L11 – The Physical Layer

50.012 Networks

Cohort 1: TT7&8 (1.409-10)

Cohort 2: TT24&25 (2.503-4)

Introduction

- Todays lecture:
  - Overview of Physical layer

    Guided media – copper and fiber

    Wireless – terrestrial radio (next week)

    Underwater and Satellite comms. (for awareness only)
  - Cables and connectors
  - Embedded Networks
  - Important Embedded Buses

Content plan for rest of term

Week 8

- PHY Layer / IoT+ IPv6

Week 9

- Wireless Networks I / II

Week 10:

- Mesh Networks / Industrial Control Networks

Week 11:

- Performance Networking & CDNs / QoS

Week 12:

- Datacenter Networks & SDNs / The Cloud

Week 13:

- Enterprise Networks & Network Topology Design / VPNs, Anonymity & Overlay Networks

The Physical Layer

The Physical Layer (PHY)

- Internet (IETF) doesn’t address the physical layer.
  - Several RFCs mention a physical layer and data link layer, but IEEE protocols do not mention any physical layer functionality or physical layer standards.
- Provides physical connection for *symbols* between interfaces
  - Protocols: PHY part of 802.3 Ethernet, 802.11 WLAN
  - No direct addressing, possibly channel selection
- Remember:
  - App layer: connection between applications
  - Transport layer: connection between processes
  - Network layer: connections between hosts
  - Link layer: connections between interfaces
- Main services of Physical layer:
  - (De)modulation and transmission of symbols, channel coding

Functions of the Physical Layer

- Representation of Bits – The bits must be encoded into signals for transmission. It defines the type of encoding – i.e. how the 1s and 0s are converted into signals.
- Data rate: Defines the rate of transmission (bits per sec).
- Interface: The physical layer defines the transmission interface between devices and transmission medium. For example the physical layer could be transmission over coaxial cable, as first proposed on Ethernet.
- Line configuration: This layer connects devices with the medium. Peer to Peer & Multipoint configuration.
- Topologies: Mesh, Star, Ring, Bus
- Transmission Modes: Simplex, Half duplex and full duplex
- Baseband and broadband transmission

Source: wikipedia

Baseband vs Broadband Transmission

Baseband

- Digital signals
- Time division multiplexing
- Transmission is bi-directional
- Short distance
- Entire bandwidth of the cable is consumed by a single signal.

Broadband

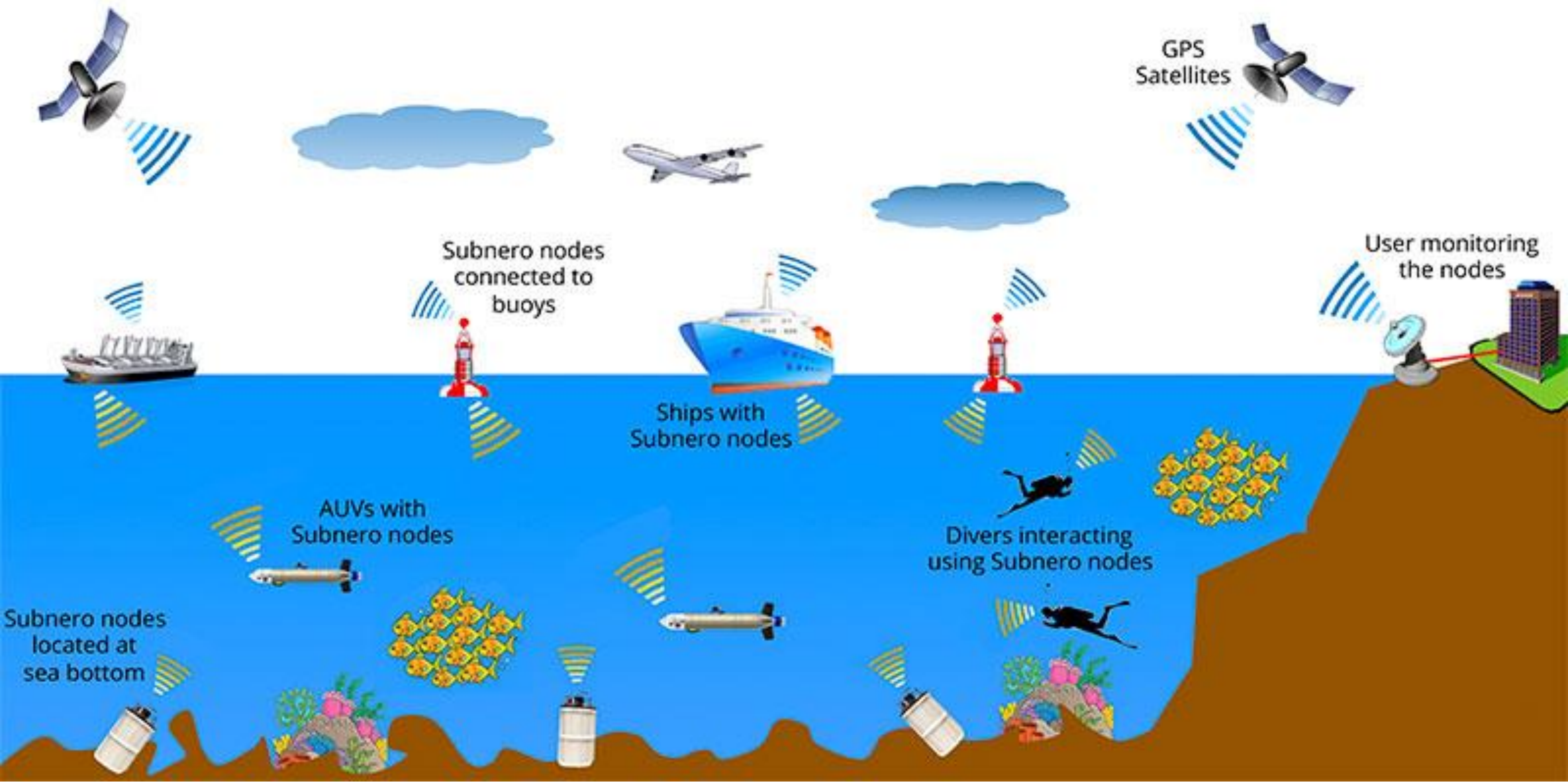
- Analog signals
- Usually frequency division multiplexing
- Transmission of data is unidirectional
- Long distance
- The signals are sent on multiple frequencies. Multiple signals are sent simultaneously.

Physical layer technologies

- BT
- CAN bus
- DSL
- EIA RS-232, 422, 423 etc
- Etherloop
- Ethernet PHY layer including 10BASE-T/5/2 100BASE-TX, FX, 100BASE-T, 1000BASE-T etc
- GSM
- I2C/I2S
- IEEE 1394
- ISDN
- IrDA Physical layer
- LIN
- Modulated ultrasound
- MOST
- Optical Transport Network (OTN)
- SPI
- SONET/SDH
- T1 and other carrier links, E1 and other E carrier links
- USB / USB3
- Telephone network modems – V.92
- Varieties of 802.11 Wifi physical layers
- X10
- … many more

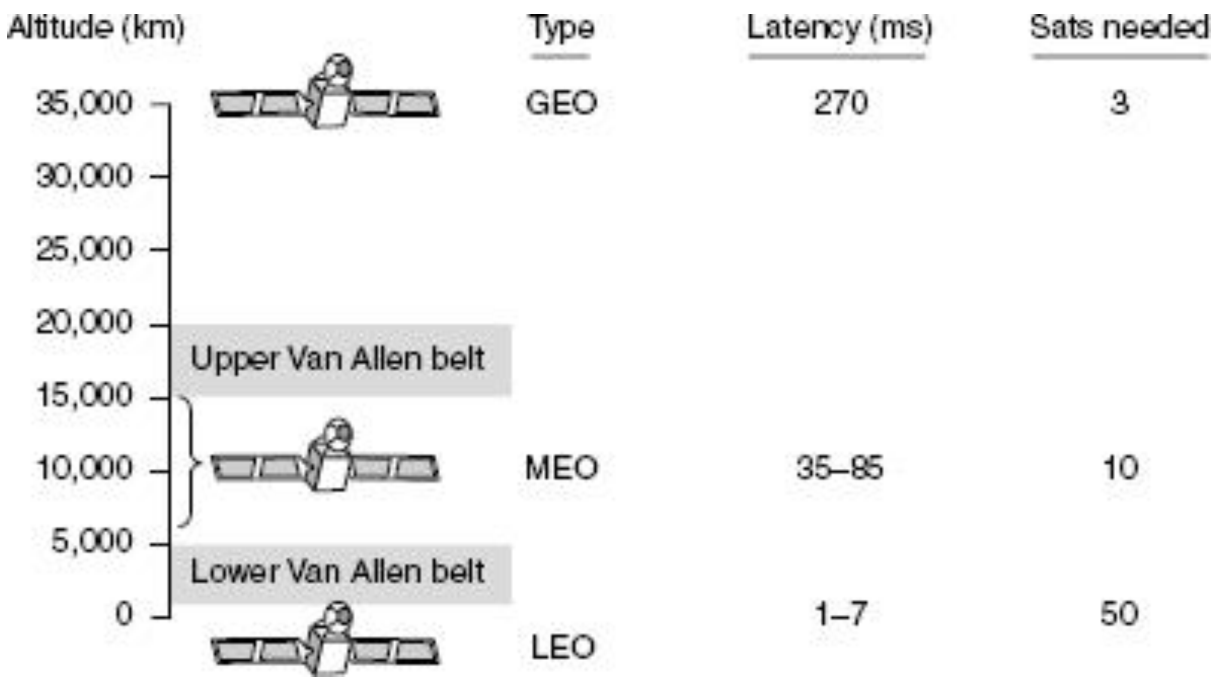
Source: wikipedia

Autonomous Underwater vehicles (AUVs) use acoustic waves for underwater communications



http://subnero.com/solutions/

Space –Communication Satellites



- Low, Medium and Geostationary Earth Orbit Communication satellites
- typical altitude above the earth
- Latency (round trip time)
- Number of satellites needed for global coverage

Source: Computer Networks, Fifth Ed. Tanenbaum, Chapter 2

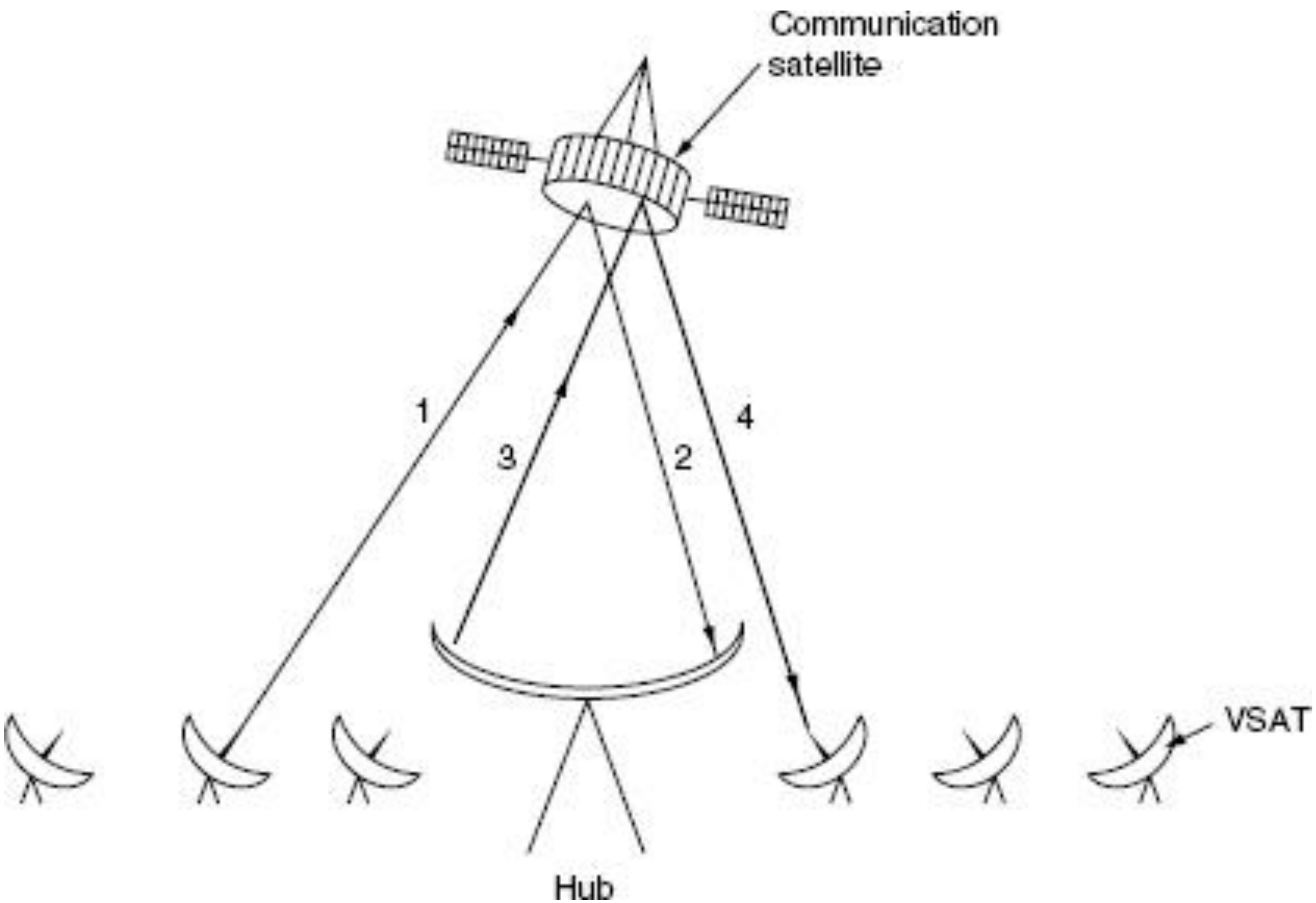
Communication Satellites – the principal bands

Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

Source: Computer Networks, Fifth Ed. Tanenbaum, Chapter 2

VSAT using hub

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN



Source: Computer Networks, Fifth Ed. Tanenbaum, Chapter 2

PHY Standards

- A wide range of PHY channels are possible
  - Copper, Fiber, Radio, TV cable, . . .
- Most common for LANs: Copper
  - 100Base-TX (802.a/b) is copper full-duplex 100MBit
  - 1000Base-T (802.a/b) is copper Gigabit
- Fibre used at SUTD:
  - 1000Base-SX

Maximal range

- Maximal range of connected depends on standards and media types:
  - 1000Base-T: 100 meters
  - 100Base-TX: 100 meters
  - 1000Base-SX: 500+ meters
- To extend the range, repeaters or switches can be used
- The increased range of 1000Base-SX (fiber) is the reason why the backbone (connections from switches to other switches/routers) are often fiber

Copper Ethernet cables

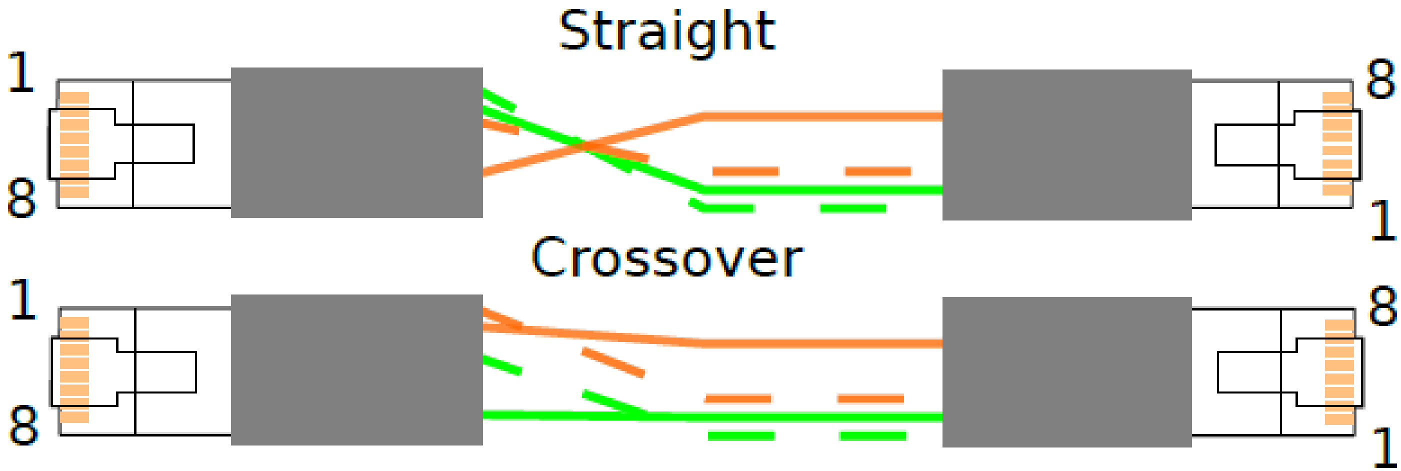
- Copper cables and interfaces are *cheap* (< 10 SGD)
- Ethernet cables typically have 4 twisted pairs
  - 100Base-TX uses two of these pairs: one receiving, other sending
  - 1000Base-T uses all four pairs
  - Connectors use the RJ45 standard
- Different categories of cables exist
  - For high the number, better bandwidth and noise performance
  - Cat 5(e): Used for 100Base-TX, 1000Base-T, now standard
  - Cat 6: Were required for 1000Base-TX, which was not successful

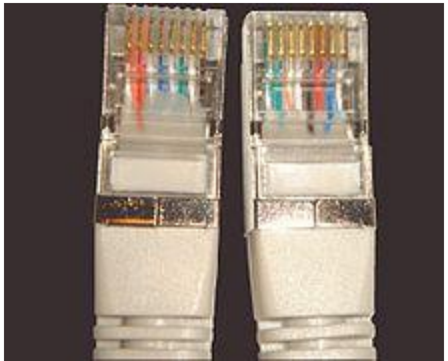
Full-Duplex

- Old Ethernet networks had a shared medium (using hubs)
- 100Base-TX and 1000Base-T are now almost always connected to switches
- At most two users are sharing the medium
  - In 100Base-TX, every user has its own twisted pair (Full-Duplex)
- This means that collisions between senders do not occur
  - More on that later when discussing WLAN

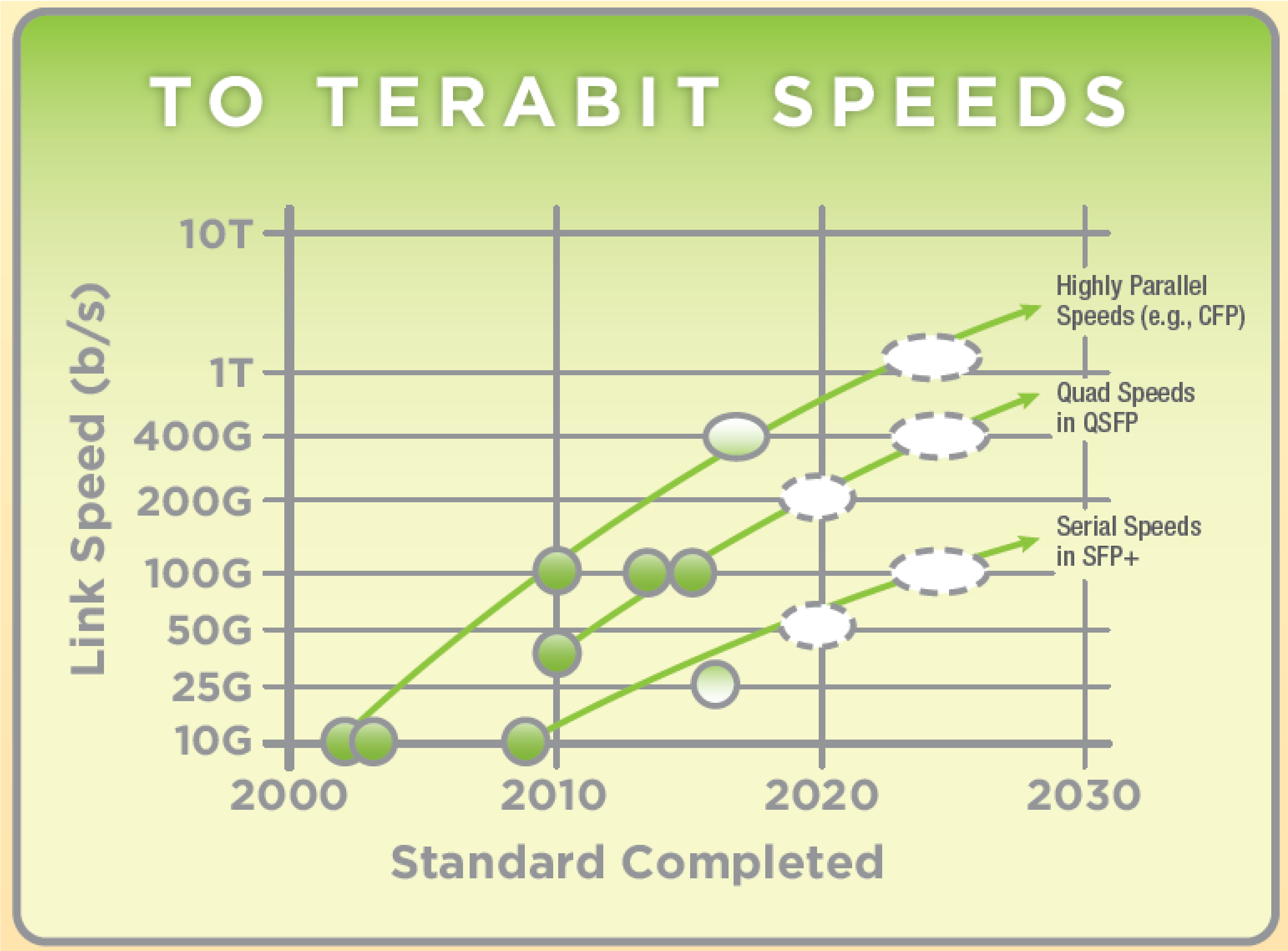
Cross-over Cables and Auto-Negotiation

- Normal cables are *straight*: both ends have same sequence of wires
  - This means direct connections between two PCs send to same wire
  - *Cross-over* cables alleviate this
- Modern adapters use *Auto-Negotiation* to allow straight cable use instead
  - If a straight cable to another host is detected, pin assignment is changed in interface





Ethernet Alliance's 2015 Roadmap



Source: http://www.ethernetalliance.org/roadmap/

Ethernet media and modules

MEDIA AND MODULES

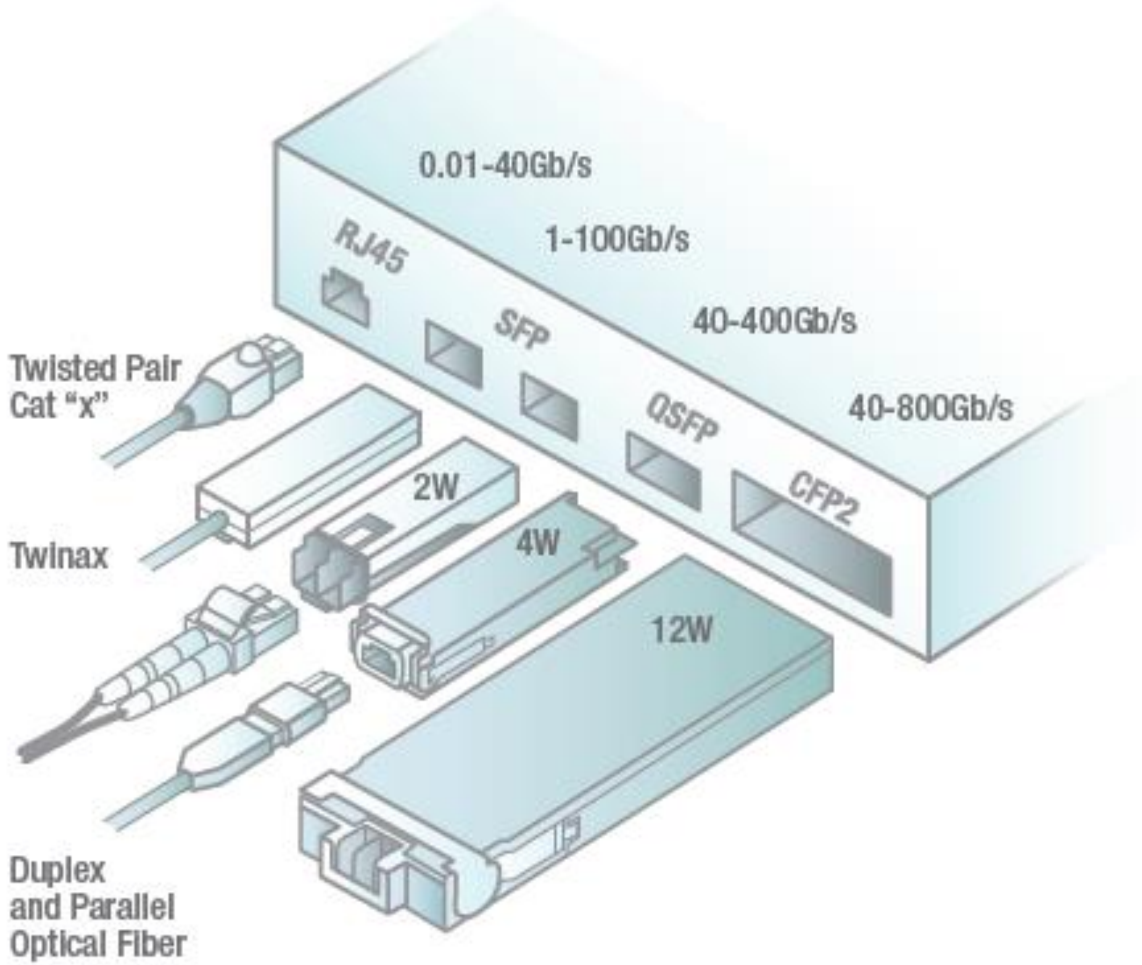
Ethernet is wired technology and supports a variety of media including backplanes, twisted pair, twinax, multimode fiber and single-mode fiber. Most people know Ethernet by the twisted pair or Cat "x" cabling with RJ45 connectors because close to a billion ports a year are sold. Cat 8 is the latest generation of twisted pair cabling that will be used in 25GBASE-T and 40GBASE-T.

Another popular copper interface is Twinax copper cables that are also known as direct attach cables (DAC)s. DACs may be passive or active and provide very low cost connectivity to servers. Passive DACs are limited to 25 meters or less while active optical cables can go hundreds of meters.

For links longer than 100 meters, fiber optics are required and the graphic below shows three of many module types. The SFP family is the most popular module and supports a single channel or lane in each direction and duplex fibers. The QSFP family supports 4 channels while the CFP2 supports up to 10 channels and duplex or parallel fibers. For 40GbE and beyond, the electrical interface to the module is being defined in IEEE and supports a variety of optical interfaces from IEEE and other sources.

Source: http://www.ethernetalliance.org/roadmap/

Ethernet media and modules

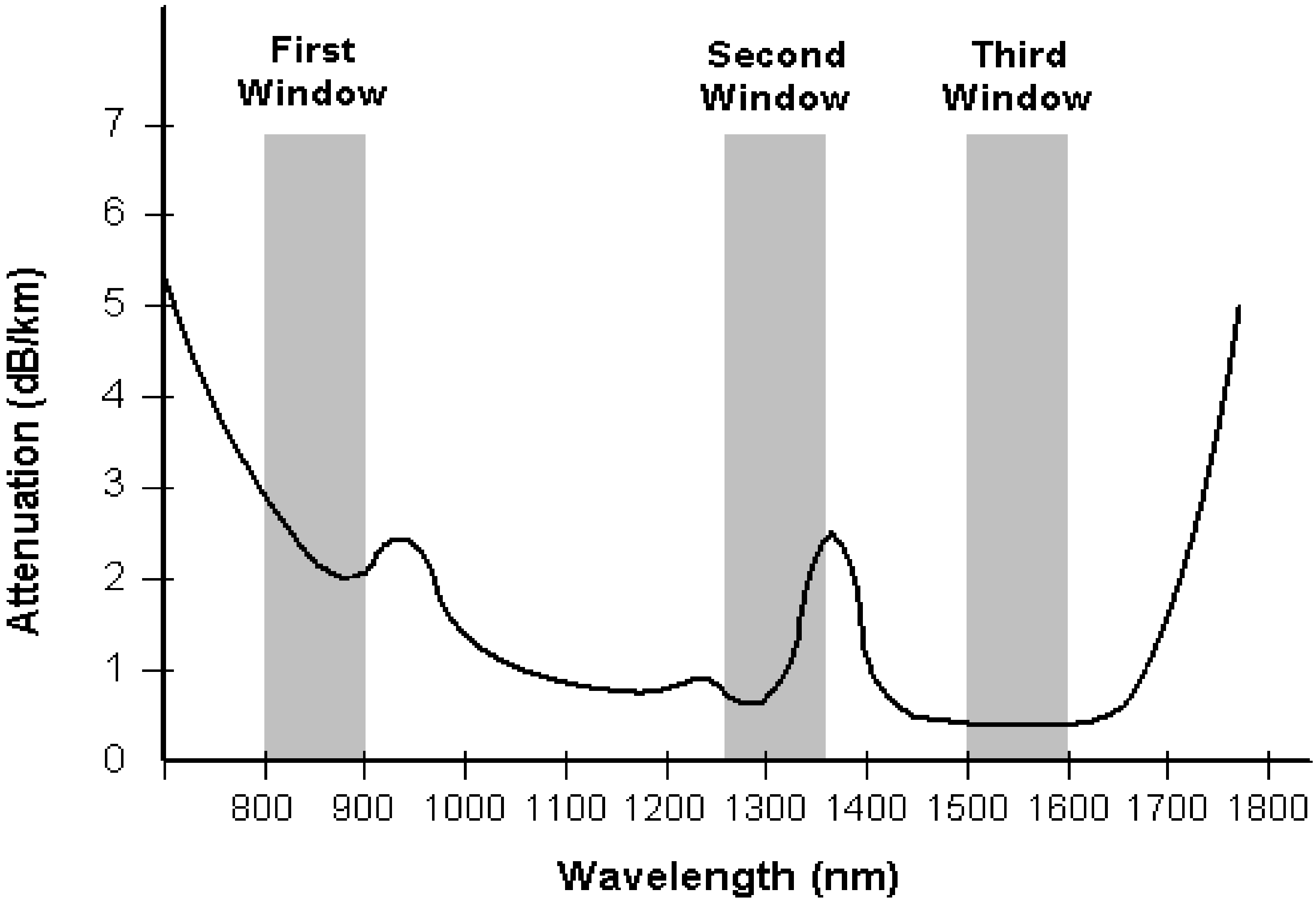


Source: http://www.ethernetalliance.org/roadmap/

Ethernet in future

- http://www.ethernetalliance.org/roadmap/

Attenuation-Wavelength curve of an optical fiber



Source: http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_8_3_OpticalFibres.html

Transmission Windows Ranges and Operating Wavelengths of Optical Fiber

	Window Range	Operating Wavelength
First Window (0.85μ band)	800 nm – 900 nm	850 nm
Second Window (1.30μ band)	1,260 nm – 1,360 nm	1,310 nm
Third Window (1.55μ band)	1,500 nm – 1,600 nm	1,550 nm

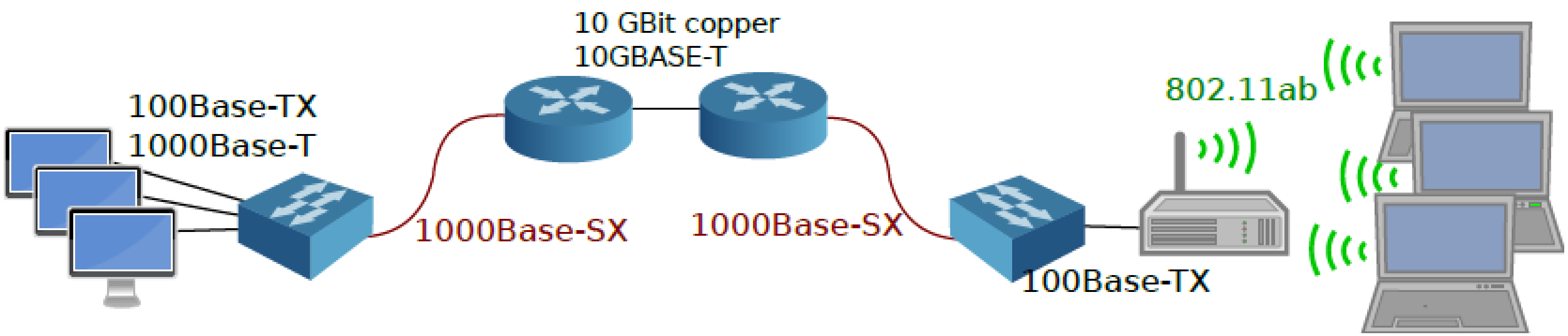
Source: http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_8_3_OpticalFibres.html

Fiber-optic Cables

- Fibre-optic cables use light to transmit data
  - 1000Base-SX uses 770 to 860 nanometer, near infrared (NIR) light wavelength
- They usually come as a pair of fiber strands
  - The fiber cannot bend as much as copper, can break under stress
- They require more expensive optics, i.e. transceivers (100 SGD+)
- Fiber-optic cables have farther ranges (up to 1 km and more)

Typical Office network

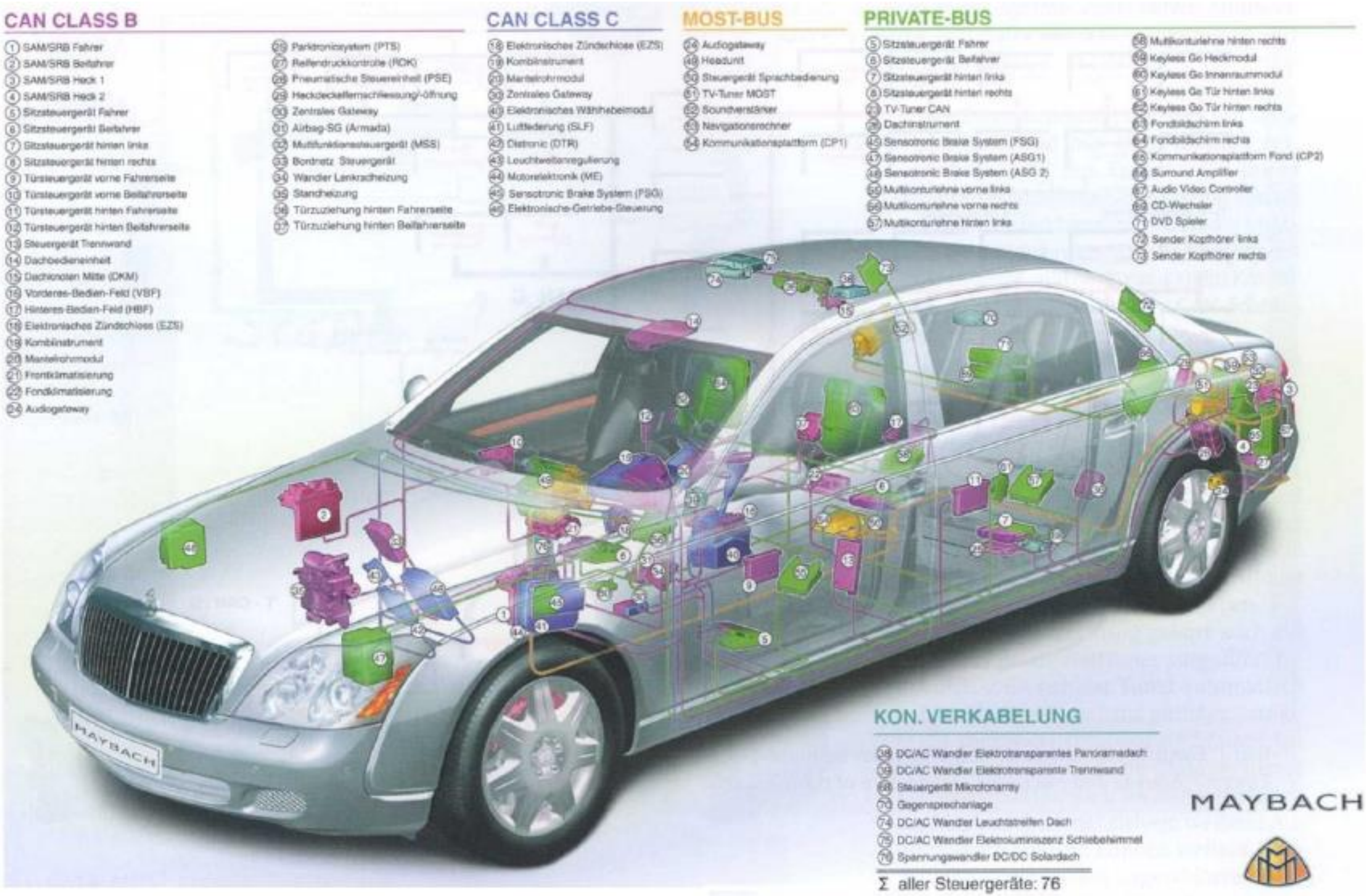
- A typical office network (such as SUTD) mixes different PHY
- Short range, high bandwidth with 10Gbit copper (10GBase-T)
- Long range, medium bandwidth 1000Base-SX fiber
- Short range, medium bandwidth 1000Base-T copper
- Short range wireless: 802.11ab



Embedded System Networks

Exampl: Maybach Luxury Car (in 2002)

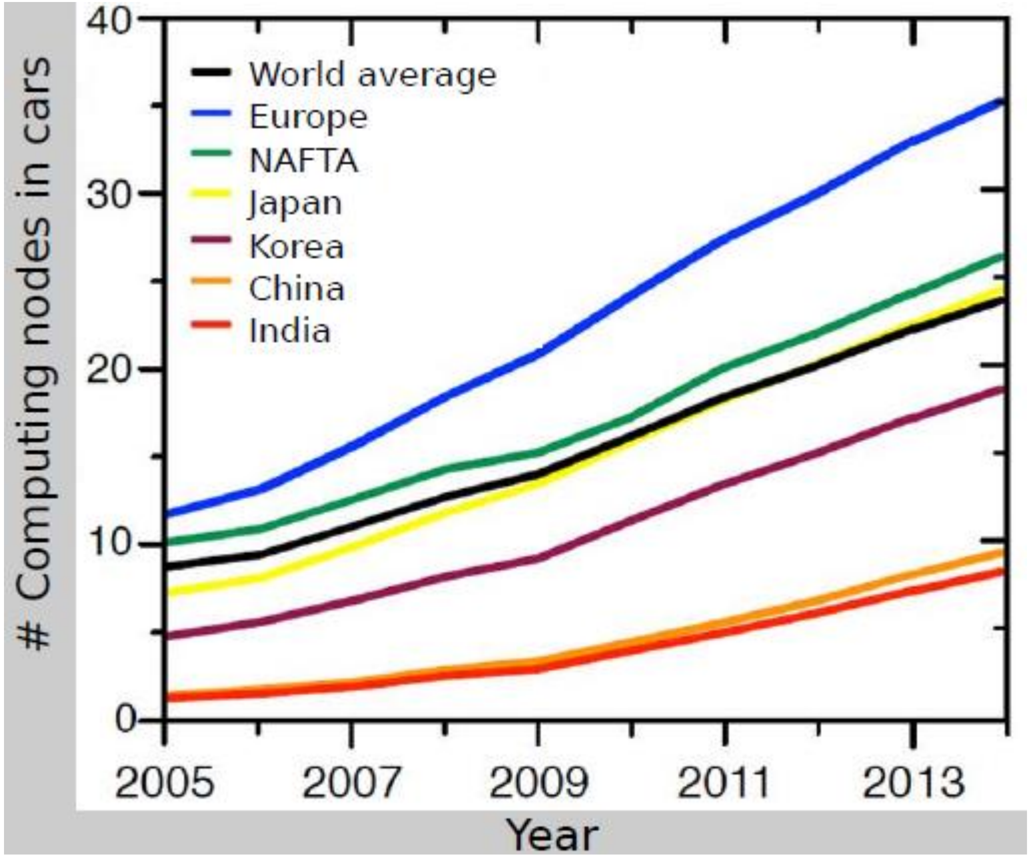
SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN



Features

- Standard features of all models include, but are not limited to: a navigation system with voice recognition; air conditioning with four-zone climate controls; power rear sunshade; rear-seat DVD entertainment system; interior air filter; front and rear seat massage; 21-speaker premium sound system; power tilt/telescopic heated wood/leather-wrapped steering wheel with radio and climate controls; power trunk open/close; voice-activated AM/FM radio with 6-disc CD changer; keyless start; heated front and rear seats; cooled front seats; adaptive cruise control; premium leather upholstery; 18-way power front seats; 14-way power rear seats; heated cup-holders; rearview camera; iPod adapter; wireless cell phone link; outside-temperature indicator; universal garage door opener.
- Options for the Maybach 62 and 62S include: 18-way power rear seats (replacing 14-way); power side sunshades; cooled rear seats; wireless headphones; electrochromic power panoramic sunroof (replacing power sunroof); steering wheel mounted navigation controls.
- The company offers various options for customers to personalize their vehicles, and provides various equipment combinations.

Is this a new problem?



- Everyday devices such as cars become increasingly automated
- How to connect all these devices?

Embedded System Networks

- Why should we need layer 3/4 other than TCP/IP?

Embedded System Networks

- Why should we need layer 3/4 other than TCP/IP?

- TCP/IP is best effort
- Designed to allow best utilization of links with high traffic
- No guarantees for delivery or latency
- TCP/IP builds on stream abstraction
  - Continuous connection
- TCP/IP also incurs overhead
  - HTTP POST of 100 Byte of data might have 500 Byte of overhead added

Typical Embedded Network Requirements

- Real-time requirements on delay
- Reliable transmission (without retransmission)
- Constant network load and topology
- Fixed allocation of bandwidth to users
- Cost of components and implementation is important
- No network of Peers, but Master/Slaves

Bus vs. Network

- Buses are typically single hop links (PHY layer)
- Every participant sees every message (broadcast)
- A hierarchy of devices exist, e.g. master and slaves
  - Master devices initiate all communication
  - Slave devices are typically only connected to one bus

Example Embedded Communication Standards

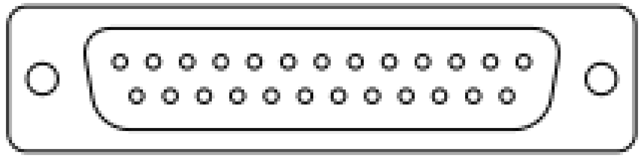
- Low end:
  - RS-232 (P2P)
  - SPI (Bus)
  - LIN (Bus)
  - I2 C (Bus)
- Medium-End
  - CAN (Bus)
  - MOST (Bus)
  - USB (Bus)
- High-End
  - USB3 (Bus)
  - Ethernet (Network)

How do they differ?

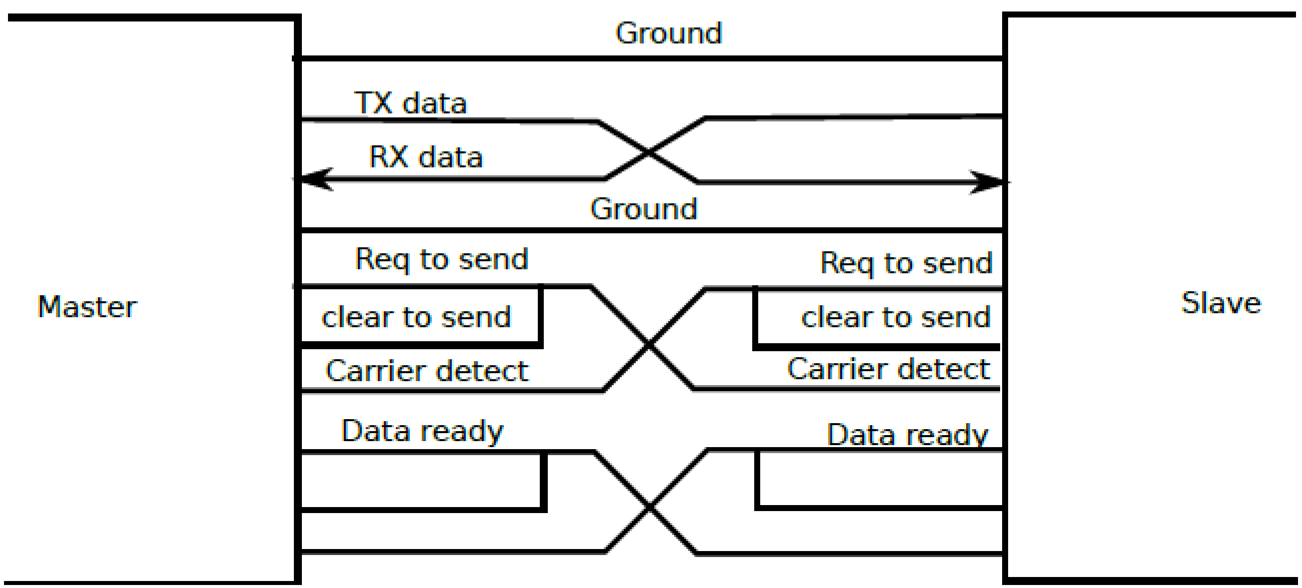
- Performance-related:
  - Bandwidth
  - Error rate (e.g. in harsh environments)
  - Transmission delay
  - Tolerance to faults
- Cost-related:
  - Circuitry required (PCB area)
  - Pins/Connectors required
  - Power consumed for communication
  - Licensing costs, transceiver cost
  - Runtime complexity, integration complexity

Important Embedded Buses

Serial / RS-232

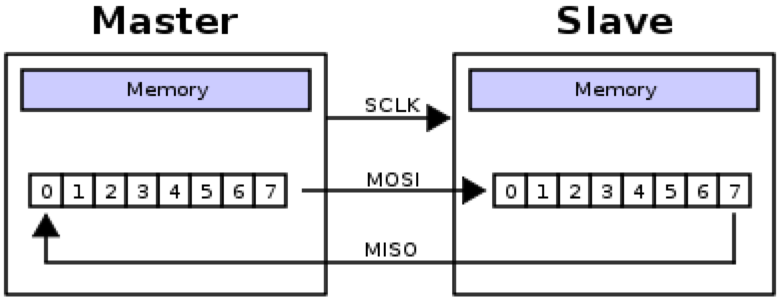


- 8 wire connection + GND (or more with secondary channel)
  - No bus, just Master/slave (one each)
- Introduced in ’62 for communication between *teletypewriters* and *modems*
- Still in use today for communication with industrial devices
  - *Our switches in the lab can be configured via RS-232*
- 15m max range, 115kbit/s max speed

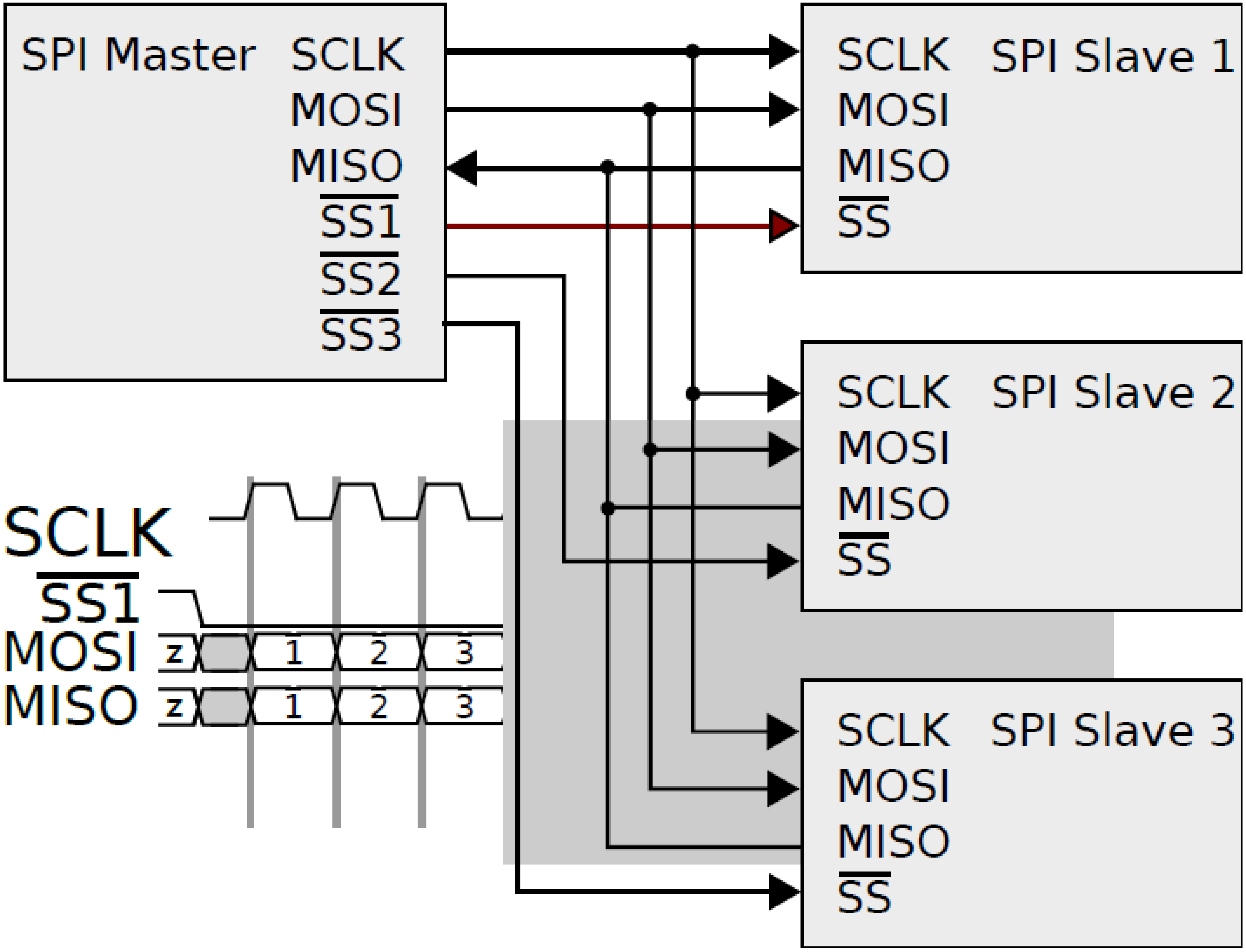


Serial Peripheral Interface (SPI)

- Four-wire bus, Master-Slave architecture with single master
- If more than one slave is present, each will have dedicated Slave-Select line to Master
  - Does not scale that gracefully with number of slaves. . .
- SPI is usually used to communicate with other ICs on PCB
- SPI is only loosely defined - a "de facto" standard
- Widely used to connect to ICs such as sensors, NICs, memory on embedded systems



SPI with multiple slaves

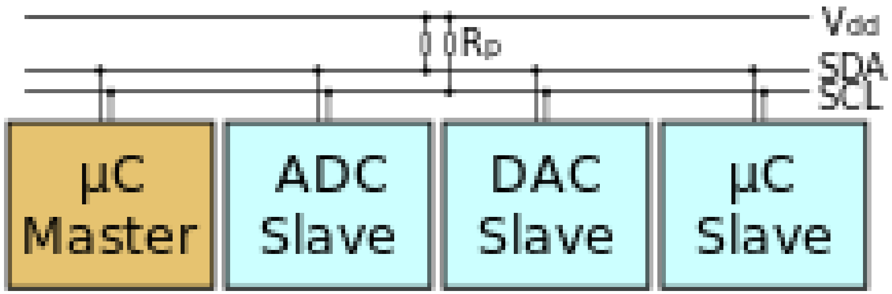


Comments on SPI

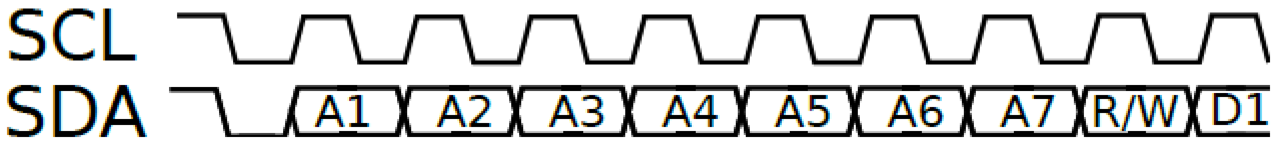
- Commonly, 8 bit are read/written in one go, but up to implementor
- SPI does not scale well for many slaves
- No direct way for slaves to initiate or slow down connection
- No inherent error detection
- Sounds familiar? No network layer, transport layer
  - Application layer sits right on link (or even PHY) layer
- Missing features can be added by adding additional intermediate layers

Inter-Integrated Circuit (I^2C)

- Two-wire bus designed by Philips for TV ICs
  - One clock line, one data line, active low
- Features:
  - Multiple masters, 7-10 bit address space
  - Range of up to 3 meters, up to 112 slaves
  - 100kbit/s standard mode, 3.400Mbit/s High speed mode
- Higher-layer protocols are defined for shared access and signaling



I2C Transmission Format



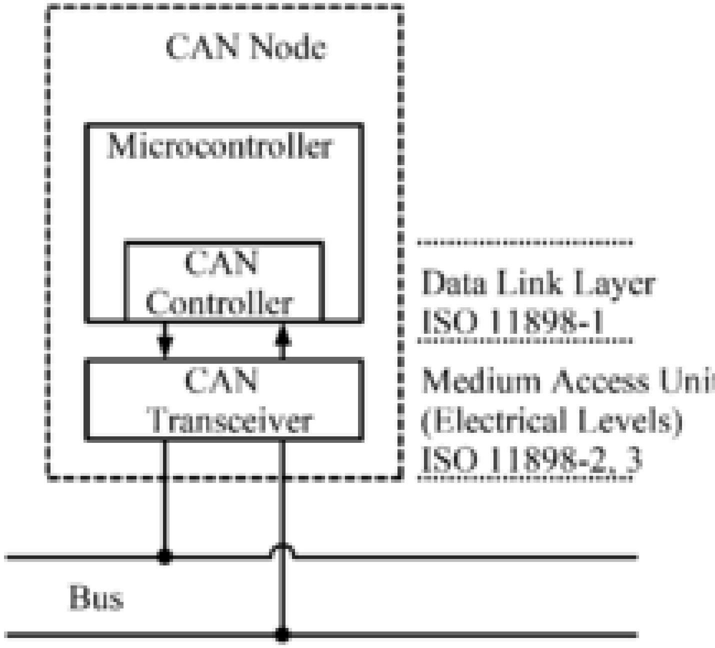
- Master pulls clock and data line low
  - In idle, both are high (pull-up resistor)
- Master then transmits 7 bit address, and R/W flag
- Then, 8-bit word is written by Master or Slave
- Receiver issues a 1 bit ACK
- Transmission stops when Master releases clock (floats to HI)
- Slaves can hold low clock to signal they need more time

Local Interconnection Network (LIN)

- Single wire automotive bus
- 1 Master/ up to 16 slaves architecture
- Slow (20kbit/s), but cheap (1$ vs 2$ for CAN)
- either 2,4, or 8 Byte of data are exchanged
- Up 40m bus length

Controller Area Network (CAN)

- The de-facto standard for in-car communication
  - Often multiple CAN buses in one car
- Multi-master serial bus, 11-bit identifiers, real-time guarantees
- CAN does not specify PHY, often twisted pair is used
- Messages have between 0 and 8 Bytes payload
- For up to 40m long buses, up to 1Mbit/s is possible
  - Up to 40kbit/s for 1000m



Comparison

Name	# Wires	# Devices	Speed	Range
RS-232	8	2	114kb/s	15m
SPI	3+n	1+n	up to implementor	"on PCB"
I2C	2	112 slaves	up to 3400kbit/s	3m
LIN	1	16	20kbit/s	40m
CAN	2	2^{11}	1000kbit/s	40m+

Conclusion

- A huge range of different serial communication standards and buses exist
- Which one to use?
  - Cost for wiring and transceivers, licenses
  - Bandwidth requirements
  - Support by devices you want to connect
- As bandwidth requirements go up, and cost goes down, continuous change towards more powerful standards
- Real-time requirements prevent direct use of Ethernet/IP/TCP