Networks

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References for this chapter

[Patterson17]
David A. Patterson & John L. Hennessy
Computer Organization and Design – The Hardware/Software Interface
Chapter 4 “The Processor”,
Chapter 6 “Parallel Processors from Client to Cloud”
ARM edition, Morgan Kaufmann 2017
Network protocols & standards

OSI network reference model

Standardized as the Open Systems Interconnection (OSI) reference model by the International Standardization Organization (ISO) in 1977

- 7 layer architecture
- Connection oriented

Hardy implemented anywhere in full ...

...but its concepts and terminology are widely used, when describing existing and designing new protocols...
Network protocols & standards

OSI Network Layers

User data

Application
Presentation
Session
Transport
Network
Data link
Physical

Network
Data link
Physical

Application
Presentation
Session
Transport
Network
Data link
Physical

User data
Network protocols & standards

1: Physical Layer

- **Service**: Transmission of a raw bit stream over a communication channel
- **Functions**: Conversion of bits into electrical or optical signals
- **Examples**: X.21, Ethernet (cable, detectors & amplifiers)
2: Data Link Layer

- **Service**: Reliable transfer of frames over a link
- **Functions**: Synchronization, error correction, flow control
- **Examples**: HDLC (high level data link control protocol), LAP-B (link access procedure, balanced), LAP-D (link access procedure, D-channel), LLC (link level control), …
Network protocols & standards

3: Network Layer

- **Service**: Transfer of packets inside the network
- **Functions**: Routing, addressing, switching, congestion control
- **Examples**: IP, X.25
Network protocols & standards

4: Transport Layer

- **Service**: Transfer of data between hosts
- **Functions**: Connection establishment, management, termination, flow-control, multiplexing, error detection
- **Examples**: TCP, UDP, ISO TP0-TP4
Network protocols & standards

5: Session Layer

- **Service**: Coordination of the dialogue between application programs
- **Functions**: Session establishment, management, termination
- **Examples**: RPC
6: Presentation Layer

- **Service**: Provision of platform independent coding and encryption
- **Functions**: Code conversion, encryption, virtual devices
- **Examples**: ISO code conversion, PGP encryption
7: Application Layer

- **Service**: Network access for application programs
- **Functions**: Application/OS specific
- **Examples**: APIs for mail, ftp, ssh, scp, discovery protocols …
Network protocols & standards

OSI
- Application
- Presentation
- Session
- Transport
- Network
- Data link
- Physical

TCP/IP
- Application
- Transport
- IP
- Network
- Data link
- Physical

OSI
- Application
- Presentation
- Session
- Transport
- Network
- Data link
- Physical
Network protocols & standards

OSI

AppleTalk over IP

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<th>AppleTalk Filing Protocol (AFP)</th>
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Network protocols & standards

Serial Peripheral Interface (SPI)

- Used by gazillions of devices ... and it’s not even a formal standard!
- Speed only limited by what both sides can survive.
- Usually push-pull drivers, i.e. fast and reliable, yet not friendly to wrong wiring/programming.
Serial Peripheral Interface (SPI)

Full Duplex, 4-wire, flexible clock rate
Serial Peripheral Interface (SPI)

Clock phase and polarity need to be agreed upon.

Network protocols & standards

Networks
Network protocols & standards (SPI)

Address and data bus

- **Receive shift register**
- **Transmit shift register**
- **Clock generator**
- **Slave selector**

**Master**
- MISO → MISO
- MOSI → MOSI
- SCK → SCK
- NSS → CS

**Slave**
- Transmit shift register
- Receive shift register

1 shift register?  
FIFOs?  
CRC?  
Data connected to an internal bus?  
DMA?  
Speed?

from STM32L4x6 advanced ARM®-based 32-bit MCUs reference manual: Figure 420 on page 1291
Network protocols & standards (SPI)

Master
- Receive shift register
- Transmit shift register
- Clock generator
- Slave selector

Slave 1
- MISO to MISO
- MOSI to MOSI
- SCK to SCK
- NSS to CS

Slave 2
- MISO to MISO
- MOSI to MOSI
- SCK to SCK
- S1 to CS

Slave 3
- MISO to MISO
- MOSI to MOSI
- SCK to SCK
- S2 to S3

Master
- Receive shift register
- Transmit shift register
- Clock generator
- Slave selector

Slave
- Transmit shift register
- Receive shift register
- Slave selector

Full duplex with 1 out of x slaves
Network protocols & standards (SPI)

Concurrent simplex with y out of x slaves
Network protocols & standards (SPI)

Master
- Receive shift register
- Transmit shift register
- Clock generator
- Slave selector

Slave 1
- Receive shift register
- Transmit shift register
- Clock generator
- Slave selector

Slave 2
- Receive shift register
- Transmit shift register

Slave 3
- Receive shift register
- Transmit shift register

Master
- Receive shift register
- Transmit shift register
- Clock generator
- Slave selector

Slave
- Receive shift register
- Transmit shift register

Concurrent daisy chaining with all slaves
Network protocols & standards

**Ethernet / IEEE 802.3**

Local area network (LAN) developed by Xerox in the 70’s

- 10 Mbps specification 1.0 by DEC, Intel, & Xerox in 1980.
- First standard as IEEE 802.3 in 1983 (10 Mbps over thick co-ax cables).
- Currently 1 Gbps (802.3ab) copper cable ports used in most desktops and laptops.
- Currently standards up to 100 Gbps (IEEE 802.3ba 2010).
- More than 85% of current LAN lines worldwide (according to the International Data Corporation (IDC)).

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
Network protocols & standards

Ethernet / IEEE 802.3

OSI relation: PHY, MAC, MAC-client
Network protocols & standards

Ethernet / IEEE 802.3

OSI relation: PHY, MAC, MAC-client
Network protocols & standards

Ethernet / IEEE 802.11

Wireless local area network (WLAN) developed in the 90’s

- First standard as IEEE 802.11 in 1997 (1-2 Mbps over 2.4 GHz).
- Typical usage at 54 Mbps over 2.4 GHz carrier at 20 MHz bandwidth.
- Current standards up to 780 Mbps (802.11ac) over 5 GHz carrier at 160 MHz bandwidth.
- Future standards are designed for up to 100 Gbps over 60 GHz carrier.
- Direct relation to IEEE 802.3 and similar OSI layer association.

- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
- Direct-Sequence Spread Spectrum (DSSS)
Network protocols & standards

Bluetooth

Wireless local area network (WLAN) developed in the 90’s with different features than 802.11:

- Lower power consumption.
- Shorter ranges.
- Lower data rates (typically < 1 Mbps).
- Ad-hoc networking (no infrastructure required).

Combinations of 802.11 and Bluetooth OSI layers are possible to achieve the required features set.
Network protocols & standards

Token Ring / IEEE 802.5 / Fibre Distributed Data Interface (FDDI)

- “Token Ring“ developed by IBM in the 70’s
- IEEE 802.5 standard is modelled after the IBM Token Ring architecture (specifications are slightly different, but basically compatible)
- IBM Token Ring requests are star topology as well as twisted pair cables, while IEEE 802.5 is unspecified in topology and medium
- Fibre Distributed Data Interface combines a token ring architecture with a dual-ring, fibre-optical, physical network.

Unlike CSMA/CD, Token ring is deterministic
(with respect to its timing behaviour)

FDDI is deterministic and failure resistant

None of the above is currently used in performance oriented applications.
Network protocols & standards

**Fibre Channel**

- Developed in the late 80’s.
- ANSI standard since 1994.
- Current standards allow for 16 Gbps per link.

- Allows for three different topologies:
  - **Point-to-point**: 2 addresses
  - **Arbitrated loop** (similar to token ring): 127 addresses deterministic, real-time capable
  - **Switched fabric**: $2^{24}$ addresses, many topologies and concurrent data links possible

- Defines OSI equivalent layers up to the session level.

- Mostly used in storage arrays, but applicable to super-computers and high integrity systems as well.
Fibre Channel

Mapping of Fibre Channel to OSI layers:

OSI | FibreChannel | FC/IP | TCP/IP | OSI
---|-------------|------|--------|---
Application | Application | Application | Application | Application
Presentation | FC-4 | FC-4 | FC-4 | Presentation
Session | FC-3 | FC-3 | FC-3 | Session
Transport | FC-2 | FC-2 | FC-2 | Transport
Network | FC-1 | FC-1 | Network | Network
Data link | FC-0 | FC-0 | Network | Data link
Physical | Physical | Physical | Physical | Physical

User data
Summary

Networks

- **Network layer models**
  - Open Systems Interconnection (OSI) reference model

- **Practical network standards**
  - Serial Peripheral Interface (SPI)
  - Ethernet / IEEE 802.3 (CSMA/CD)
  - Tokenring / IEEE 802.5 / FDDI
  - Wireless networks / IEEE 802.11 (CSMA/CA, DSSS)
  - Fibre Channel