fails
- An abstraction layer is used to exchange **Control Message Data Unit (CMDU)** among 1905.1 compliant devices
- No changes to underlying technologies is required.



IEEE 1905.1 Management

- 1905.1 compliant devices speak Abstraction Layer Management Entity (ALME) Protocol



IEEE 1905.1 Management (Cont)

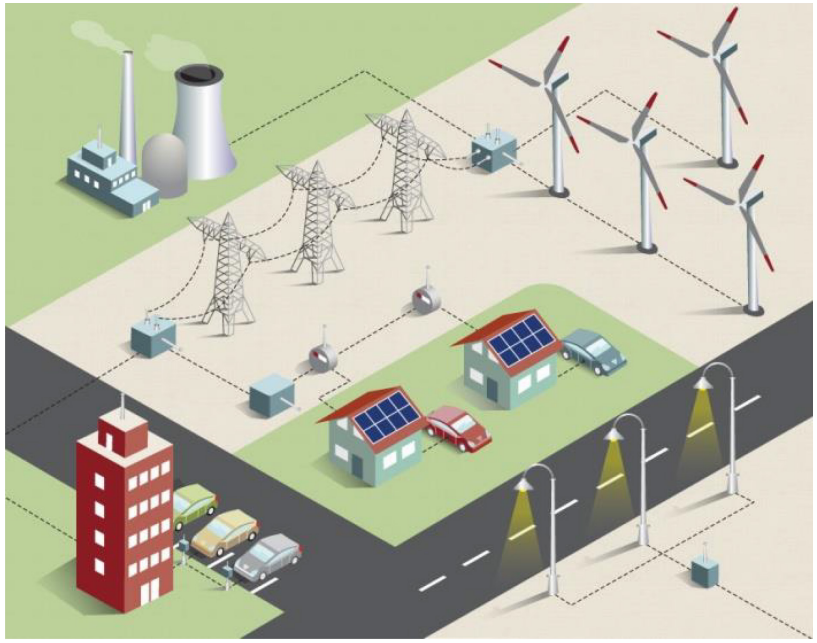
- ALME has messages for
  - Neighbor discovery,
  - Topology exchange,
  - Topology change notification,
  - Measured traffic statistics exchange,
  - Flow forwarding rules, and
  - Security associations
- HomePlug AV2 can be used as a backbone for Wi-Fi
- Existing IEEE 802.1 bridging protocols are used for loop prevention and forwarding

IEEE 1905.1 Security and Configuration

- Security Setup:
  - **Push Button**: Press buttons on new and existing devices The new device gets the keys from the existing device
  - User can configure **passphrase/key** in the new device
  - **NFC**: User touches the new device with a NFC equipped smart phone which is existing member of the network
- Auto configuration:
  - New Access Points (APs) can get configuration information from existing APs
- The certification program for IEEE 1905.1 is called "**nVoy**" Connects disparate networks = Network Diplomat = Network Envoy ⇒ nVoy
- Qualcomm Atheros products implementing IEEE 1905.1 are called **Hy-Fi** (for Hybrid Fidelity)

Netricity

- Long-range outside-the-home PLC for smart grid applications
- Certification for IEEE 1901.2 Low Frequency, Narrowband Powerline Communications Standard is called "Netricity"



Industrial Ethernet

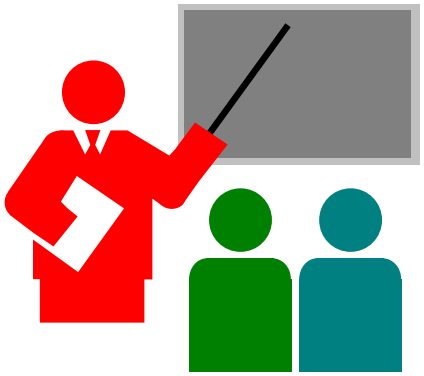
- Same as regular Ethernet but with rugged connectors and designed for extended temperature/humidity environment
- Full duplex links (no CSMA/CD)
- Optical fibers (electrical interference)
- Min frame size of 64 byte may be too big for some applications

Ref: http://en.wikipedia.org/wiki/Industrial_Ethernet

IEEE 1451

- Set of smart transducer interface for sensors and actuators
- Transducer electronic data sheets (TEDS) is a memory device that stores transducer id, calibration, correction data, and manufacturer information
- Allows access to transducer data regardless of wired or wireless connection
- XML based ⇒ Allows manufacturers to change the contents

Ref: http://en.wikipedia.org/wiki/IEEE_1451



Summary

1. A number of datalink protocols have been proposed for IoT. Among non-wireless protocols, the most common is HomePlug.
2. HomePlug has been extended to provided higher data rate of up to 600 Mbps by HomePlug AV2 standard and to a energy saving HomePlug GP.
3. IEEE 1905.1 provides an abstraction layer to hide the details of various datalink layers, such as, ZigBee, HomePlug, WiFi, …

Reading List

- Tara Salman, Raj Jain, "A Survey of Protocols and Standards for Internet of Things," Advanced Computing and Communications, Vol. 1, No. 1, March 2017, http://www.cse.wustl.edu/~jain/papers/iot_accs.htm
- HomePlug Alliance, "HomePlug AV White Paper," https://www.solwise.co.uk/downloads/files/hpav-white-paper_050818.pdf
- HomePlug Alliance, "HomePlug AV2 Technology," https://www.codico.com/fxdata/codico/prod/media/Datenblaetter/AKT/HomePlug_AV2_whitepaper_20130909.pdf
- HomePlug Alliance, "HomePlug GreenPHY Overview," http://groups.homeplug.org/tech/whitepapers/HomePlug_GreenPHY_Overview.pdf

Additional Reading

- H. Chaouchi, "The Internet of Things: Connecting Objects," Wiley, Jun 2010, 288 pp., ISBN: 9781848211407 (Safari Book)
- H. Zhou, "The Internet of Things in the Cloud: A middleware Perspective," CRC Press, 2013, 366pp., ISBN:9781439892992 (Safari Book)
- Dave Evans, "The Internet of Things: How the Next Evolution of the Internet Is Changing Everything,", Cisco white paper, April 2011, https://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

Wikipedia Links

- http://en.wikipedia.org/wiki/IEEE_1905
- http://en.wikipedia.org/wiki/IEEE_1901
- http://en.wikipedia.org/wiki/Broadband_over_power_lines
- http://en.wikipedia.org/wiki/Power_line_communication
- http://en.wikipedia.org/wiki/HomePlug
- http://en.wikipedia.org/wiki/Cyber-physical_system
- http://en.wikipedia.org/wiki/HomePlug_Powerline_Alliance
- http://en.wikipedia.org/wiki/MIMO
- http://en.wikipedia.org/wiki/SCADA
- http://en.wikipedia.org/wiki/Smart_grid
- http://en.wikipedia.org/wiki/G.hn
- http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing
- http://en.wikipedia.org/wiki/IEEE_Smart_Grid
- http://en.wikipedia.org/wiki/Fieldbus
- http://en.wikipedia.org/wiki/Industrial_Ethernet
- http://en.wikipedia.org/wiki/IEEE_1451

Wikipedia Links (Cont)

- http://en.wikipedia.org/wiki/List_of_broadband_over_power_line_deployments
- http://en.wikipedia.org/wiki/Qualcomm_Atheros
- http://en.wikipedia.org/wiki/G.9972
- http://en.wikipedia.org/wiki/Home_network
- http://en.wikipedia.org/wiki/SPiDCOM
- http://en.wikipedia.org/wiki/Smart_meter
- http://en.wikipedia.org/wiki/IEC_62196

Acronyms

- 6LowPAN IPv6 over Low Power Wireless Personal Area Network
- AES Advanced Encryption
- ALME Abstraction Layer Management Entity
- AMQP Advanced Queueing Message Protocol
- AP Access Point
- AV Audio-Visual
- AVLN Audio-Visual Logical Network
- BPL Broadband Over Power Lines
- BPSK Binary Phase-Shift Keying
- CCo Central Coordinator
- CD Collision Detection
- CEBus Consumer Electronic Bus
- CMDU Control Message Data Unit
- CoAP Constrained Application Protocol
- CP Cyber Physical

Acronyms (Cont)

- CPS Cyber Physical Systems
- CSIA Cyber Security and Information Assurance
- CSMA Carrier Sense Multiple Access
- CSMA/CD Carrier Sense Multiple Access with Collision Detection
- DARPA Defense Advance Research Project Agency
- DCS DIstributed Control Systems
- DECT Digital Enchanced Cordless Telephony
- DOE Department of Energy
- DS2 Design of Systems on Silicon (name of a company)
- DSL Digital Subscriber Line
- DVB-H Digital Video Broadcast handheld
- ECMA European Computer Manufacturers Association
- FFT Fast Fourier Transform
- GE General Electric
- GP Green PHY
- GreenPHY Green Physical Layer

Acronyms (Cont)

- HAN Home Area Network
- HCSS High Confidence Software and Systems
- HD High Definition
- HDLC High-Level Datalink Control
- HEC High-End Computing
- HP HomePlug
- HPAV HomePlug Audio-Visual
- ID Identifier
- IEC International Electrotelecommunications Commission
- IEEE Institution of Electrical and Electronic Engineers
- IFFT Inverse Fast Fourier Transform
- IM Information Management
- IoT Internet of Things
- IP Internet Protocol
- IPv6 Internet Protocol V6
- ISO International Standards Organization

Acronyms (Cont)

- IT Information Technology
- kHz Kilo Hertz
- LonWorks Local Operating Network
- LSN Large Scale Networking
- MAC Media Access Control
- MHz Mega Hertz
- MIMO Multiple-input Multiple-output
- MoCA Multimedia over Coax
- MQ Multi-Queue
- MQTT MQ Telemetry Transport
- NASA National Aeronautical and Space Administration
- NFC Near Field Communication
- NIH National Institute of Health
- NITRD Networking and Info Technology Res and Development
- NMK Network Membership Key
- NSF National Science Foundation

Acronyms (Cont)

- OAuth Open Standard for Authorization
- OFDM Orthogonal Frequency Division Multiplexing
- ONR Office of Naval Research
- PHY Physical Layer
- PLC Power Line Communication
- PROFIBUS Process Field Bus
- QAM Quadrature Amplitude Modulation
- QPSK Quadrature Phase Shift Keying
- RF Radio Frequency
- RFID Radio Frequency Identification
- RPL Routing Protocol for Low Power and Lossy Networks
- SCADA Supervisory Control and Data Acquisition
- SDP Software Design and Productivity
- SPiDCOM Name of a company
- TDMA Time division multiple access
- TEDS Transducer electronic data sheets

Acronyms (Cont)

- US United States
- WiFi Wireless Fidelity
- WorldFIP Factory Instrumentation Protocol
- XML Extensible Markup Language

Scan This to Download These Slides

Raj Jain
http://rajjain.com

Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Wireless and Mobile Networking (Spring 2016),
https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs_HCd5c4wXF

CSE571S: Network Security (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw