M2M Wired/Wireless Protocols

Embedded Interface Design

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Learning Objectives

- Students will be able to…
  - Recognize common M2M wired and wireless protocols
  - Compare and contrast protocol use in designs and applications

M2M/IoT Wireless Protocols – Network Types

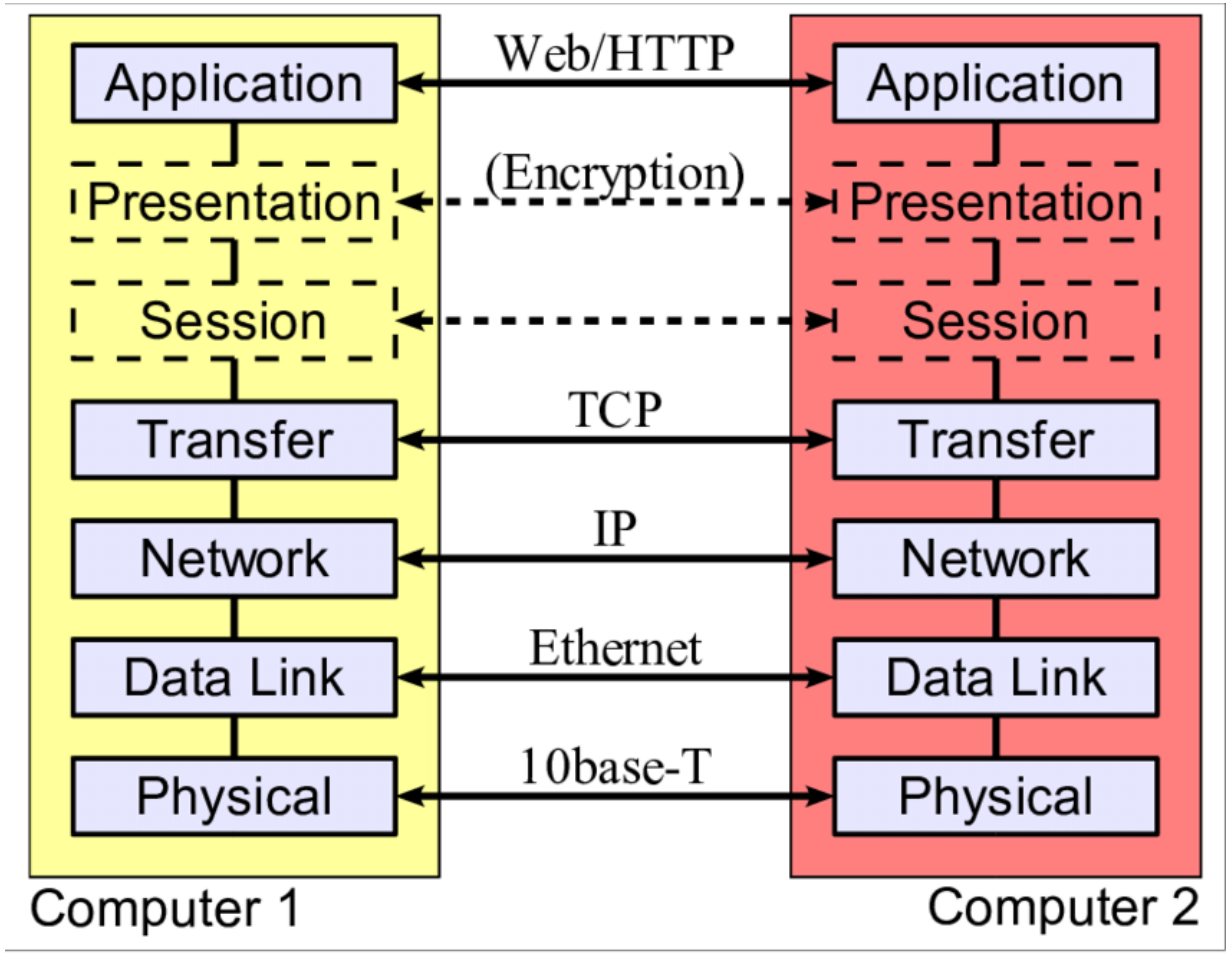
- WAN: Wide Area Network – longest range – miles/kilometers
  - MAN: Metropolitan Area Network
  - CAN: Campus Area Network, Controller Area Network, or sometimes Cluster Area Network
- WLAN: Wireless Local Area Network – buildings, local areas – 10s to 100s of meters
- LAN: Local Area Network – smaller, generally wired network – 10s of meters
- PAN: Personal Area Network – personal level devices – ex. phone to earphones – directly adjacent
- https://www.lifewire.com/lans-wans-and-other-area-networks-817376

M2M Wired Protocols - Ethernet

- Generally used for Wired LANs (Local Area Networks)
- Ethernet (IEEE 802.3) [1]
  - 10BASE-T (10 Mbit/s) – Unshielded twisted pair, 8 conductor, 100m range
  - Key network enabler for most of the planet
  - 10BASE-F – 2 Strand Optical Fiber, 2 km range
  - 100BASE-T (100 Mbin/s) – Unshielded twisted pair, 8 conductor, 100m (if cable supports)
  - 1000BASE-T (1 Gbit/s) - Unshielded twisted pair, 8 conductor, 100m (if cable supports)
  - Also 10GBase-T, 100Base-T versions
- Networks: Bus or star topologies with hubs, switches, repeaters etc. – supports many devices (based on IP addressing schemes)

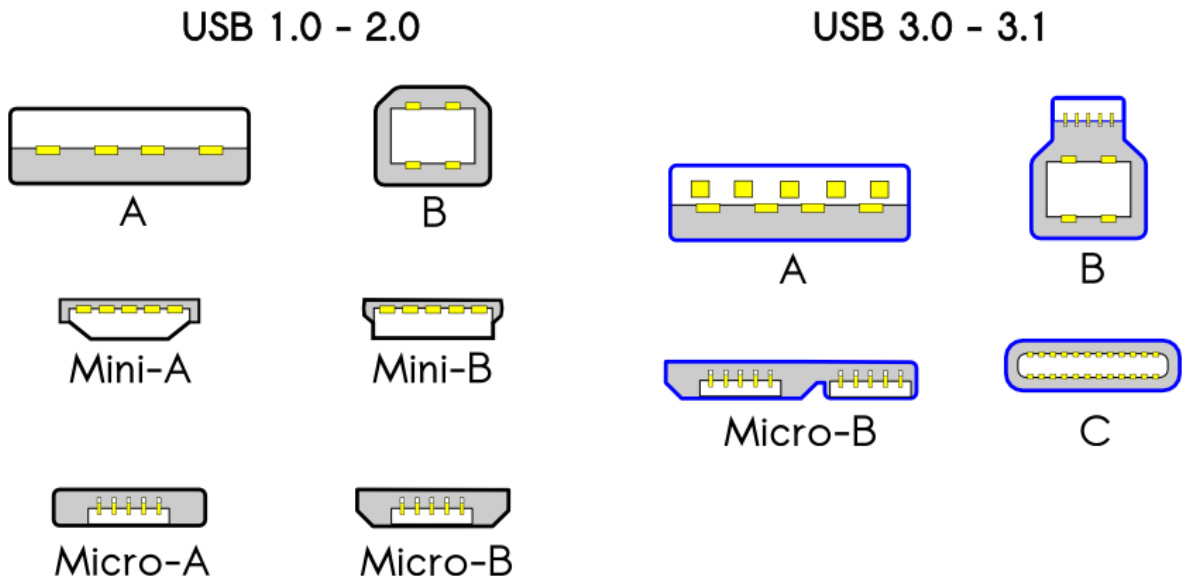
OSI Model/ISO Layers for IP over Ethernet

- Application, Presentation, and Session layer protocols focus on presenting (HTTP, FTP) and managing data including encryption (TLS, SSL)
- Transfer manages segments (TCP handshakes or UDP datagrams)
- The network level focuses on packet transfer (IP)
- The datalink layer manages data frames (Ethernet)
- The physical layer provides for representing bits via hardware (10base-T)
- https://www.researchgate.net/figure/The-seven-layer-OSI-model-for-networking-showing-example -protocols-from-the-world-wide_fig5_290559621



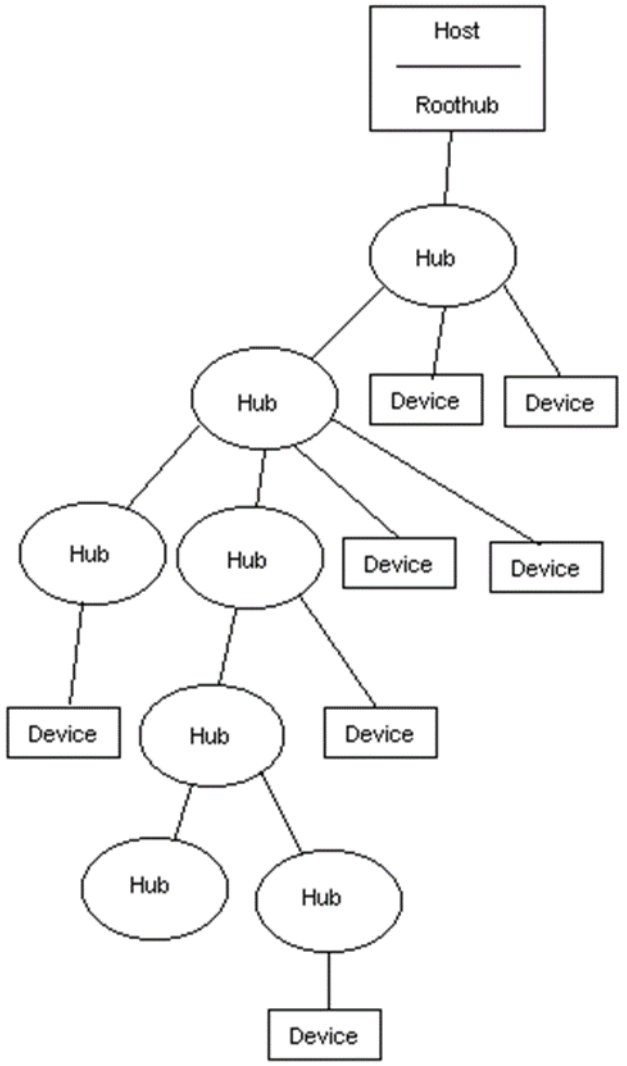
M2M Wired Protocols

- Generally used for Wired LANs (Local Area Networks)
- USB (Universal Serial Bus) [2]
  - 1.5 Mbit/s up to 10 Gbit/s (SuperSpeed+), 5 meter maximum cable length
  - 4 wires plus shield (9 wires for SuperSpeed) – tiered star networks – 127 Devices



USB

- Generally a single host device and up to 127 slave devices
- 5 meter cables, 30 meter maximum distance using powered hubs
- Communications initiated by the host
  - Exception: USB On-The-Go gives a device limited host role
- Communications is as a bus – either the host is transmitting OR a device is transmitting
- All devices receive packets sent from the host, but only the addressed device accepts the data
- Devices can transmit to the host – hubs repeat data to the host as received from devices



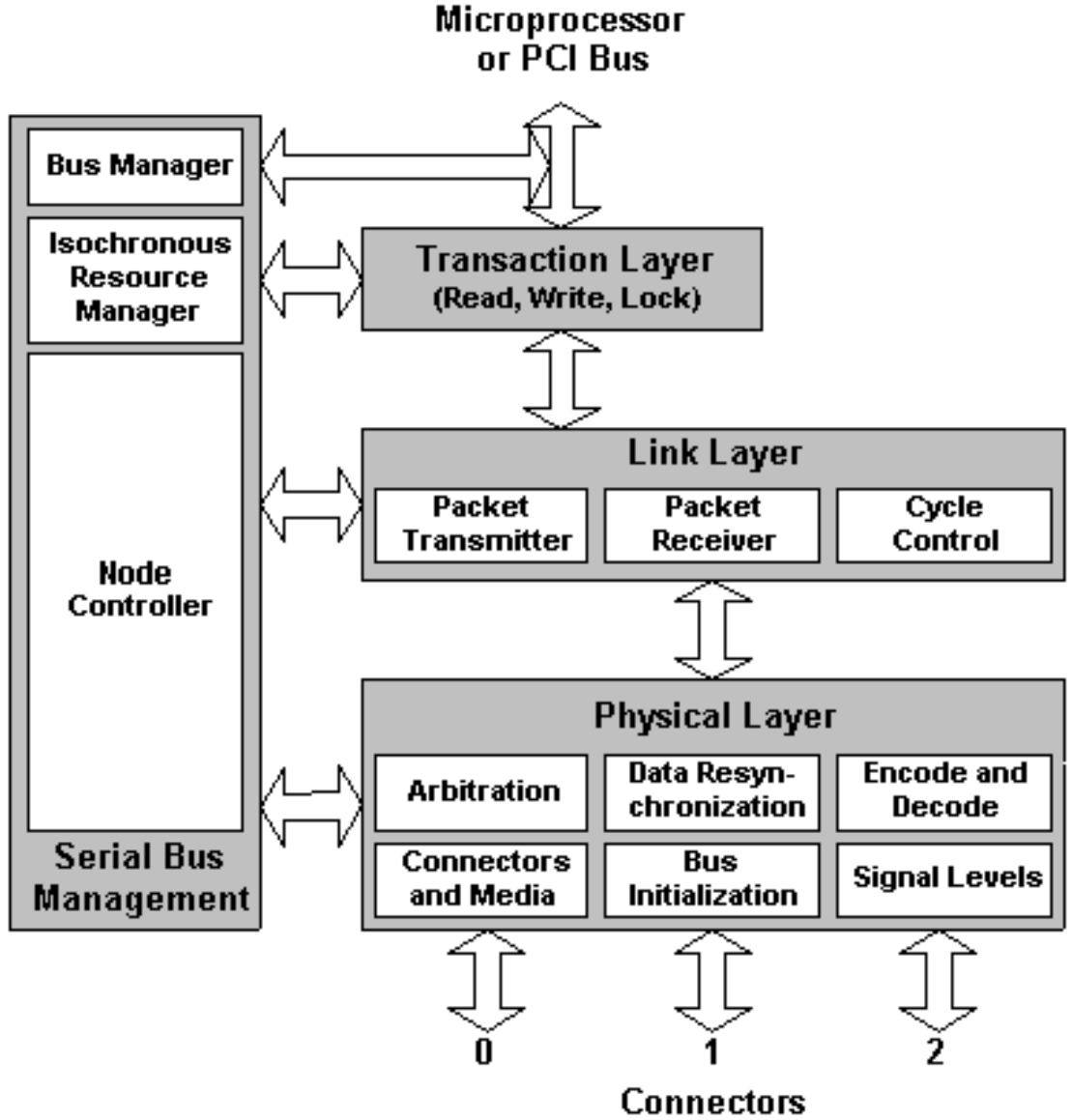
Reference [3]

M2M Wired Protocols - Serial

- Older serial protocols [4]
  - RS-232 (EIA RS-232-C)
    - <20K bits/sec, 15m cable length maximum at 9600 bps (2500 pF capacitance)
    - Multi-wire serial cable (at least ground, rx, tx, RTS, CTS) – point to point – 2 devices
  - RS-422 (TIA/EIA-422)
    - 100 kbit/s to 10 Mbit/s
    - Twisted pair - point-to-point or multi-drop – 1 driver, 10 recievers
  - RS-485 (TIA/EIA-485)
    - Up to 10 Mbit/s
    - Balanced interconnected cable – multi-drop/multi-point – 32 devices

M2M Wired Protocols - Other

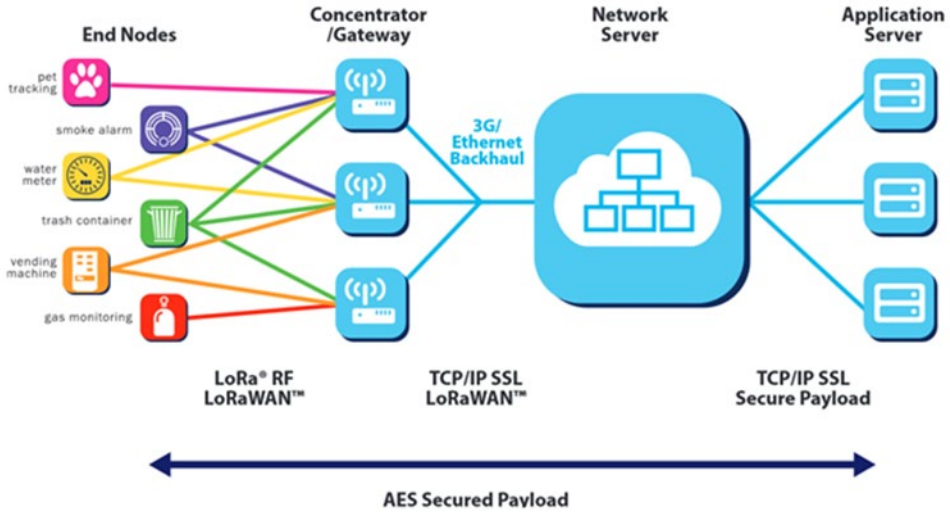
- Firewire (IEEE 1394) – printers and storage interface [5] - shown
- MIDI – custom musical instrument protocol [6]
- Thunderbolt - high speed video (40 gb/sec, wired USB-C physical connection) [7]
- Industrial Control Protocols: BACnet, Modbus
- CANbus – automotive control protocol (ISO 11898)

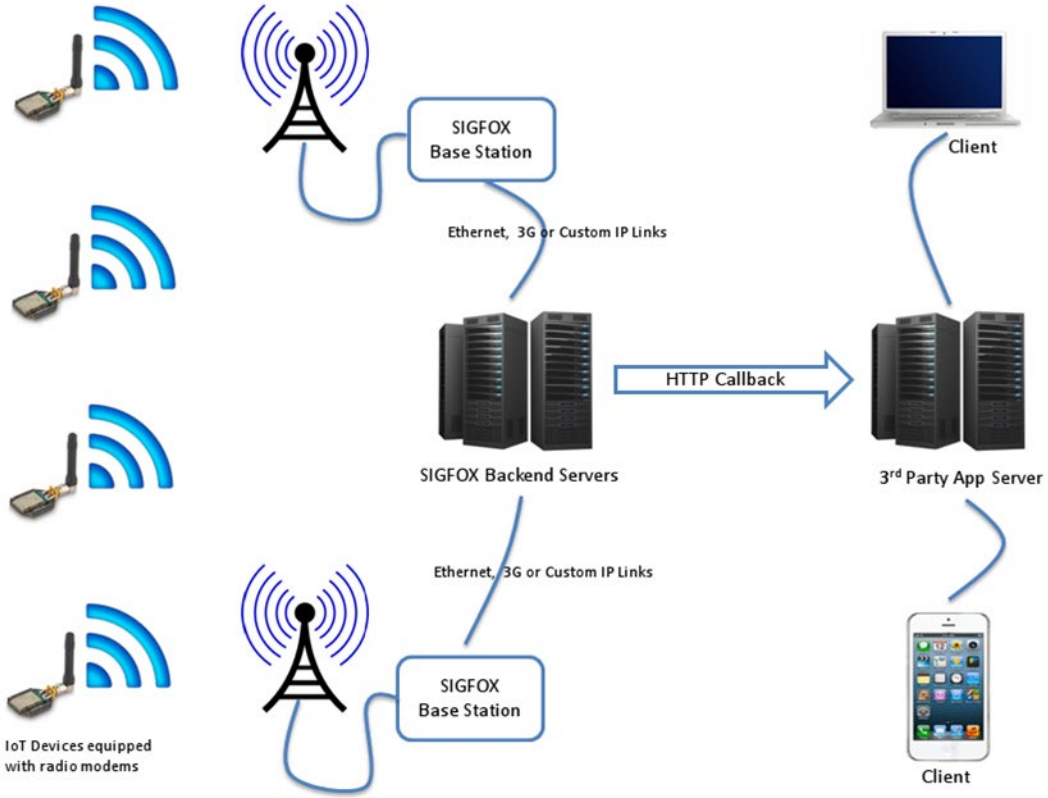


https://allpinouts.org/pinouts/connectors/buses/ieee-1394-serial-bus-firewire/

M2M/IoT Wireless Protocols for (LP)WANs

- (LP)WAN (Low Power) Wide Area Network
  [More next lecture]
- Cellular
  - 2G (GSM), 3G, 4G, LTE (Cat 0, 1, 3), LTE-M, NB-IoT (Narrowband IoT), 5G
- LoRaWAN (several to 20 mile range) [8]
- SigFox (3 to 50 km range) [9]





M2M Wireless Protocols

- For a general or custom WLAN (Wireless Local Area Network)
- Wi-Fi – IEEE 802.11a/b/g/n – 2.4 GHz (b, g, n) or 5 GHz (a), 100 m range – WiFi Alliance certification
- Wi-Fi HaLow (IEEE 802.11ah) – <1 GHz, longer range, low power
- ZigBee 3.0 (IEEE 802.15.4) – 915 MHz or 2.4 GHz – ZigBee Alliance annual fee – mesh of coordinators, routers, end devices [10]
- Z-Wave (also IEEE 802.15.4) – 908.4; 916.0 MHz – Z-Wave Alliance – mesh network of 232 devices, with network bridging [11]
- 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks), Thread
- EnOcean (ISO/IEC 14543-3-10) – 902 MHz – energy harvesting (100 operations/day for 25 years)
- Others: Wireless HART, DigiMesh

Zigbee vs. Z-Wave in the Home

- Both are popularly used in home automation solutions
- Zigbee is known for low power requirements but can require some technical prowess by users to install and connect to the device mesh network
- Z-Wave is easier to manage and set-up, in a home system all devices are configured at a single hub, but it is known for being more expensive

Implementation issues with Zigbee and Z-Wave

- Both are mesh network based, so nodes act as both endpoints and repeaters
- Zigbee uses the 2.4 GHz ISM bands, which can interfere with Wi-Fi or Bluetooth
- Z-Wave uses the 915 MHz ISM band, which provides longer range for less power
- Zigbee had early interoperability issues between manufacturers
- Z-Wave is less prone to this, by using Z-Wave transceiver hardware elements for certified devices (Z-Wave 700 SiLabs Gecko - pictured)
  - https://www.silabs.com/support/getting-started/mesh-networking/z-wave/z-wave-700
- Have seen Zigbee system range issues between devices requiring extra devices to maintain the mesh connectivity

M2M Wireless Protocols - Custom

- Inovonics [14] uses EchoStream: a proprietary 902–928 MHz Frequency-hopping spread spectrum
- Communications between custom endpoints, repeaters, and gateways
- Broadcast and Directed versions of protocol
- For Directed, a self-organizing layered mesh network
- Why a custom network?
  - Interoperability is not needed for markets
  - Ease of installation and Reliability of Event Delivery are key differentiators
- Used in Security, Senior Care, Sub-metering Utility Use, Sensor & Control

M2M Wireless Protocols - PAN

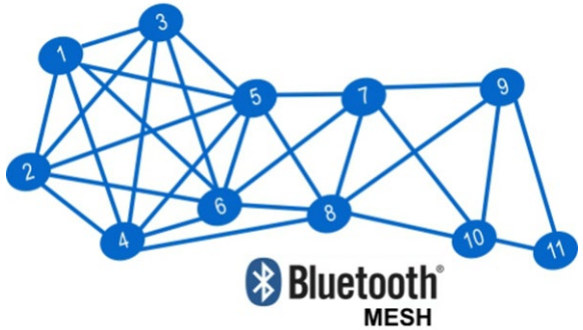
- PAN (Personal Area Network) protocols
- Bluetooth – Basic Rate/Enhanced Data Rate (2.0, 2.1, 3.0) – 2.4 GHz, ~3 Mbit/s (3.0 adds a 24 Mbit/s 802.11 link) , <= 10m range, 1 master and 7 slaves active (200+ inactive), standard device profiles and advertising methods
- Bluetooth Low Energy (BLE) (4.0, 4.1, 4.2) – 2.4 GHz, 25 Mbit/s, 60m range
- Bluetooth 5.0 – 2.4 GHz, up to 50 Mbit/s, 240m range – moving into WANs
- NFC – 13.56 MHz – 106 to 424 kbit/s, 10 to 20cm max range
- RFID – various bands, ranges from 10 cm to 200 m (with active tags)
- ANT/ANT+ – 2.4GHz, 12.8 kbit/s to 60 kbit/s bursts, 30m range, many network topologies possible, 65k devices in net

Bluetooth vs. NFC [15]

- Both Bluetooth and NFC are ubiquitous, both are supported on most mobile devices
- NFC became popular as it became available on phones for mobile payments (on iPhone 6 and later)
- NFC connectivity is easier, sets up more quickly – Bluetooth requires pairing
- NFC typically requires much less power for connectivity
- Could be used well in combination – use NFC to establish a connection, hand over to Bluetooth?

Aspect	NFC	Bluetooth	Bluetooth Low Energy
RFID compatible	ISO 18000-3	active	active
Standardisation body	ISO/IEC	Bluetooth SIG	Bluetooth SIG
Network Standard	ISO 13157 etc.	IEEE 802.15.1	IEEE 802.15.1
Network Type	Point-to-point	WPAN	WPAN
Cryptography	not with RFID	available	available
Range	< 0.2 m	~100 m (class 1)	~50 m
Frequency	13.56 MHz	2.4–2.5 GHz	2.4–2.5 GHz
Bit rate	424 kbit/s	2.1 Mbit/s	25 Mbit/s
Set-up time	< 0.1 s	< 6 s	< 0.006 s
Power consumption	< 15mA (read)	varies with class	< 15 mA (read and transmit)

Bluetooth Mesh



- Key architecture decisions
  - Centralized vs. Decentralized/Distributed?
    - Decentralized – no single failure point, easy device replacement, reduced setup and traffic
  - Message forwarding: Flood or Routing?
    - “Managed” Flood – message caching, time to live counter, subnets, enable/disable relay, friend nodes for low power nodes to check in with
  - Addressing: Unicast or Publish/Subscribe?
    - Pub/sub but can unicast for configuration and maintenance
  - Complete Security
    - Device provisioning and disposal/blacklisting
    - Network/app layer security
    - Message privacy
    - Periodic Key Refresh
    - “80% of BLE Mesh Design was security issues”

Example: Control GPIO w/Bluetooth and Android app

- Libraries for application
  - Blueman – a desktop interface to manage and control Bluetooth devices
  - Bluez – official Bluetooth protocol stack, supports all the core Bluetooth protocols
  - Python-Bluetooth – Python library for Bluetooth comms
  - Example code from https://electronicshobbyists.com/controlling-gpio-through-android-app-over-bluetooth-raspberry-pi-bluetooth-tutorial/

```
import Bluetooth   # Bluetooth Socket library
host = ""
port = 1  # Raspberry Pi uses port 1 for Bluetooth Comms
# Creating Socket Bluetooth RFCOMM communication
server = bluetooth.BluetoothSocket(bluetooth.RFCOMM)
print('Bluetooth Socket Created')
try:
        server.bind((host, port))
        print("Bluetooth Binding Completed")
except:
        print("Bluetooth Binding Failed")
server.listen(1) # One connection at a time
# Server accepts the clients request, assigns a mac address.
client, address = server.accept()
print("Connected To", address)
print("Client:", client)
```

References

[1] http://www.itpro.co.uk/network-internet/30276/what-is-ethernet-the-standards-explained
[2] https://en.wikipedia.org/wiki/USB_(Physical)
[3] http://www.usbmadesimple.co.uk/ums_1.htm
[4] http://www.ni.com/white-paper/11390/en/
[5] https://www.lifewire.com/what-is-firewire-2625918
[6] https://www.cs.cmu.edu/~music/cmsip/readings/MIDI%20tutorial%20for%20programmers.html
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