Local Area Network: Ethernet and Advanced Bridging

http://cours.touta.in/?page_id=516 for discussion and exercises

Laurent Toutain

August 27, 2011

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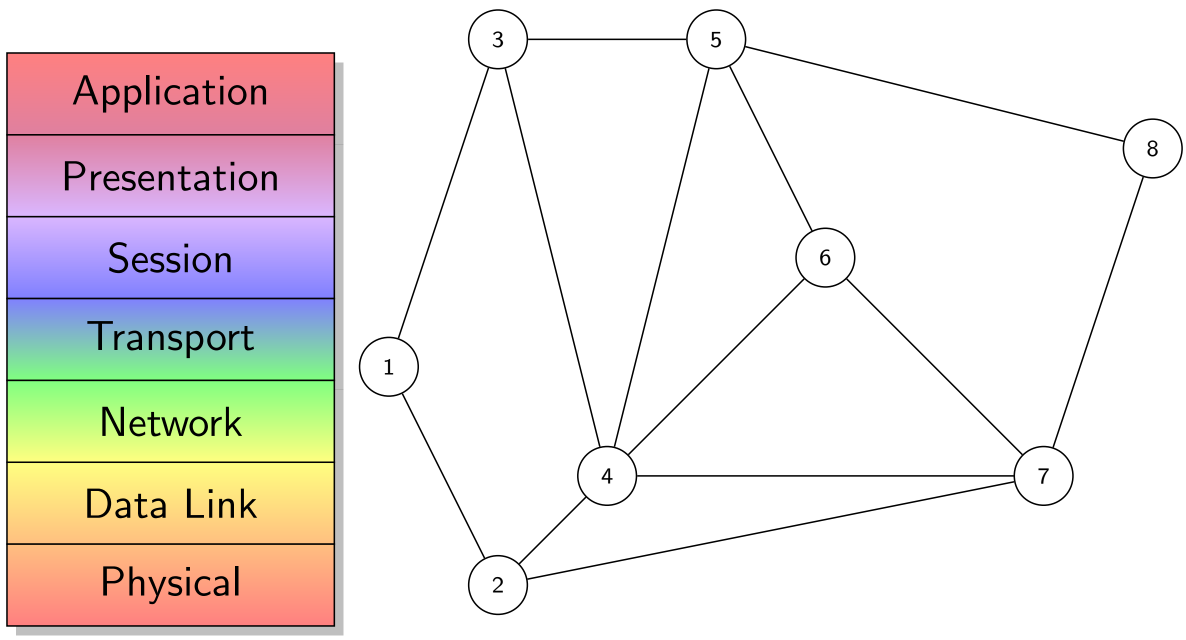
ISO Reference Model



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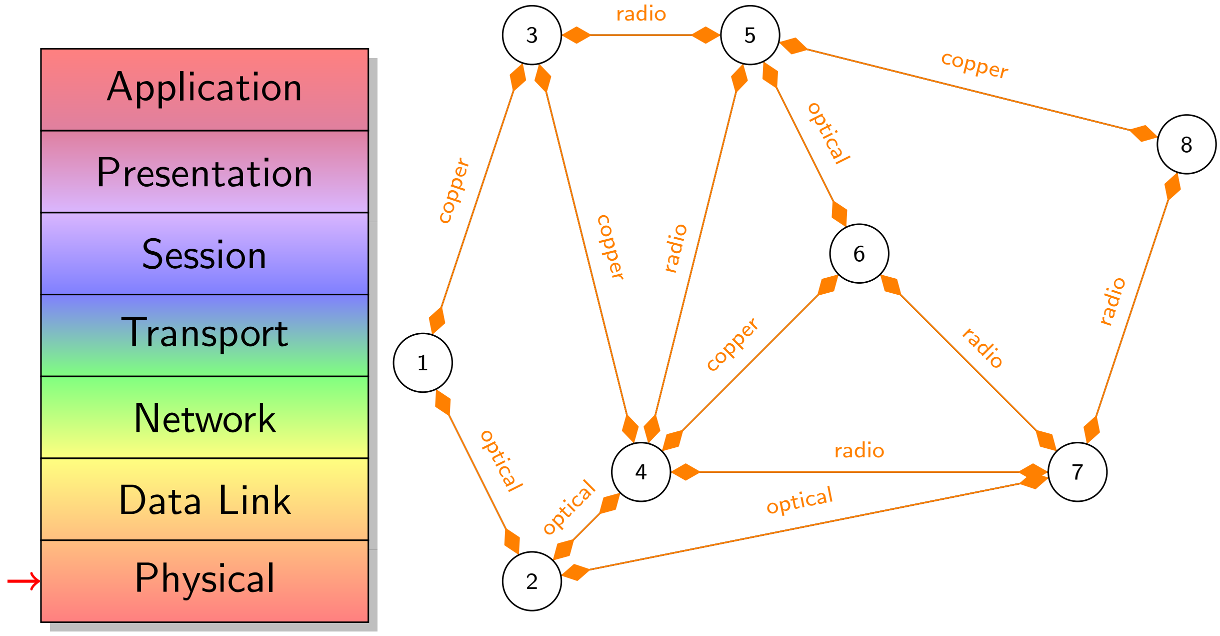

ISO Reference Model

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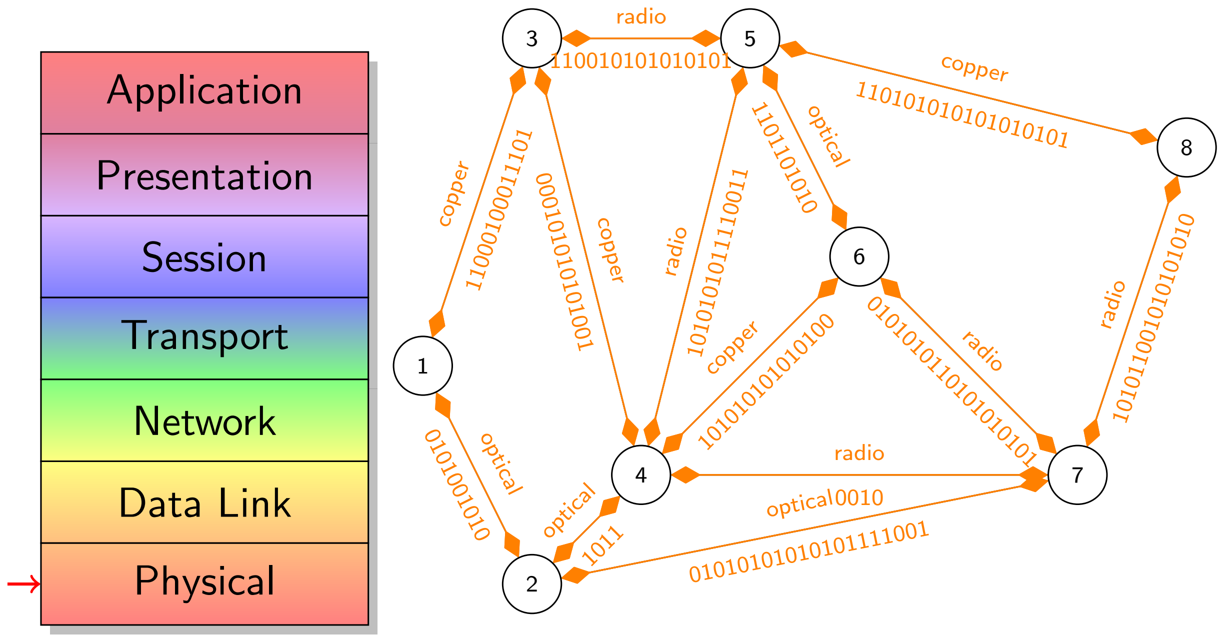

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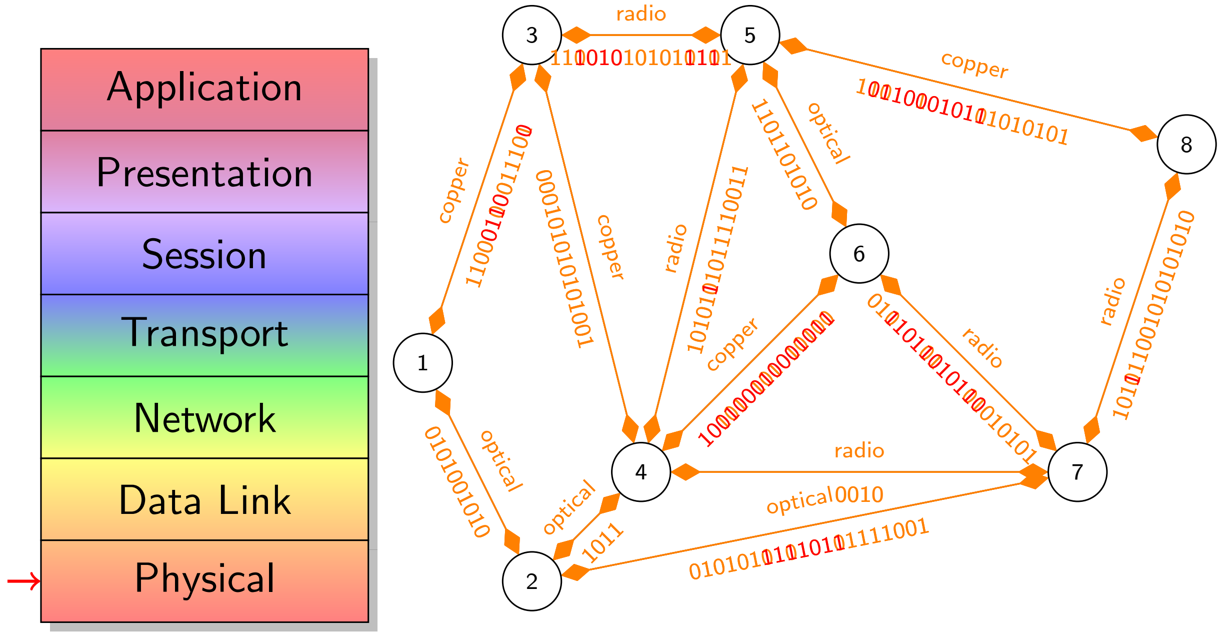

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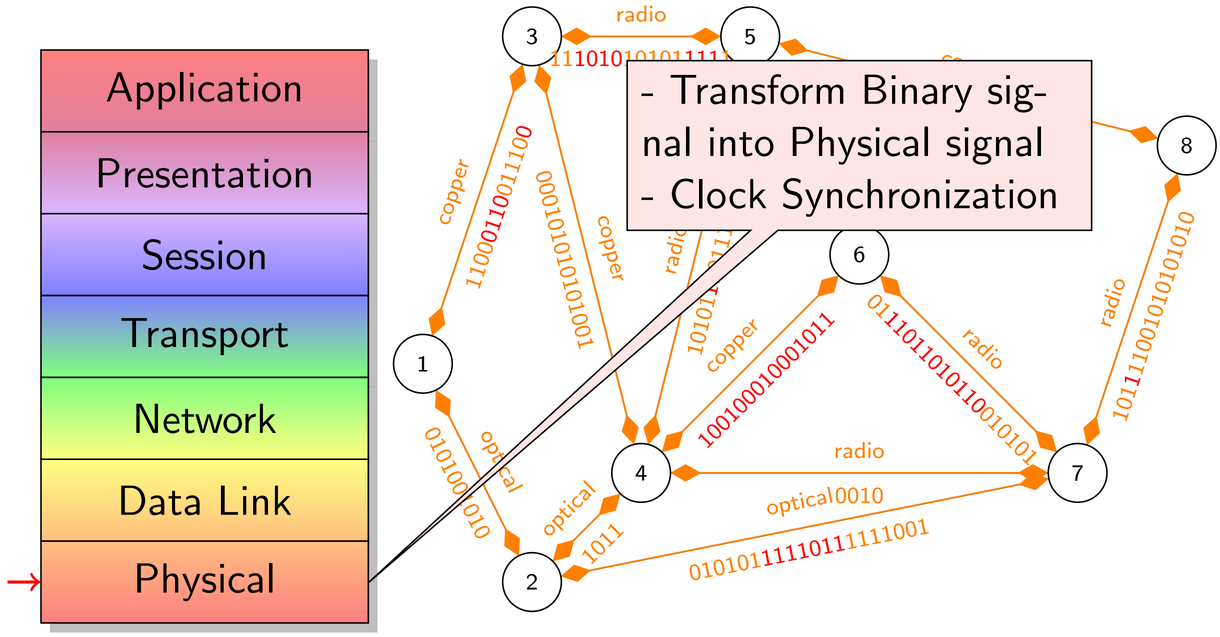

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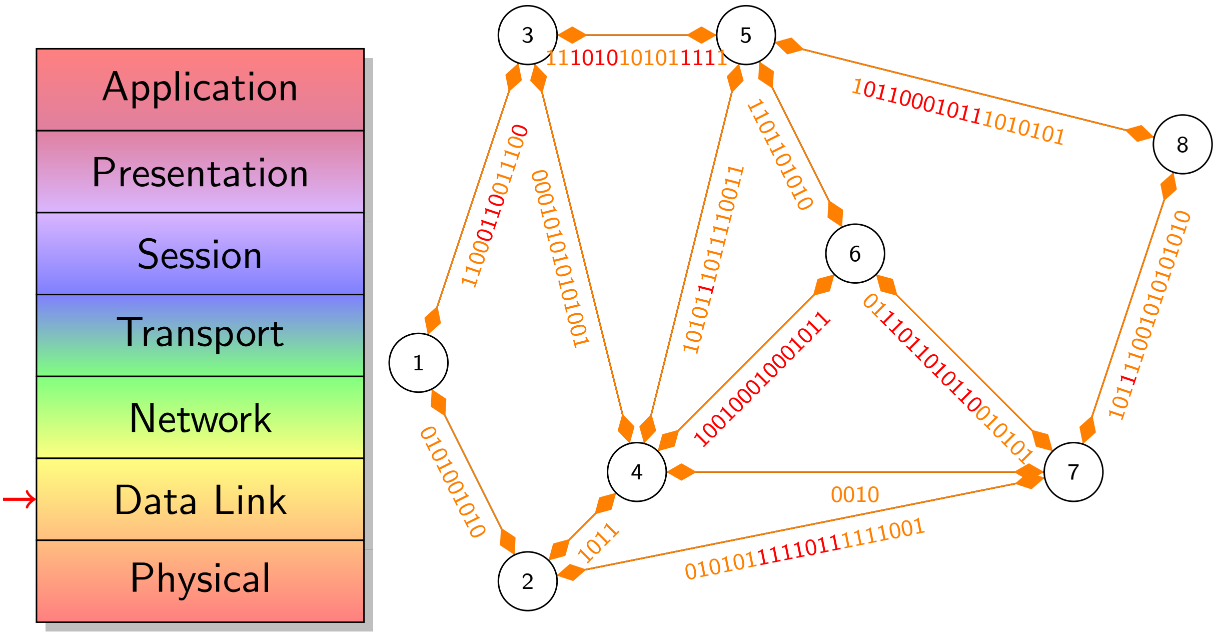

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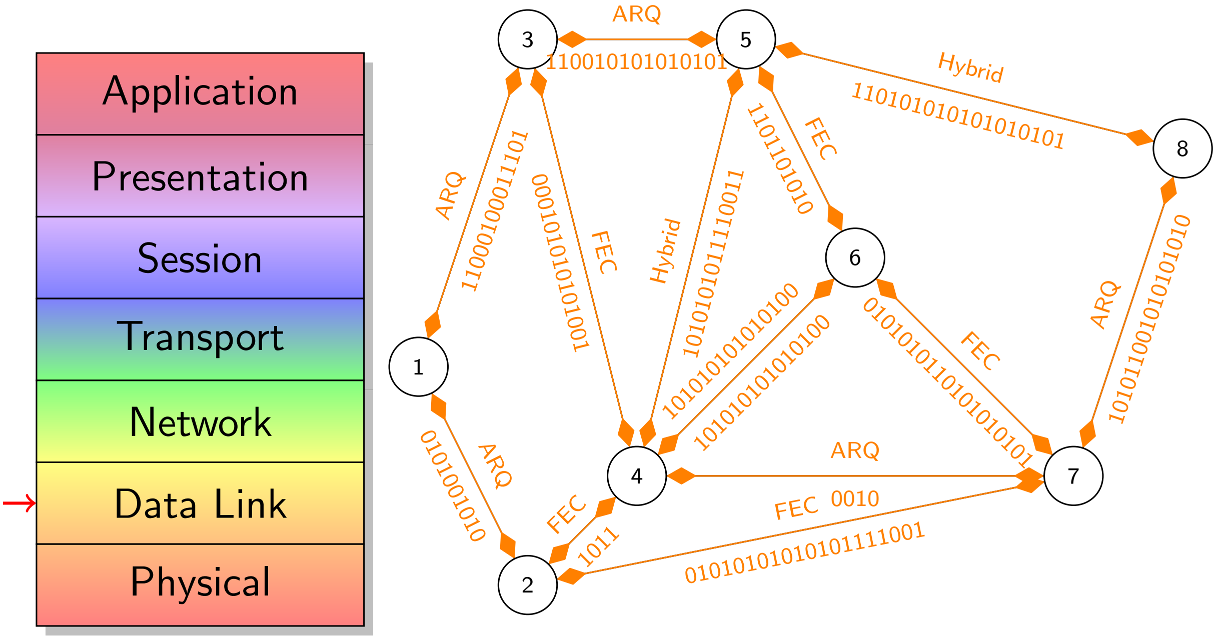
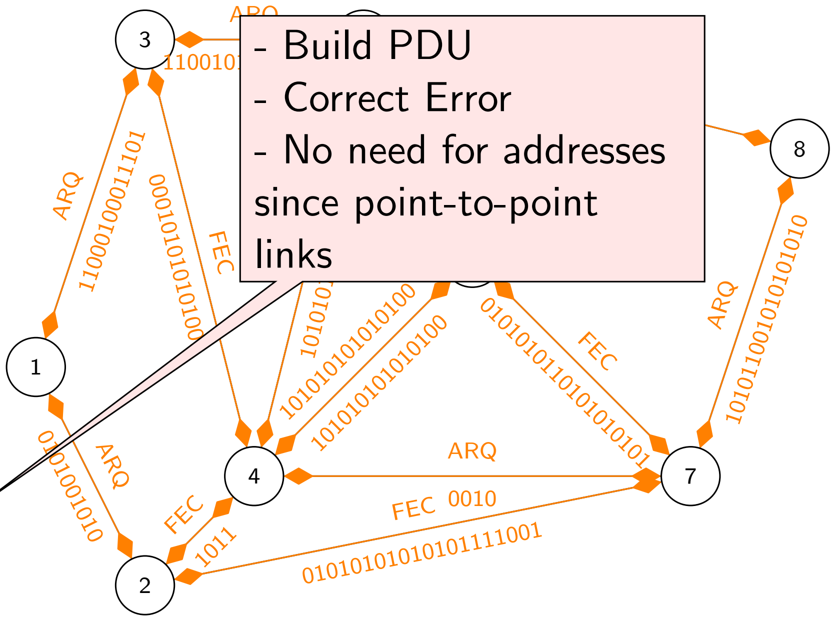


ISO Reference Model

- Application
- Presentation
- Session
- Transport
- Network
- → Data Link
- Physical



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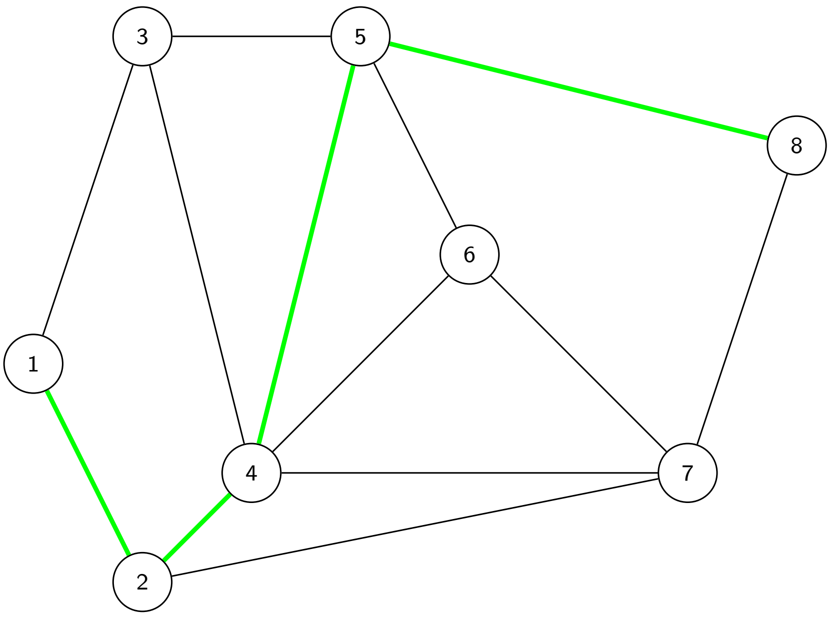

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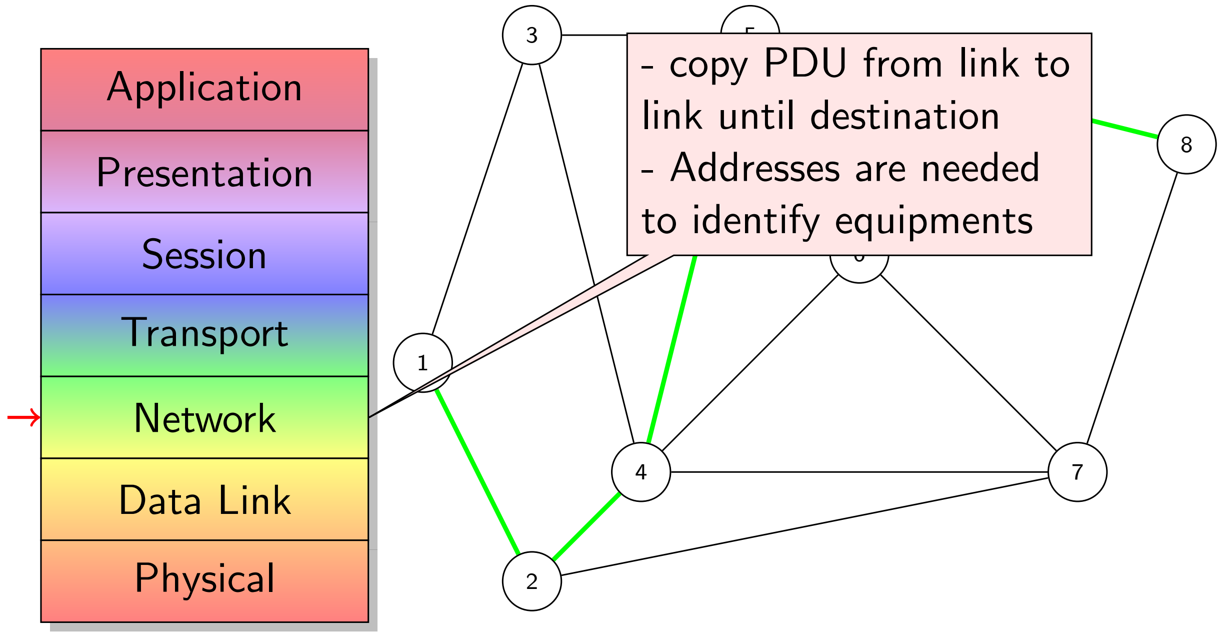

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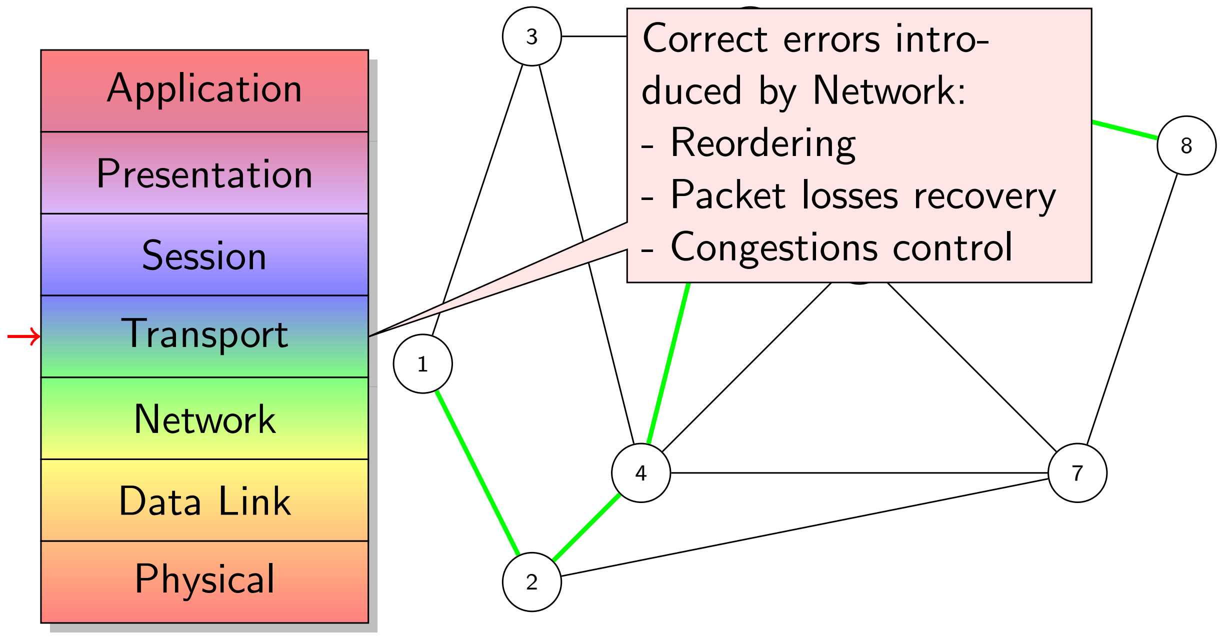

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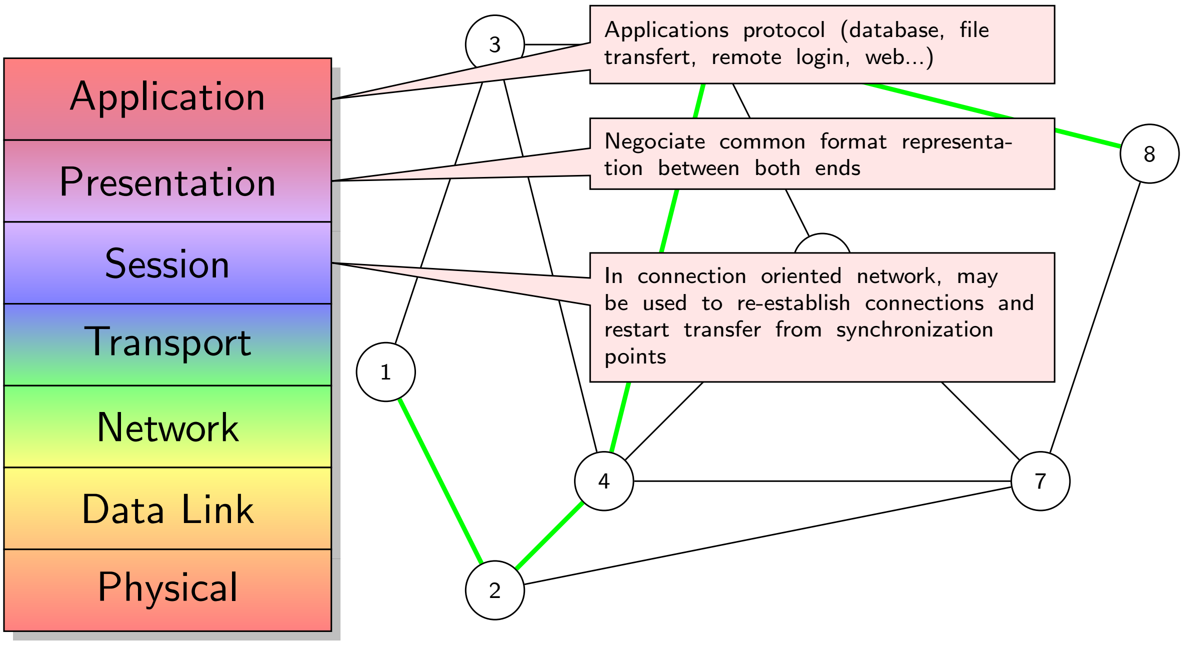
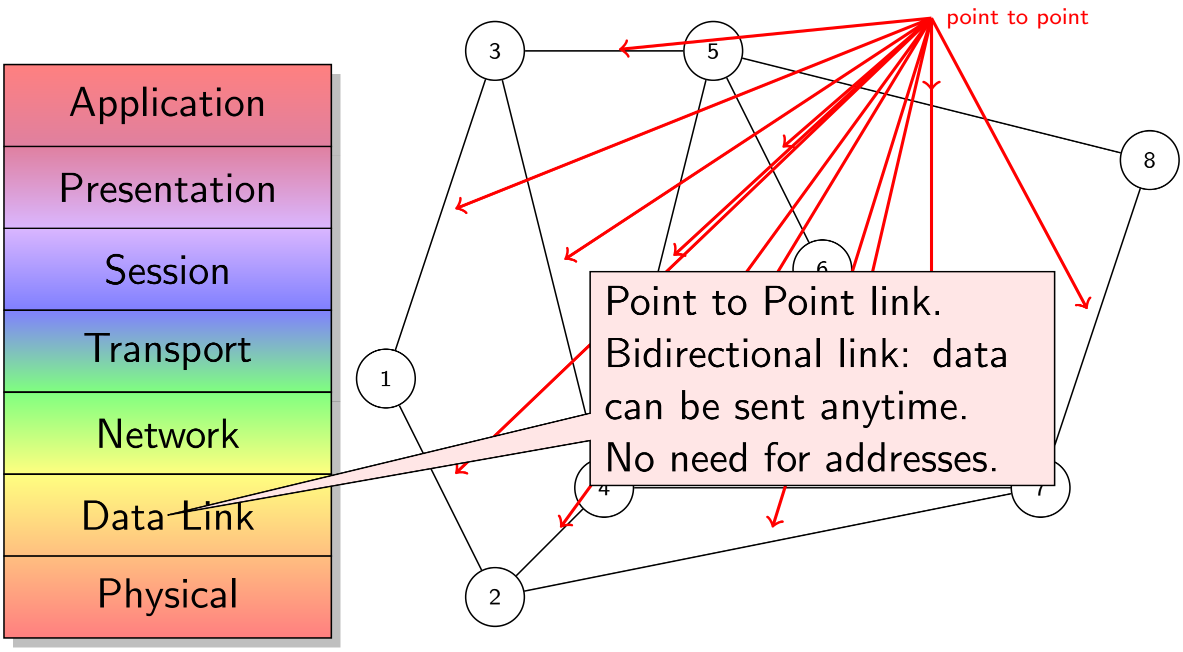


ISO Reference Model: Limits



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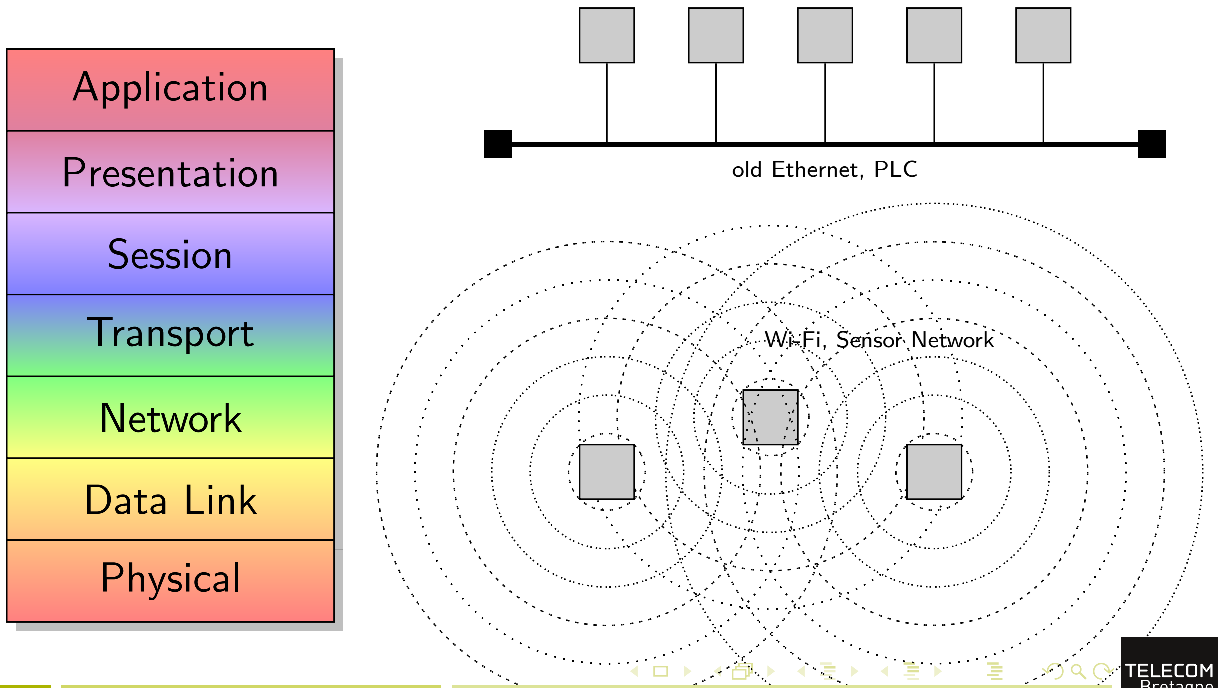

ISO Reference Model: Limits

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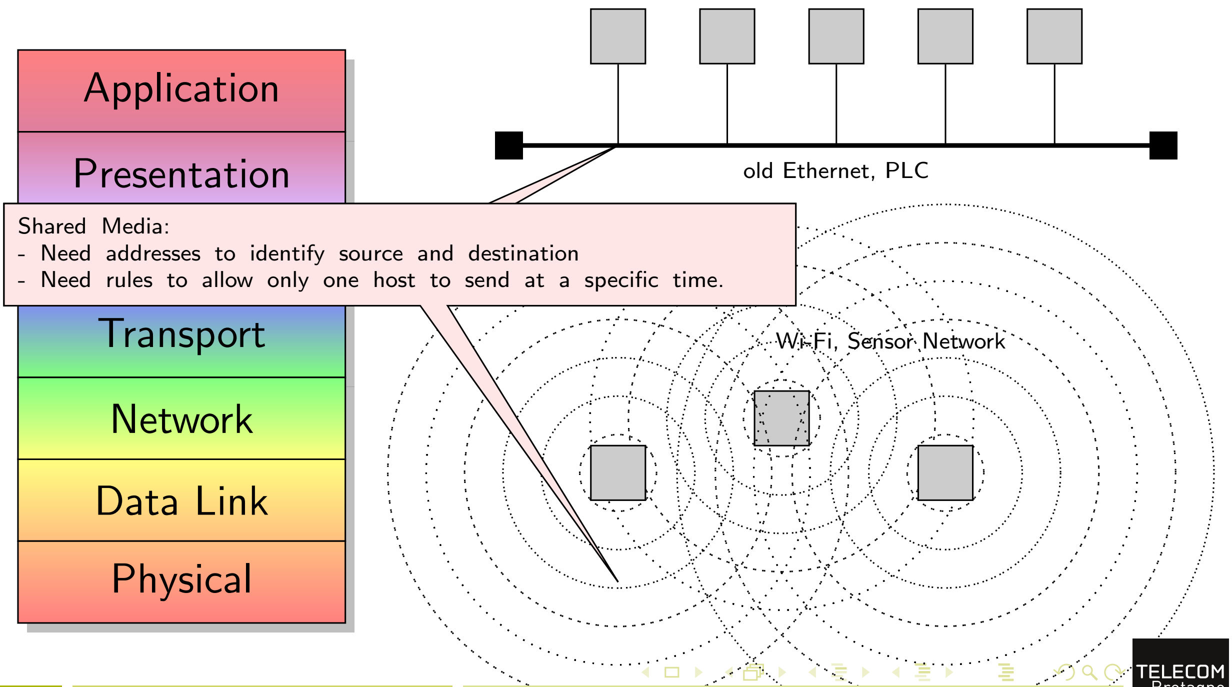

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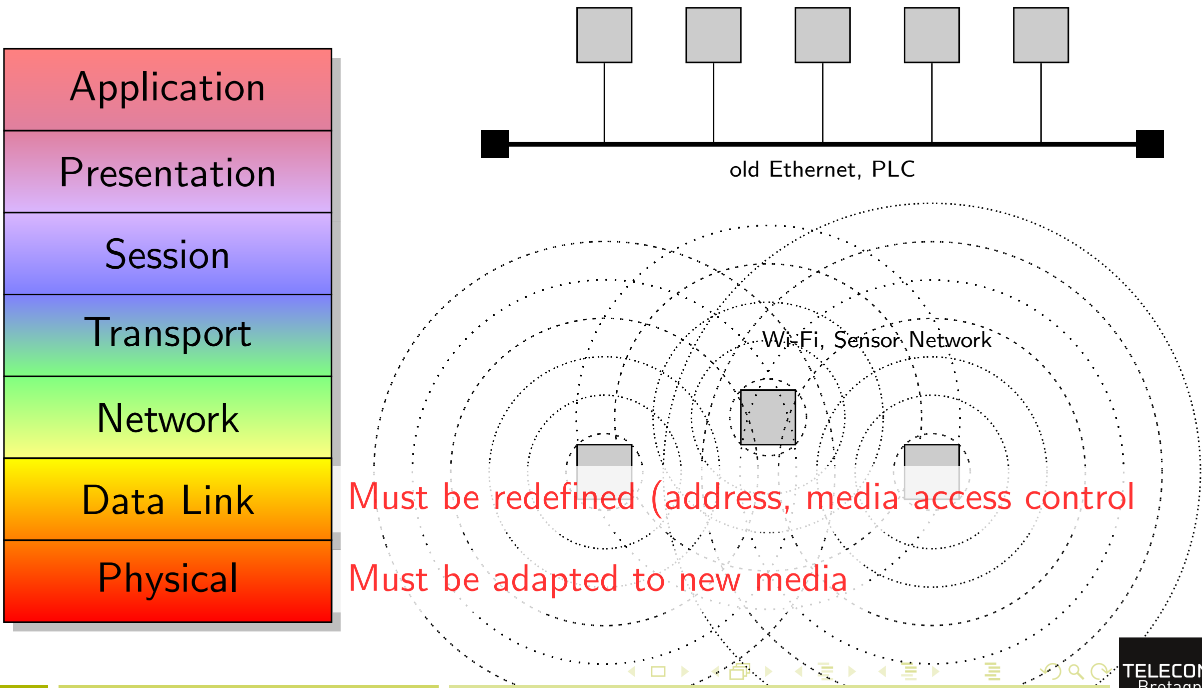

Main characteristics

- Transmission support (media) shared by several equipments:
  - Operating mode: broadcast + Media Access Control
  - When an equipment send data, all others may receive it
  - A equipment should not send data when another one is sending.
  - ⇒ Possible conflict
  - Avoid centralized transmission right management
- A shared media imposes:
  - A way to identity unambiguously any equipments,
  - Decentralized transmission right management
  - No configuration from the user
  - Scalability limitations due to broadcast media
- IEEE defines a model for those kind of networks (layer 1 and 2 of OSI Reference Model)

Network Classification

By scope

By scope

	LAN	Access	Metropolitan	WAN
Scope	*hist: 1m to 2 km*		*hist: 100 Mbit/s*	No limit
	1 m to 100 m	up to 10 km		
# equipments	*hist: 2 to 200*		200 km	No limit
	2 to 50	2 to 100	2 to 100	
Owner	User	provider : direct facturation	provider (indirect facturation)	Provider (indirect facturation)
Cost	No charge	f(throughput)	Subscription (SLA: Service Level Agreement)	Distance, Duration, Subscription (SLA)
Throughput	*hist: 4 to 10 Mbit/s*			50 bit/s to 2 Mbit/s
	100 Mbit/s to 1 Gbit/s	2 to 20 Mbit/s	10Gbit/s	Multiple of 2.5 Gbit/s
Error rate	$< 10^{-9}$	$< 10^{-6}$	$< 10^{-9}$	10^{-9}
Delay	1 to 100μ	10 to 15 ms		Mostly propagation delays
Technologies	Ethernet - Wi-Fi	ADSL (ATM Ethernet) WiMAX (Ethernet) 3G	Ethernet	SDH/WDM, Ethernet

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Questions

Where was historically located the bottleneck ? and currently ?

- ◯ LAN
- ◯ Access
- ◯ Metro
- ◯ WAN

Will Future WAN technologies will reduce delays ?

- ◯ Yes
- ◯ No

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Categories of network

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2 << *unknown* >>
3 te4-1-caen-rtr-021.noc.renater.fr 7 ms
4 te4-1-rouen-rtr-021.noc.renater.fr 7 ms
5 te0-0-0-1-paris1-rtr-001.noc.renater.fr 7 ms
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LAN

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Network Classification

By Access method

By Access method

- Broadcast: Ethernet, Wi-Fi, PLC, Sensor Networks
- Non Broadcast Multiple Access:
  - Any equipment can be joined, but only once at a specific time
  - Telephony Network, ATM.
- Point-to-Point: Leased Line, Virtual Circuit once established
- Master/Slave: communication only possible between the master and a slave (no direct communication between slaves)
  - ISDN, GSM (communication between the mobile phone and the relay)

Questions

Which technologies require addresses (and how many) ?

- ◯ Broadcast
- ◯ NBMA
- ◯ point-to-Point
- ◯ Master/Slave

Which of these technologies are scalable ?

- ◯ Broadcast
- ◯ NBMA
- ◯ point-to-Point
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Questions

Which technologies require addresses (and how many) ?

- Unique ② Broadcast
- Hierarchical ② NBMA
- ⓪ point-to-Point
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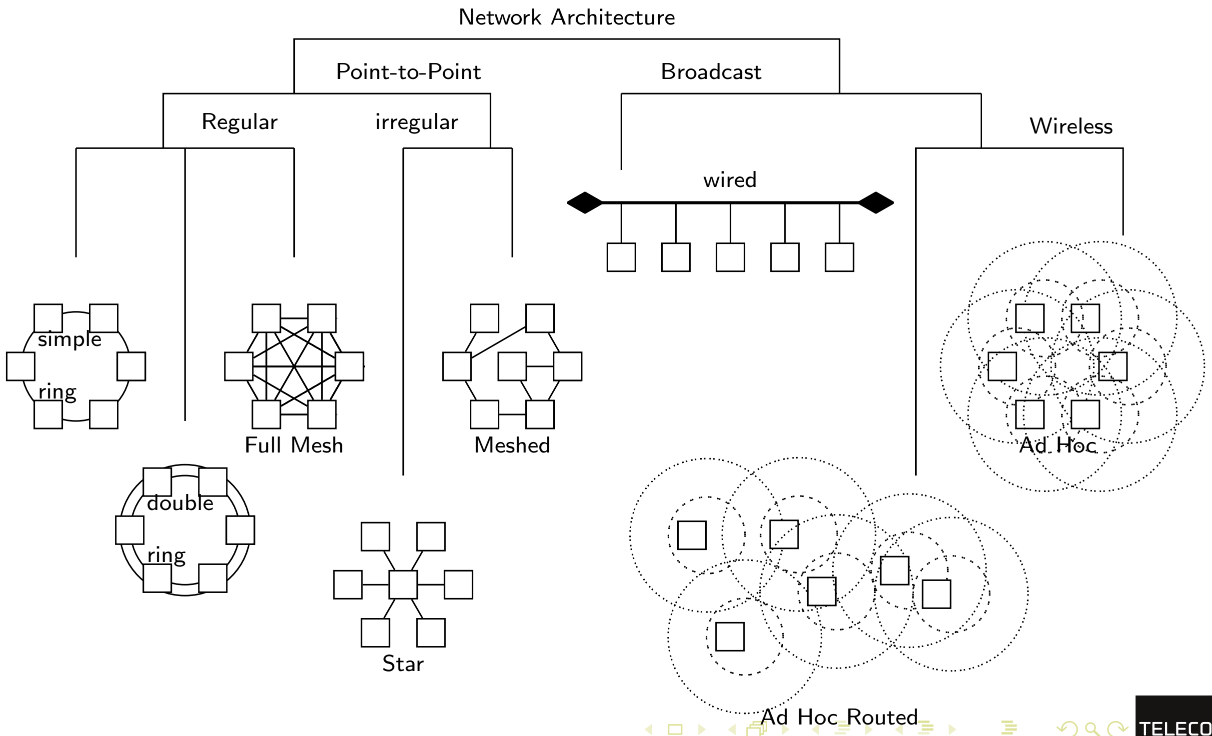
Network Classification

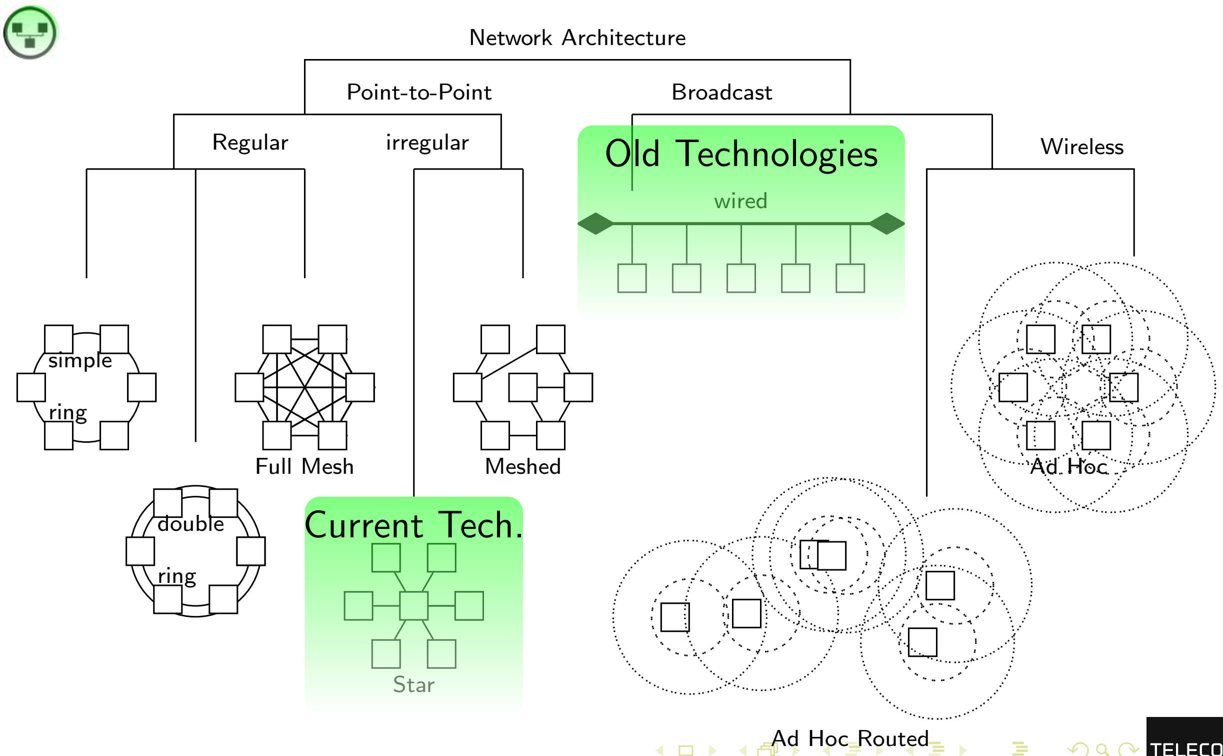
By topology

Network Architecture



Network Architecture

Network Classification ▶ By topology



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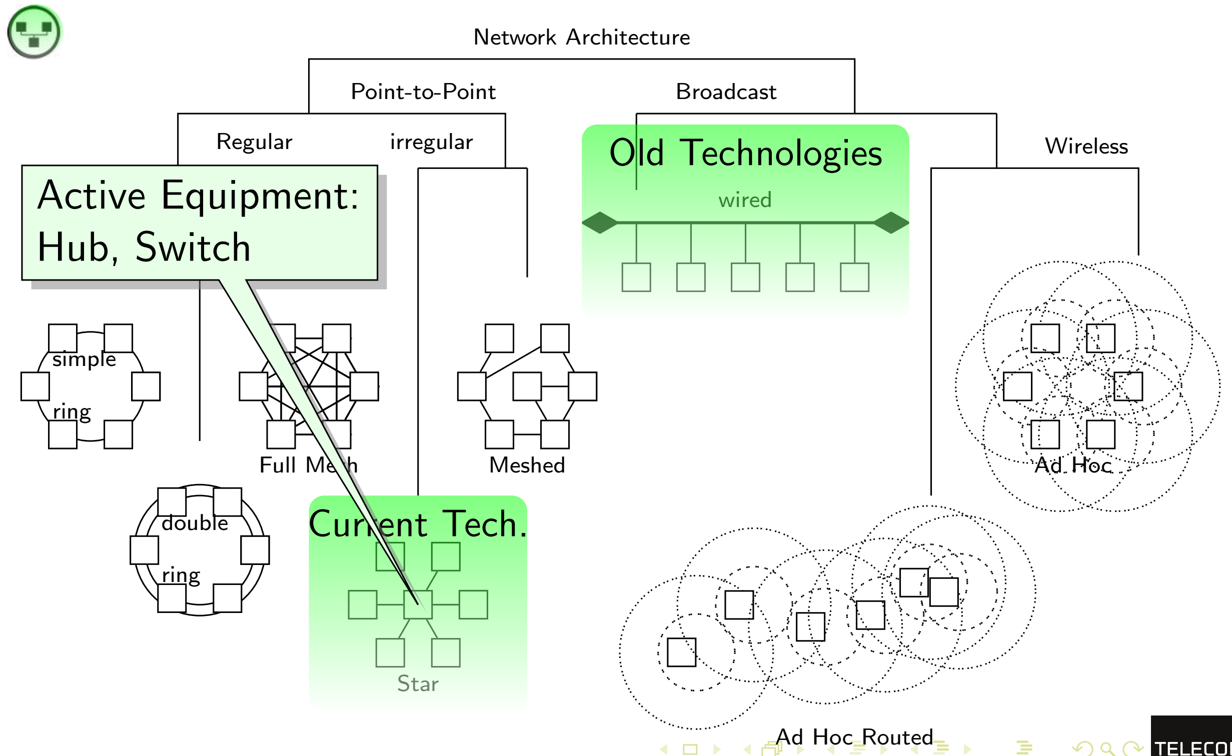
Network Architecture



Network Classification ▶ By topology

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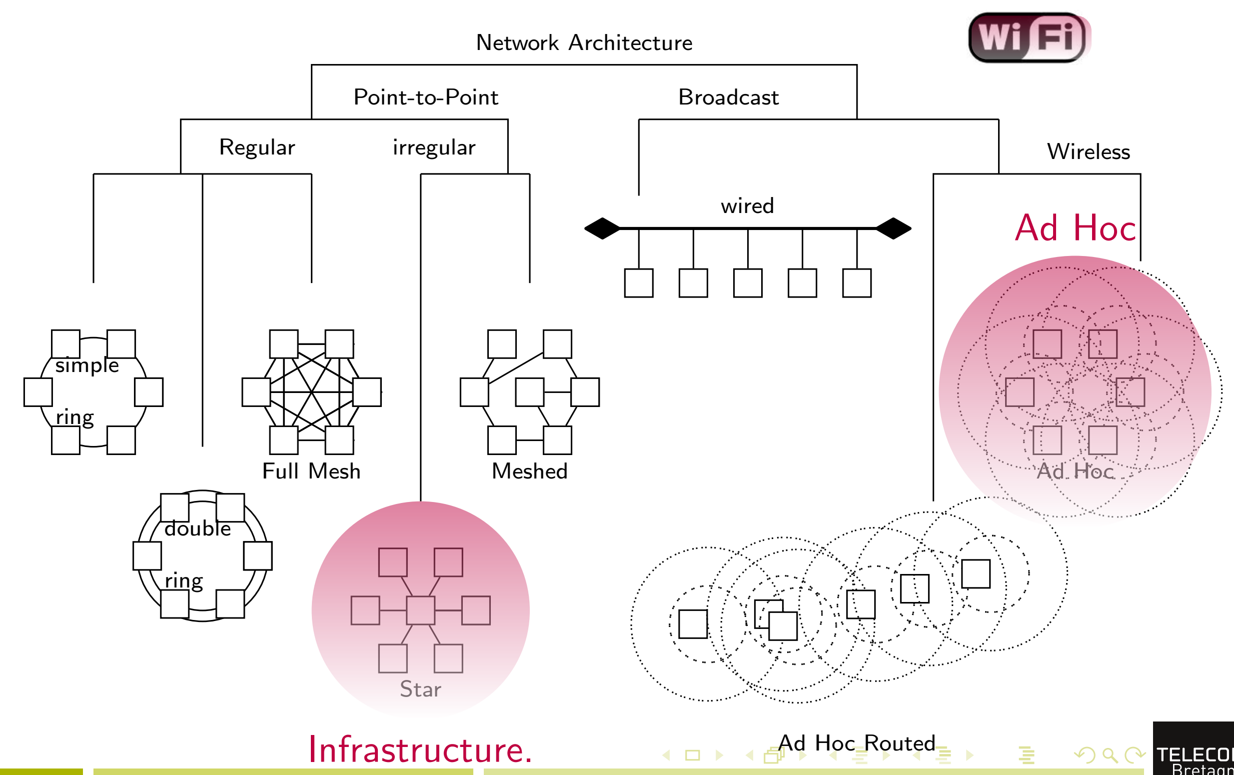
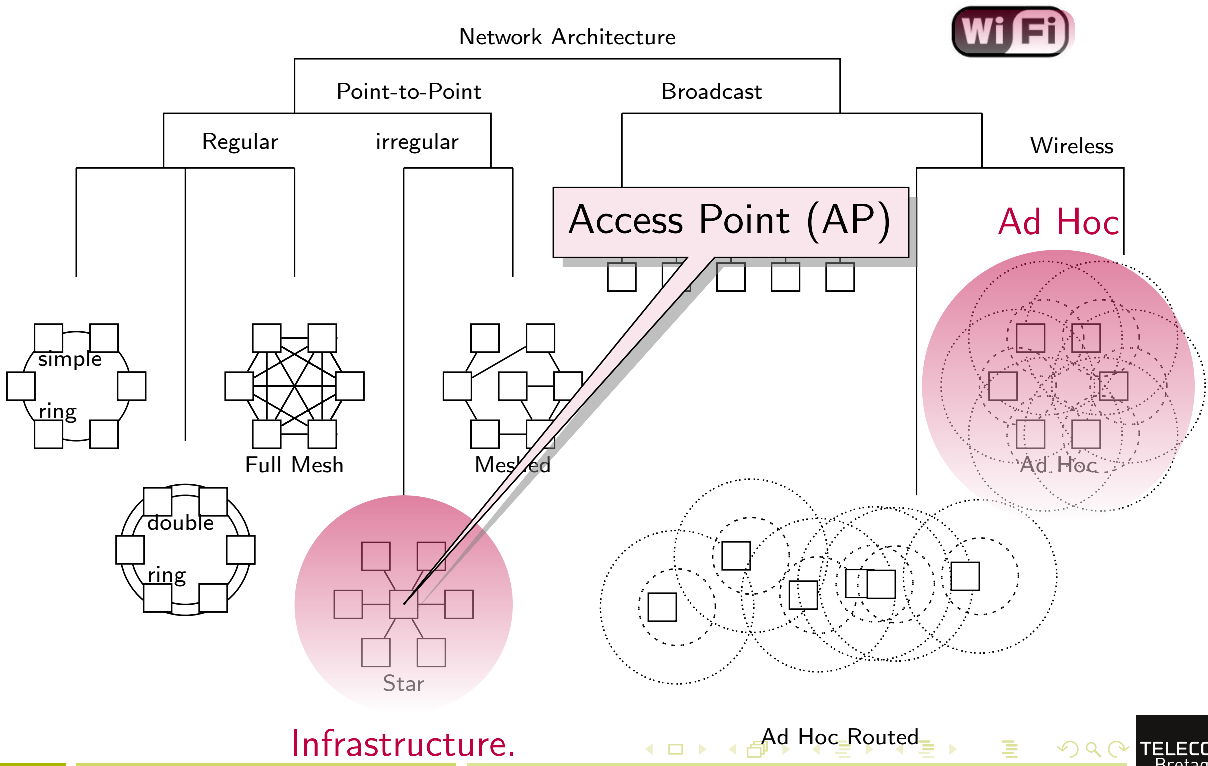
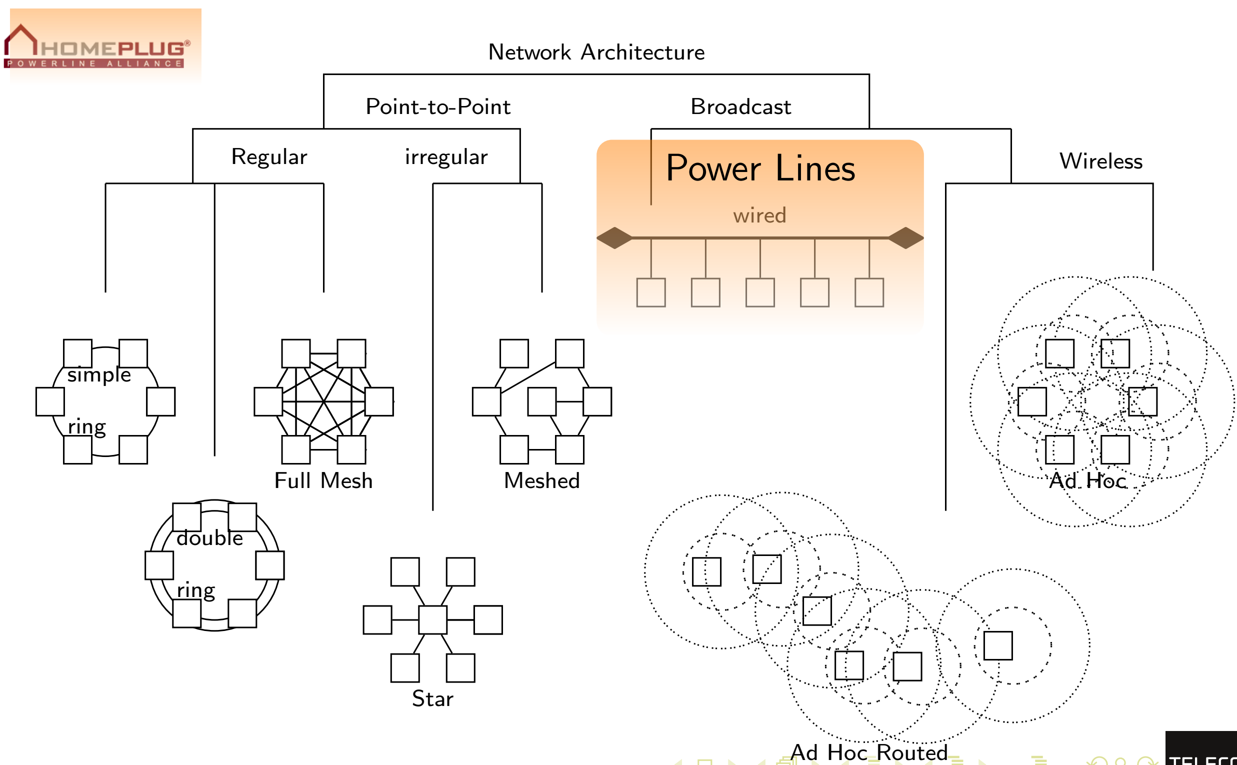


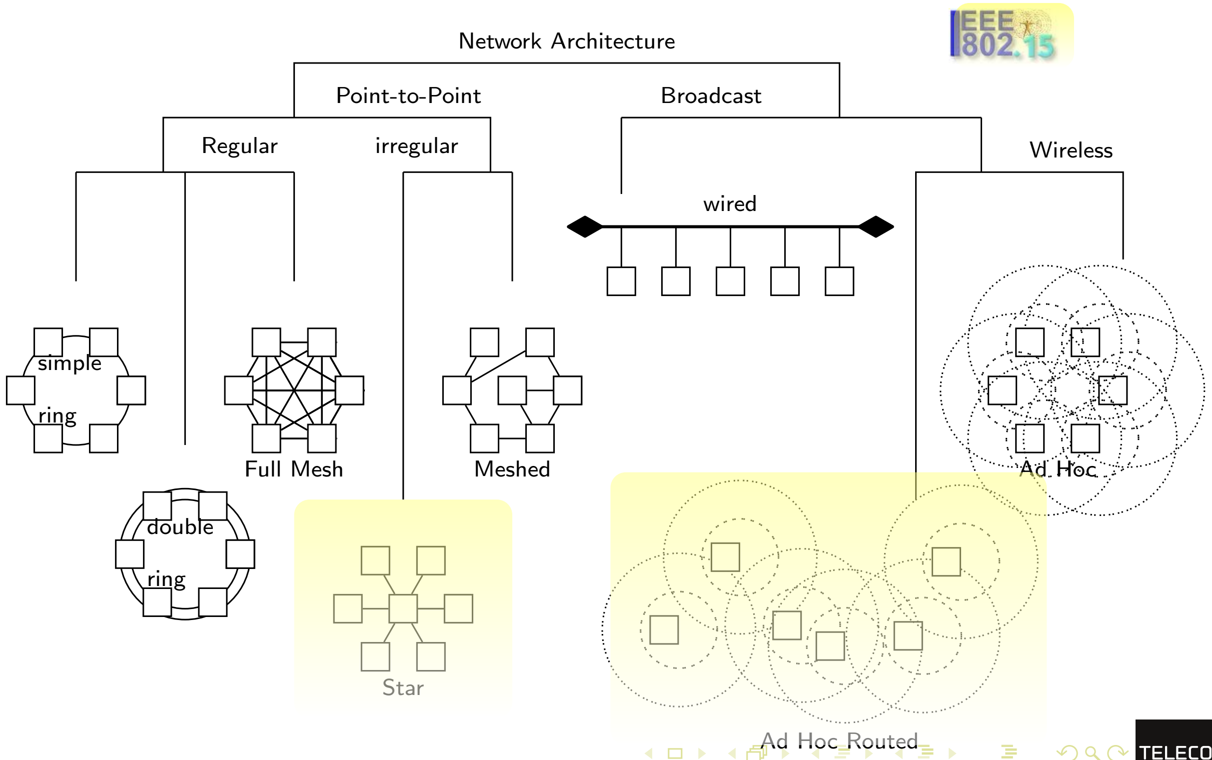
Network Architecture



Network Architecture



Network Architecture



IEEE Model

Introduction

IEEE Model

- Effort started in February 1980 (802) to specify LAN protocols
  - Currently covers also all others technologies (Access, Metro and some part of WAN)
- Adapt ISO Reference Model to broadcast media.
- No centralized equipment (i.e. Master/Slave):
  - Any host can leave or enter the network at any time.
  - USB[1] is not a LAN technology, since a master is needed.
- Not a single solution:
  - No universal solution (depending on the media)
    - Wired and wireless media react differently
    - Industrial may push different technologies
    - Competition exists between IEEE 802 solutions
    - Market will decide
- But a current architecture to ease interconnection.

[1] Universal Serial Bus

IEEE groups

- Standardization is a dynamic process:
  - Some technologies disappear due to la lack of interest from the market
  - Some technologies appear:
    - New areas (wireless, Wireless Sensor Network, Personal Area Network,. . .)
  - All technologies must evolve
    - Increment speed
    - Use new media
    - New usages (energy aware,...)
- IEEE 802 is divided into subgroups.
- Each Working Group is designated by a number[2].
  - For instance IEEE802.3 does standardization for Ethernet

[2] See; W http://ieee802.org/dots.shtml

IEEE groups

- Each Working Group issues regularly a new version of the standard:
  - IEEE 802.3-2008, IEEE 802.3-2005, IEEE Std 802.3-2002,
- Subworking group are working on make evolve some specific part of the standard:
  - They are designated by a letter.
  - Capital letter: a new document
  - Small letter: a modification to an existing document.
  - These results are merged in the next issue of the full standard
  - Sometime the letter continues to be used to refer to the technology:
    - IEEE 802.1Q: Virtual LANs
    - IEEE 802.11g: Wi-Fi at 54 Mbit/s
    - ...
- Standards and approved extensions to standards are available on IEEE Explorer:
  - http://ieeexplore.ieee.org/xpl/standards.jsp#

IEEE Model

Architecture

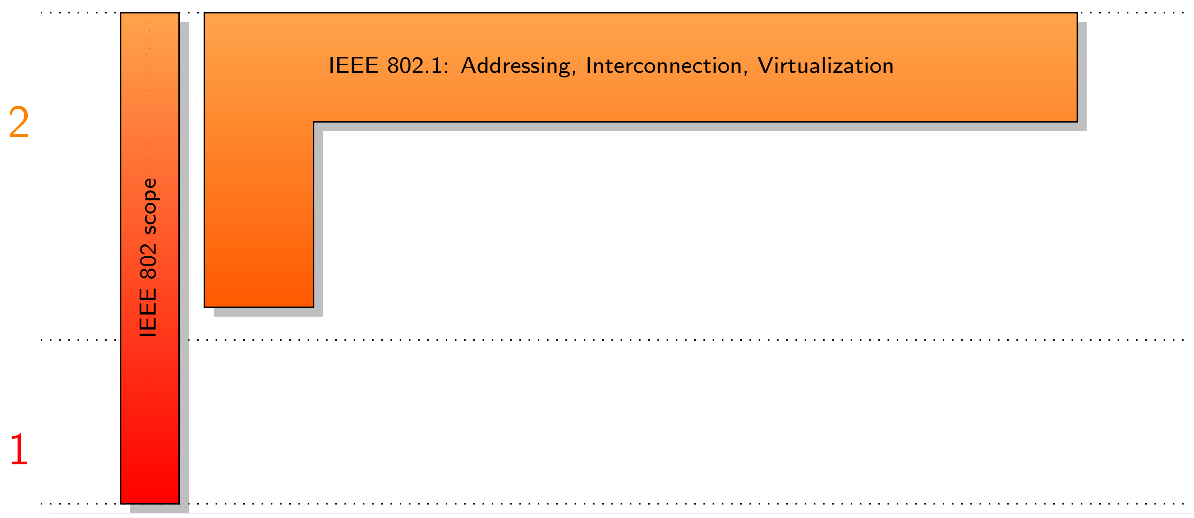
IEEE Architecture

ISO

IEEE Architecture

IEEE Model ▶ Architecture

ISO



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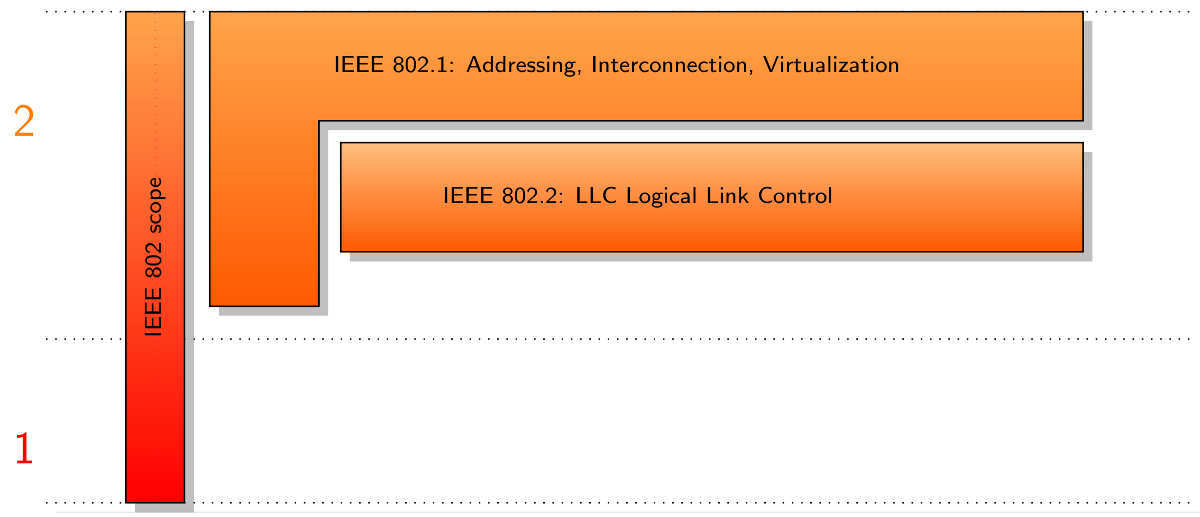
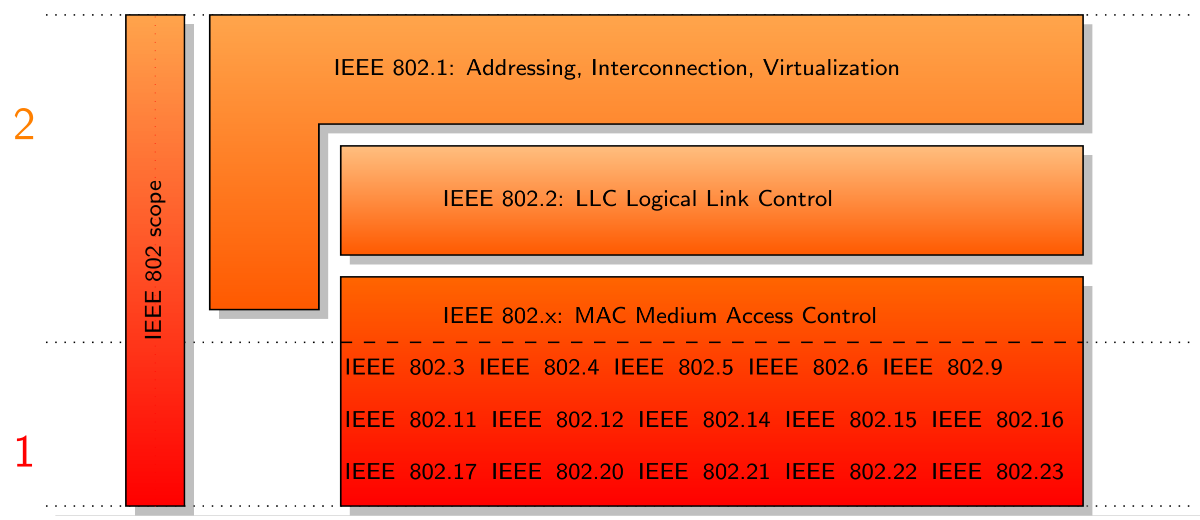
ISO

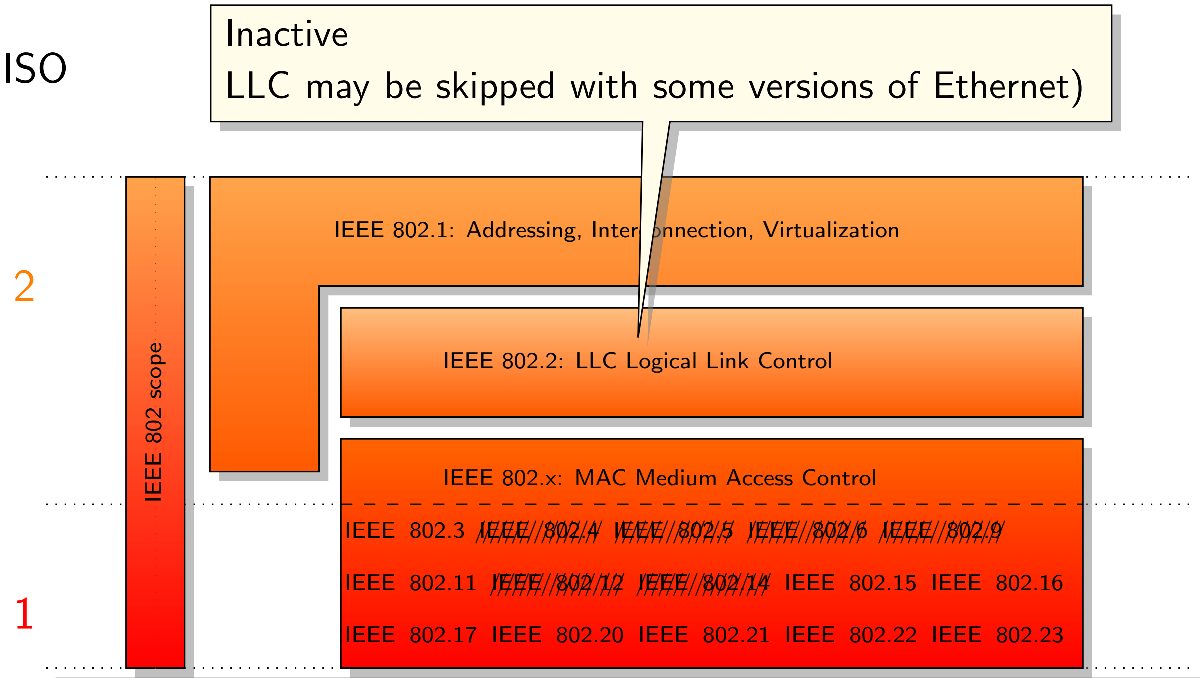


IEEE Architecture
IEEE Model ▶ Architecture

ISO



IEEE Architecture



IEEE Model

Addresses

IEEE 802 Addresses

- Addresses need to be unique on the link,
- Addresses must be assigned without any centralized server,
- Addresses are assigned by the manufacturer:
  - Network card or Equipment manufacturer,
  - They are globaly (worldwide) unique
  - Addresses can be changed by the network manager (do not base security on them).
- IEEE defines three length:
  - MAC-16: 16 bit long, used on network where frame size is important (e.g. Wireless Sensor Networks)
  - MAC-48: 48 bit long, mainly used in LAN technologies (Ethernet, Wi-Fi)
    - no exhaustion before 2100.
  - MAC-64: 64 bit long, not actually used.
- IEEE makes the difference between MAC and EUI (Extended Unique Identifier):
  - used to identify a equipment (not used to send frames)
  - EUI-48 or EUI-64.

How to make addresses globally unique ?

OUI

How to make addresses globally unique ?

Organizational Unit Identifier: Allocated ($1450) by IEEE

OUI

How to make addresses globally unique ?

IEEE Model ▶ Addresses

MAC
EUI
48

OUI	Vendor ID

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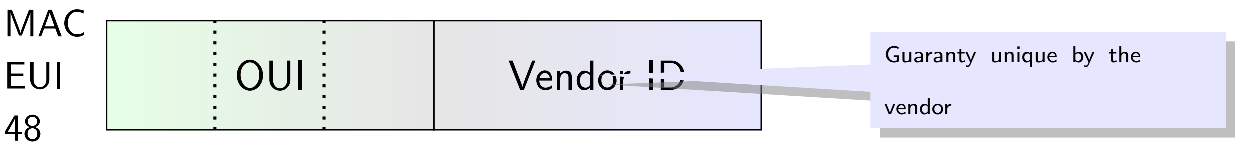
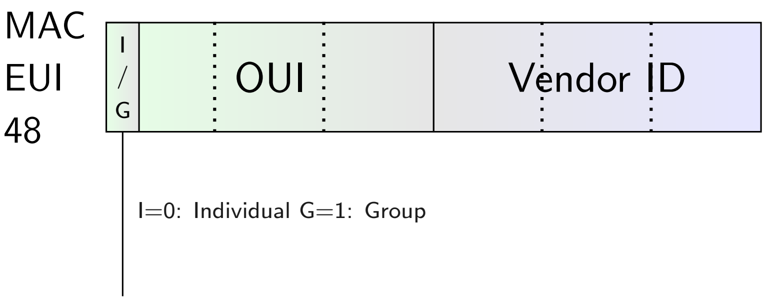
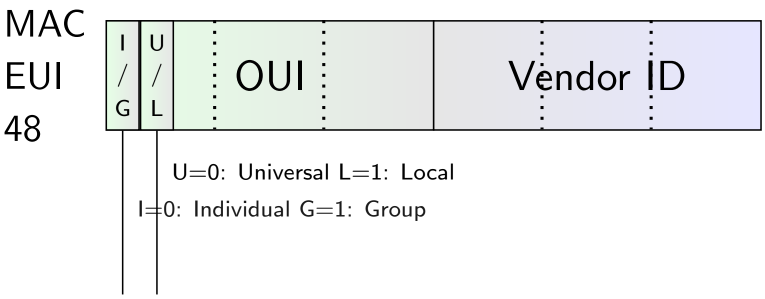
How to make addresses globally unique ?



How to make addresses globally unique ?

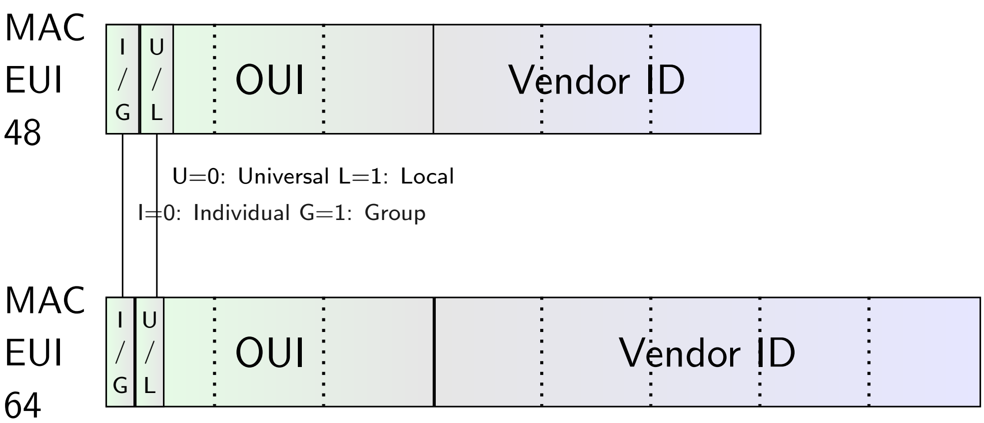


How to make addresses globally unique ?



IEEE Model ▶ Addresses

How to make addresses globally unique ?



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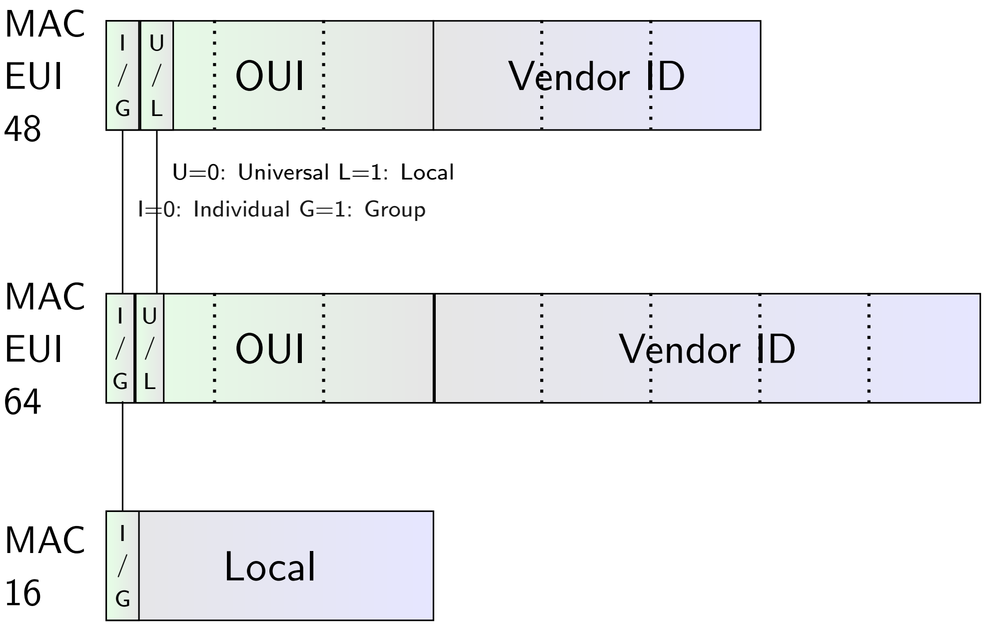
How to make addresses globally unique ?



Different Addresses I

- Representation:
  - Bytes separated by dashes (sometime by column)
  - Ex: `00-23-df-a9-f7-ac`
- Unicast Addresses:
  - I/G bit = 0
  - The frame is sent to only one host on the link
  - OUI is allocated by IEEE; See http://standards.ieee.org/regauth/oui/ to find some values.
  - Who is the vendor of `00-23-df-a9-f7-ac`
    - ----------
- Broadcast Address
  - Sent to all the hosts connected to the link.
  - All bits equal to 1
  - `ff-ff-ff-ff-ff-ff`

Different Addresses I

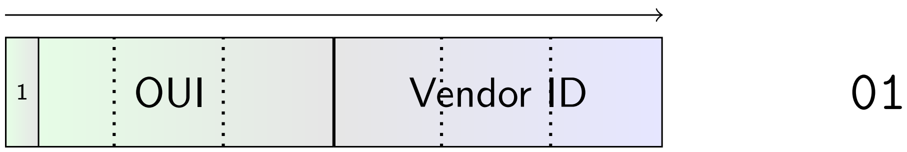
- Representation:
  - Bytes separated by dashes (sometime by column)
  - Ex: `00-23-df-a9-f7-ac`
- Unicast Addresses:
  - I/G bit = 0
  - The frame is sent to only one host on the link
  - OUI is allocated by IEEE; See http://standards.ieee.org/regauth/oui/ to find some values.
  - Who is the vendor of `00-23-df-a9-f7-ac`
    - Apple Inc.
- Broadcast Address
  - Sent to all the hosts connected to the link.
  - All bits equal to 1
  - `ff-ff-ff-ff-ff-ff`

Different Addresses II

- Multicast Address:
  - bit I/G = 1 and address is different from Broadcast address.
  - Nodes must subscribe to this address to receive data.
  - No need to subscribe to send.
- Warning:
  - First bit send is the I/G bit
  - Inform interconnection elements (bridges) to copy the frame on other media.
  - In numerical representation, this bit is on the right.

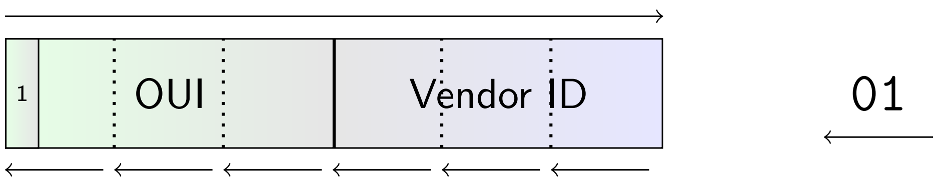
Different Addresses II

- Multicast Address:
  - bit I/G = 1 and address is different from Broadcast address.
  - Nodes must subscribe to this address to receive data.
  - No need to subscribe to send.
- Warning:
  - First bit send is the I/G bit
  - Inform interconnection elements (bridges) to copy the frame on other media.
  - In numerical representation, this bit is on the right.

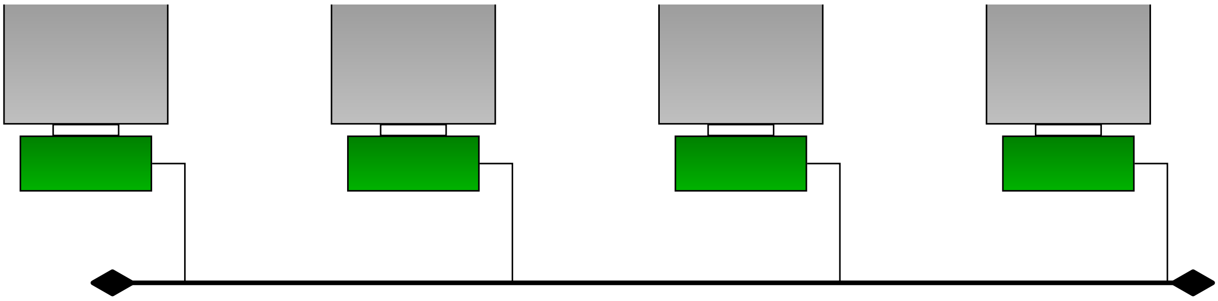


Different Addresses II
IEEE Model ▶ Addresses

- Multicast Address:
  - bit I/G = 1 and address is different from Broadcast address.
  - Nodes must subscribe to this address to receive data.
  - No need to subscribe to send.
- Warning:
  - First bit send is the I/G bit
  - Inform interconnection elements (bridges) to copy the frame on other media.
  - In numerical representation, this bit is on the right.

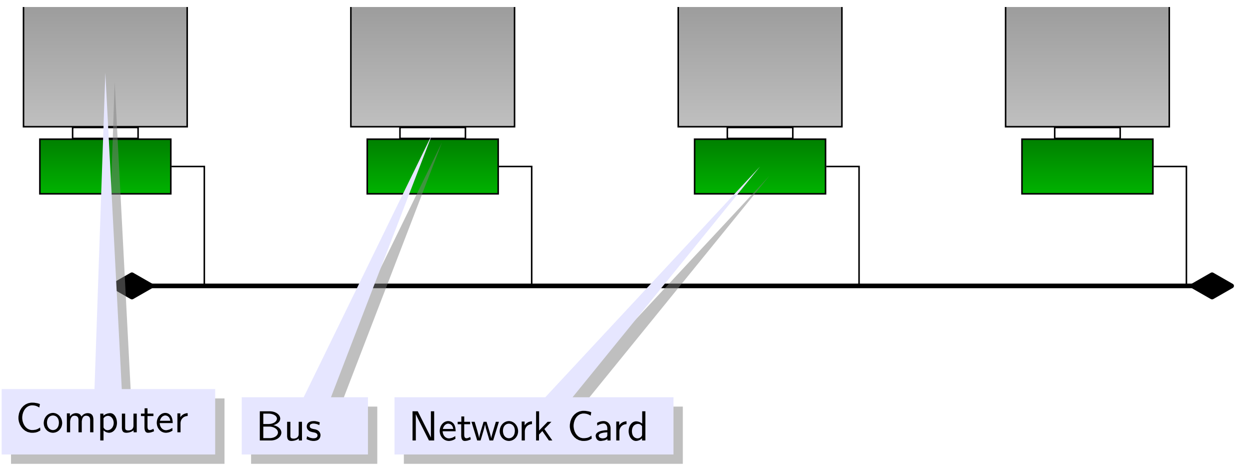


Addresses Management: Computer Architecture



Addresses Management: Computer Architecture

IEEE Model ▶ Addresses



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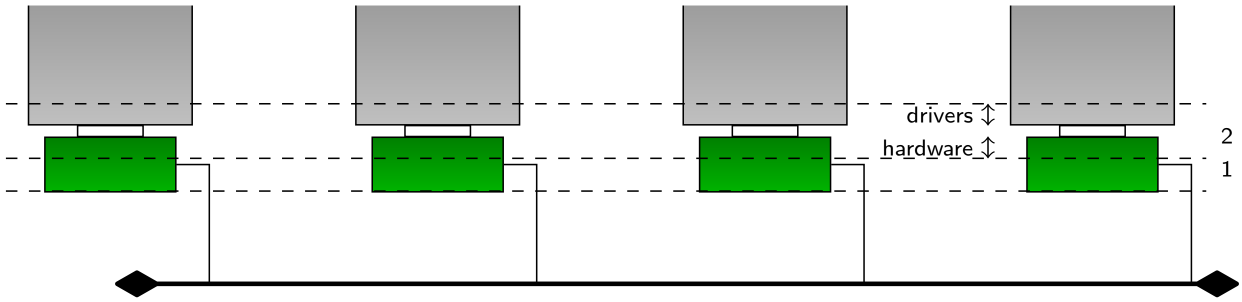
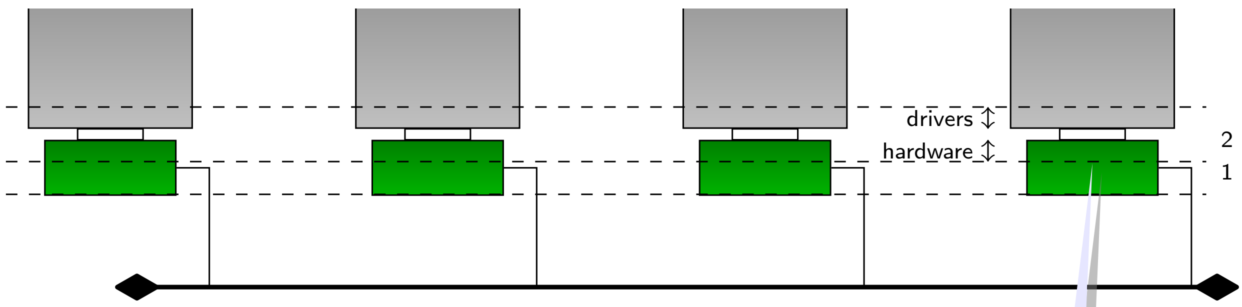
Addresses Management: Computer Architecture



Addresses Management: Computer Architecture

IEEE Model ▶ Addresses



Physical Layer: Information Coding/Decoding

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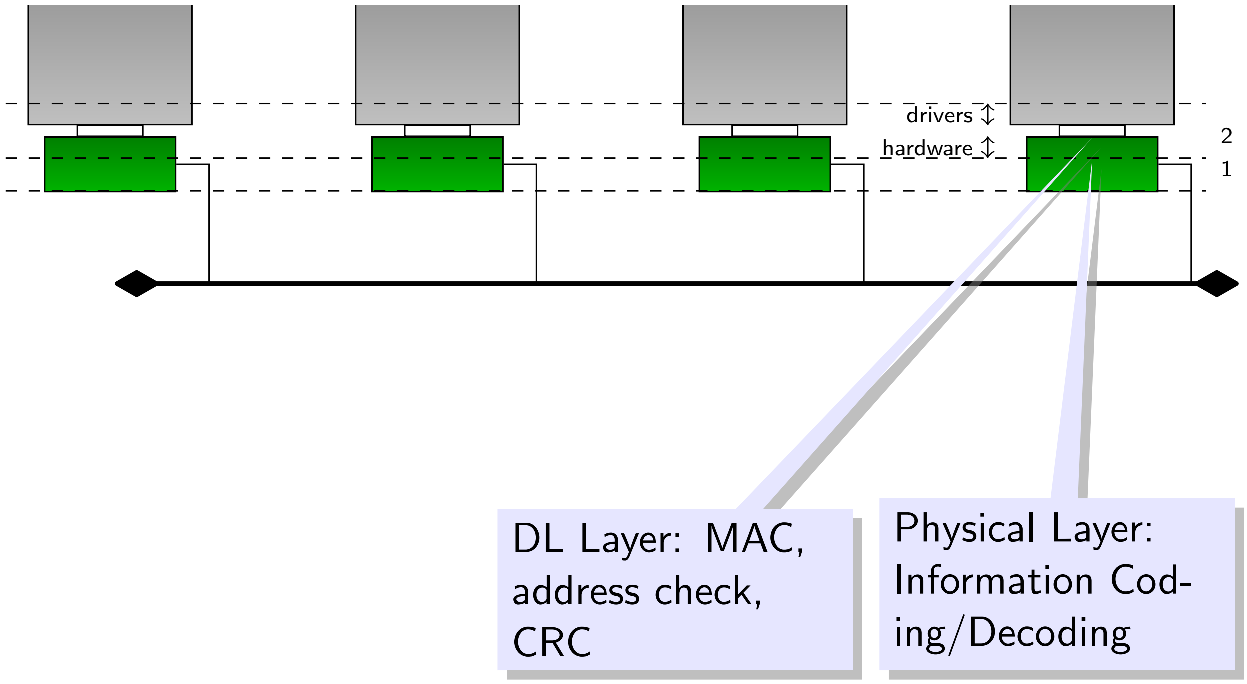
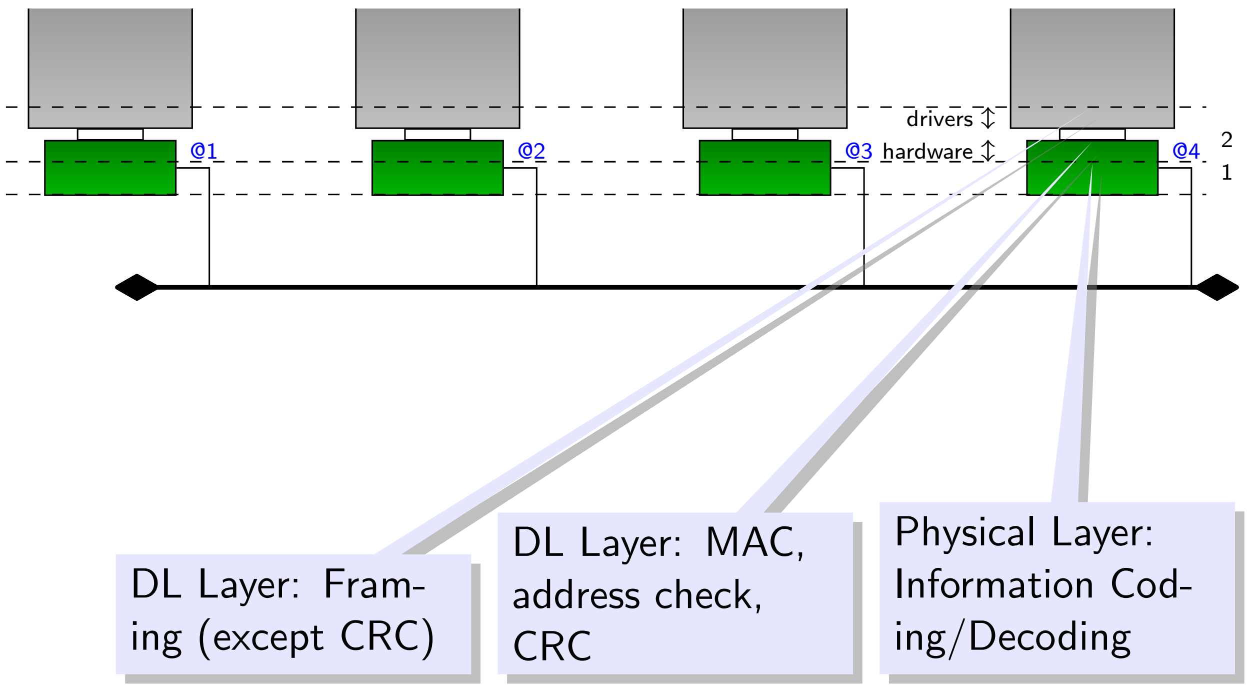
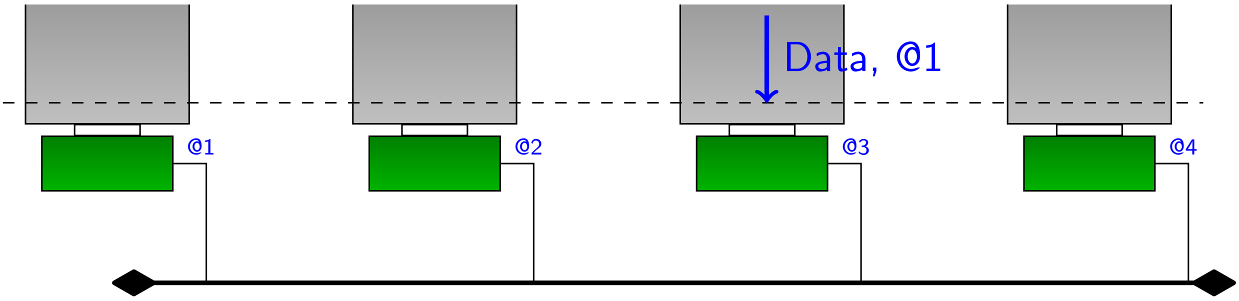
Addresses Management: Computer Architecture



Addresses Management: Computer Architecture

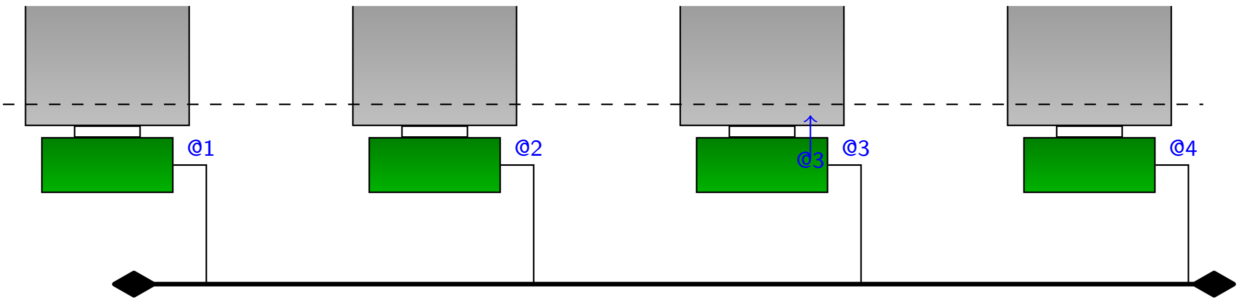


Addresses Management: Unicast



1) MAC Layer receives data.request for @1

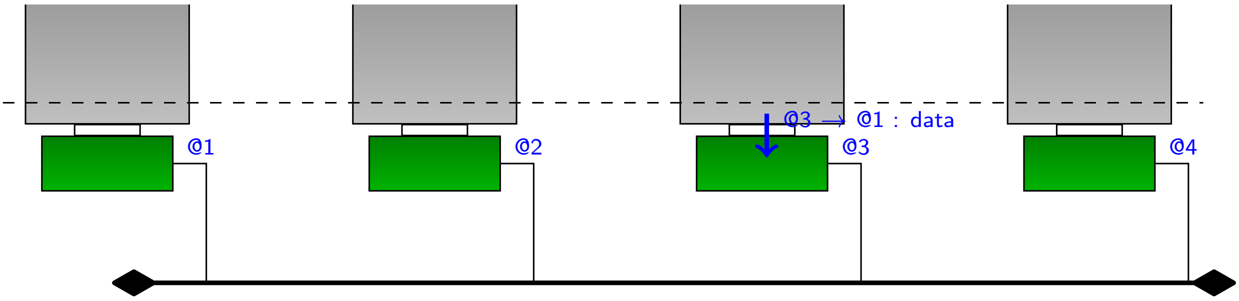
Addresses Management: Unicast



1) MAC Layer receives data.request for @1

2) MAC Layer reads source MAC address (can be overloaded)

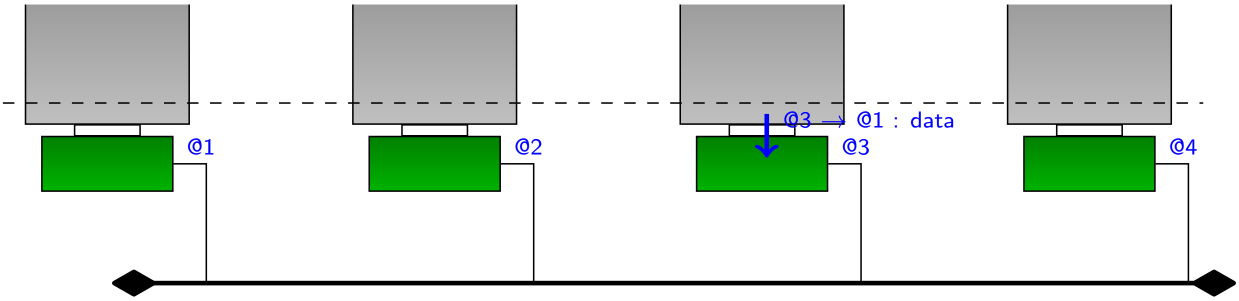
Addresses Management: Unicast



1) MAC Layer receives data.request for @1
2) MAC Layer reads source MAC address (can be overloaded)
3) MAC Layer creates the frame and sends it to the Network card

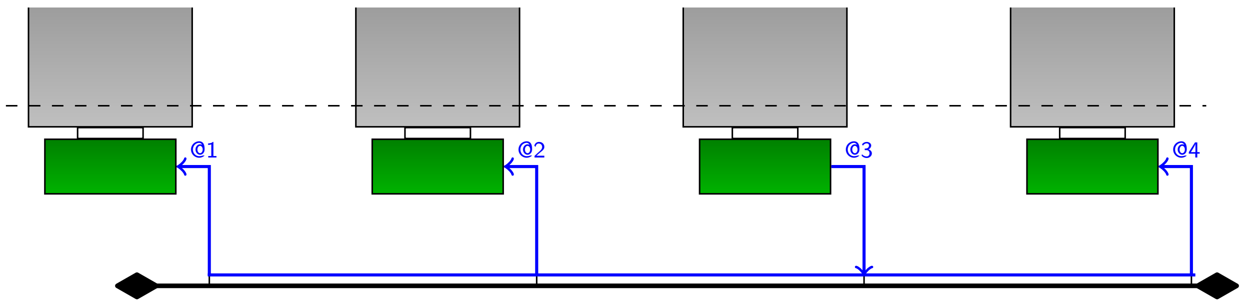
Addresses Management: Unicast

IEEE Model ▶ Addresses



1) MAC Layer receives data.request for @1
2) MAC Layer reads source MAC address (can be overloaded)
3) MAC Layer creates the frame and sends it to the Network card
4) MAC Layer computes the CRC and perform the
MAC protocol and sends the frame on the wire

Addresses Management: Unicast



1) MAC Layer receives data.request for @1

2) MAC Layer reads source MAC address (can be overloaded)

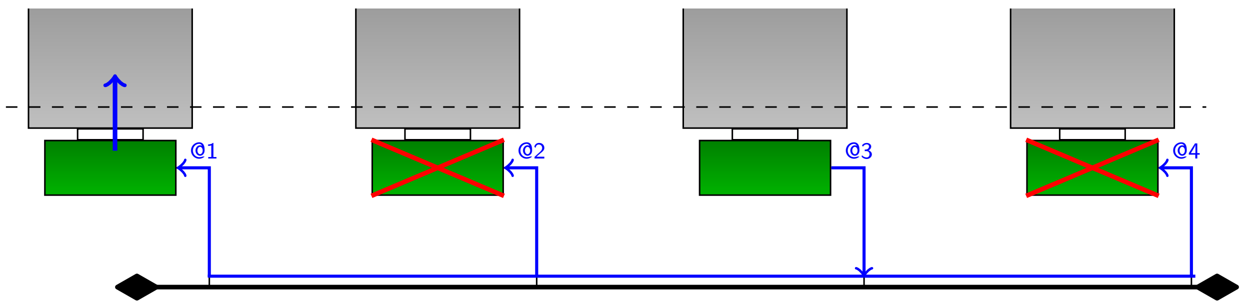
3) MAC Layer creates the frame and sends it to the Network card

4) MAC Layer computes the CRC and perform the MAC protocol and sends the frame on the wire

5) Only @1 recognizes its address and sends it to upper layer. Others discard the card and the frame is not seen by equipments.

Addresses Management: Unicast

IEEE Model ▶ Addresses



1) MAC Layer receives data.request for @1

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3) MAC Layer creates the frame and sends it to the Network card

4) MAC Layer computes the CRC and perform the MAC protocol and sends the frame on the wire

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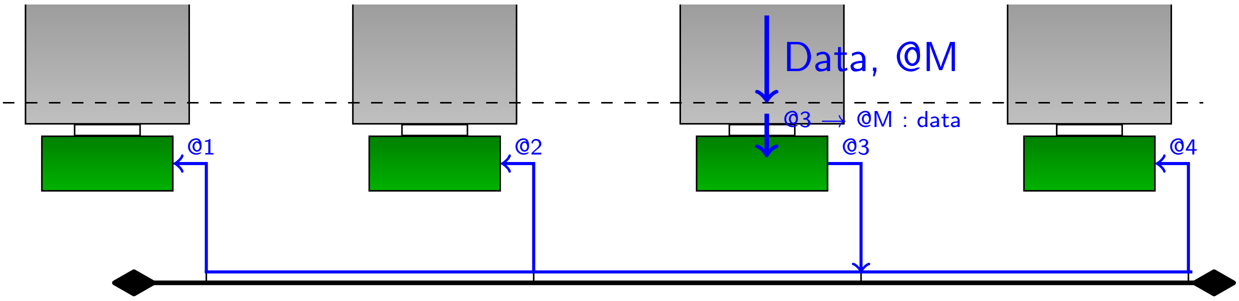
Addresses Management: Broadcast



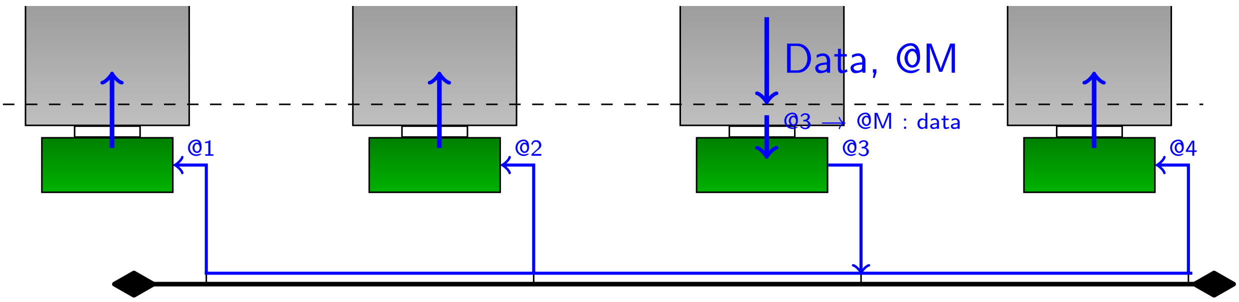
1) MAC Layer receives data.request for FF

2) MAC Layer reads source MAC address (can be overloaded)

3) MAC Layer creates the frame and sends it to the Network card

4) MAC Layer computes the CRC and perform the
MAC protocol and sends the frame on the wire

Addresses Management: Broadcast



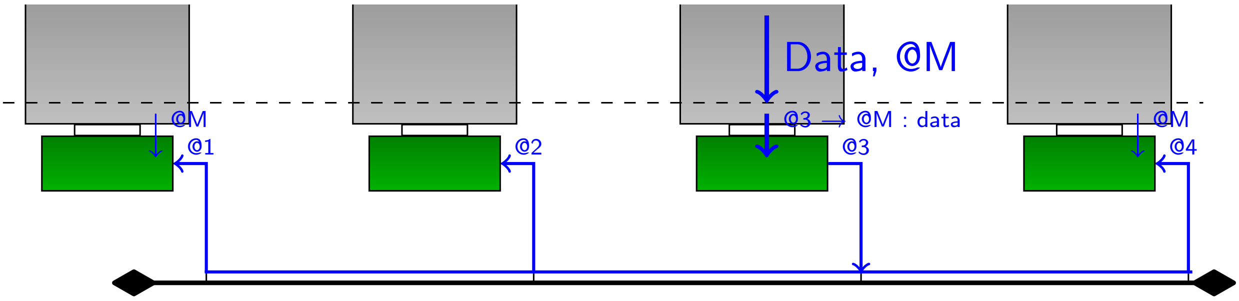
1) MAC Layer receives data.request for FF

2) MAC Layer reads source MAC address (can be overloaded)

3) MAC Layer creates the frame and sends it to the Network card

4) MAC Layer computes the CRC and perform the
MAC protocol and sends the frame on the wire

5) All equipments recognize the broadcast address
and transmit the information to the upper layer.



0) Equipments register the multicast address

1) MAC Layer receives data.request for @M

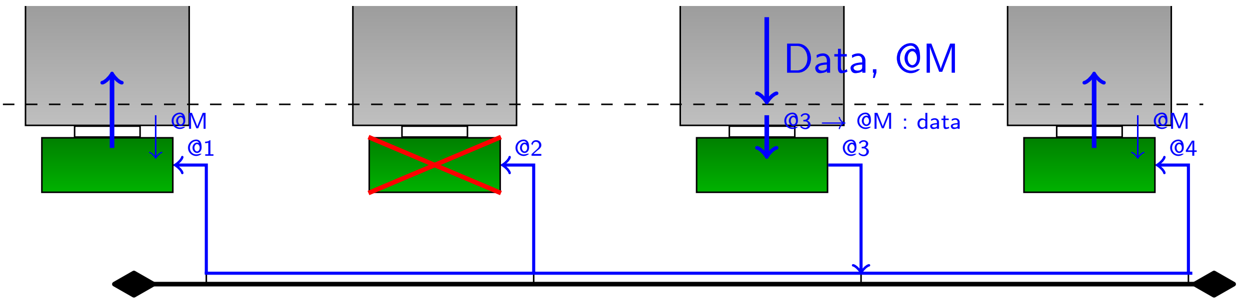
2) MAC Layer reads source MAC address (can be overloaded)

3) MAC Layer creates the frame and sends it to the Network card

4) MAC Layer computes the CRC and perform the MAC protocol and sends the frame on the wire

Addresses Management: Multicast

IEEE Model ▶ Addresses



0) Equipments register the multicast address

1) MAC Layer receives data.request for @M

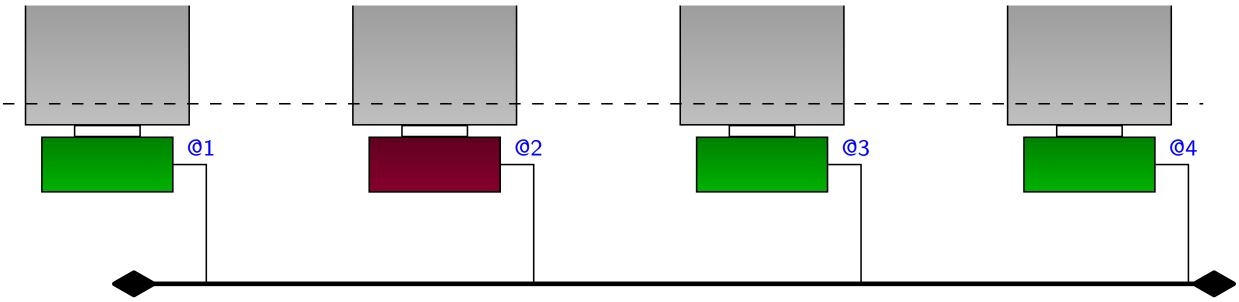
2) MAC Layer reads source MAC address (can be overloaded)

3) MAC Layer creates the frame and sends it to the Network card

4) MAC Layer computes the CRC and perform the MAC protocol and sends the frame on the wire

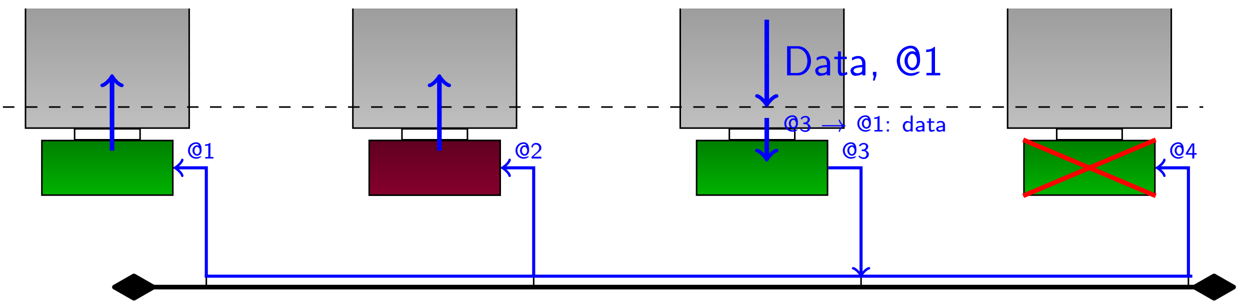
5) Equipment which have registered the multicast address receive the information..

Addresses Management: Promiscuous



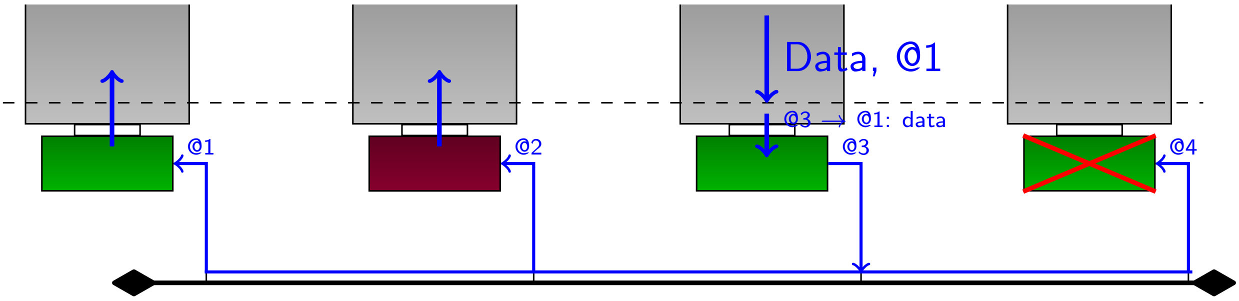
1) @2 sets promiscuous mode (some privileges are needed)

Addresses Management: Promiscuous



1) @2 sets promiscuous mode (some privileges are needed)
2) @3 sends a frame to @1

Addresses Management: Promiscuous

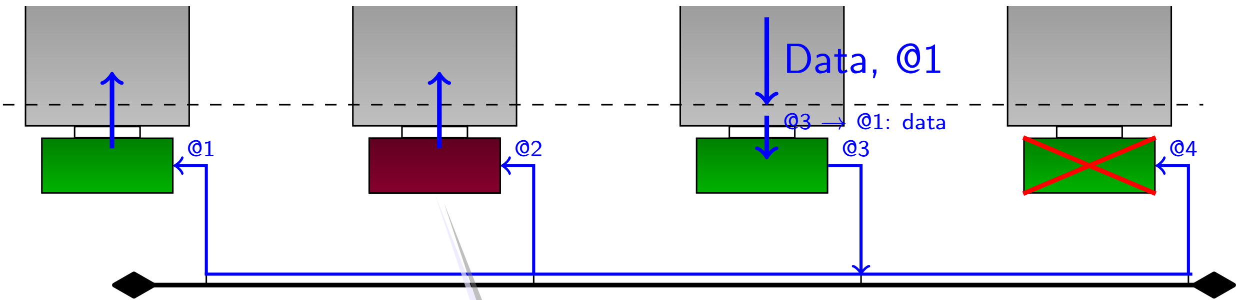


1) @2 sets promiscuous mode (some privileges are needed)
2) @3 sends a frame to @1

3) @1 accepts the frame (its address), @2 accepts the frame (promiscuous), @4 discards the frame

IEEE Model ▶ Addresses

Addresses Management: Promiscuous



1) @2 sets promiscuous mode (some privileges are needed)
2) @3 sends a frame to @1

3) @1 accepts the frame (its address), @2 accepts the frame (promiscuous), @4 discards the frame

Promiscuous is used either to analyze traffic (see wireshark, tcpdump) or by L2 interconnection elements such as bridges

Questions

	F	T
- Multicast is possible with MAC-16?		
- Local addresses can be set with bit U/L=0		
- `FF-01-02-03-04-06` is a broadcast address		
- It is possible to forge the MAC address of another equipment		

- IPv6 uses MAC addresses such as `33-33-FF-31-67-A1`, What is the nature of this address ?

Questions

IEEE Model ▶ Addresses

	F	T
- Multicast is possible with MAC-16?		X
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Questions

	F	T
- Multicast is possible with MAC-16?	○	⊗
- Local addresses can be set with bit U/L=0	○	⊗
- `FF-01-02-03-04-06` is a broadcast address	⊗	○
- It is possible to forge the MAC address of another equipment	○	⊗

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Questions

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- Local addresses can be set with bit U/L=0	○	⊗
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- It is possible to forge the MAC address of another equipment	○	⊗

- IPv6 uses MAC addresses such as `33-33-FF-31-67-A1`, What is the nature of this address ?

Multicast

IEEE Model

Interconnection

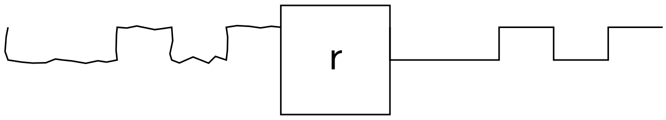
Interconnection

- IEEE 802.1 group defines interconnection method.
- Interconnection can occur at different level in the OSI Reference Model
  - Layer 1: Repeater
  - Layer 2: Bridge
  - Layer 3: Router
  - Layer 7: Gateway, Proxy, ALG (*Application Level Gateway*)
    - Some old documentation uses Gateway for Router
- IEEE works on Repeaters . . .
  - at bit level
- . . . and Bridges
  - In store and forward mode; store frames, analyze them and forward on appropriate interface,
  - Bridges learns addresses location reading the frame source field
  - No configuration is needed

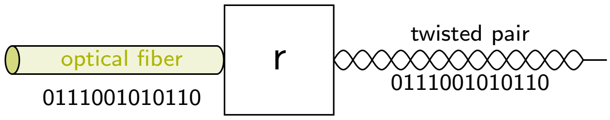
Repeater

Different functions:

- Regenerate signals

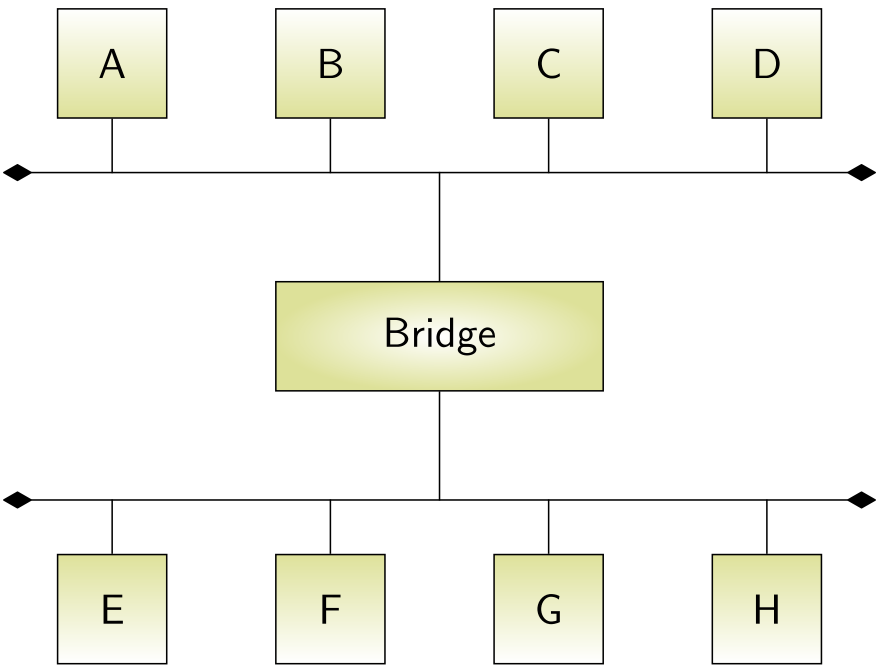


- Change media

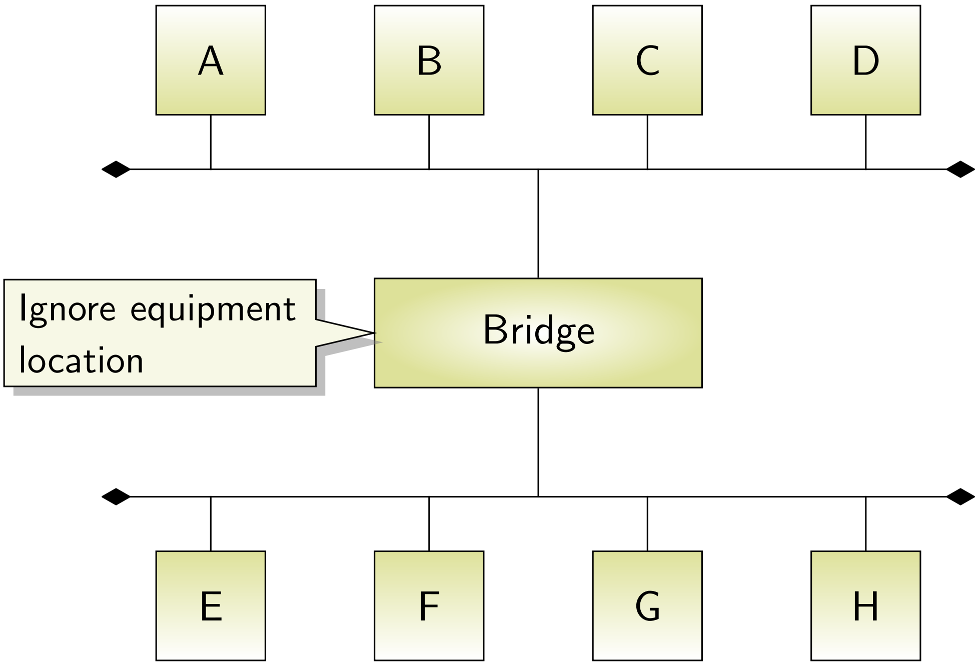


- Propagation delay inside the repeater can be longer than equivalent cable length:
  - time to detect binary values and generate a new signal.
- Almost invisible to upper layers

Bridge

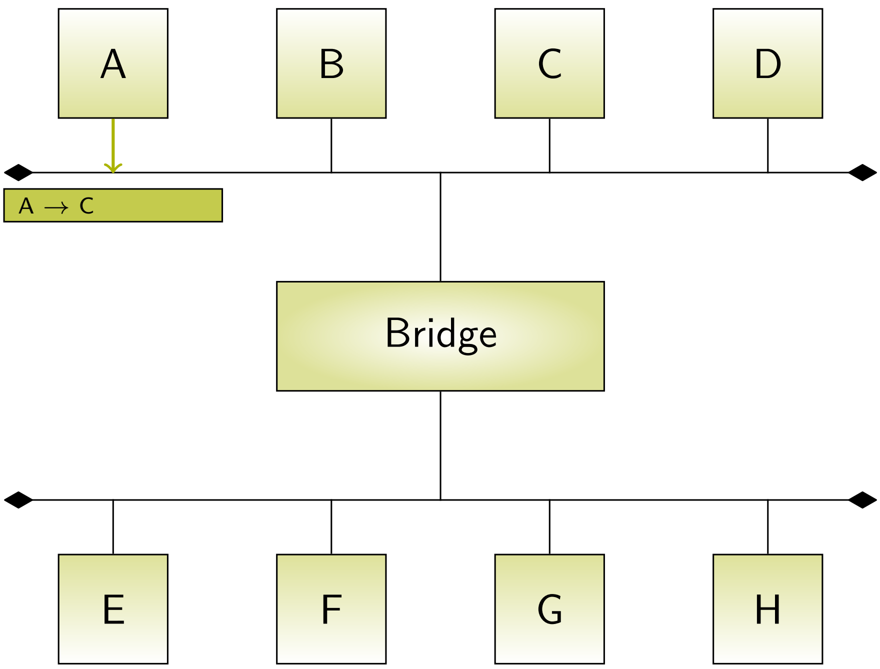


Bridge



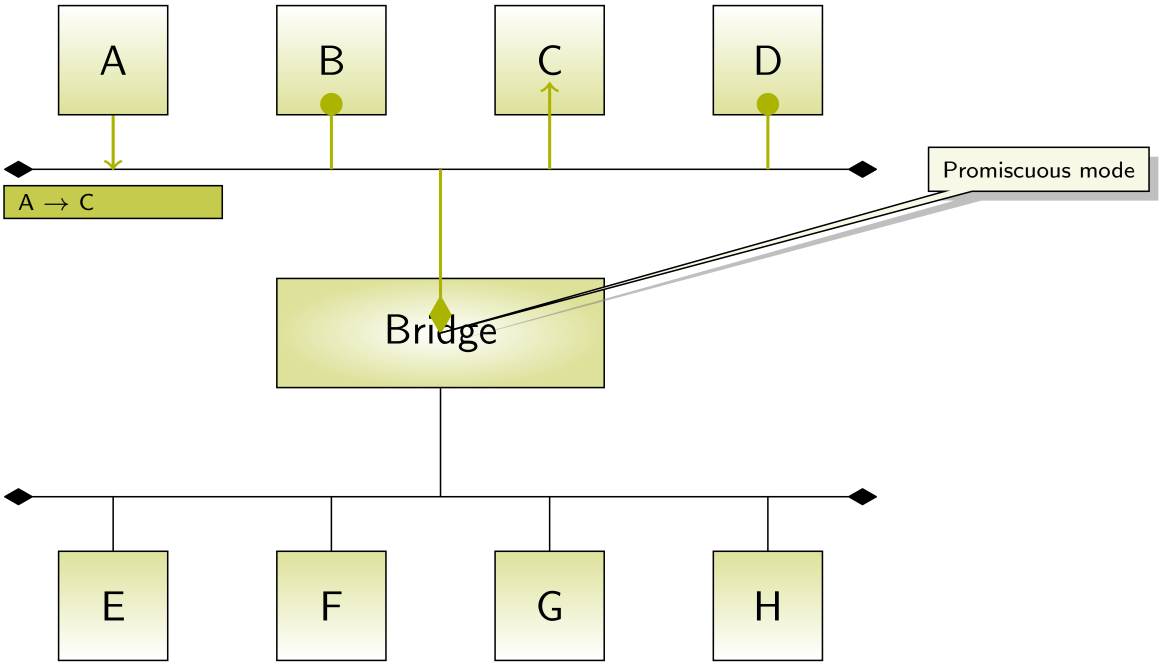
TELECOM Bretagne

Bridge

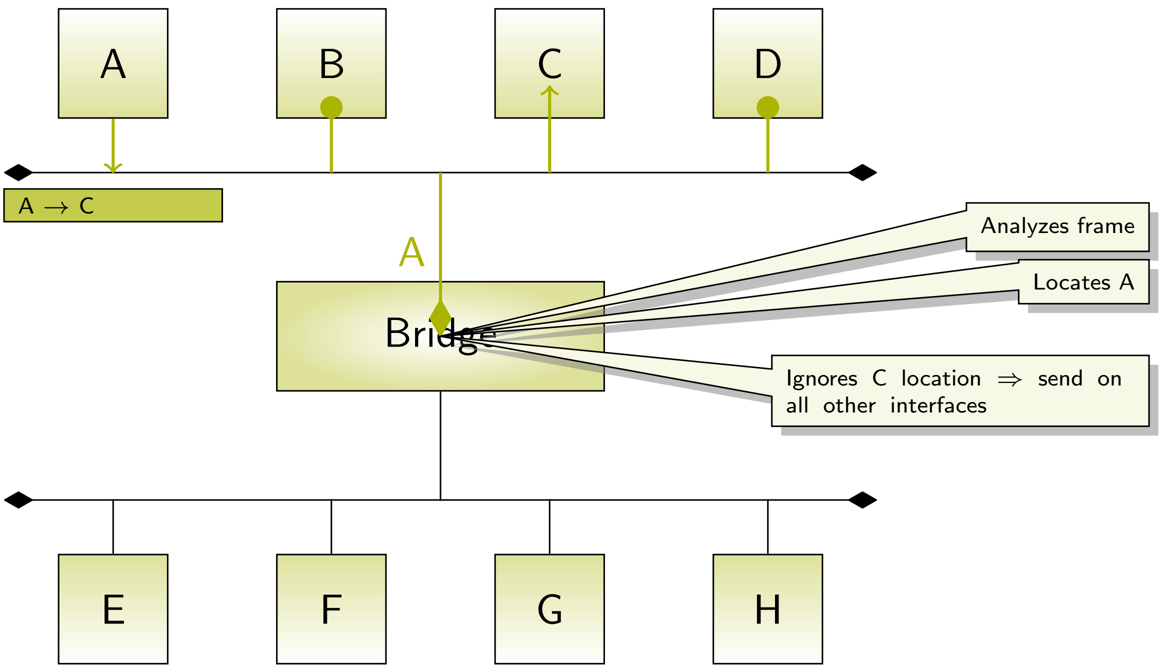


TELECOM Bretagne

Bridge



Bridge



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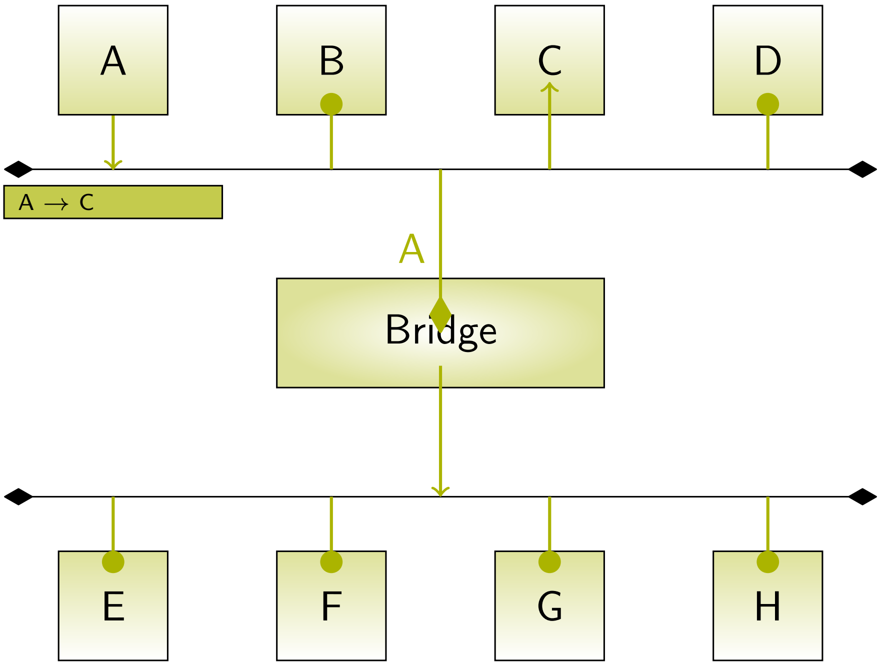
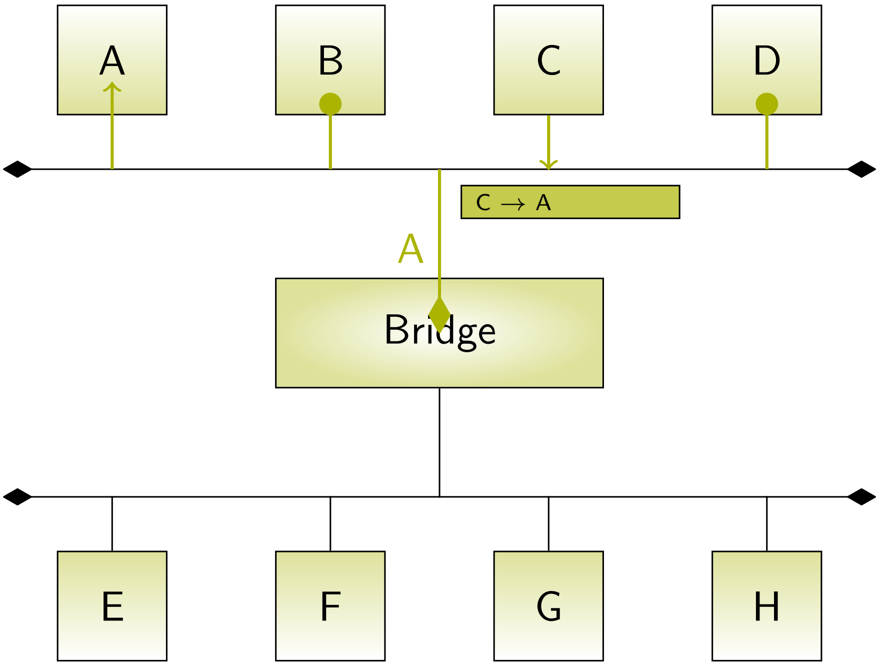
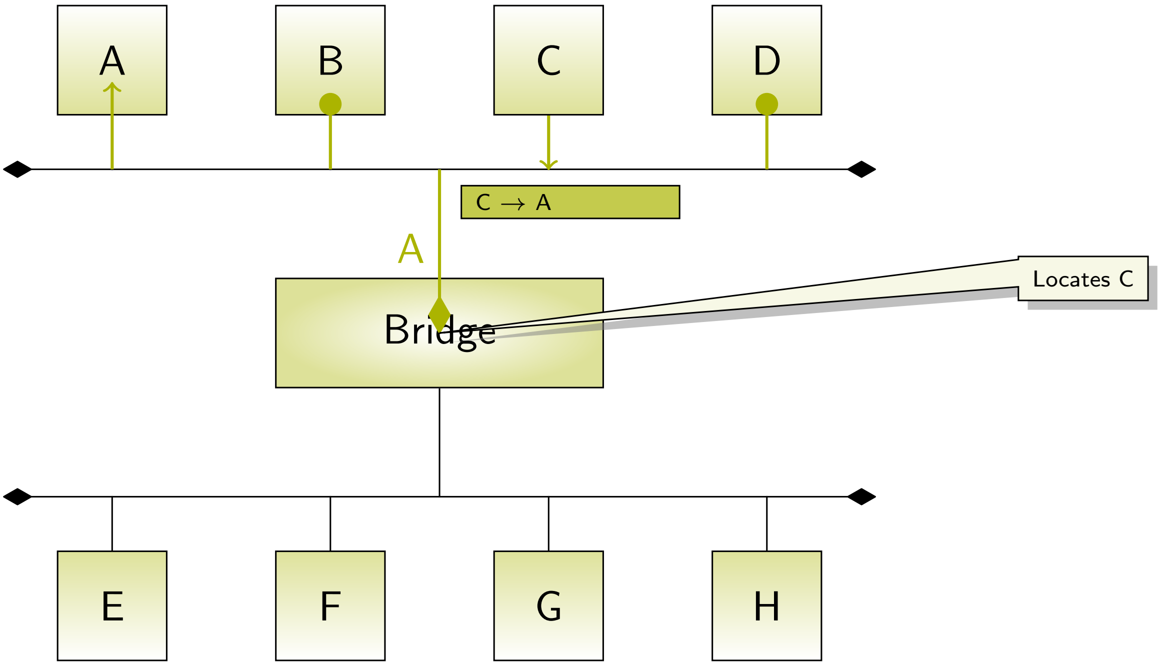


Bridge

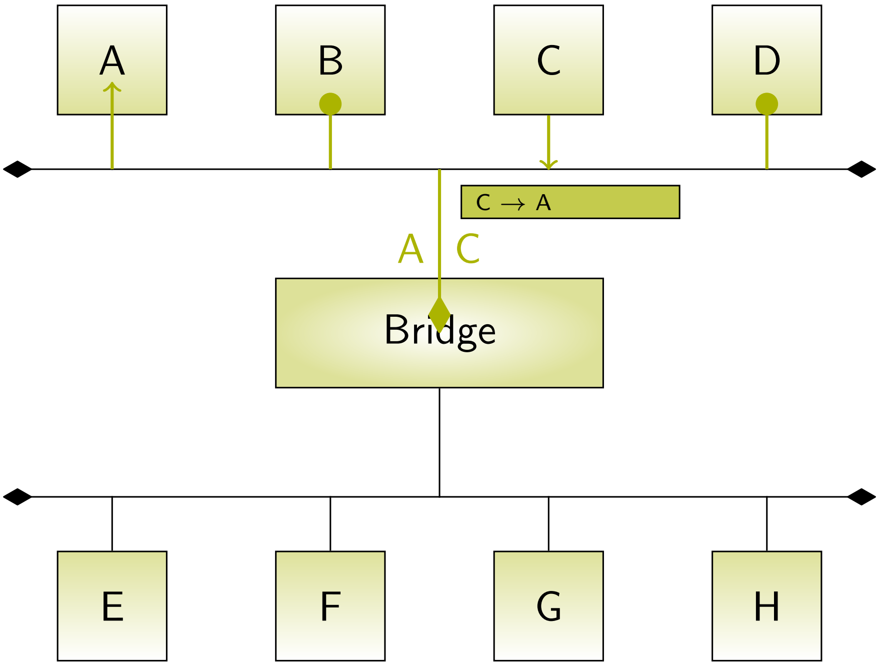


Bridge

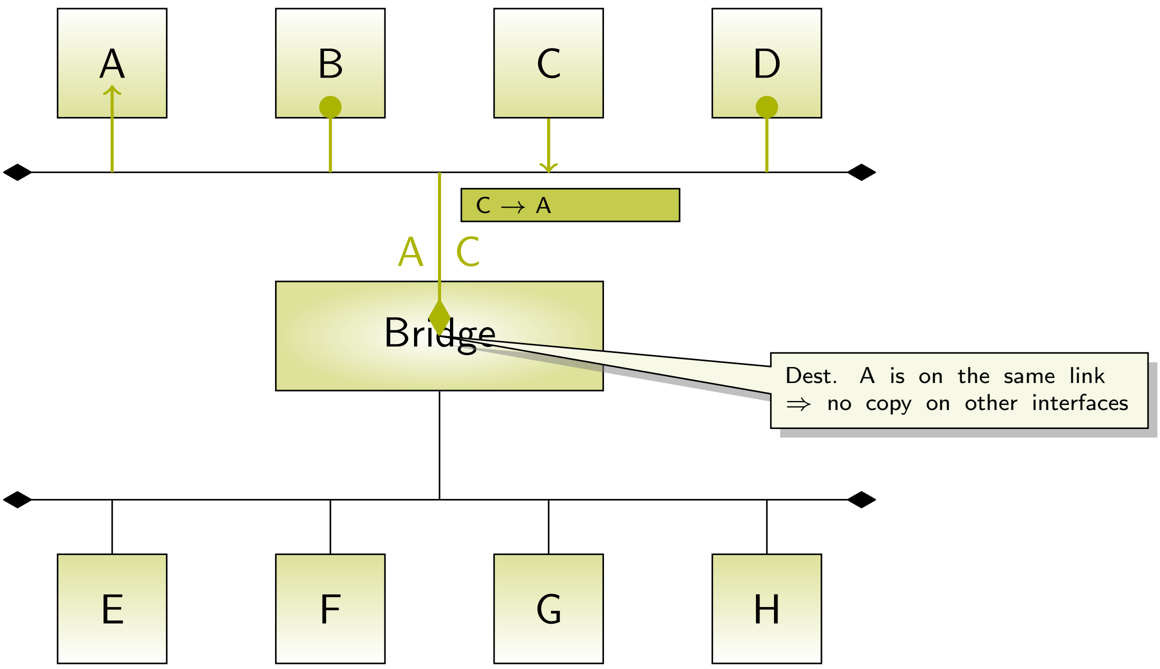


Bridge

IEEE Model ▶ Interconnection

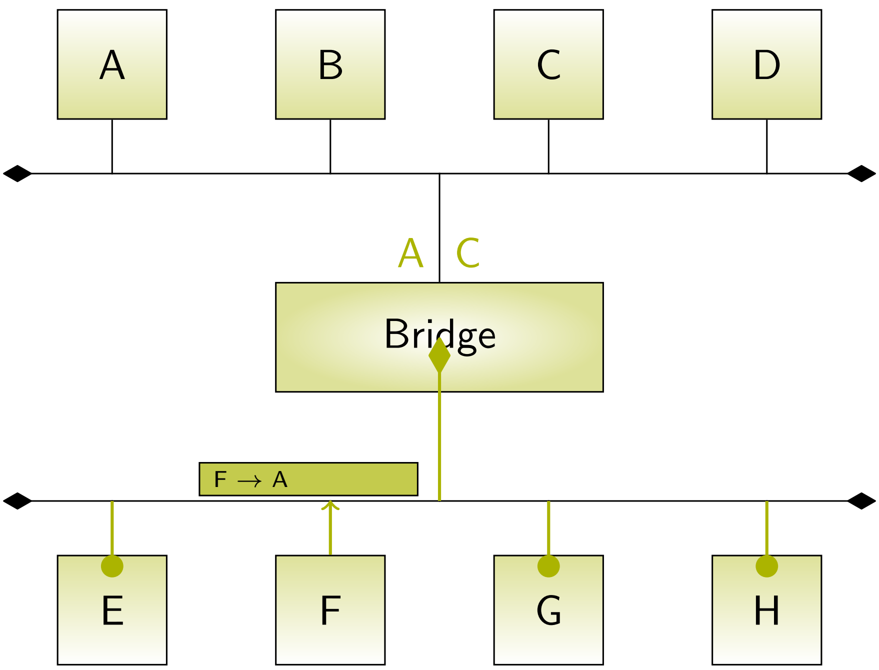


Bridge



IEEE Model ▶ Interconnection

Bridge



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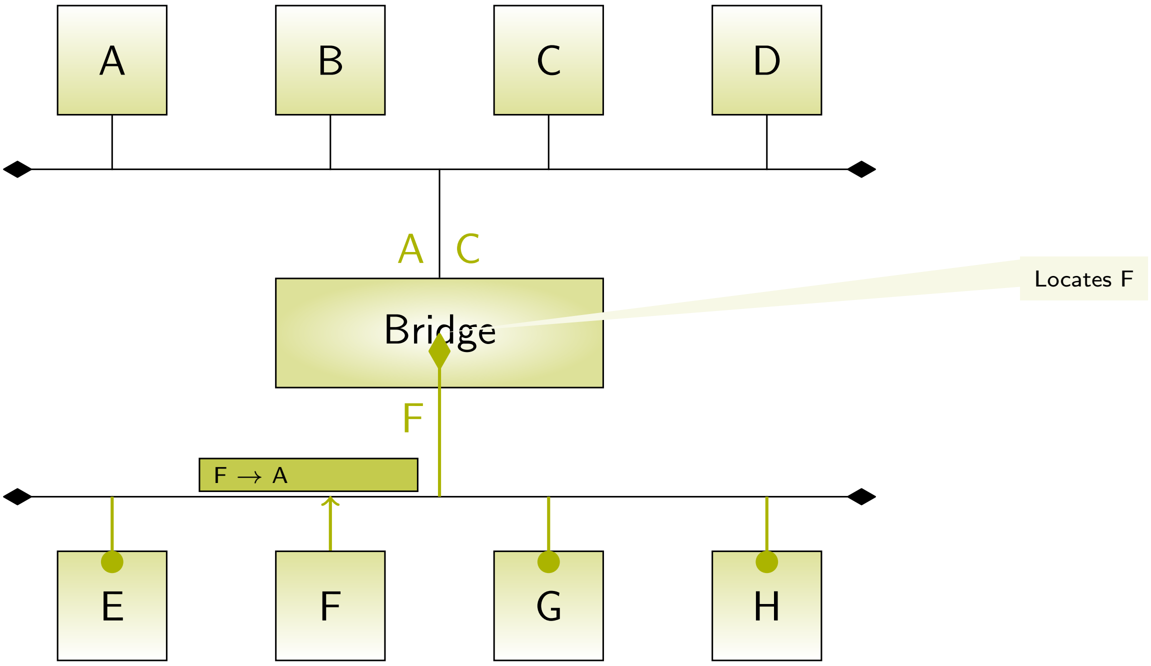

IEEE Model ▶ Interconnection

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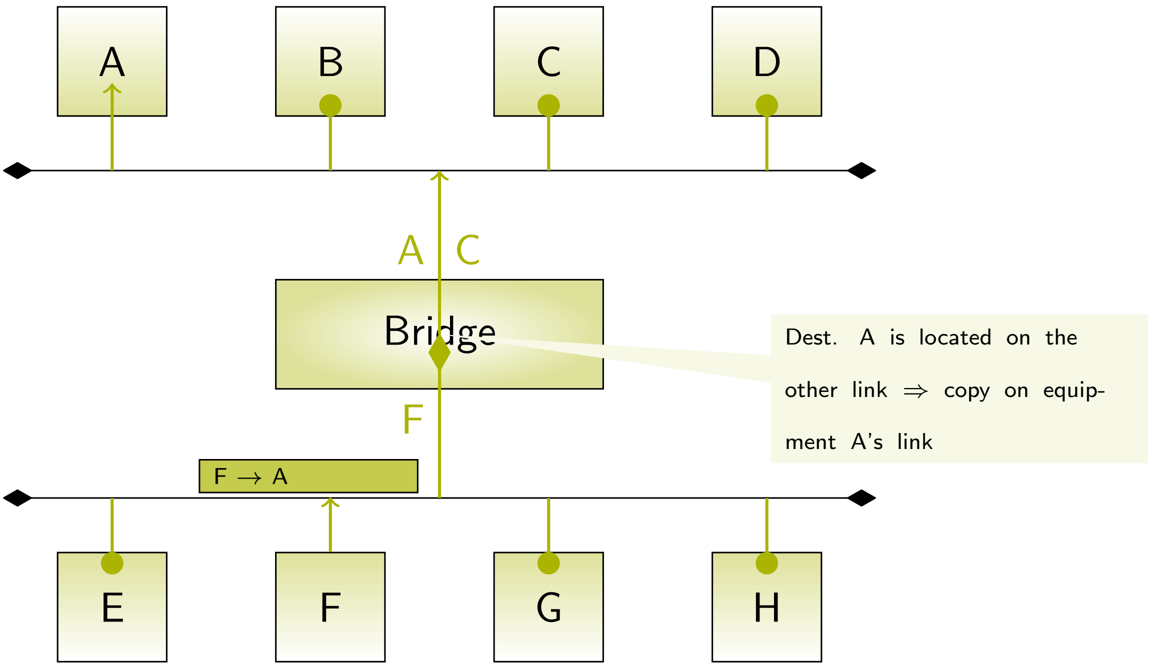

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Advantage

- Bridges learns equipments' location
- Copy frame on other interface only when needed
  - improve security: cannot listen traffic between two equipments located on another link
  - decrease traffic on a link.
- Can work with different L2 technologies:
  - Addressing rules must be the same: e.g. MAC-48
  - All fields must be easily filled:
    - No configuration,
    - No queries on the link.
  - For instance: Wi-Fi and Ethernet
    - Bridge is called an Access Point
- No scalability
  - All equipments' addresses must be memorized
  - Broadcast/Multicast is sent everywhere

Questions

What does a bridge when it receives a Broadcast frame ?

- ◯ Discard frame
- ◯ Copy frame on all other interfaces

	F	T
A bridge may change the frame format	◯	◯
A bridge does not work if interfaces' speed is different	◯	◯
A bridge is limited to two interfaces	◯	◯
It is possible to put more than one bridge on a network	◯	◯

Questions

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IEEE Model ▶ Interconnection

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Questions

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Questions

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A bridge does not work if interfaces' speed is different	⊗	◯
A bridge is limited to two interfaces	⊗	◯
It is possible to put more than one bridge on a network	⊗	⊗

Routers

- Work at L3 (packet) level:
  - IP Layer
- Addresses follow a logic (generally hierarchical)
  - ⇒ common part of the address (prefix) is used to locate equipments
- Routers uses this property for scalability
- Routers have to be configured
  - Manually and through routing protocols
- Bridges and routers have almost the same behavior, they can be implemented in the same equipment
  - Bridge some protocols, router the others
  - Bridge some parts of the network, route traffic between these parts

Gateways

- Work at application level
- Depend of the application
  - From a L7 application to another
  - i.e. change Telephony Signalization (SIP to H.323)
- Application can be the same on both side:
  - Security: filtering (proxy)
    - Only known and well formed application protocols are authorized.
  - Performances (cache)
    - Some information are stored locally to reduce traffic (P2P, HTTP, ...)
  - Transition from IPv4 to IPv6 (ALG: Application Level Gateway)
    - Same application, but different L3 protocols
    - Also used from a private Internet to the public Internet
- Not all L7 protocols can use gateways

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IEEE Model

IEEE groups overview

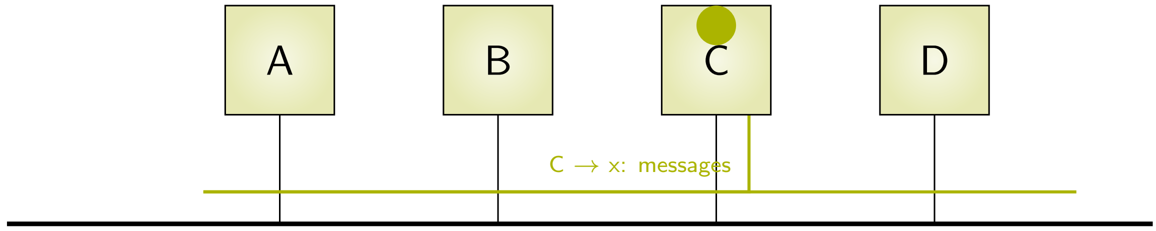
IEEE groups overview

- IEEE 802.1: Architecture, Addresses, Interconnection, Virtualization
- IEEE 802.2: Equivalent of Link Layer (see later)
- IEEE 802.3: Ethernet
  - Physical Layer (see later)
    - from 10 Mbit/s to 100Gbit/s
    - support: Coaxial (obsolete), twisted pair, optical fiber
  - MAC Algorithm:
    - From shared media with CSMA/CD (Carrier Sense Multiple Access/Collision Detect) to switched (brigded) full duplex links
  - Compatible Frame Format since first proposals

IEEE 802.4; Token Bus

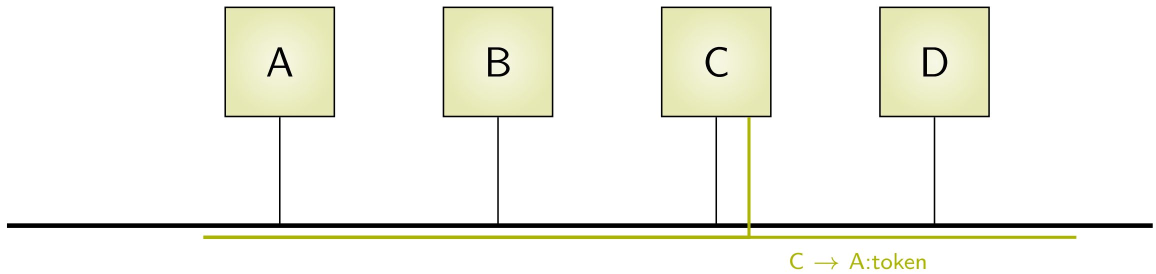
- Bus: Coaxial cable where all equipments are connected
  - Broadband: only a range of frequencies where allocated to token bus
- Token: Right to talk, must circulate among equipments
  - more deterministic than CSMA/CD
  - each equipment can keep the token for a maximum time
  - can easily compute maximum waiting time
  - better performances than CSMA/CD when the network is loaded,
  - worse performances when the network is not loaded.

Token Management



- How to manage token circulation on a bus ?
  - What his the next equipment?
  - How new equipments can enter into the network?
  - What append if the token disappear ?
- Expensive technology, reserved to factories:
  - broadband, token management, less production

Token Management



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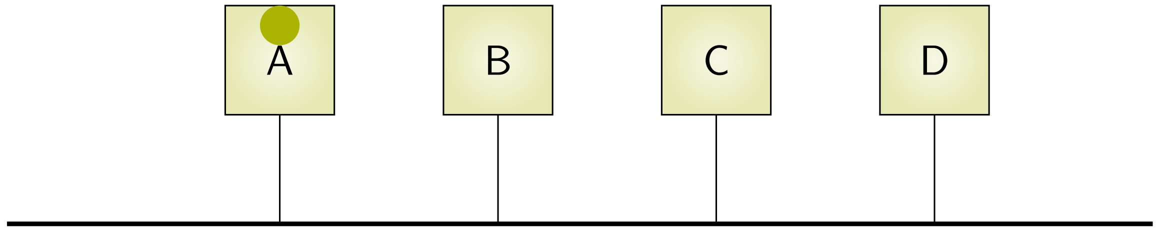

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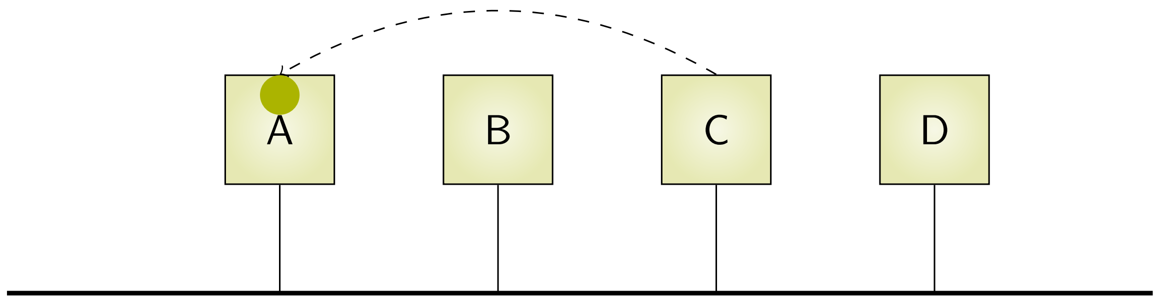

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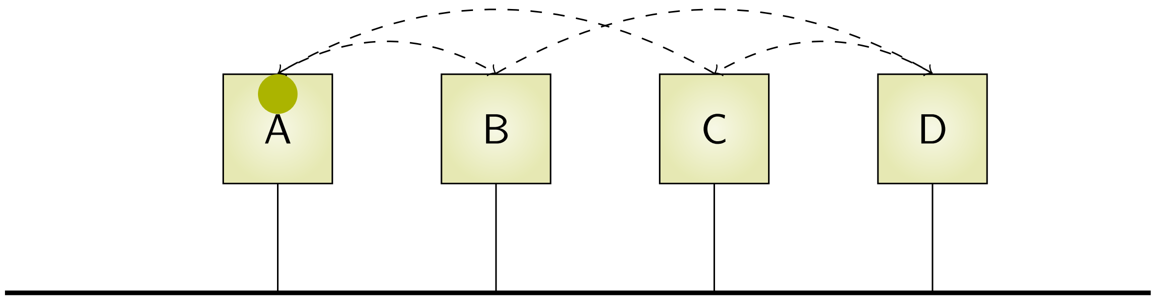

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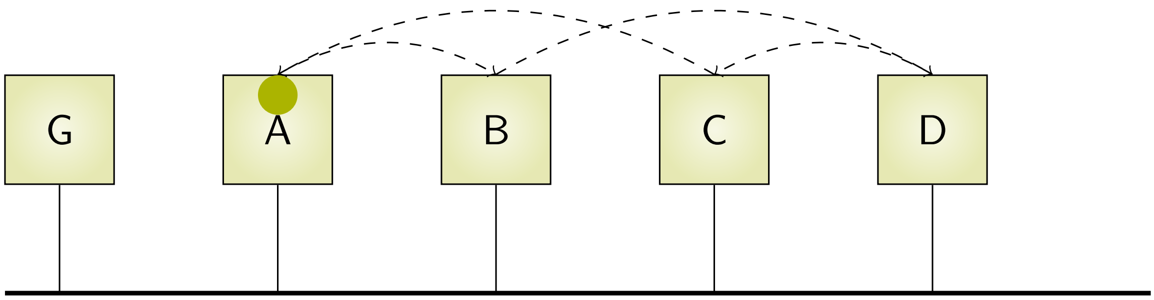
Token Management

IEEE Model ▶ IEEE groups overview



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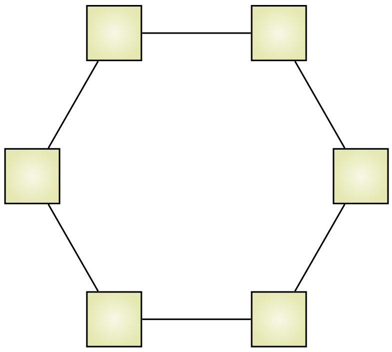
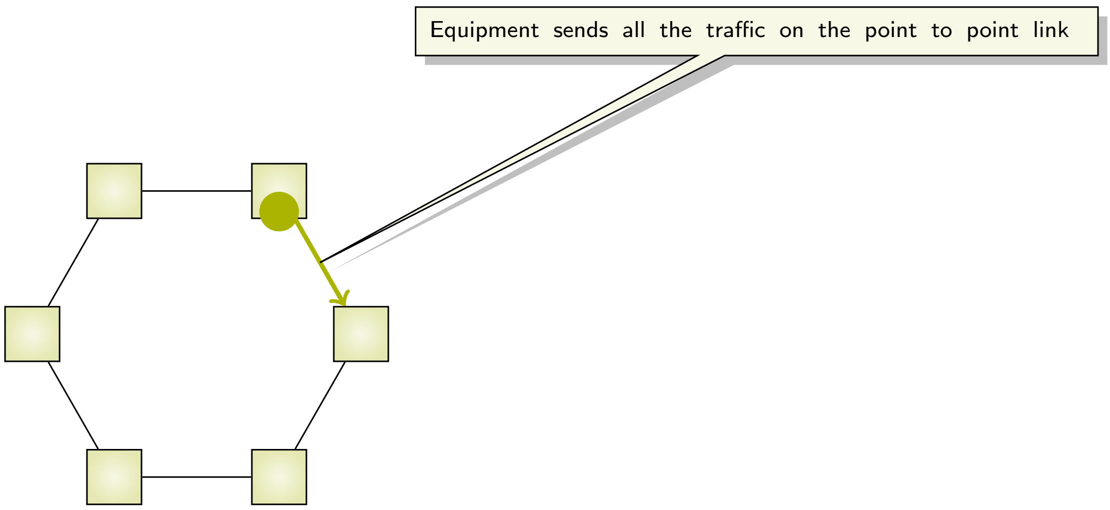
IEEE 802.5; Token Ring



IEEE Model ▶ IEEE groups overview

IEEE 802.5; Token Ring



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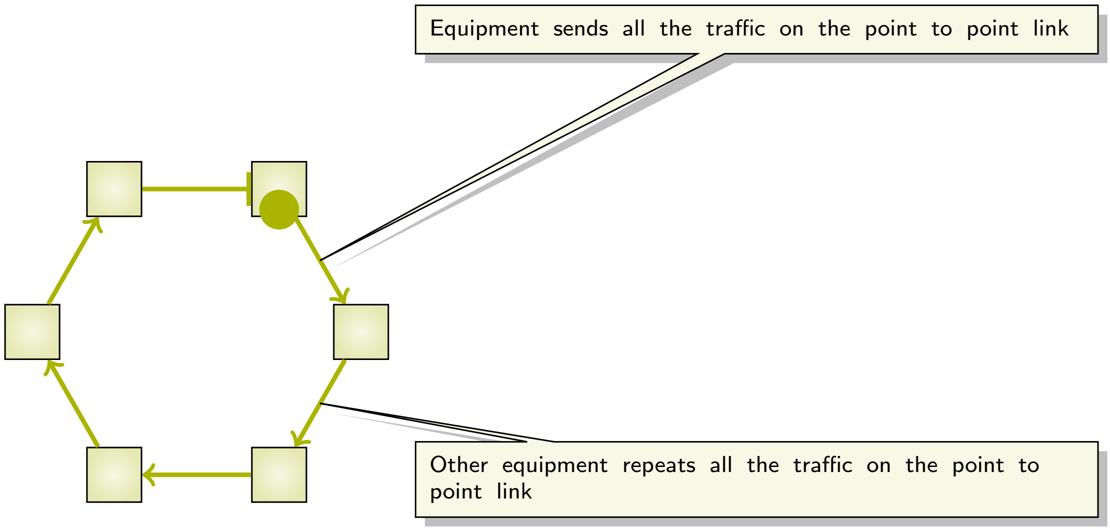

IEEE 802.5; Token Ring

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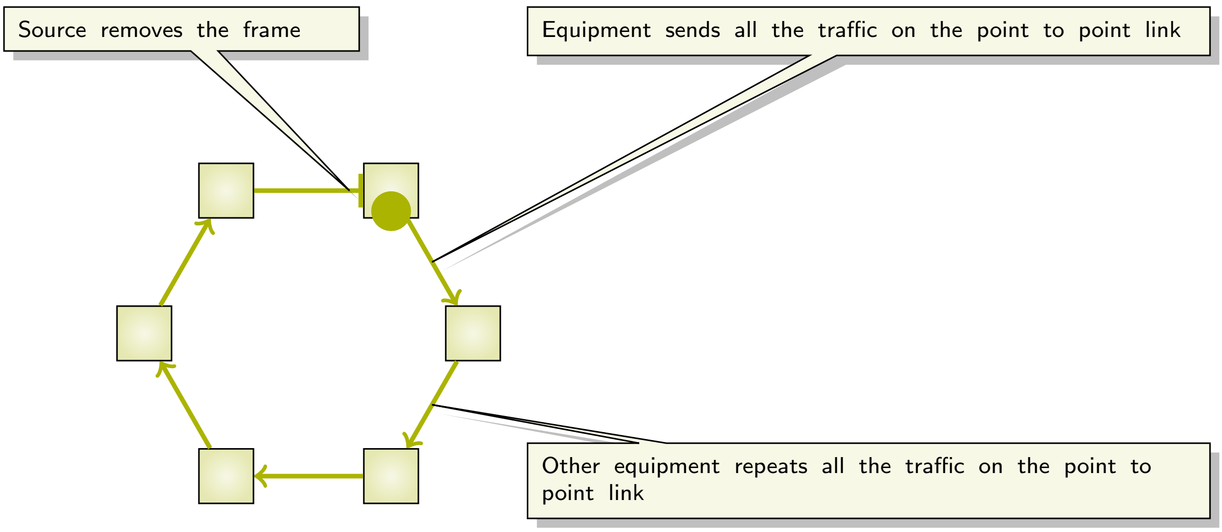
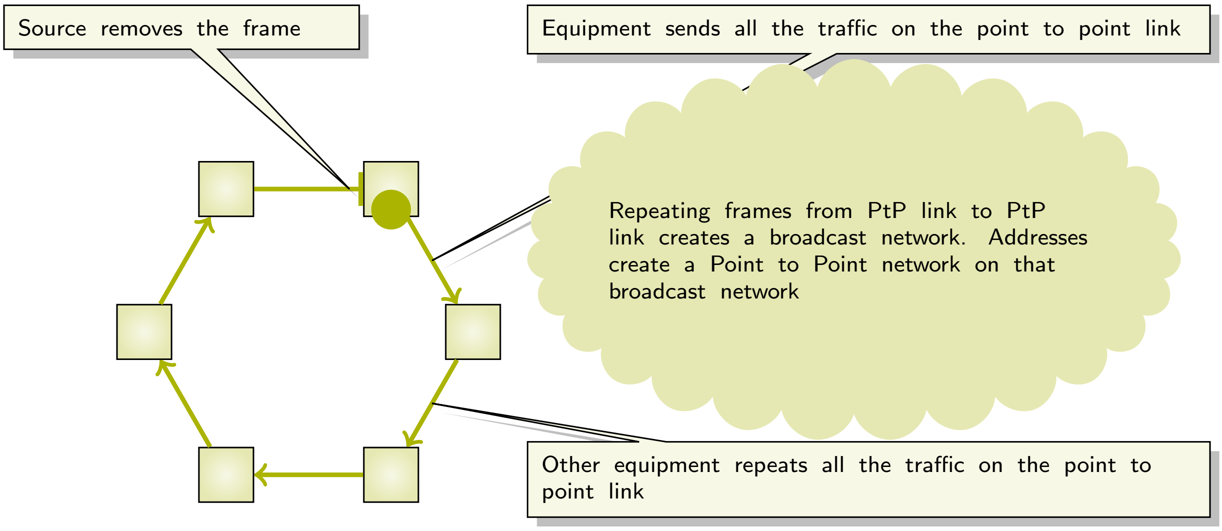
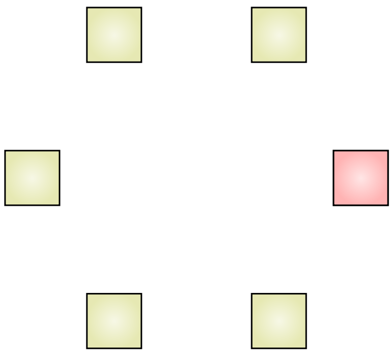


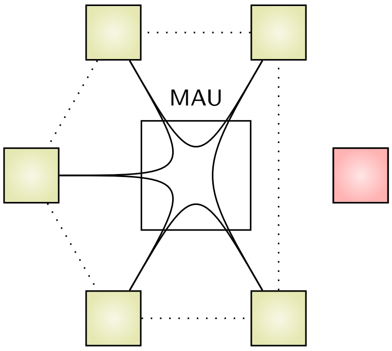
IEEE 802.5; Token Ring



IEEE 802.5; Token Ring



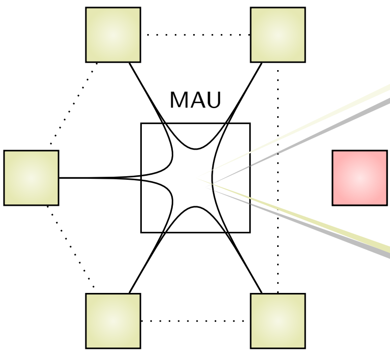
IEEE 802.5; Token Ring



IEEE 802.5; Token Ring

IEEE Model ▶ IEEE groups overview

Medium Attachment Unit (MAU) emulates ring topology.
Real topology is a start topology
MAU detects if an equipment is down. In that case it is excluded from the ring



Almost all the LAN are based on that topology, cabling is the same, only the central equipment gives the nature of the network.

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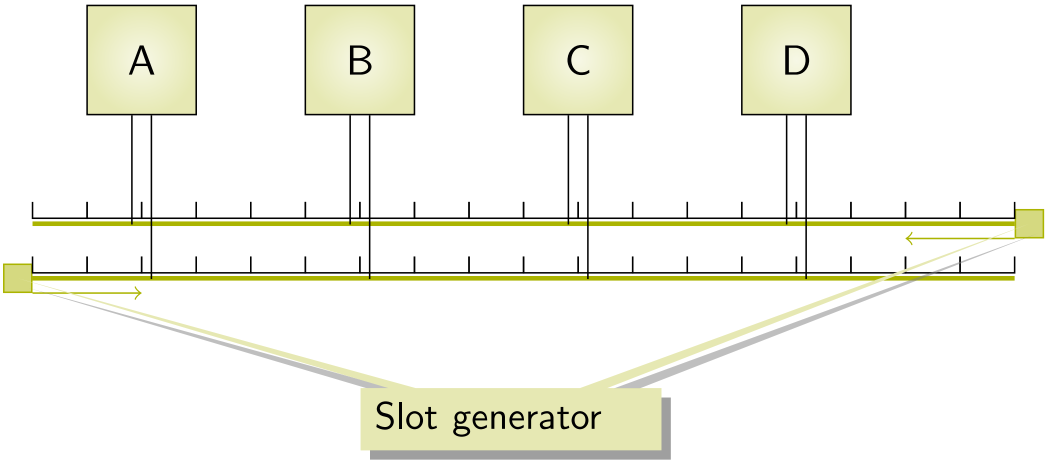
Token Ring management

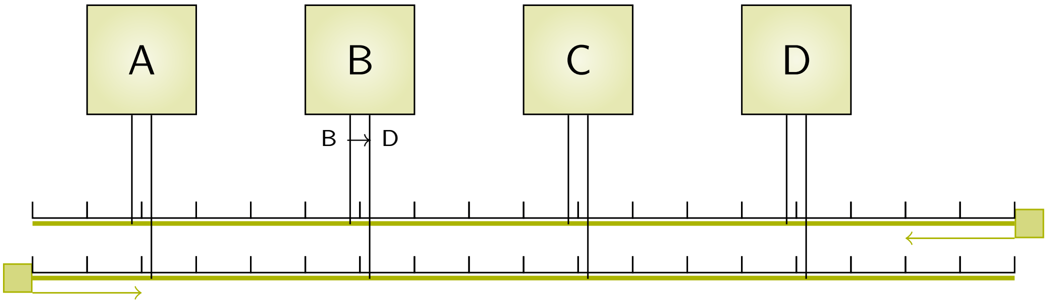
- Token management is simpler than Token Bus;
  - Token follow the physical link
  - No need to address the token destination, just send it on the wire
- Token Ring was very popular:
  - Supported by IBM,
  - Offer some delays guaranties
- Two speeds 4 Mbit/s the 16 Mbits
  - 100 MBit/s standardization arrived too late
  - Some proprietaries solutions exists, but without standards it was risky to move
  - Ethernet evolutions: 100Mbit/s, switching made Token Ring not so competitive

IEEE 802.6; Distribute Queue Dual Bus

- Protocol for Metropolitan Area Networks:
  - Long propagation delay
  - None of the original solutions (shared Ethernet, Token Bus or Token Ring have good performances if propagation delays are high)
- Based on two buses, each with a direction:
  - A slot generator gives the place where equipment can send information
- Equipments knows their and others positions.
- Send information on the right bus to reach the destination
- To maintain fairness between equipments, DQDB develops an algorithm:
  - set a bit to one on slot going the opposite way.
  - when receiving a slot with a bit set to one, don't use the slot



DQDB
IEEE Model ▶ IEEE groups overview



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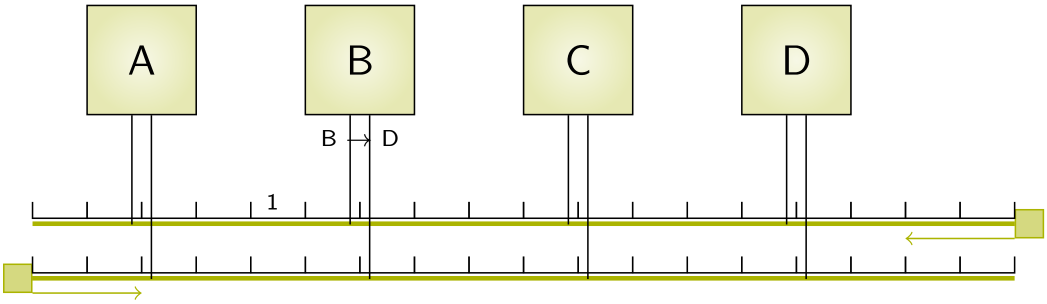
DQDB



DQDB

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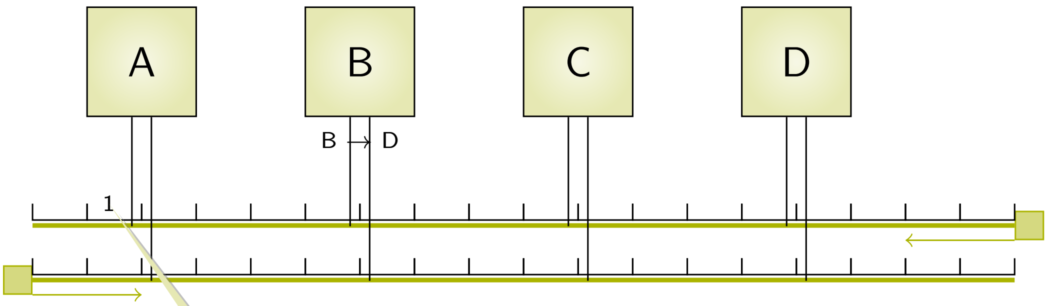

Must leave a slot free on the other channel

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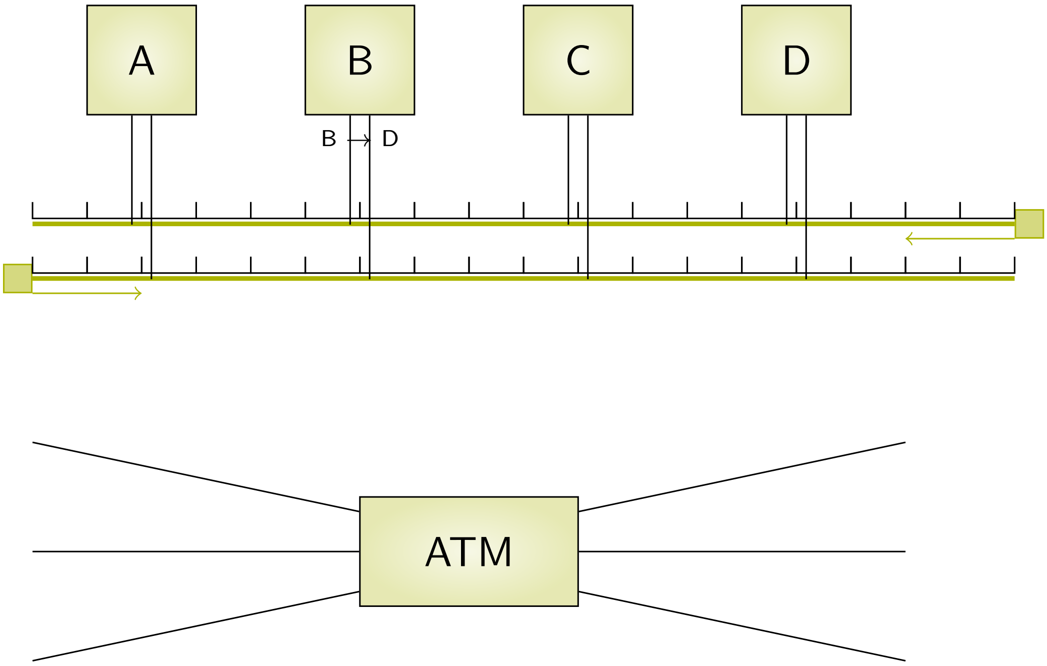
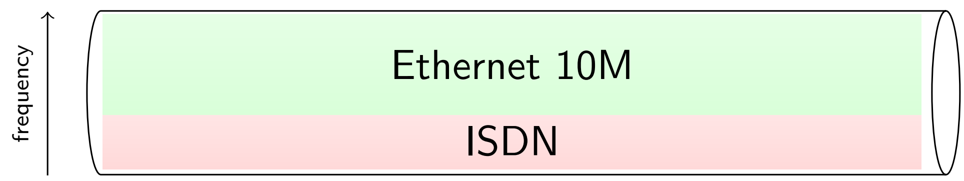


- No real fairness:
  - End equipments got more bandwidth than central ones.
- Last attempt to use a distributed shared media:
- ATM was used instead
  - Star topology around a switch;
  - Also based on fixed slots (cells)
- then Ethernet
  - switched mode has no distance limitation
  - optical fiber allows long distance
- Metro Internet Forum focuses on those architectures:
  - add scalability
  - add flow separation between groups of users.
  - http://metroethernetforum.org

IEEE 802.7-9

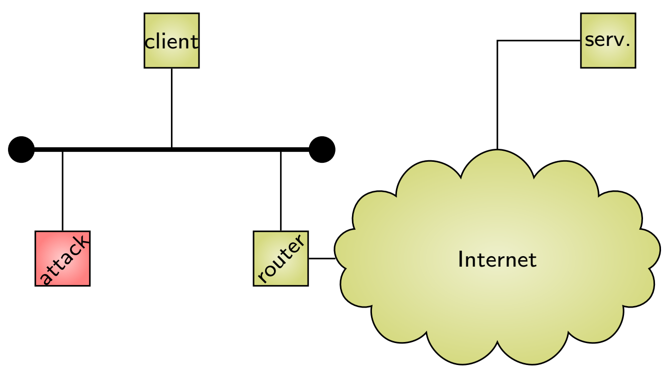
- Technical Advisery Group (TAG):
  - don't produce standards, help other groups and make liaison with other organizations
  - IEEE 802.7: Broadband
  - IEEE 802.8: Optical Fiber
- IEEE 802.9: Integrated Services LAN (isoEthernet)
  - Share physically telephony and data networks



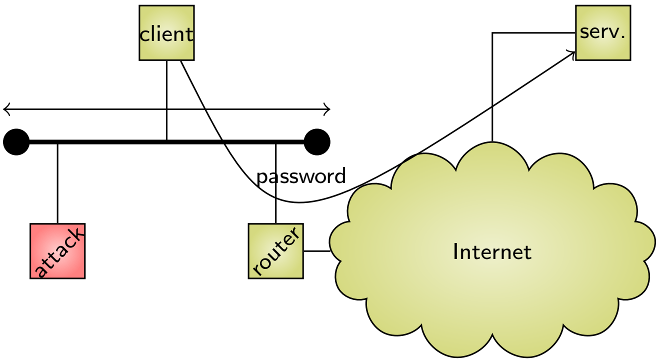
- Too expensive and too limited
  - replace with Voice over IP (VoIP)
  - voice is digitalized and put into frames
  - possible with the throughput raise and frame switching

IEEE 802.10; Security

- Cypher frames on the LAN



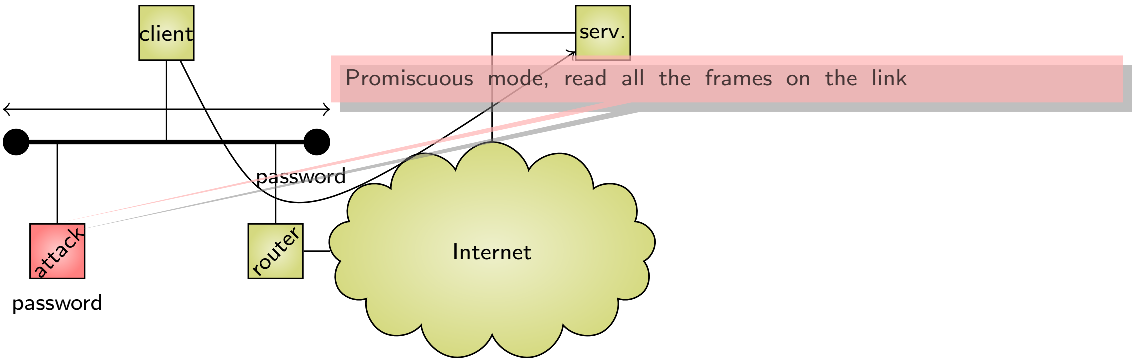
- Cypher frames on the LAN



IEEE 802.10; Security

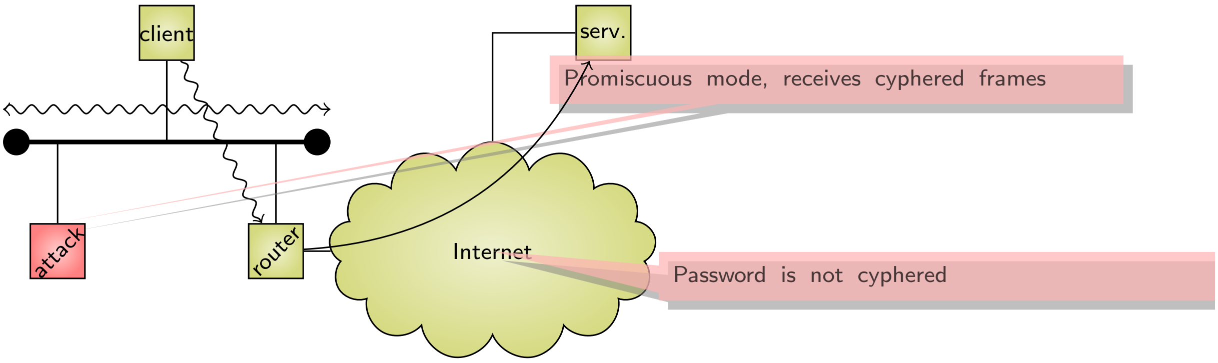
IEEE Model ▶ IEEE groups overview

- Cypher frames on the LAN



IEEE 802.10; Security

- Cypher frames on the LAN



IEEE 802.10; Security

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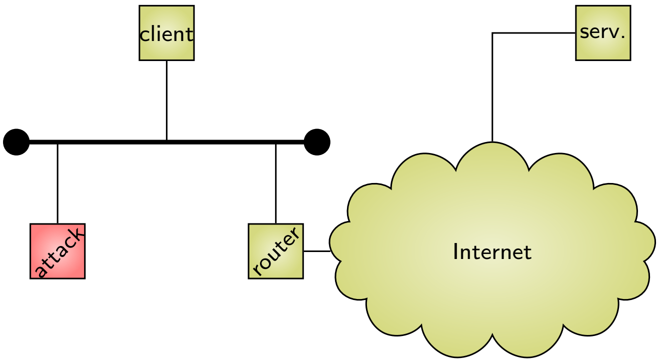
- Cypher frames on the LAN



- only efficient on LAN
  - At layer 3 (IPsec) or 7 (TLS) cyphering is end-to-end
- Ethernet with switching makes this attack impossible
- Wi-Fi uses WEP or WPA (IEEE 802.11i)

IEEE 802.11-14

- IEEE 802.11: Wi-Fi since IEEE 802.11b (shared 11 Mbit/s)
  - Evolution up to 100 MBit/s
  - See later in this class
- IEEE 802.12: Attempt to develop a 100 Mbit/s network: failure
- IEEE 802.13: does not exist
- IEEE 802.14: Cable Television Network: failure
  - ITU succeed with DOSCIS (J.112, J.122, J.222)

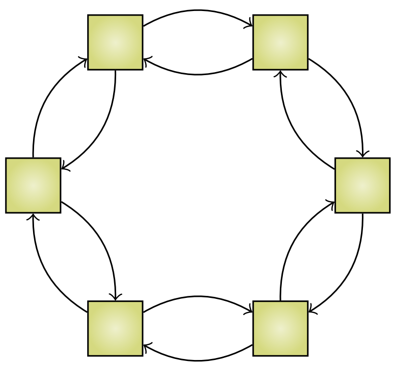
IEEE 802.15

- 802.15.1: Bluetooth
- 802.15.2:
- 802.15.3: UWB Ultra Wide Band network:
  - Dismantled
- 802.15.4: WSN Wireless Sensor Network
  - Low Power Network
  - Used by ZigBee, 6LoWPAN (IETF)

IEEE 802.16: WiMAX

- Oct 2004 : Publication of IEEE 802.16-2004 standard, first WiMAX complete standard, known as Fixed WiMAX. Based on OFDM PHYsical Layer
  - Advertisement Range: 50 kms
  - Practical value: 5-10 kms
- Dec 2005 : 802.16e amendment of 802.16, base of Mobile WIMAX technology
- 2010 : 802.16m Next generation of WiMAX. Data rates of the order of 100 Mb/s, designed as a 4G cellular network (competitor to LTE)

IEEE 802.17: Resilient Packet Ring



More details see:

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.8026&rep=rep1&type=pdf

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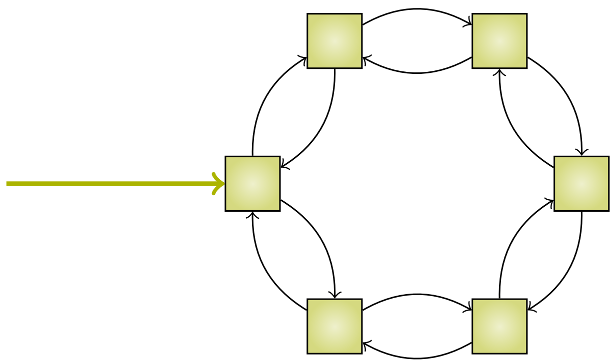

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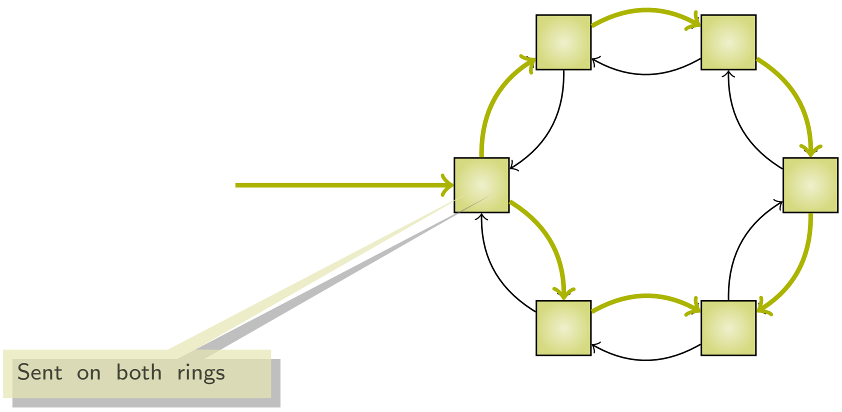
IEEE 802.17: Resilient Packet Ring

IEEE Model ▶ IEEE groups overview



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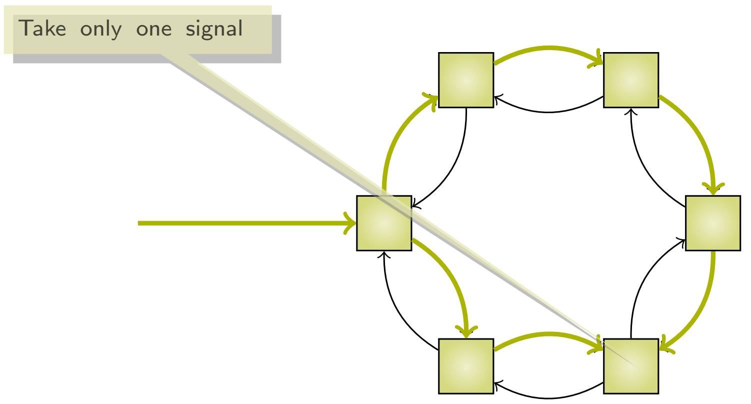

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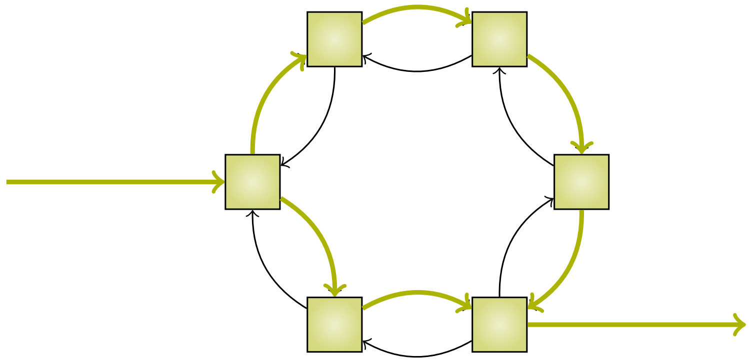
IEEE 802.17: Resilient Packet Ring
IEEE Model ▶ IEEE groups overview



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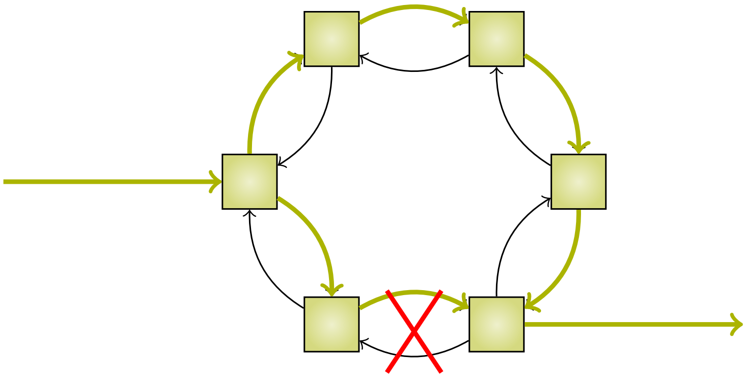

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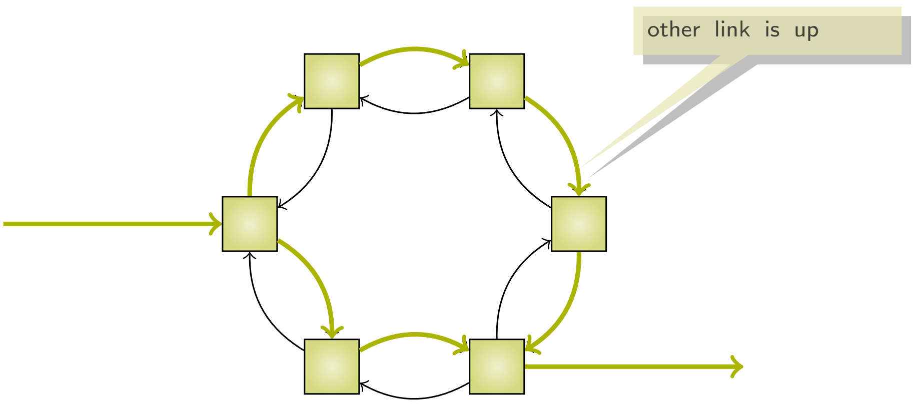
IEEE Model ▶ IEEE groups overview



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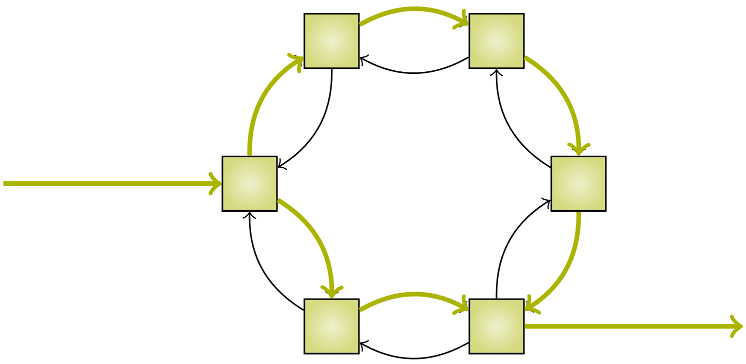
IEEE 802.17: Resilient Packet Ring

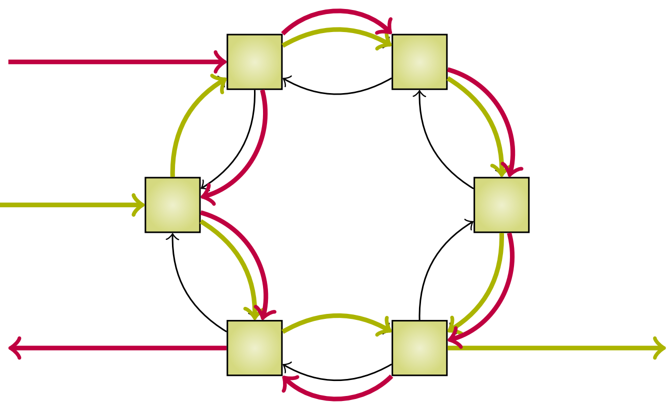


More details see:

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.8026&rep=rep1&type=pdf

IEEE 802.17: Resilient Packet Ring

IEEE Model ▶ IEEE groups overview



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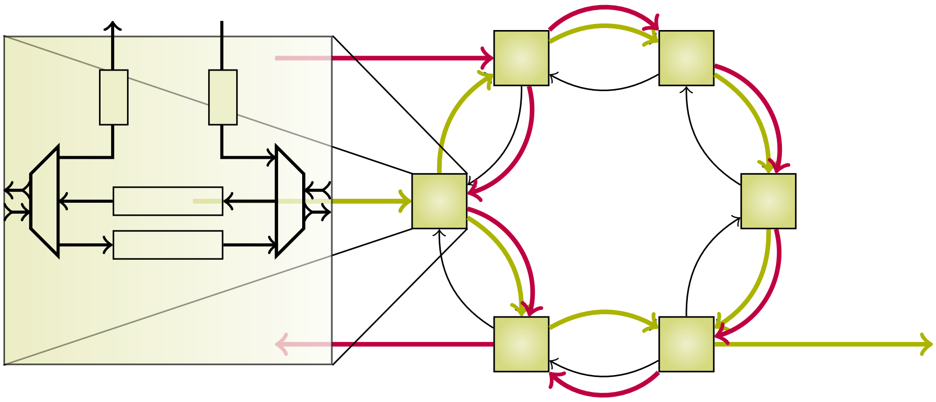

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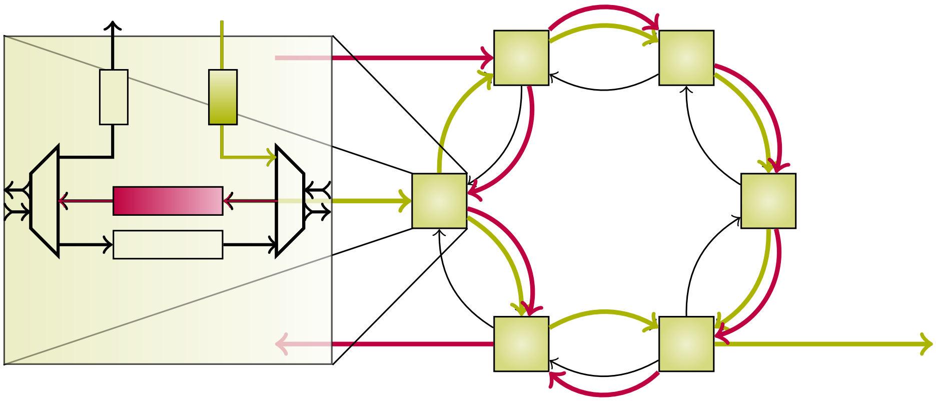

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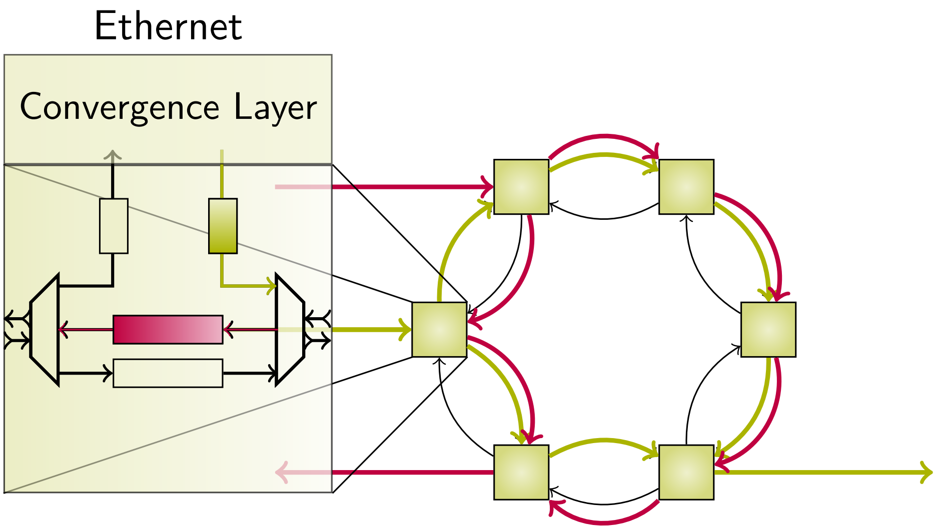

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IEEE Model ▶ IEEE groups overview

IEEE 802.18-23

- IEEE 802.18 and IEEE 802.19 : TAG
  - Radio Regulatory: Liaison with other standardization bodies (such as ITU-T)
  - Wireless Coexistence: How standards can work together in the unlicensed frequencies.
- IEEE 802.20: Mobility
- IEEE 802.21: hand over
- IEEE 802.22: Regional
- IEEE 802.23: Emergency Services

Aloha

Aloha

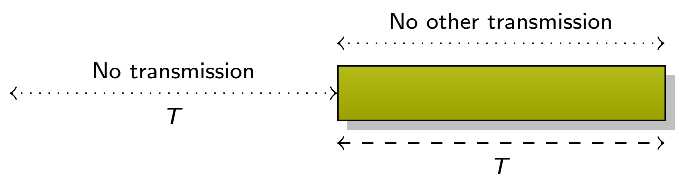
- Simplest protocol on a shared media
- Send when a station want to send
  - Does not listen to neighbor's traffic
  - Collisions (two stations sending at the same time) can occur
  - Unreceived messages are sent again latter.
- Was primary used by Hawaiian universities
  - works well when traffic is very limited
  - unstable when the network is loaded
- Aloha is not CSMA since the media is not sensed before sending

Hypothesis

- All messages have the same size and the then the same duration
- The number of stations is ∞
- The global traffic can be modelized by a Poisson process
  - Inter-arrival is given by an exponential law
- T: Message duration
- λ: number of messages generated in the system per second
- g: number of messages sent per second
- s: number of successful messages per second
  - message without any collision
- Reminder: for a Poisson process with parameter g the probability of having k messages during a period T is $P_k(T) = \frac{(gT)^k e^{-gT}}{k!}$

First step: no retransmission

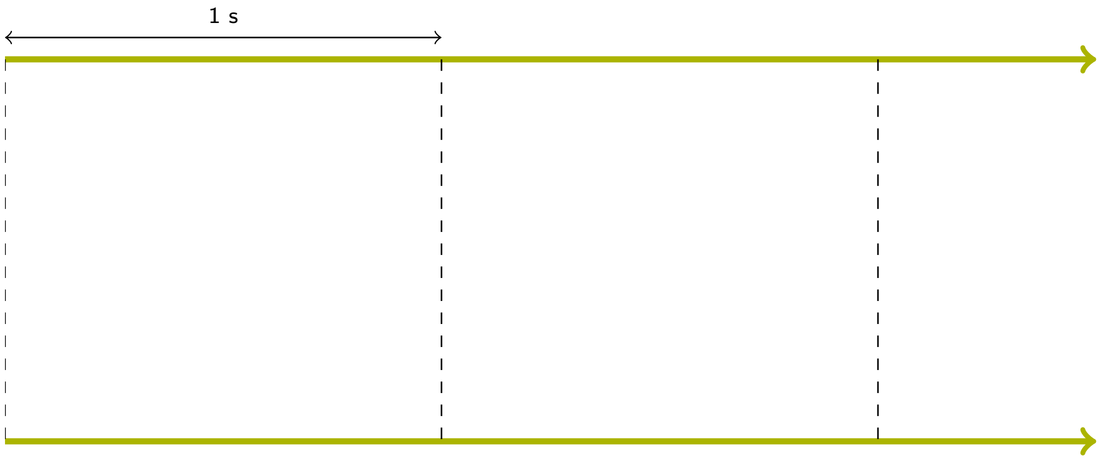
- λ: number of messages generated in the system per second
- g: number of messages sent per second, $g = \lambda$
- s: number of successful messages per second



- $P_{Succ} = P_0(2T) = \frac{(2gT)^0 e^{-2gT}}{0!} = e^{-2gT}$
- $P_{Succ} = \frac{s}{g}$
- $TransmissionNumber = \frac{g}{s}$

S and G

- Normalized throughput $G = g.T$
  - percentage of successful transmission
- Offered load $S = s.T$
  - percentage of channel usage
  - can be > 1



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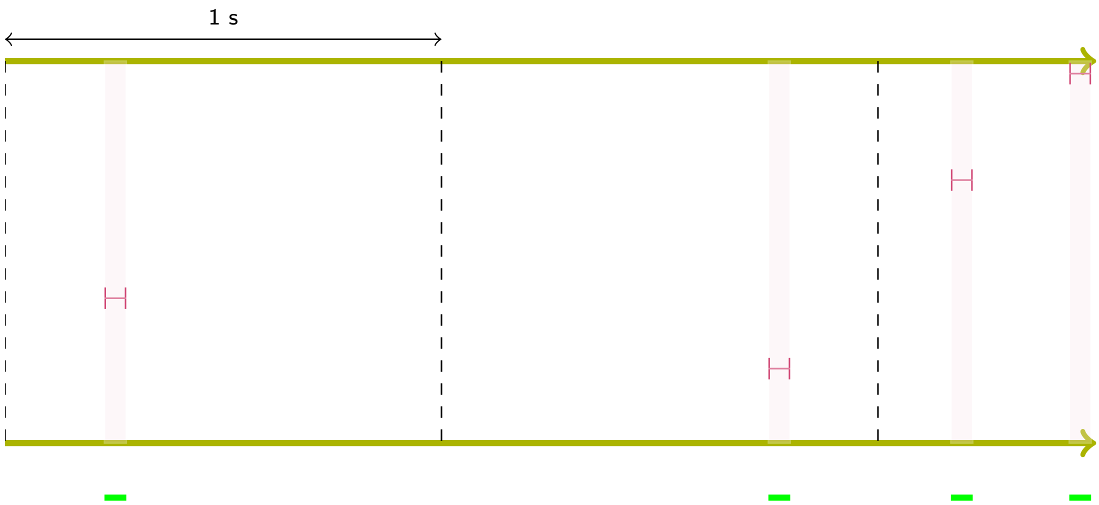

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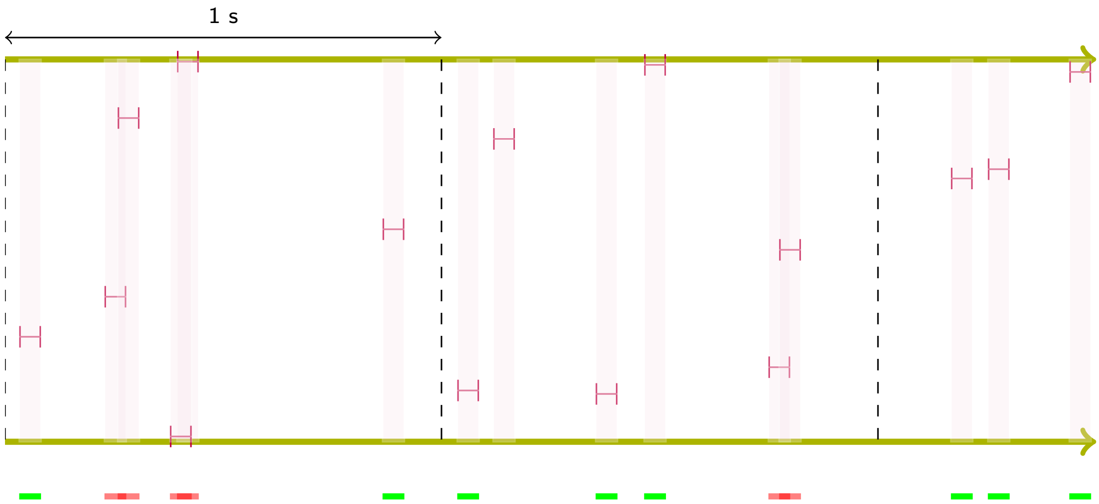

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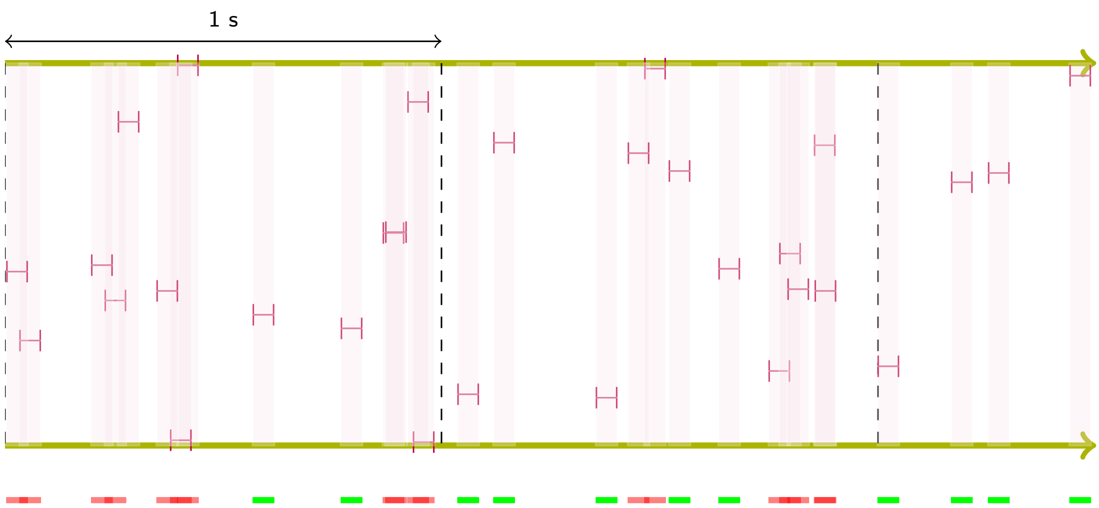

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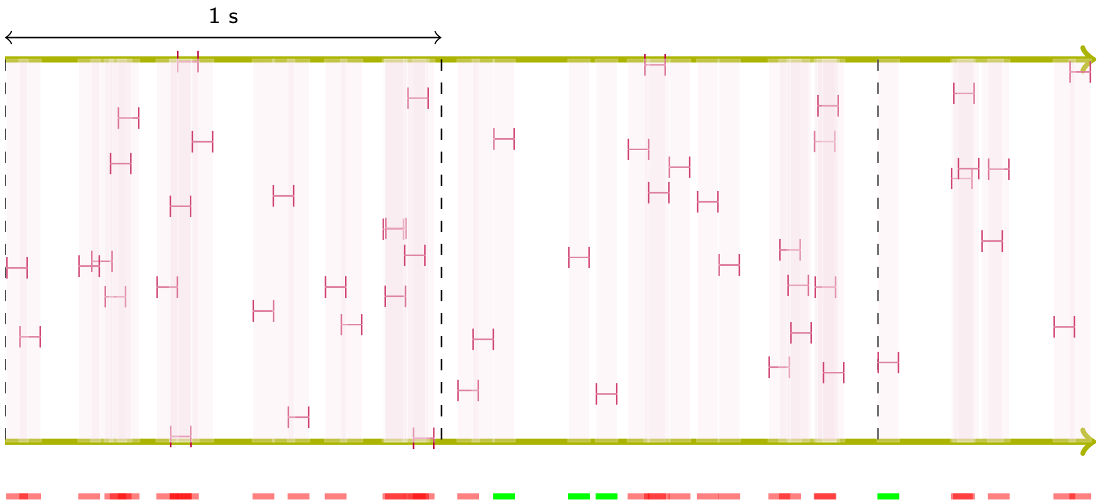

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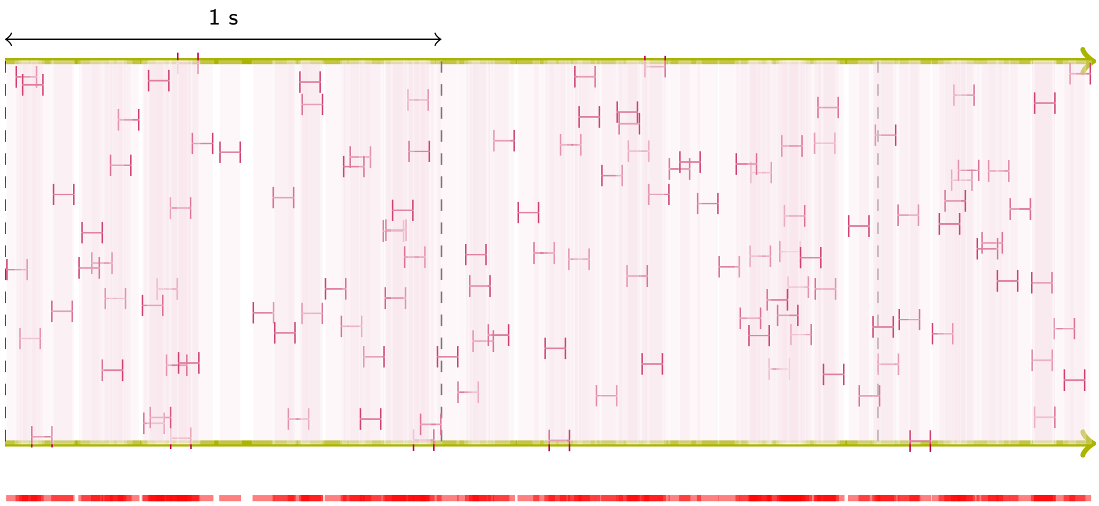

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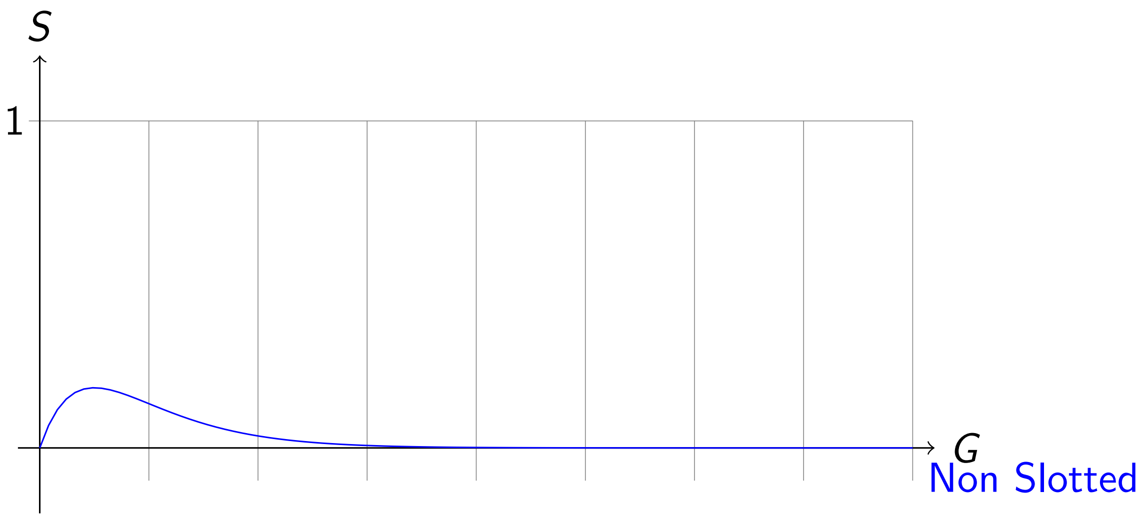
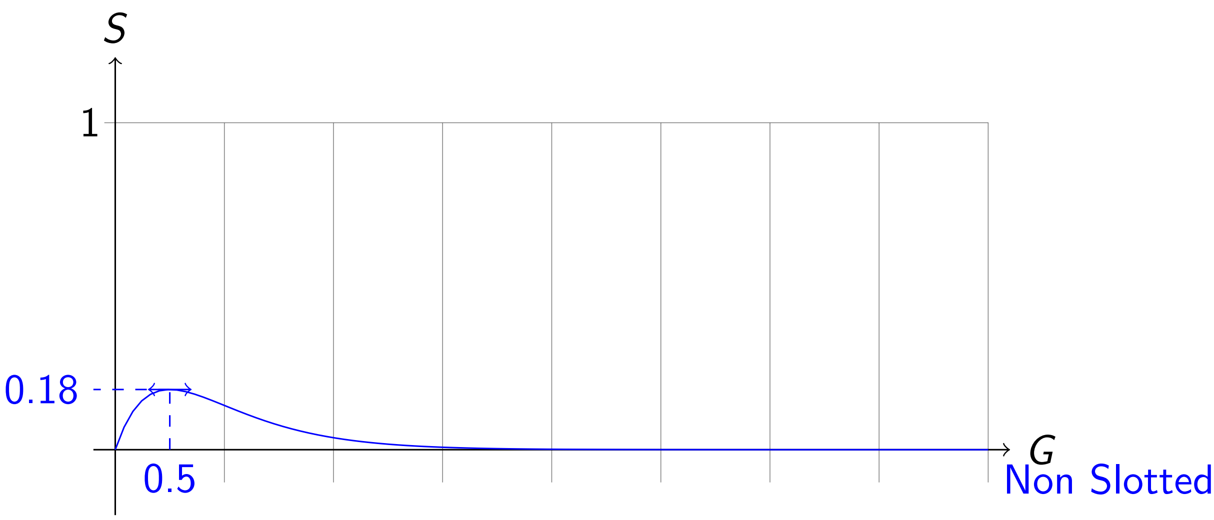


- $P_{Succ} = e^{-2gT} = \frac{s}{g}$ and $G = gT$, $S = sT$
- $S = G.e^{-2G}$
- The maximum of S is $1/2e$ for $G = 1/2$

Performance of non-slotted Aloha

Aloha ▶

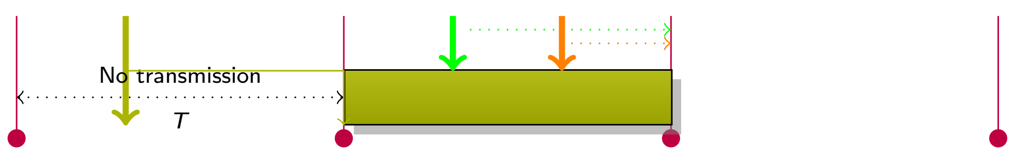


- $P_{Succ} = e^{-2gT} = \frac{s}{g}$ and $G = gT$, $S = sT$
- $S = G.e^{-2G}$
- The maximum of S is $1/2e$ for $G = 1/2$

Aloha with a retransmission procedure

- λ: number of messages generated in the system per second
- g: number of messages sent per second
  - Arriving messages (fresh load) plus retransmissions
- s: number of successful messages per second
  - message without any collision
  - when the system works correctly $s = \lambda$
- The global transmission process is assumed to be a Poisson process
- Same result: $S = G.e^{-2G}$ but
  - S is fixed
  - G is to determined
- G/S gives the average number of transmissions per message

Slotted Aloha: Success Probability



- $P_{Succ} = P_0(T) = \frac{(gT)^0 e^{-gT}}{0!} = e^{-gT} = e^{-G}$
- $P_{Succ} = \frac{S}{G}$
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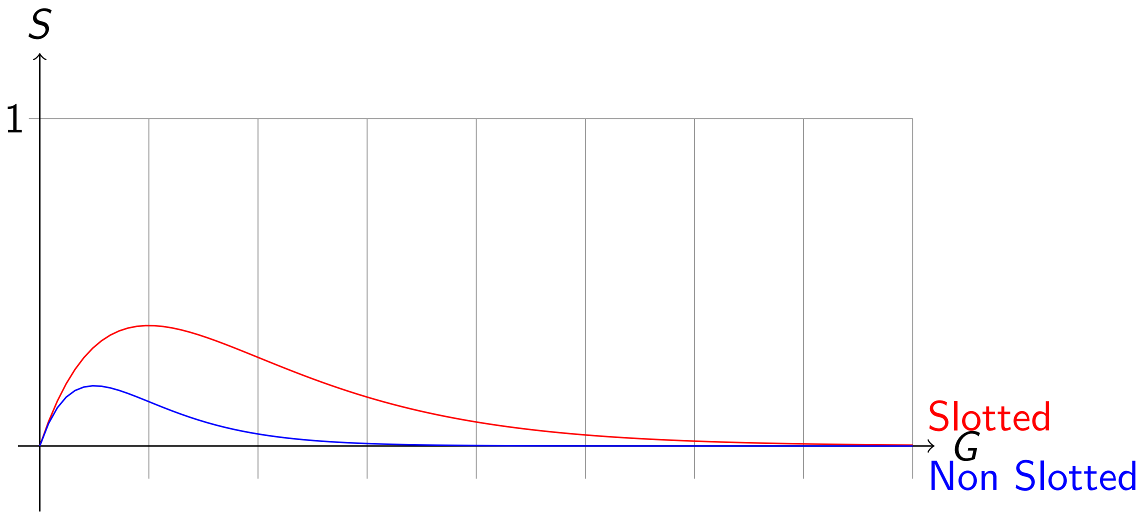
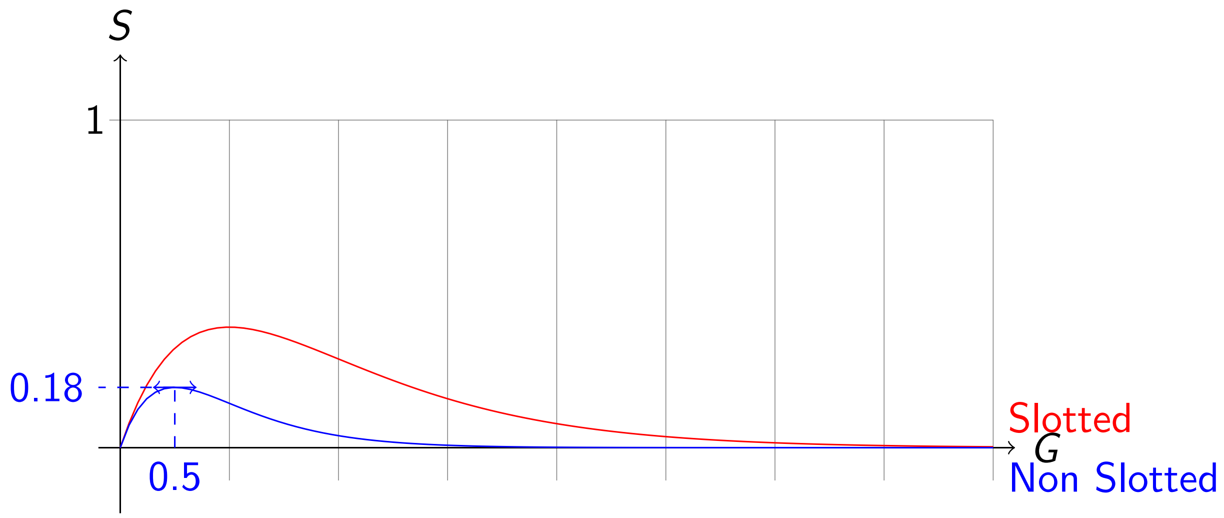
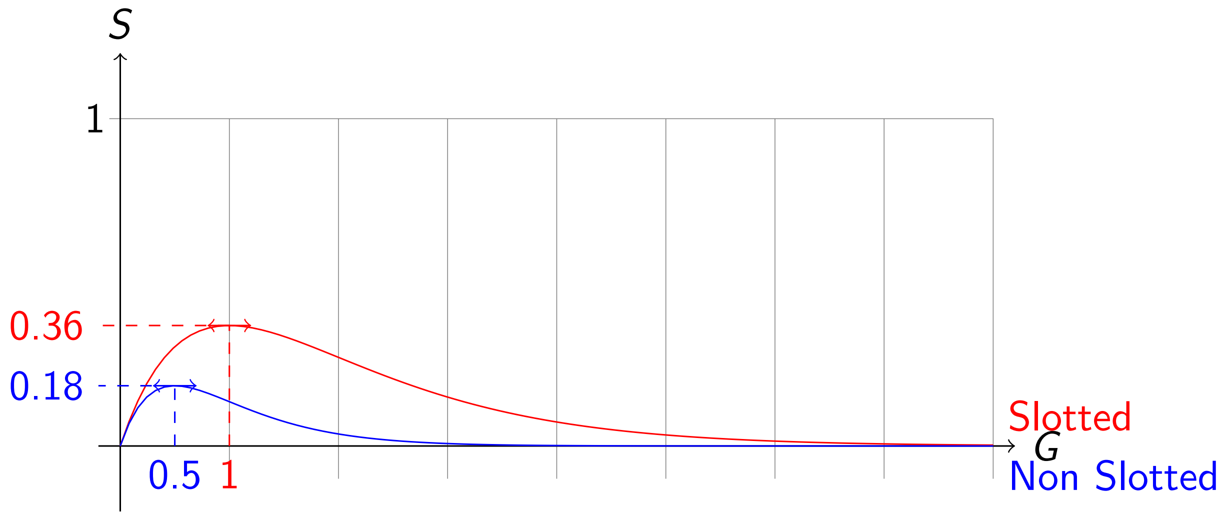
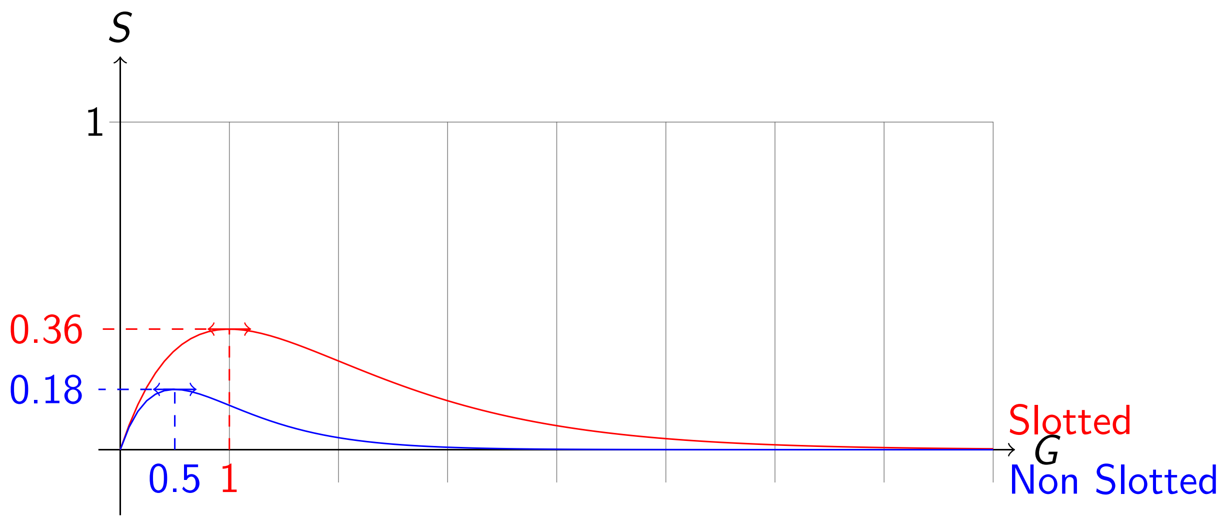




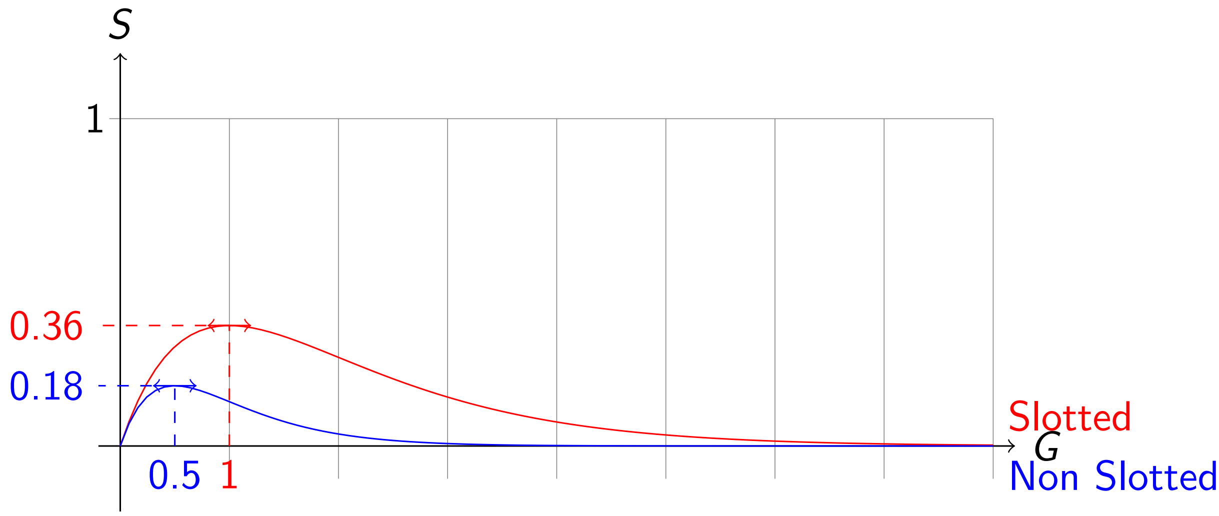
- Non Slotted Aloha: max 18% of the channel bandwidth



- Non Slotted Aloha: max 18% of the channel bandwidth
- Slotted Aloha: max 36% of the channel bandwidth



- Non Slotted Aloha: max 18% of the channel bandwidth
- Slotted Aloha: max 36% of the channel bandwidth
- When this limit is reached, system become instable
  - Before the limit, increasing the load increase success
  - After the limit, increasing the load, decrease success



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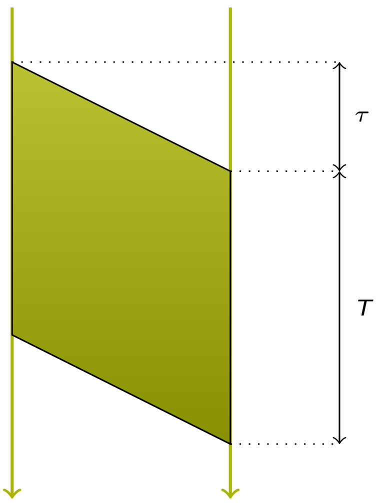
- Slotted Aloha: max 36% of the channel bandwidth
- When this limit is reached, system become instable
  - Before the limit, increasing the load increase success
  - After the limit, increasing the load, decrease success
- Getting closer to limit, increases instability risk

CSMA: Carrier Sense Multiple Access

- Listen to channel before sending
  - Easy with wired technologies, difficult with wireless



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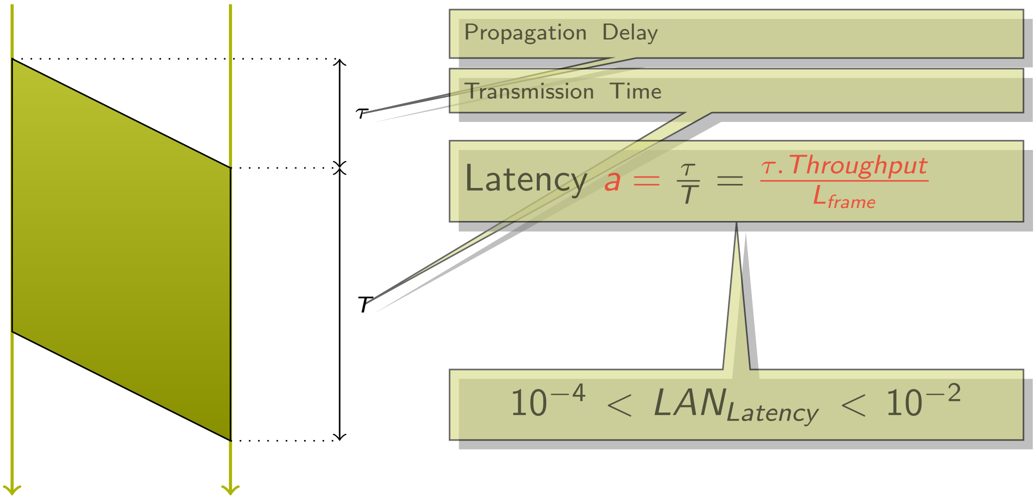

Aloha ▶

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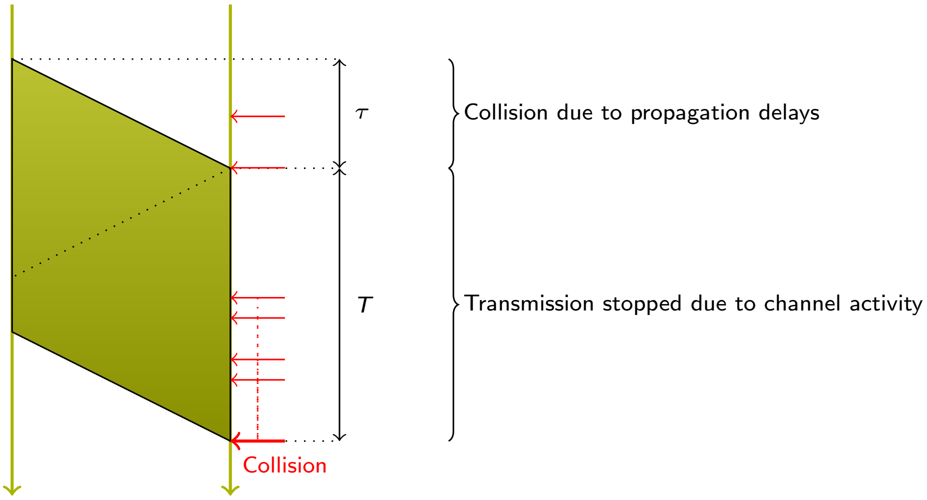

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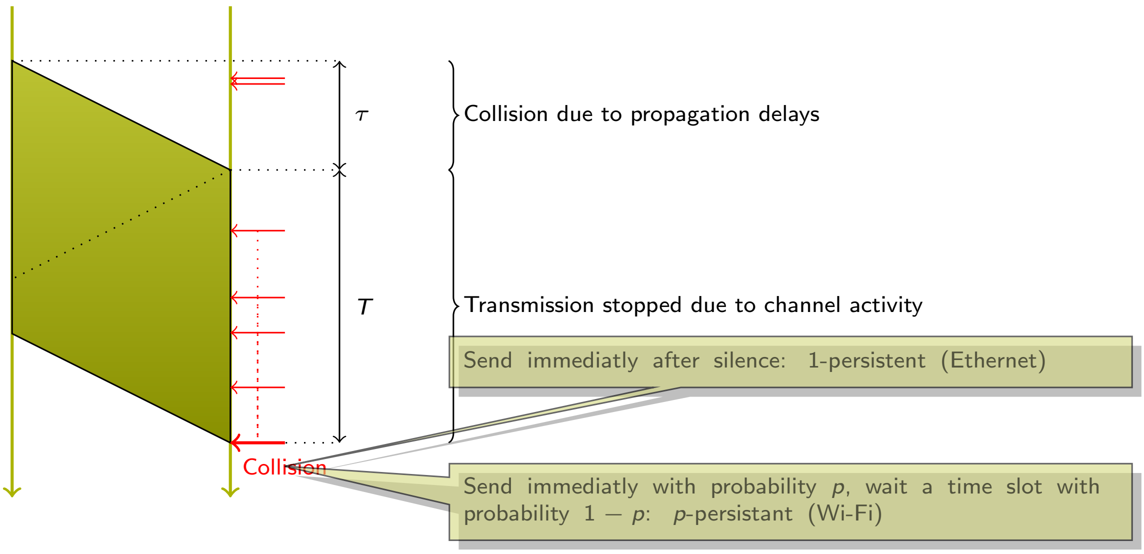
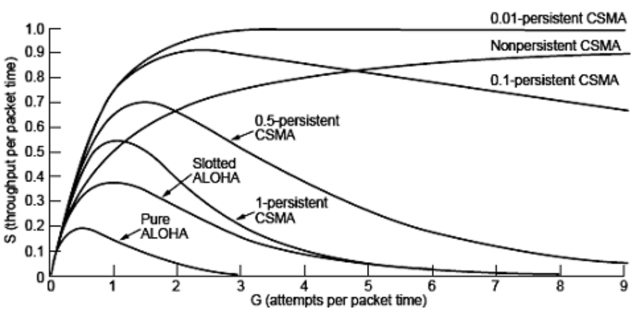


Access Method comparison

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.74.8411&rep=rep1&type=pdf



Pure ALOHA	$S = ge^{-2g}$
slotted ALOHA	$S = ge^{-g}$
unslotted 1-persistant CSMA	$S = \dfrac{g\left[1+g+ag\left(1+g+\frac{ag}{2}\right)\right]e^{-g(1+2a)}}{g(1+2a)-\left(1-e^{-ag}\right)+(1+ag)e^{-g(1+a)}}$
slotted 1-persistant CSMA	$S = \dfrac{g\left[1+a-e^{-ag}\right]e^{-g(1+a)}}{(1+a)\left(1-e^{-ag}\right)+ae^{-g(1+a)}}$
unslotted nonpersistant CSMA	$S = \dfrac{ge^{-ag}}{g(1+2a)+e^{-ag}}$
slotted nonpersistant CSMA	$S = \dfrac{age^{-ag}}{1-e^{-ag}+a}$

Ethernet

Introduction

History and Evolutions

- Developed initially by Digital, Intel and Xerox to share first laser printers
- First version in 1 976 at 3 Mbit/s
- Second version standardized by IEEE at 10 Mbit/s:
  - Subtle changes in frame field leads to two way to manage protocol stack.
  - Frame format slightly changed but physical medium evolved:
    - from 10 Mbit/s to 100 MBit/s them 1GBit/s and 10 or 40 GBit/s.
    - standardization is currently working on 100 GBit/s links.
    - From coaxial link to twisted pair and optical fiber (No support for radio link)
  - MAC get simplified:
    - Shared media (coaxial or twisted pair with hub) uses CSMA/CD algorithm
    - Switched media or point to point links do not require MAC algorithm (there is a dedicated resource between the equipment and the switch).

Ethernet

IEEE at 10 Mbit/s

Technology names: 10BASE-5 & 10BASE-2

Speed: 10, 100, 1000, 10G, 40G, 100G

10BASE-T

Technology names: 10BASE-5 & 10BASE-2

10BASE-T

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Ethernet ▶ IEEE at 10 Mbit/s

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Physical Layer: ~~5~~, ~~2~~, Tx, Fx, ...

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Obsoleted technologies:

- 10BASE-5 (*Thick Ethernet*) and 10BASE-2 (*Thin Ethernet*)
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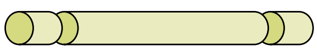

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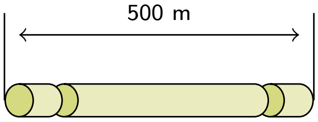

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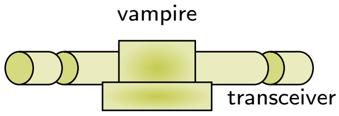

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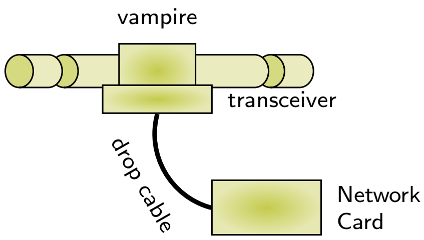

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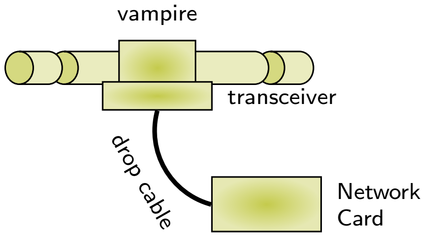

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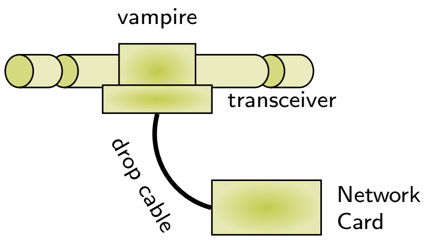

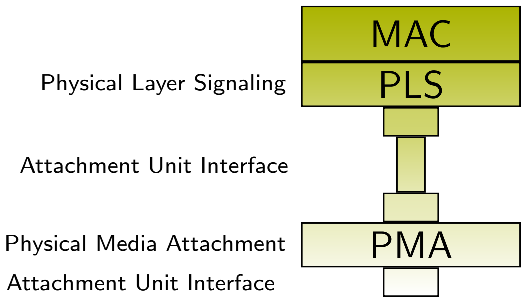

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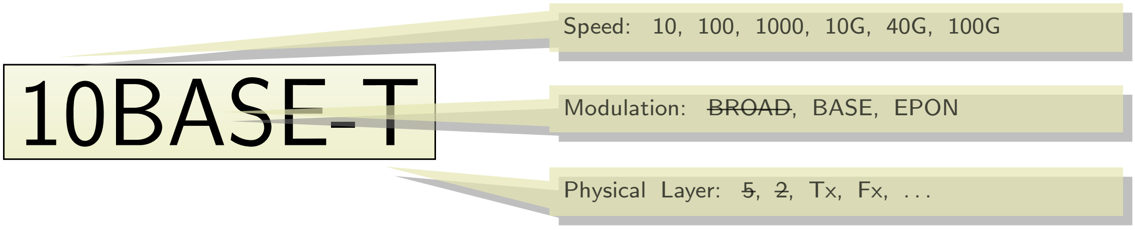

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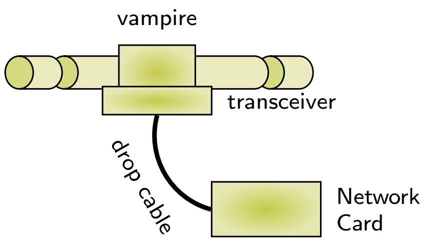

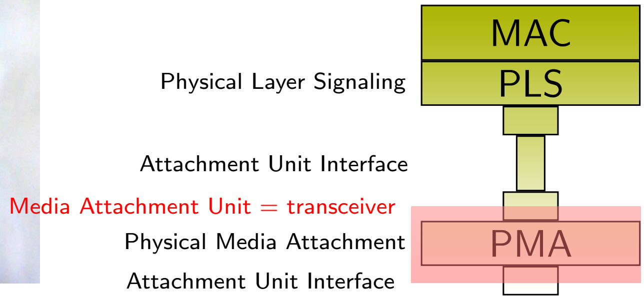

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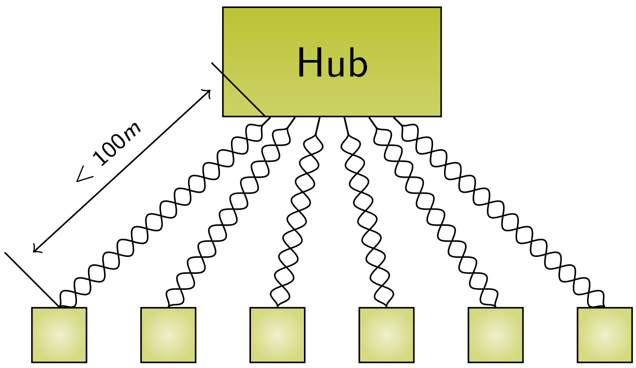
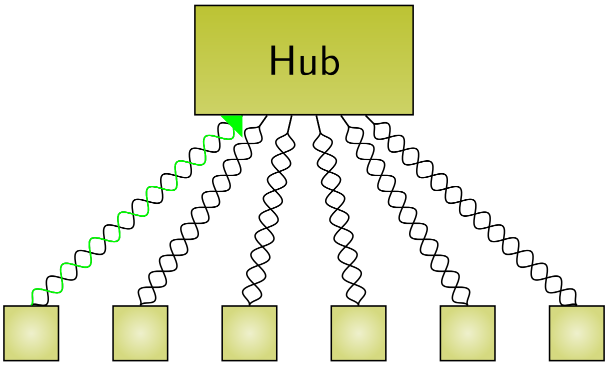


- Hub: Active equipment repeating signal on other ports
- Generate collision signal when two equipments send at the same time
- Hub is viewed as a shared network by equipments.
  - More reliable than co-axial cable. Cable cut just isolates one equipment.
  - Use standard wires (telephony wires for 10BASE-T)

10BASE-T



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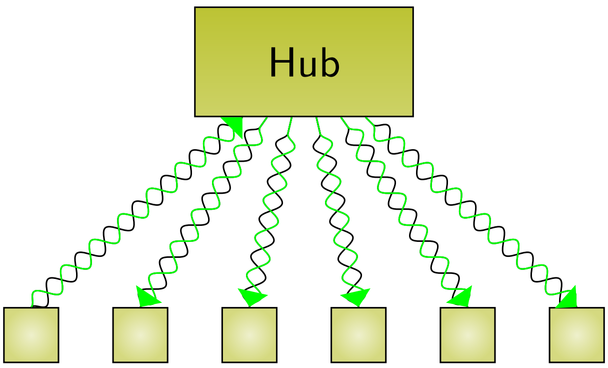

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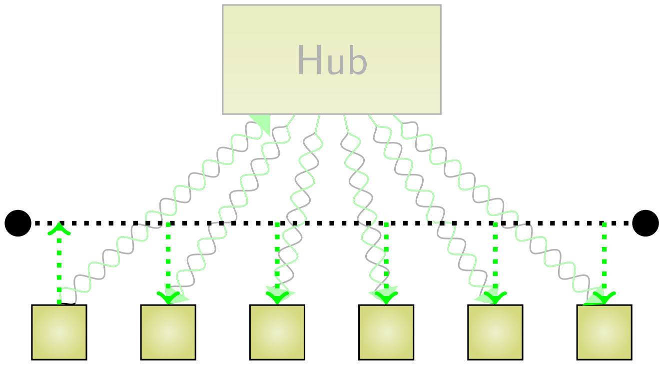
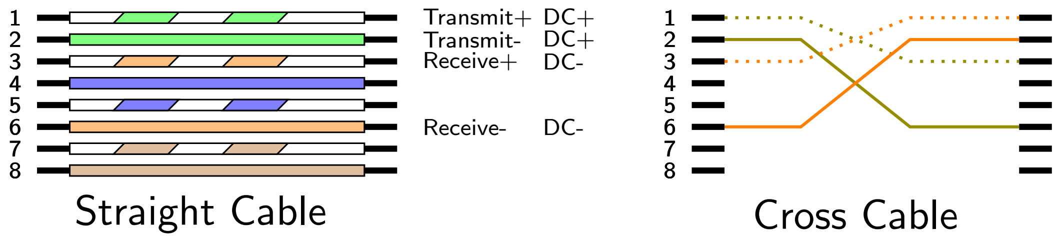


- Hub: Active equipment repeating signal on other ports
- Generate collision signal when two equipments send at the same time
- Hub is viewed as a shared network by equipments.
  - More reliable than co-axial cable. Cable cut just isolates one equipment.
  - Use standard wires (telephony wires for 10BASE-T)

RJ-45

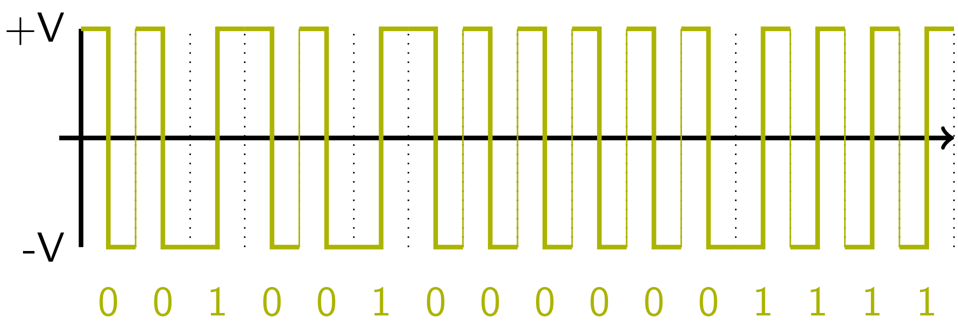
- RJ-45 plug and cable contains 4 twisted pairs
  - 10M and 100M generally use only 2 pairs, 1G uses 4 pairs
- Modulation signal is the difference between both wires
  - PoE (Power on Ethernet) (IEEE 802.3at): continuous voltage is added to data or use the blue and brown pairs
- Straight cable to connect equipment to switch/hub, cross cable to connect equipment/switch/hub together
  - equipments may select to the appropriate cabling.



http://www.ertyu.org/steven_nikkel/ethernetcables.html

Coding technique at 10 Mbit/s

- Manchester coding:
  - transition $0 \rightarrow 1 = 1$
  - transition $1 \rightarrow 0 = 0$
- Each bit sent allows clock synchronization by the receiver
  - Cannot be used a 100 Mbit/s and higher due to the high number of transitions



http://en.wikipedia.org/wiki/Manchester_code

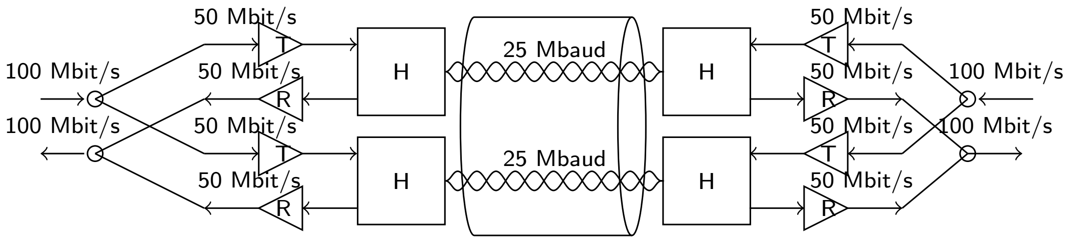
TELECOM Bretagne

Ethernet

100 Mbit/s

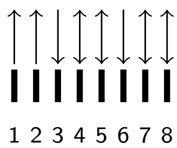
Ethernet 100 Mbit/s on Twisted Pairs

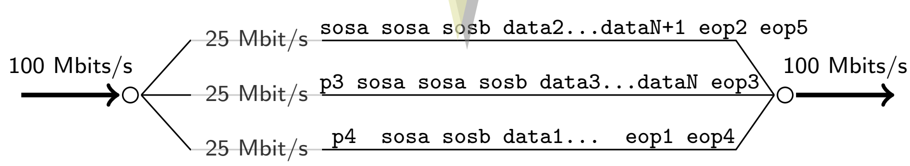
- Only based on star topologies (hub or switch);
- 100BASE-T2 (cat 3)



- 100BASE-T4 (cat 3) half-duplex

8B/6T (T=-/0/+) $2^8 = 256 < 3^6 = 729$





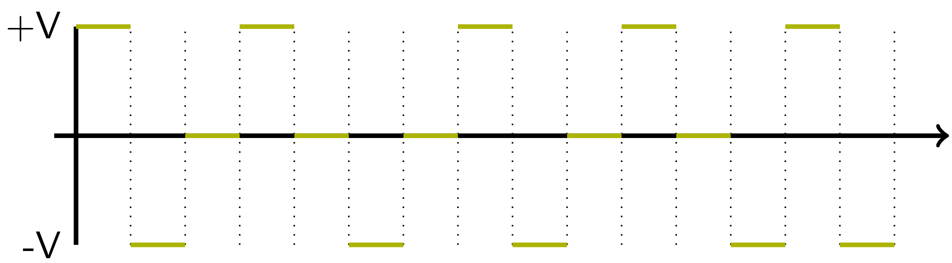
100Base-TX coding

Use 4B/5B coding (4 bits are coded into 5 bits).

Binary values		5B	Binary values		5B	Signal	5B	Meaning
0	0000	11110	8	1000	10010	Q	00000	Quiet (signal lost)
1	0001	01001	9	1001	10011	I	11111	Idle
2	0010	10100	A	1010	10110	J	11000	Start #1
3	0011	10101	B	1011	10111	K	10001	Start #2
4	0100	01010	C	1100	11010	T	01101	End
5	0101	01011	D	1101	11011	R	00111	Reset
6	0110	01110	E	1110	11100	S	11001	Set
7	0111	01111	F	1111	11101	H	00100	Halt

Coding uses MLT-3

- 1 are alternatively coded by +V and -V, 0 are coded with 0V



Which value is sent ?

100Base-TX coding

Use 4B/5B coding (4 bits are coded into 5 bits).

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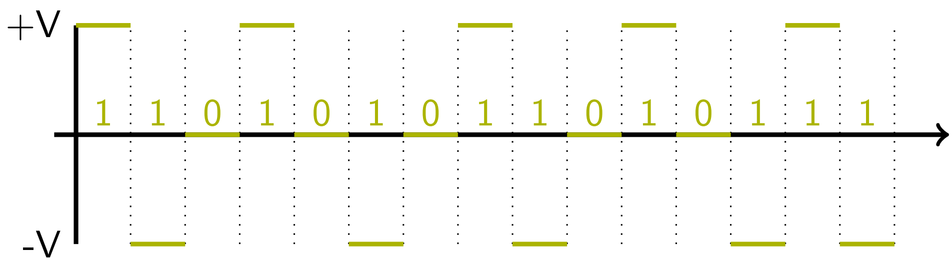


Which value is sent ?

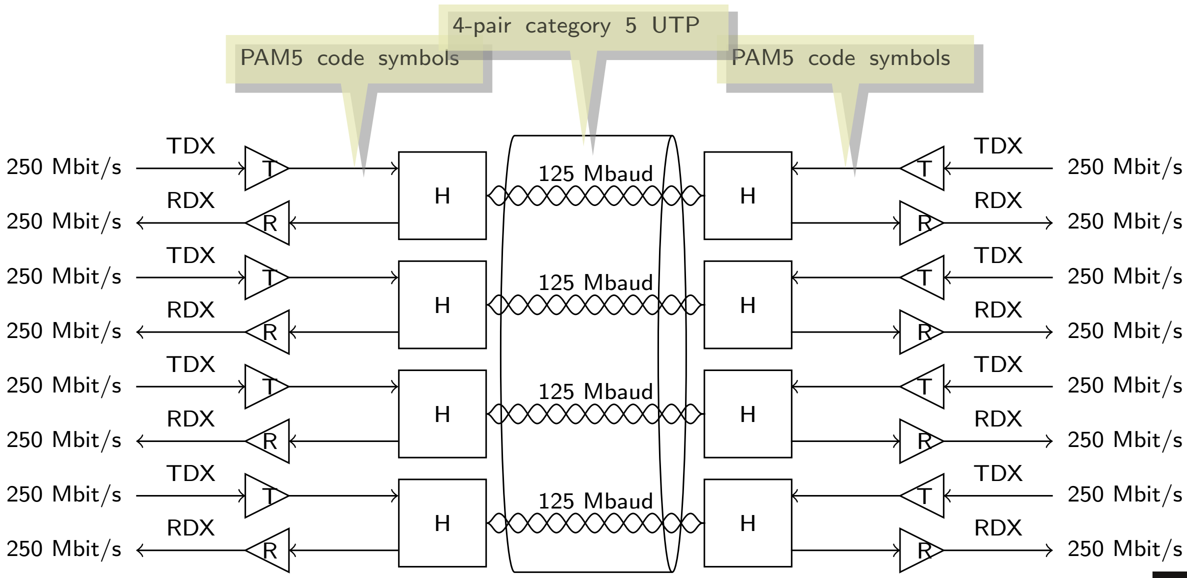
0xC, 0xA, 0xB

Ethernet 100 Mbit/s on Optical Fiber

- 100BASE-FX
  - Multimode Optical Fiber
  - up to 2 km in switched full duplex mode
  - limited to 400 m in half duplex CSMA/CD mode
- 100BASE-SX
  - Cheaper lasers, less distance, about 550 m.
- 100BASE-LX
  - Up to 10 km
  - monomode fiber
- ...

Ethernet 1 Gbit/s

- 1000BASE-T (IEEE 802.3ab)
  - category 5 cable and over all 4 pairs
  - up to 100 m



1000BASE-X

- 1000BASE-TX
  - Use two twisted pairs of cat6 cable, using 8B/10B coding
  - less popular than 1000BASE-T widely deployed on computers
- 1000BASE-CX (IEEE 802.3z)
  - initial standard for twisted pair on a max distance of 25 m, replaced by 1000BASE-T
- 1000BASE-LX
  - Multi-mode optical fiber, up to 550
- 1000BASE-ZX
  - Single mode optical fiber, up to 70 km
- ...

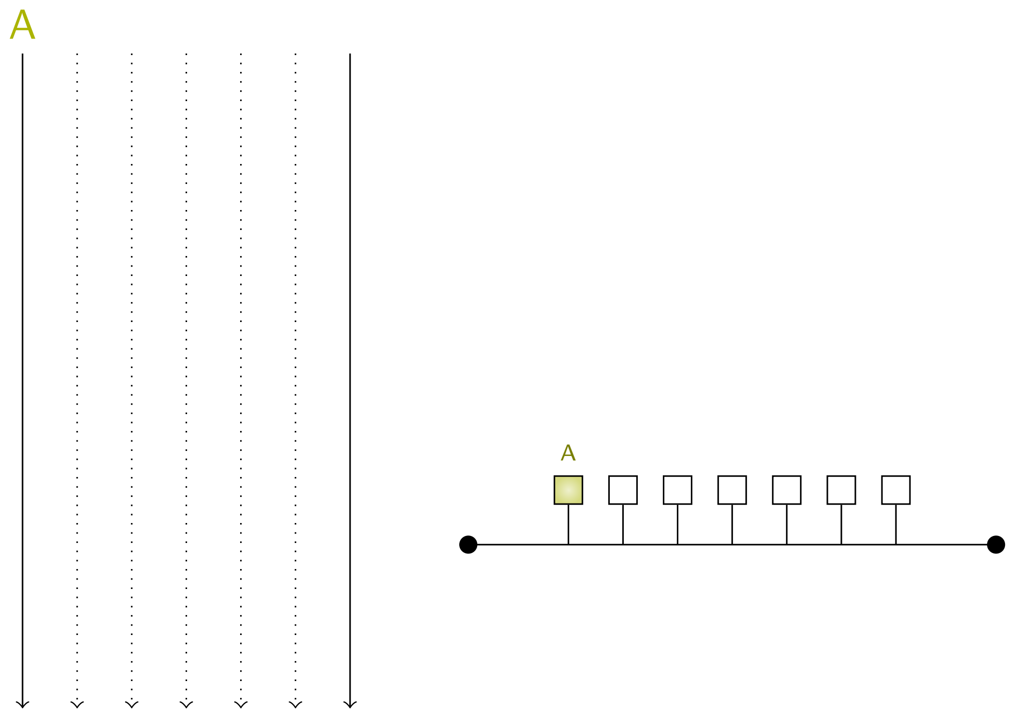
Ethernet

CSMA/CD

Carrier Sense Multiple Access / Collision Detect

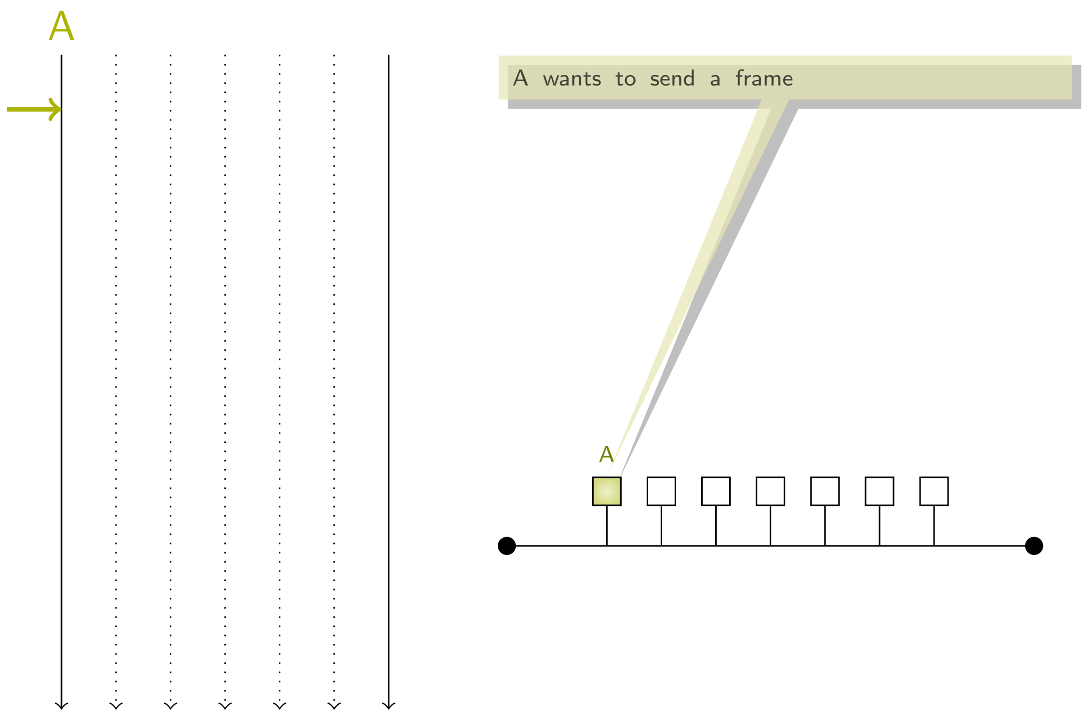
- Carrier Sense: Listen to the channel to detect the status
  - Idle: Not transmission
  - Busy: Regular transmission is occuring
  - Collision: Several equipments are sending at the same time.
    - Standard impose that signal level cannot be reduce by more than half in the whole link
    - If reception level is higher than the standardized transmission level, then at least two equipments are sending.
    - This not work on radio network, reception level is much smaller than transmission lever and some station may be hidden
  - if the channel is Idle, then send the frame
  - if the channel is busy, then delay the transmission
- Collision Detect: If a collision occurs during the frame transmission: stop and restart.
- Impossible to detect on radio links

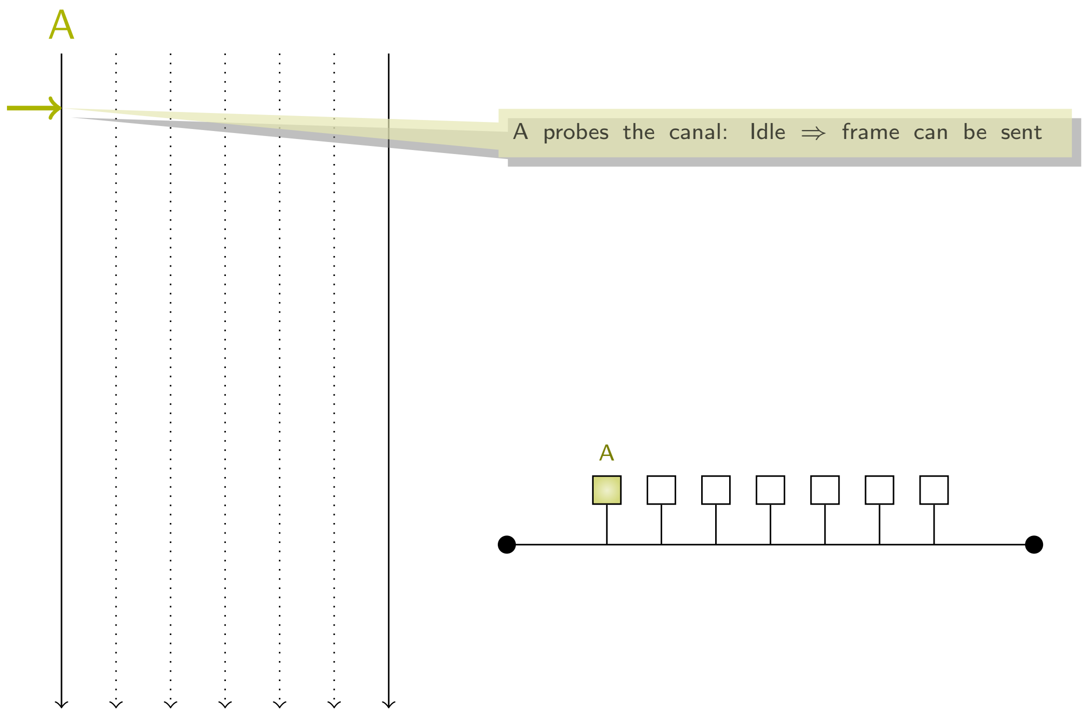
CSMA/CD



Ethernet ▶ CSMA/CD

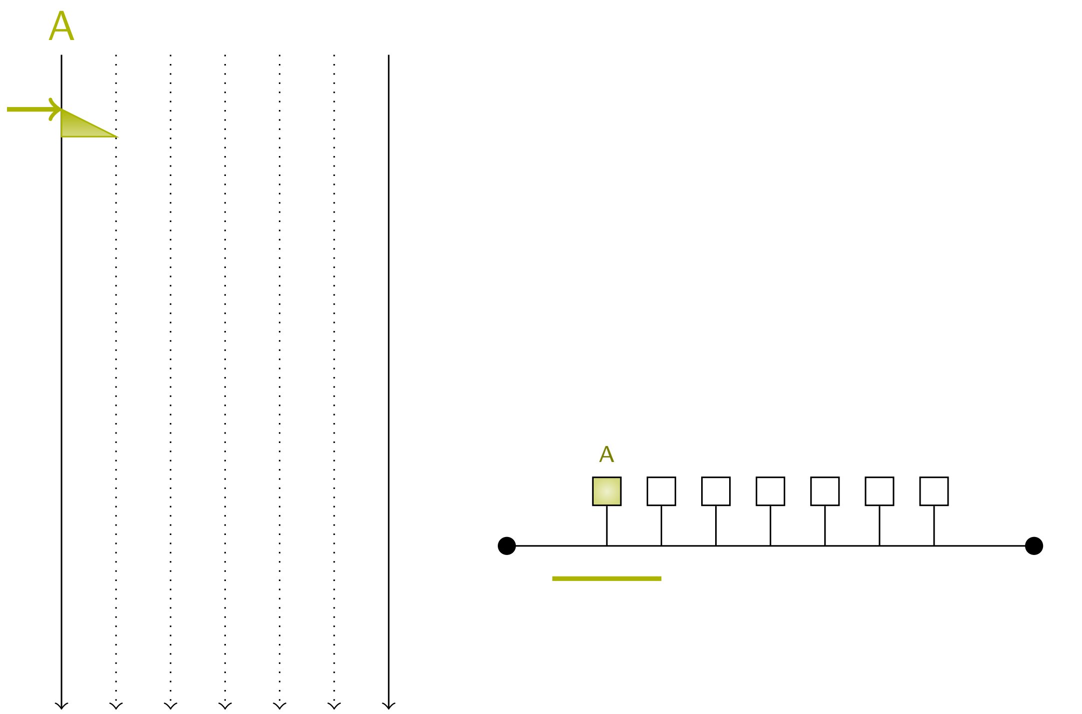
CSMA/CD



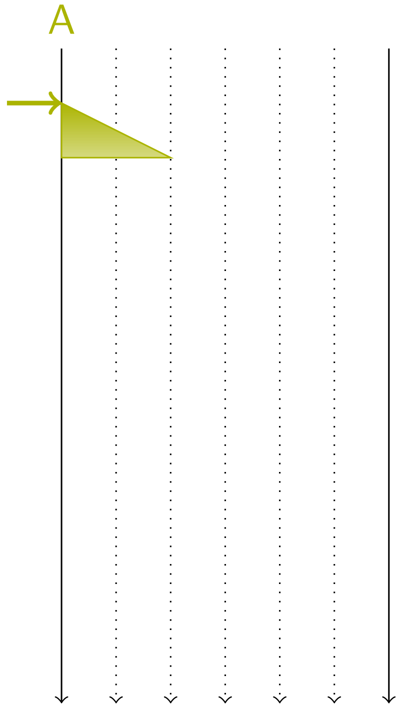


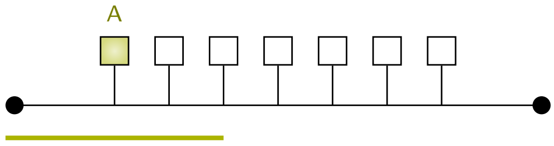
CSMA/CD

Ethernet ▶ CSMA/CD



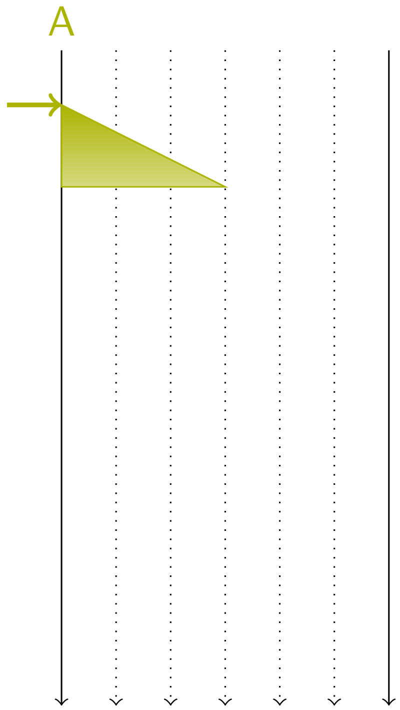
CSMA/CD

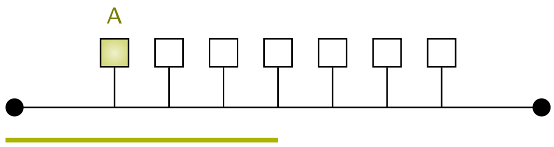


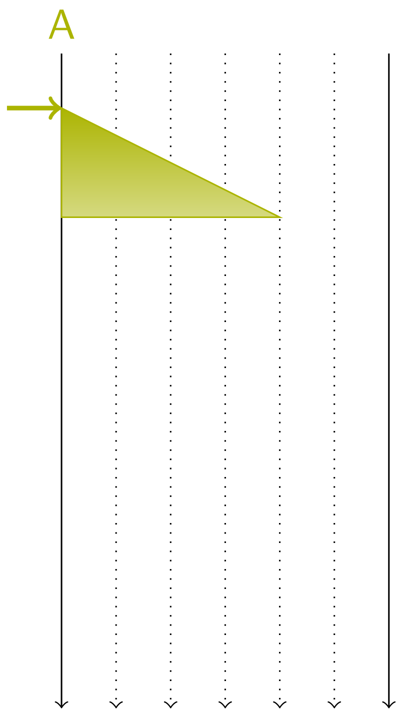


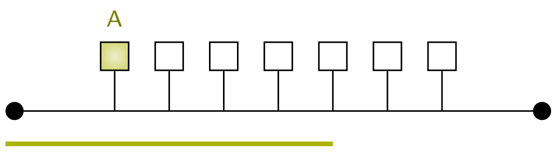
Ethernet ▶ CSMA/CD

CSMA/CD

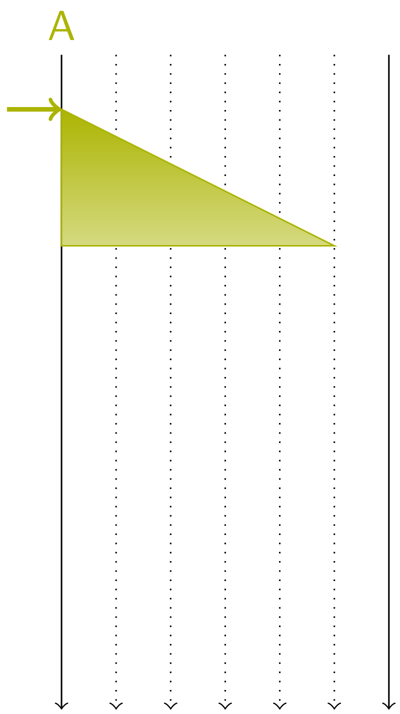


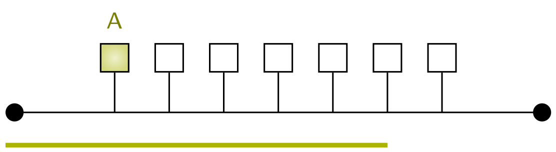






CSMA/CD
Ethernet ▶ CSMA/CD





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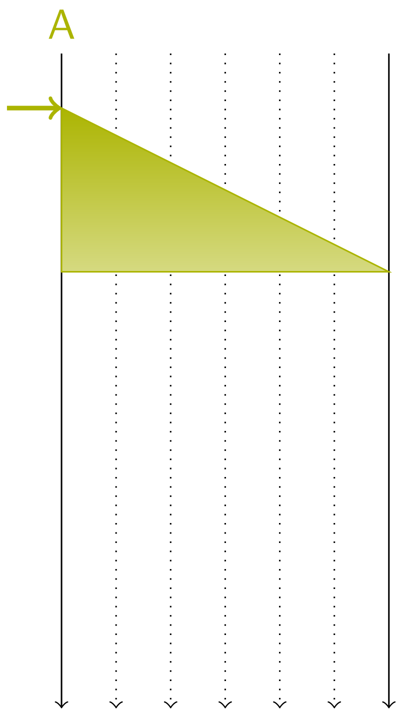
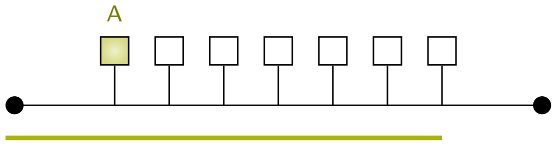
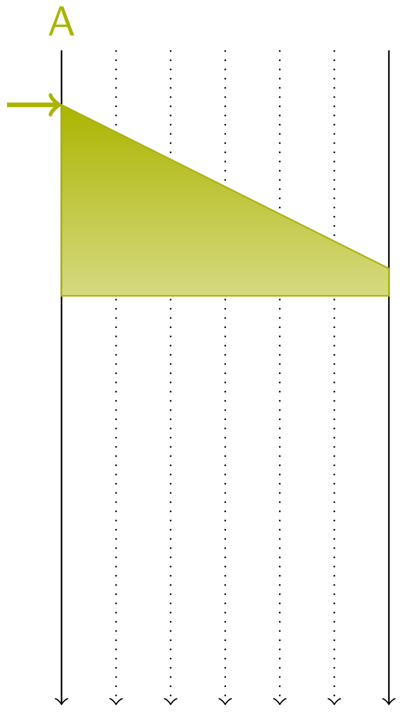
CSMA/CD

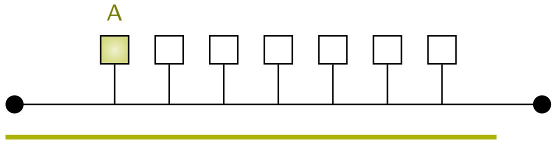




CSMA/CD

Ethernet ▶ CSMA/CD





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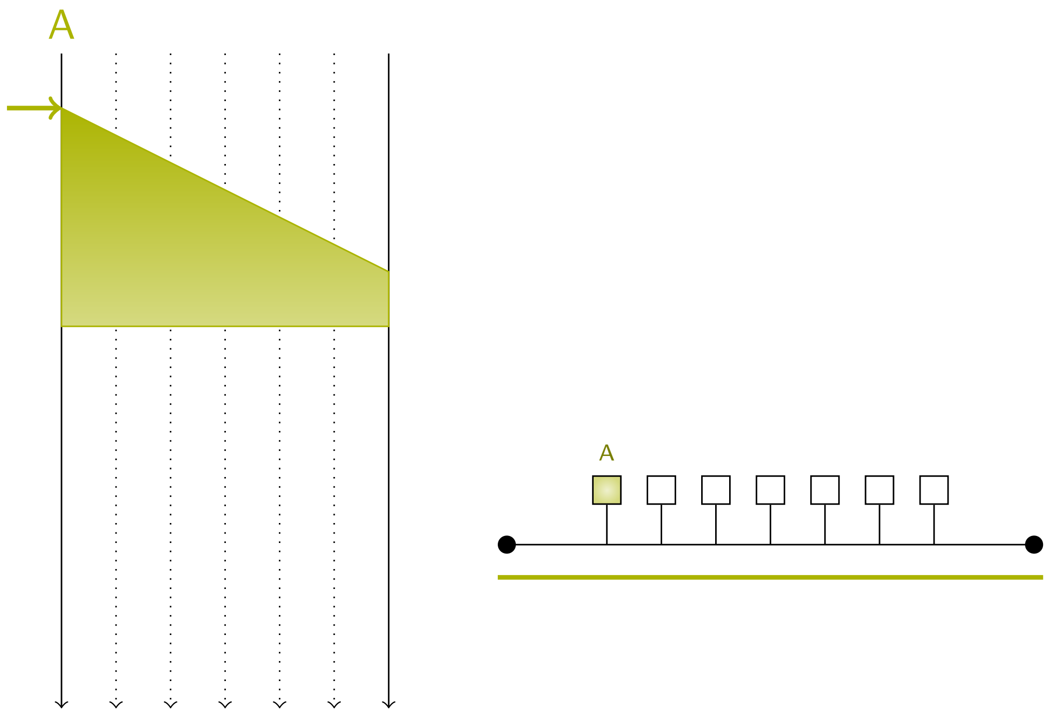
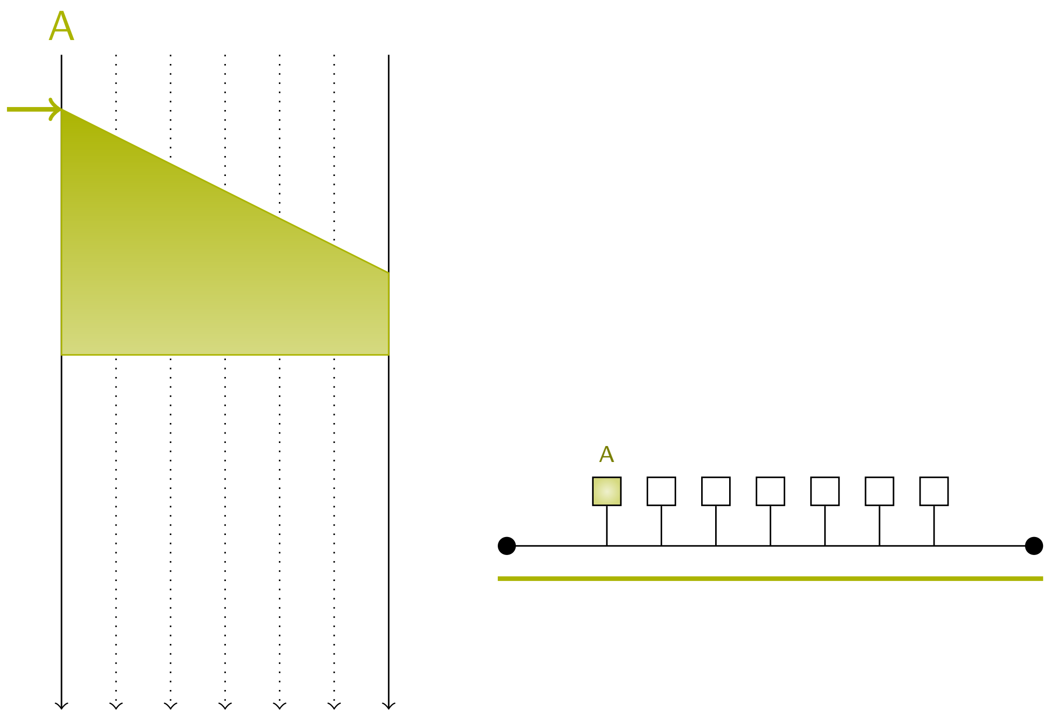
CSMA/CD



Ethernet ▶ CSMA/CD

CSMA/CD



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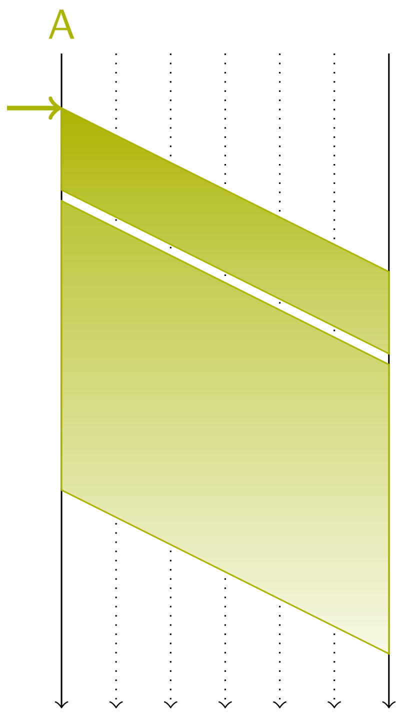
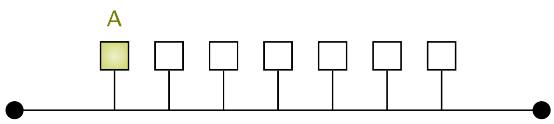
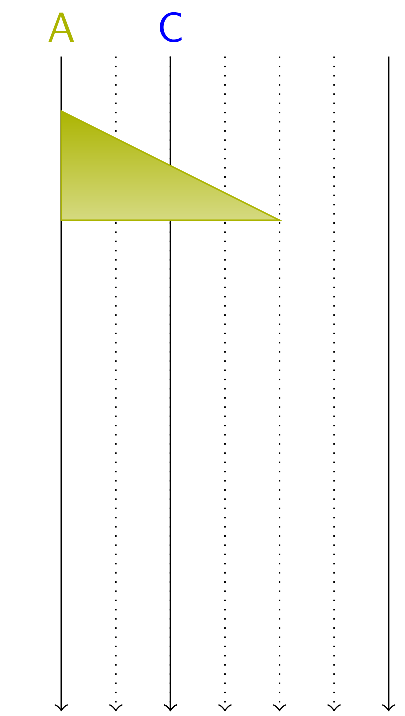
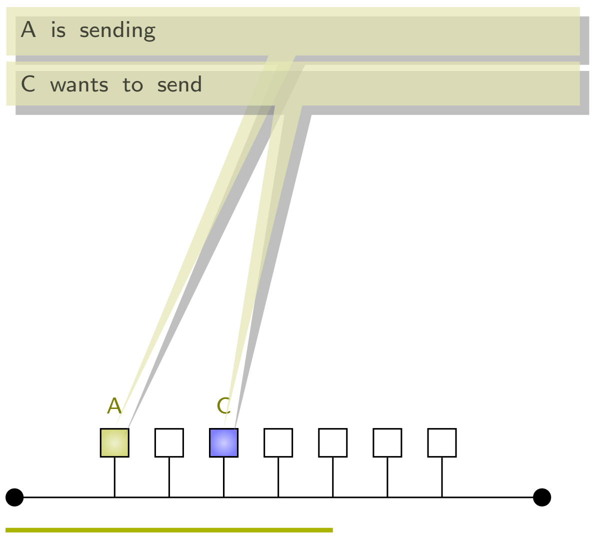
CSMA/CD





CSMA/CD: Delayed transmission





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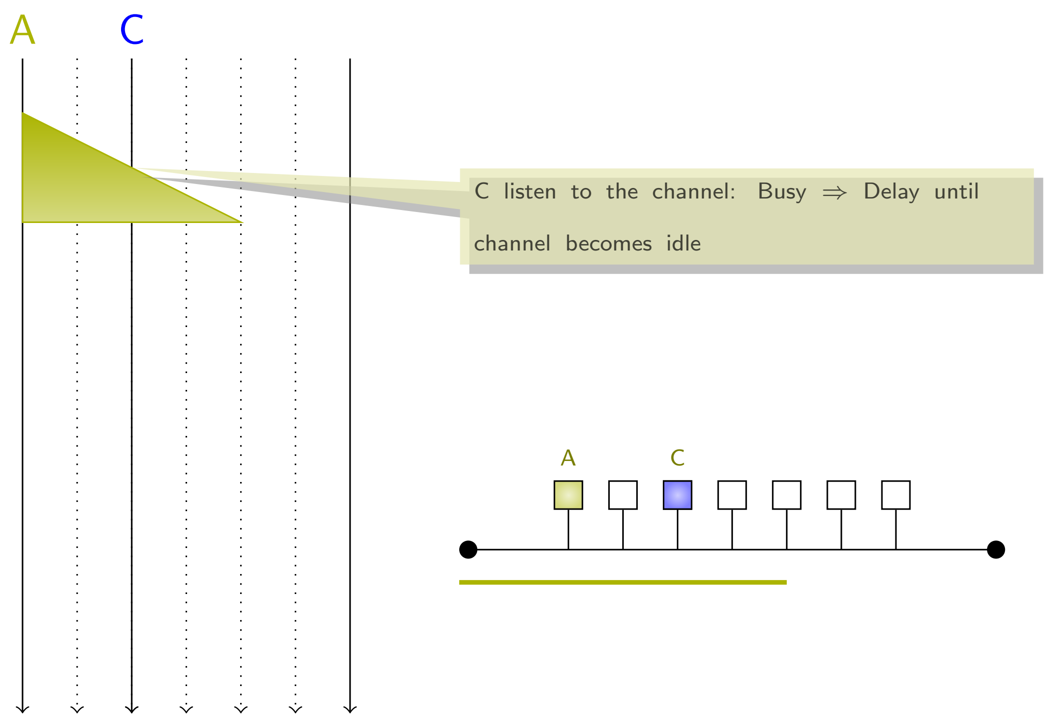
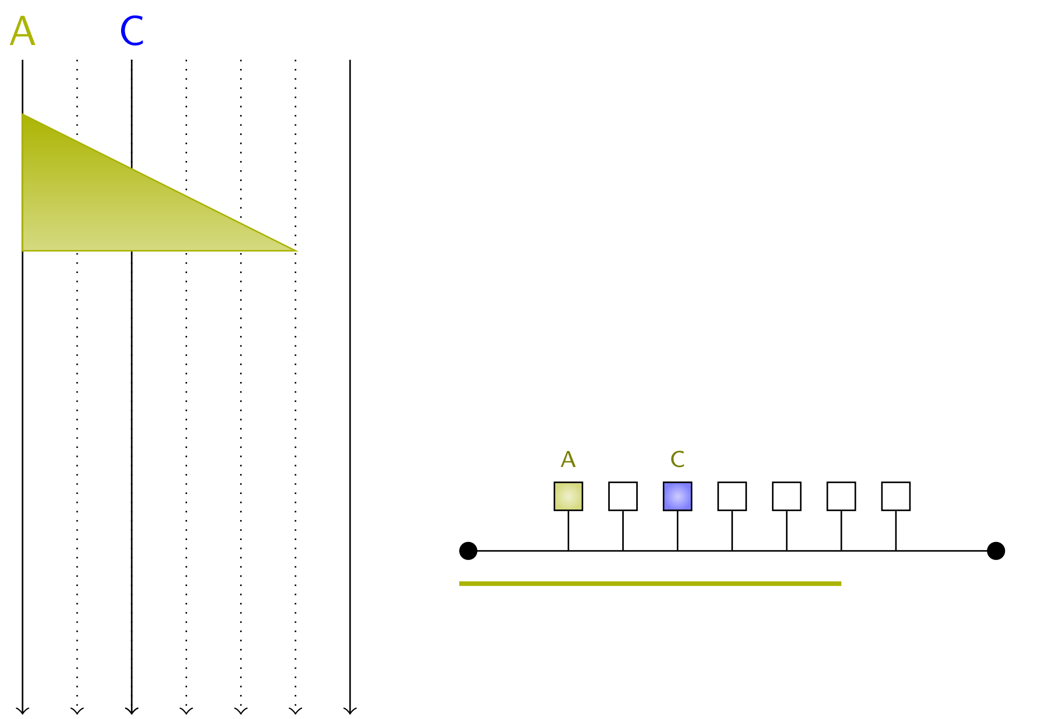
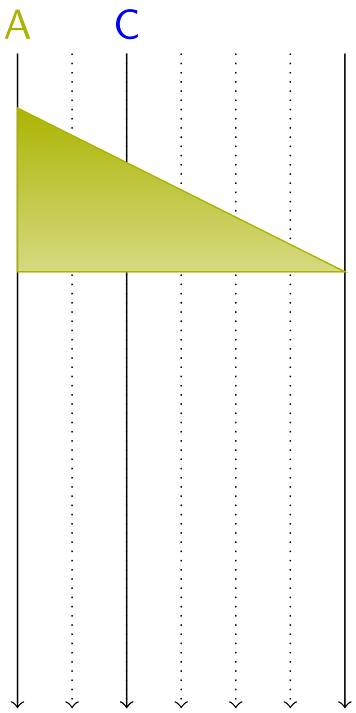


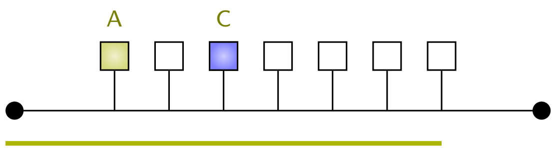
CSMA/CD: Delayed transmission

Ethernet ▶ CSMA/CD



CSMA/CD: Delayed transmission





Ethernet ▶ CSMA/CD

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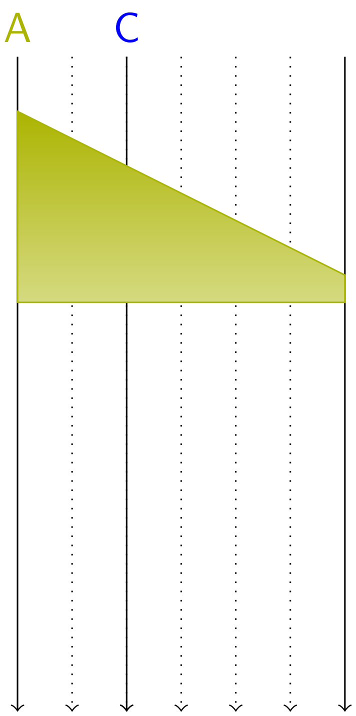

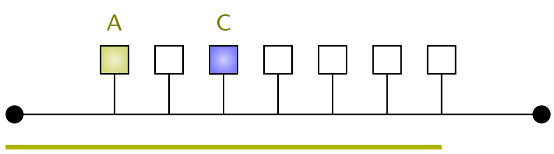

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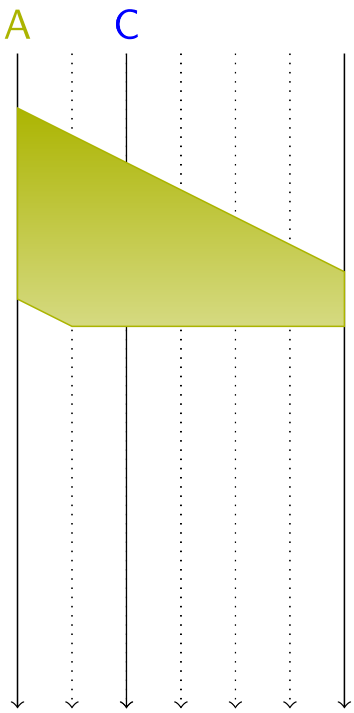
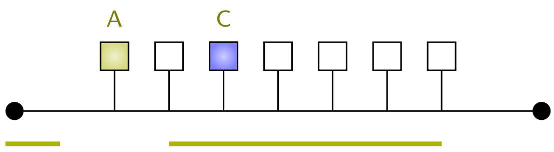
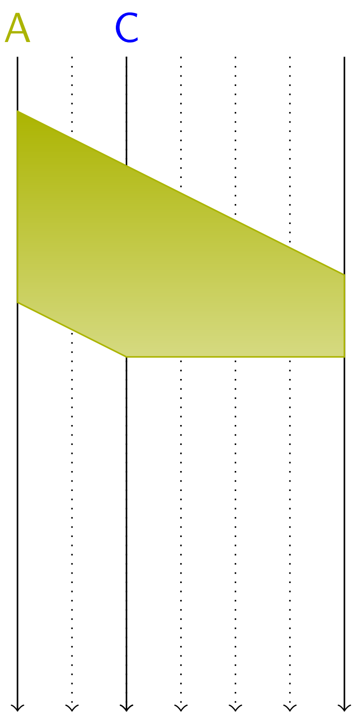
CSMA/CD: Delayed transmission

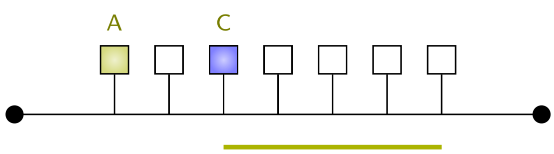




CSMA/CD: Delayed transmission

Ethernet ▶ CSMA/CD





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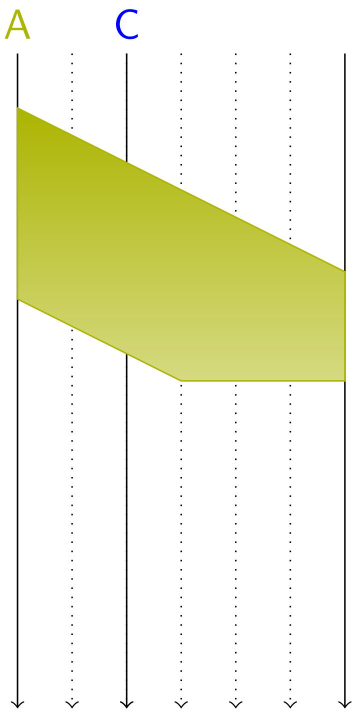
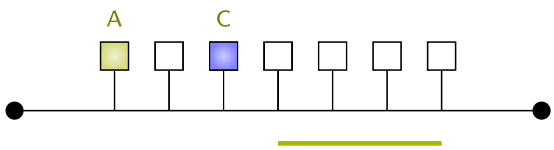
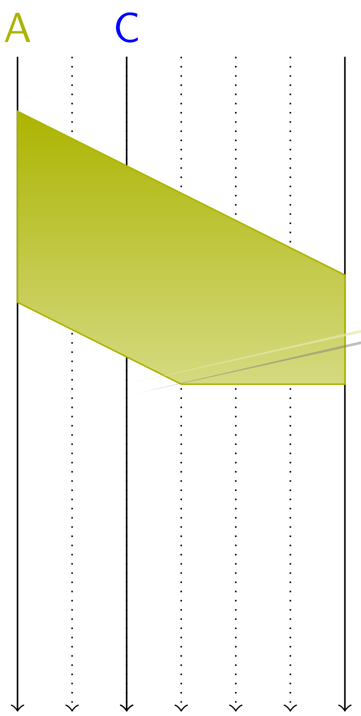


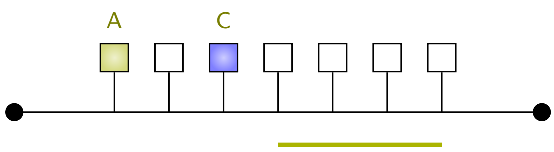


CSMA/CD: Delayed transmission

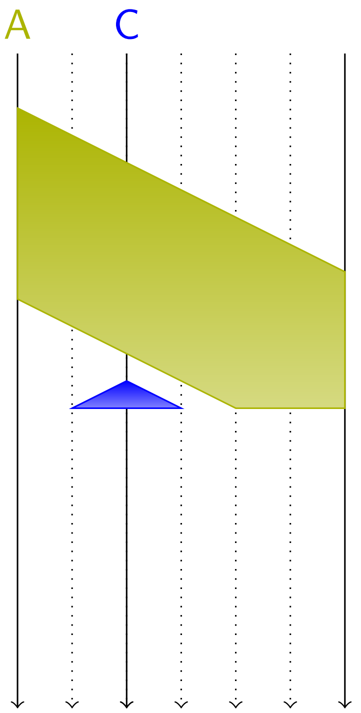
Ethernet ▶ CSMA/CD

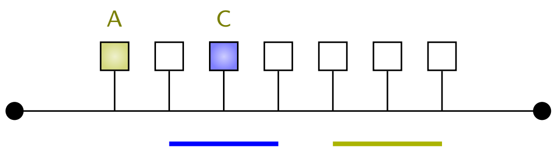


Channel becomes idle ⇒ C starts sending

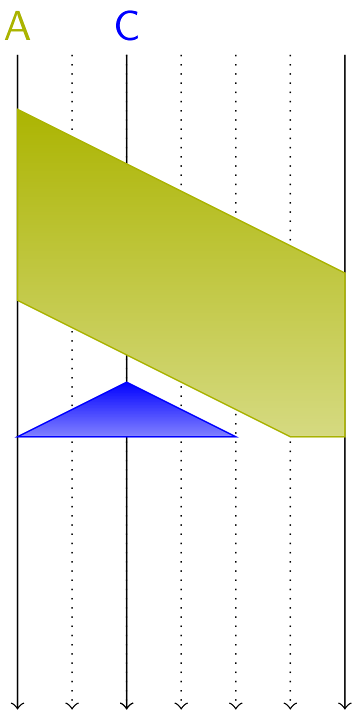


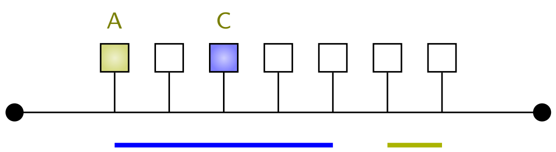
CSMA/CD: Delayed transmission



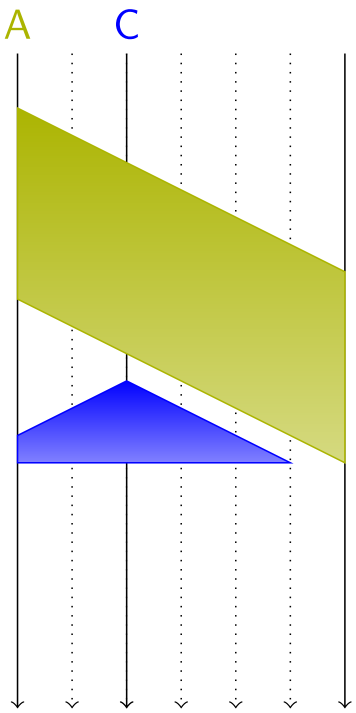


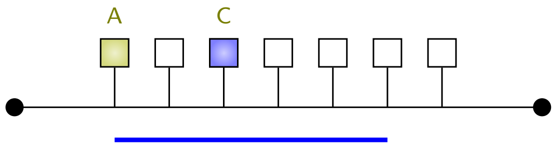
CSMA/CD: Delayed transmission





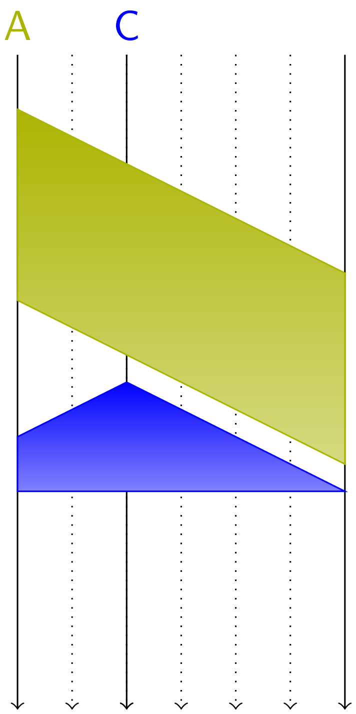
CSMA/CD: Delayed transmission

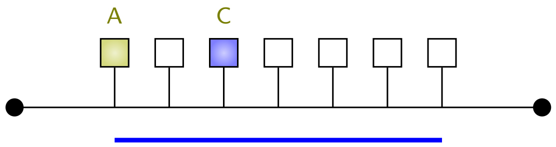




CSMA/CD: Delayed transmission

Ethernet ▶ CSMA/CD





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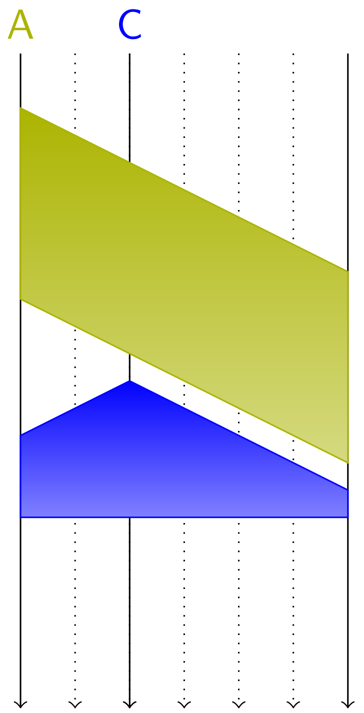
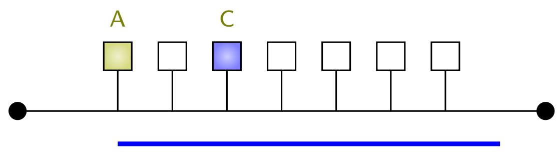
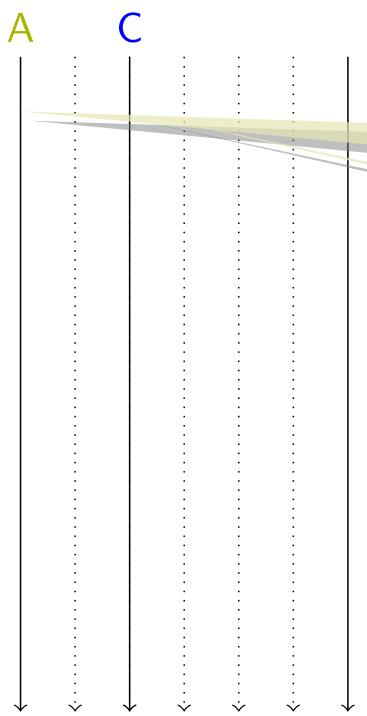
CSMA/CD: Delayed transmission





CSMA/CD: Collision

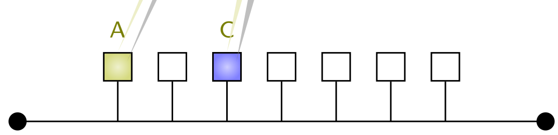


A wants to send a frame

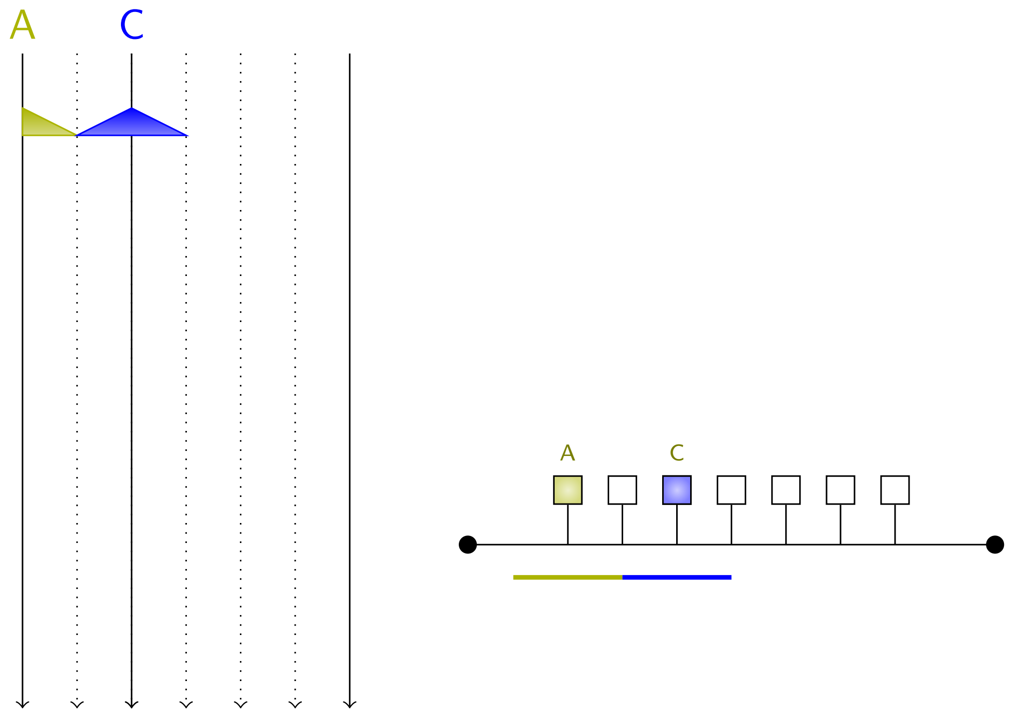
A probes the canal: Idle ⇒ frame can be sent

C wants to send a frame

C probes the canal: Idle ⇒ frame can be sent

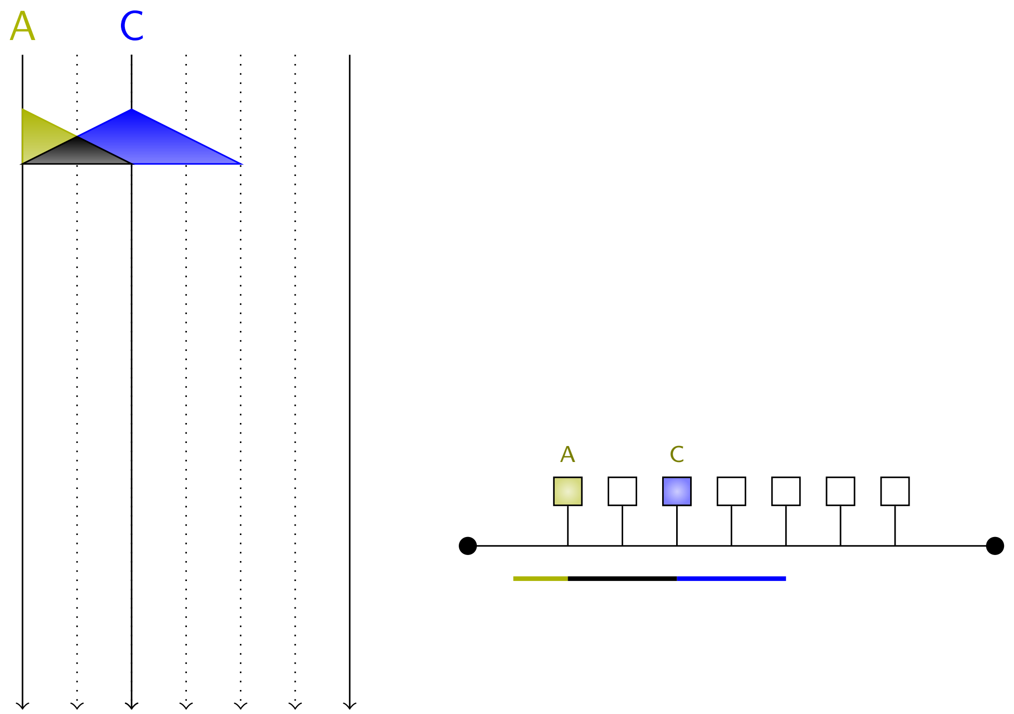


CSMA/CD: Collision

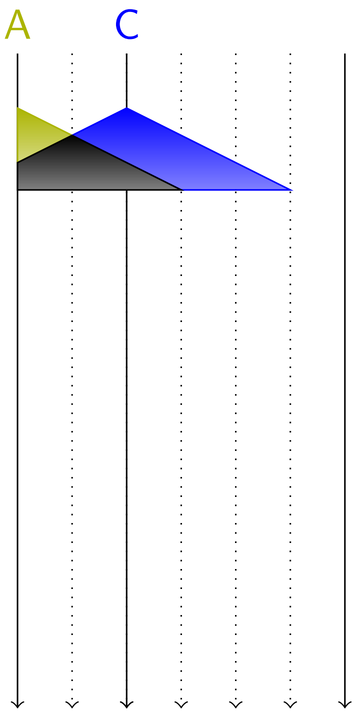


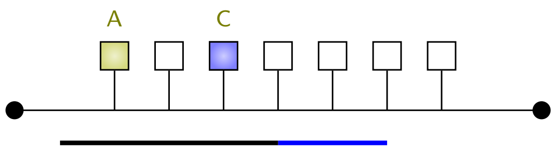
CSMA/CD: Collision

Ethernet ▶ CSMA/CD



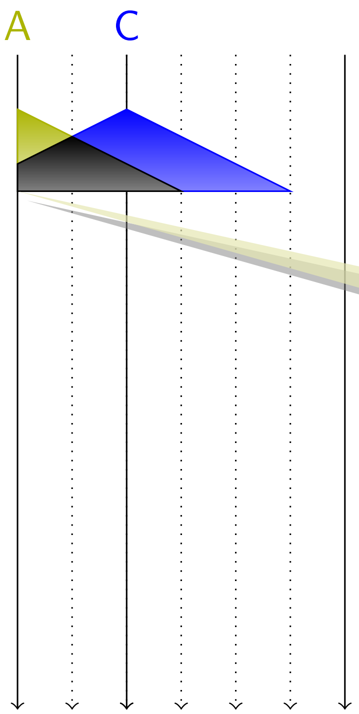
CSMA/CD: Collision



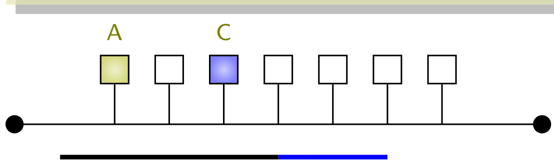


CSMA/CD: Collision

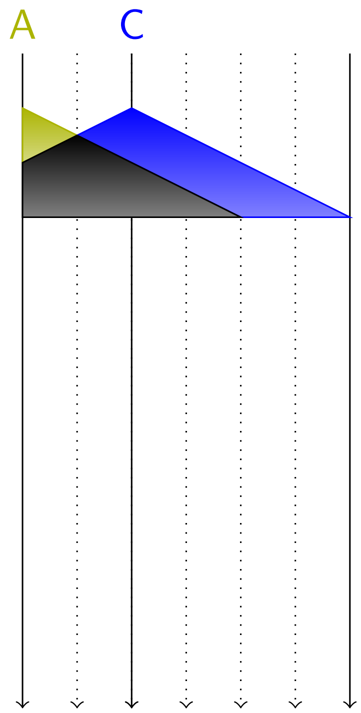
Ethernet ▶ CSMA/CD

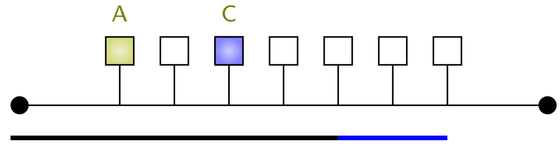


A and C detect the collision ⇒ Continue to send some bit to allow other equipments to detect the collision, then stop



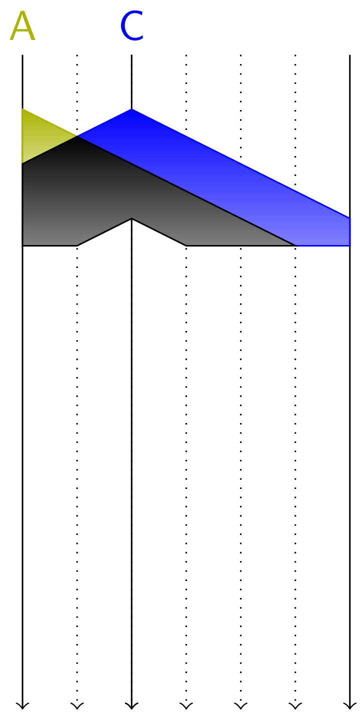
CSMA/CD: Collision

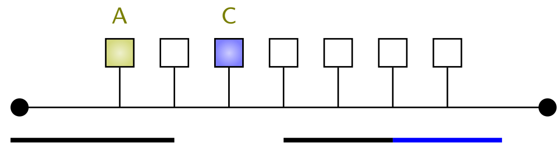




CSMA/CD: Collision

Ethernet ▶ CSMA/CD





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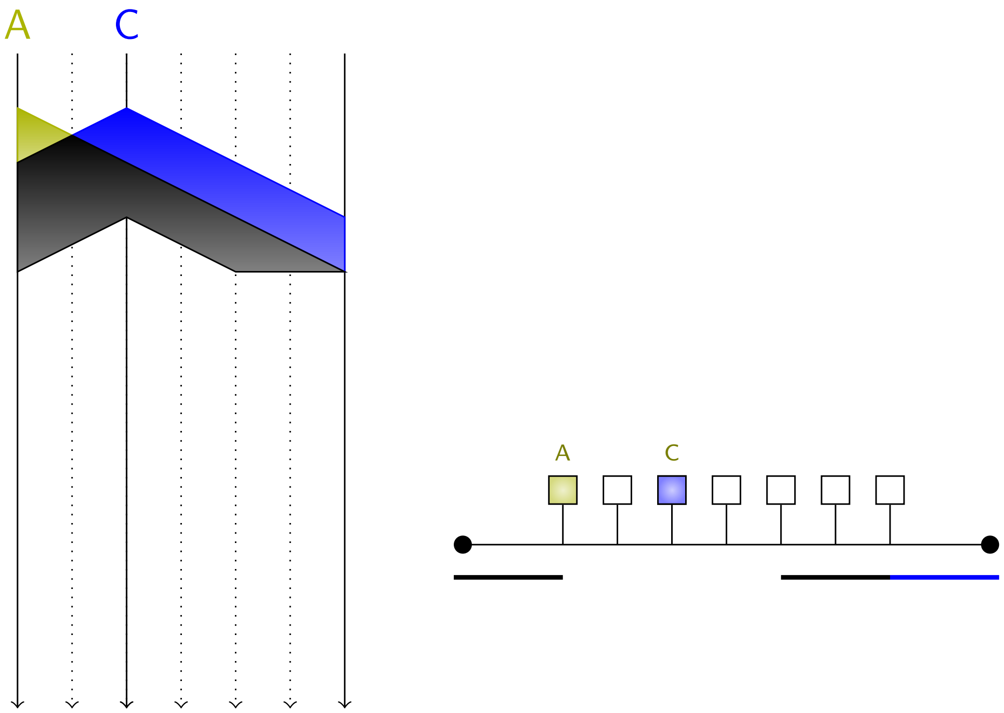
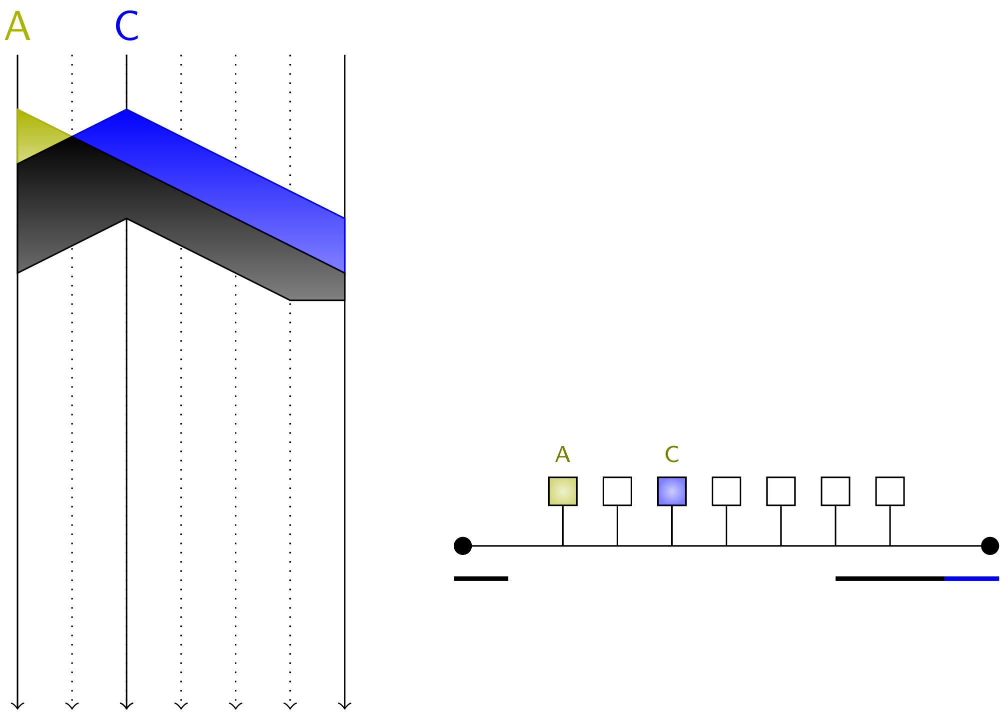
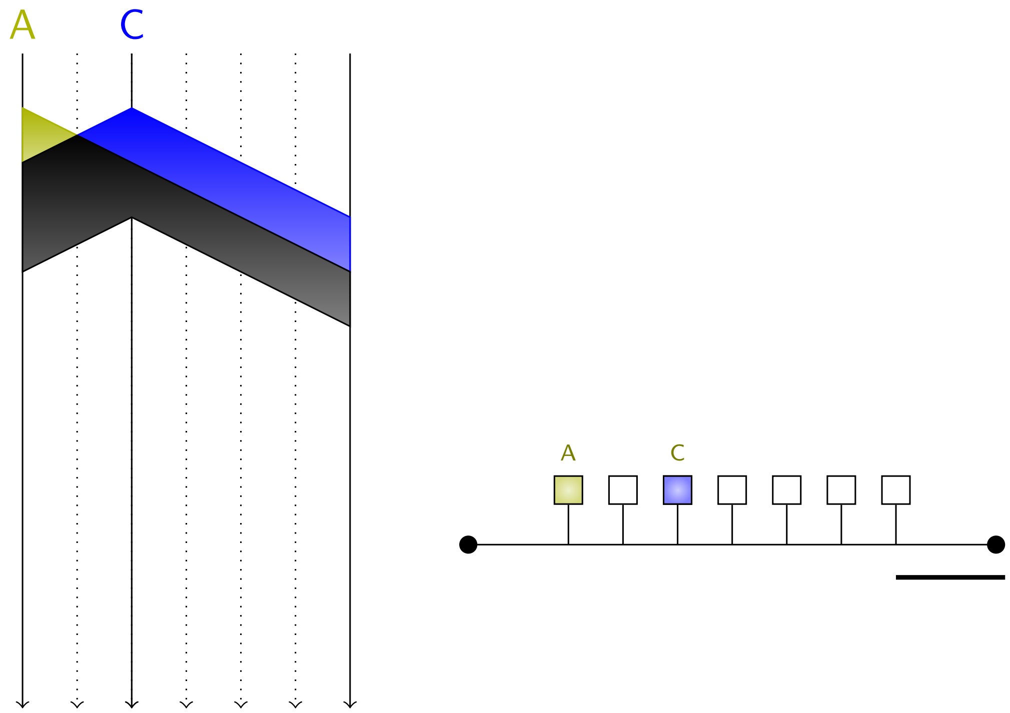
CSMA/CD: Collision



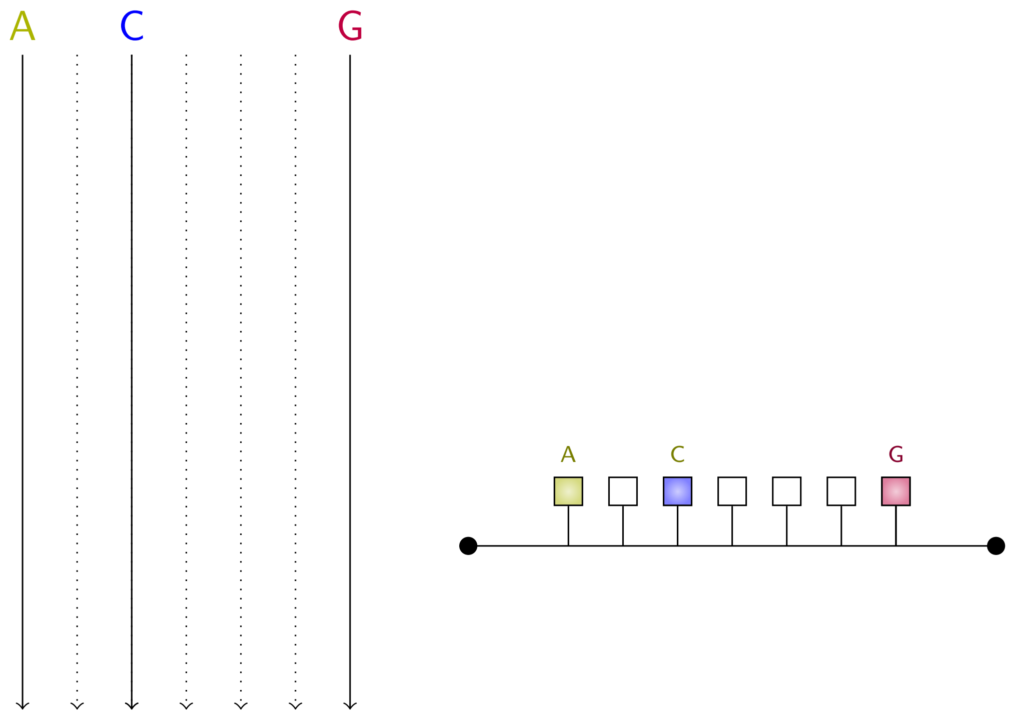
CSMA/CD: Collision



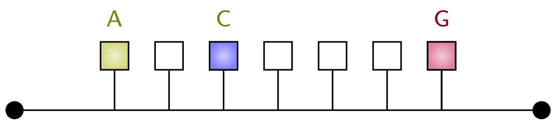
CSMA/CD: Collision



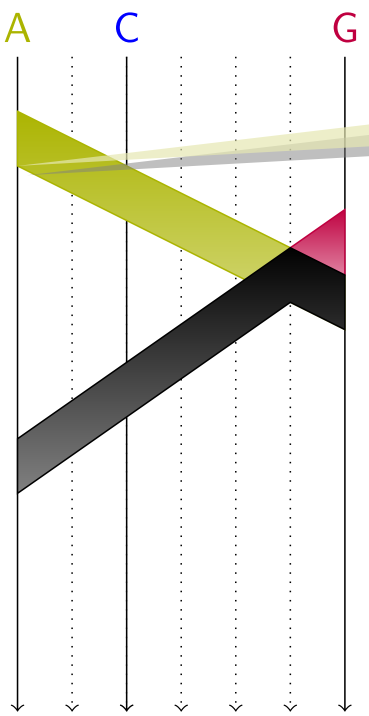
CSMA/CD: Minimal frame size



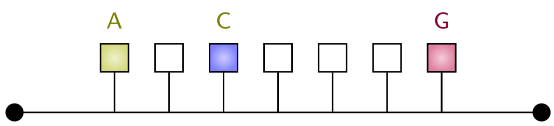
CSMA/CD: Minimal frame size



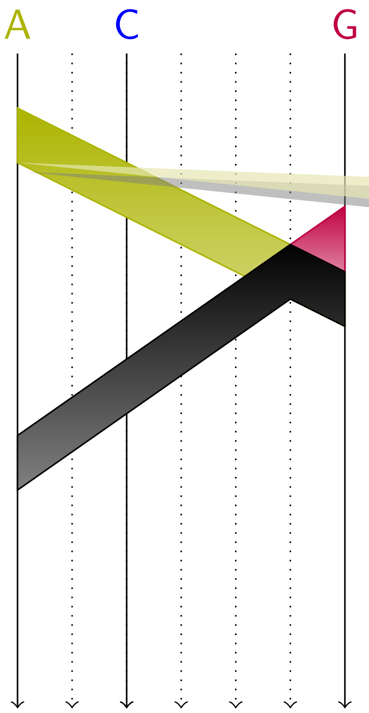
CSMA/CD: Minimal frame size



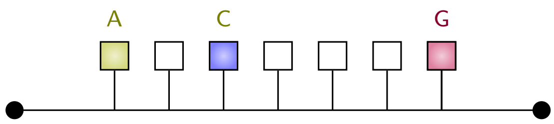
A send succefully its frame, even if some of the equipment on the link will not receive it due to collision



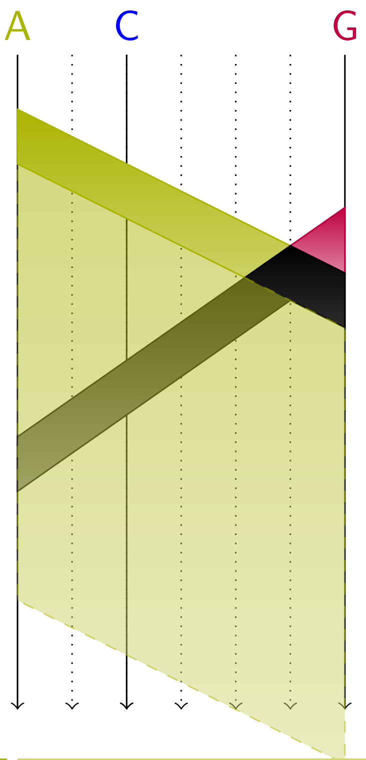
CSMA/CD: Minimal frame size

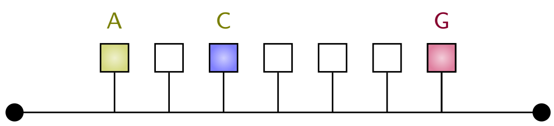


Solution: Artificially raise the frame size until this problem could append. This way A will be aware that its frame got a collision.

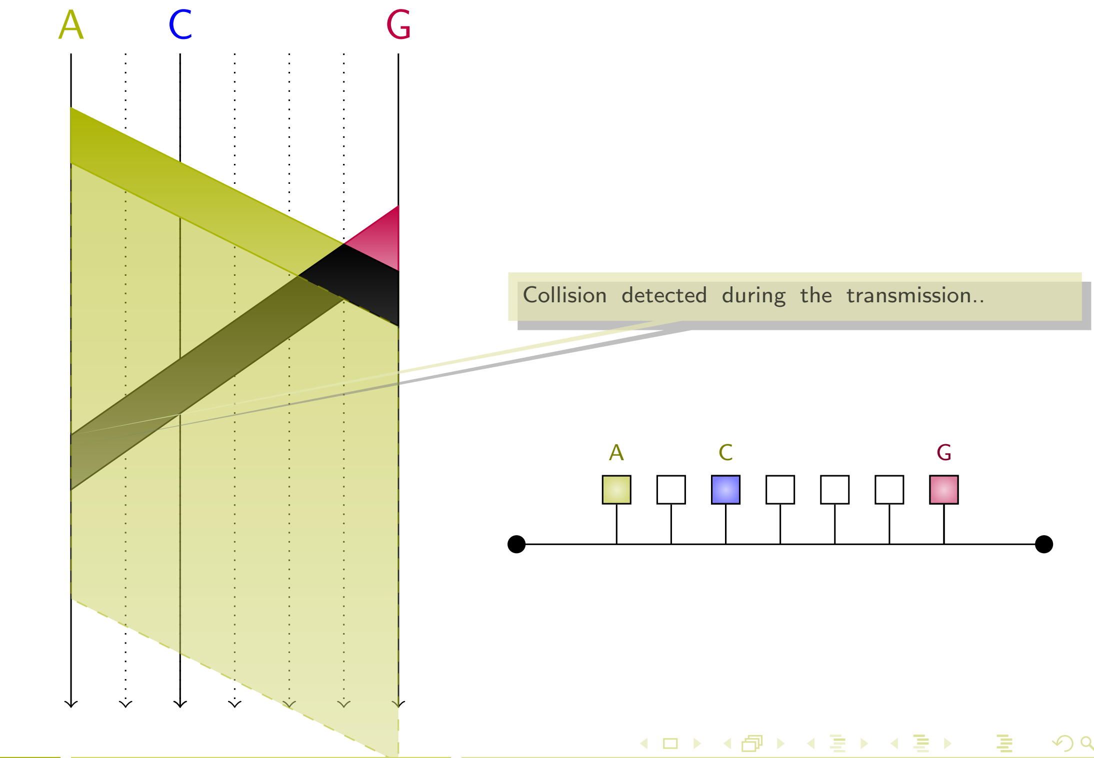


CSMA/CD: Minimal frame size



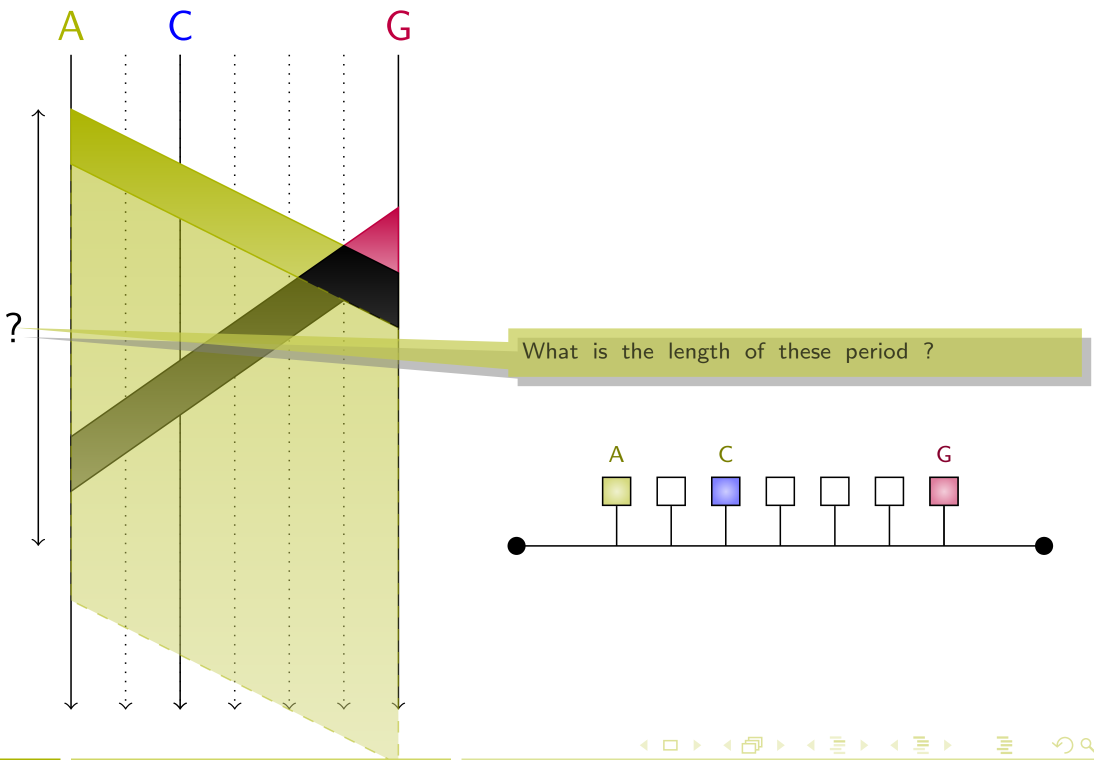


CSMA/CD: Minimal frame size



Ethernet ▶ CSMA/CD

CSMA/CD: Minimal frame size



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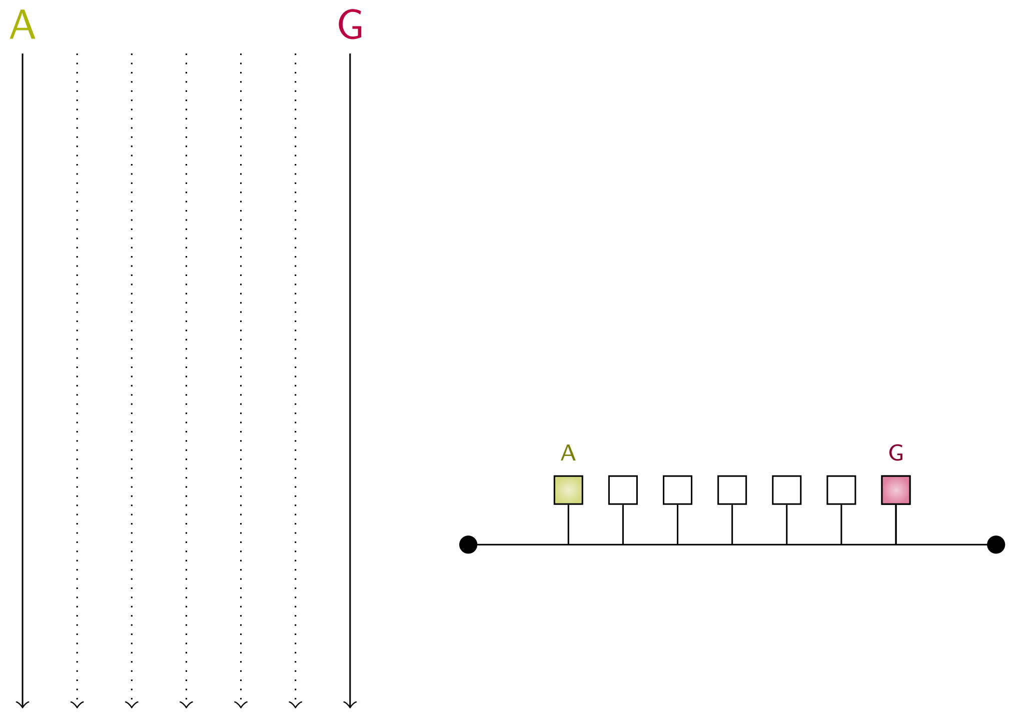
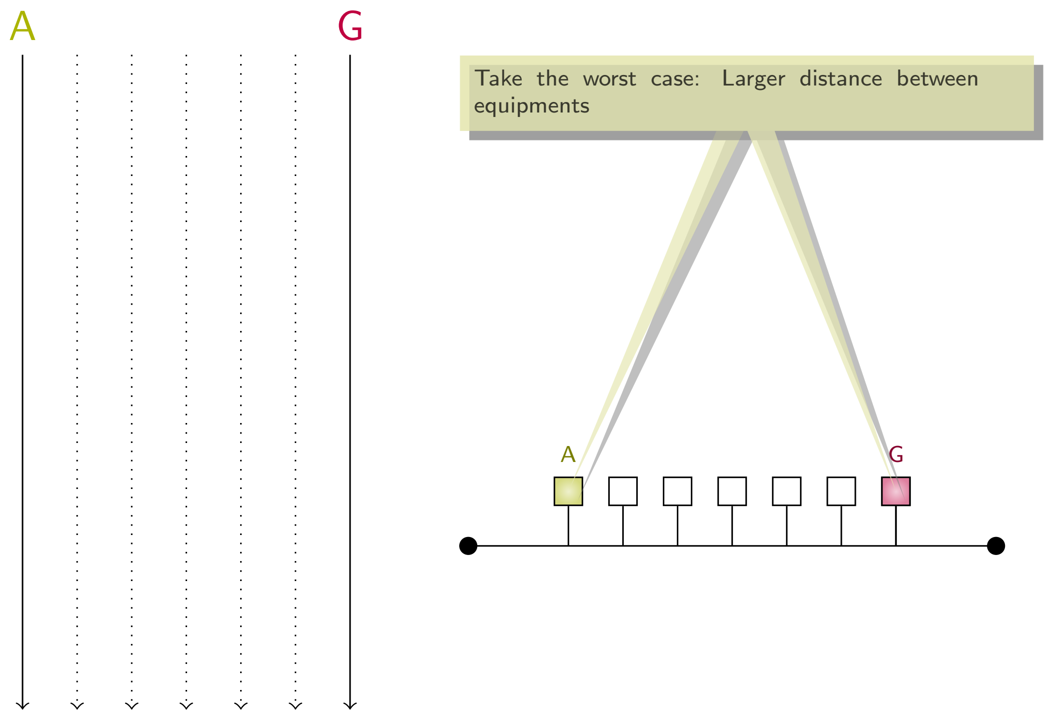
CSMA/CD: Minimal frame size computation



Ethernet ▶ CSMA/CD

CSMA/CD: Minimal frame size computation



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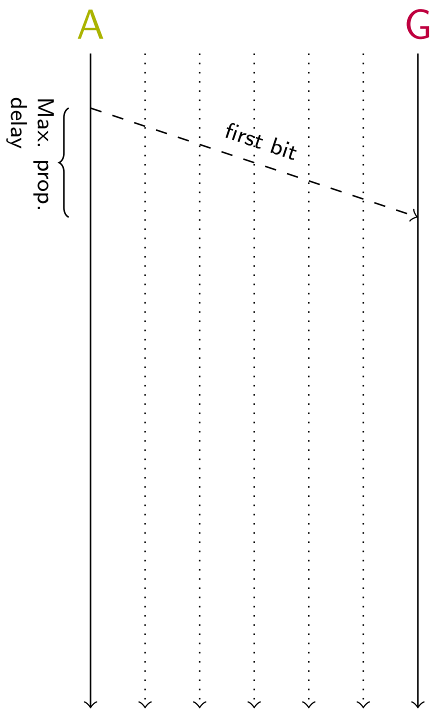
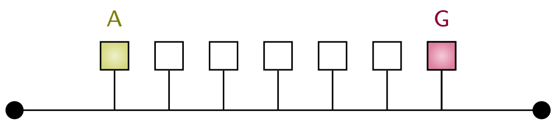
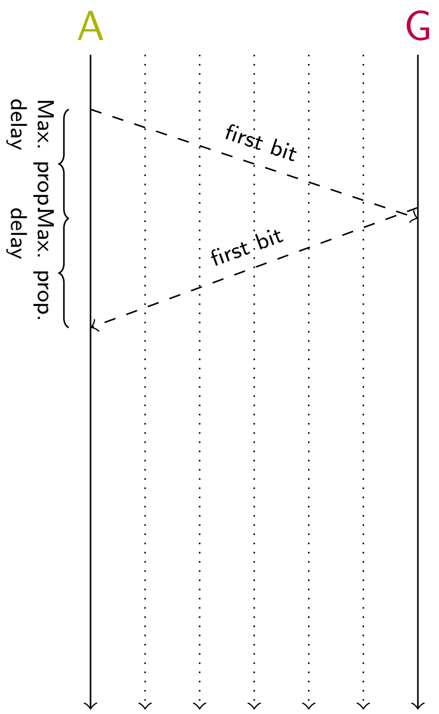
CSMA/CD: Minimal frame size computation

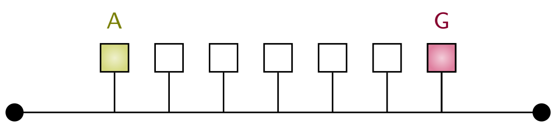




Ethernet ▶ CSMA/CD

CSMA/CD: Minimal frame size computation





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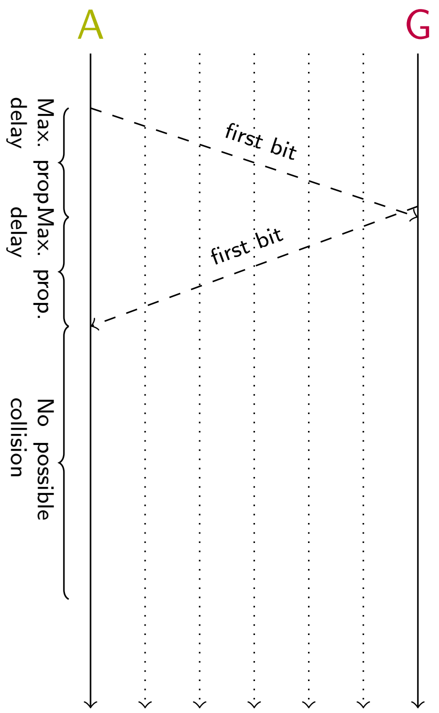
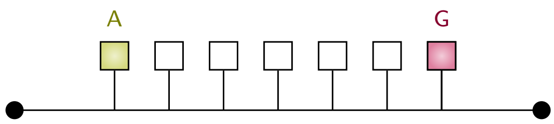
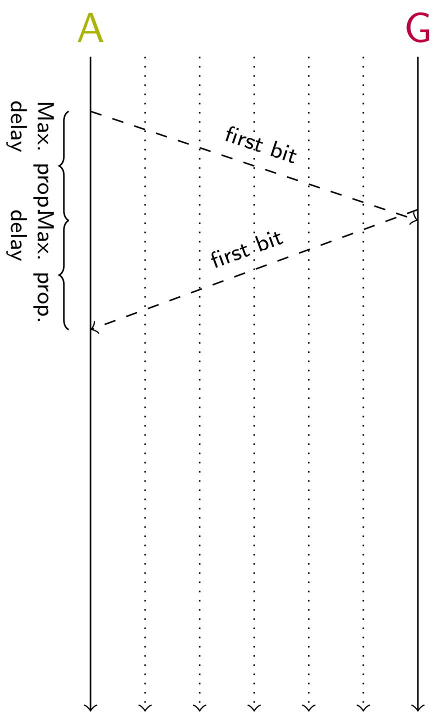
CSMA/CD: Minimal frame size computation



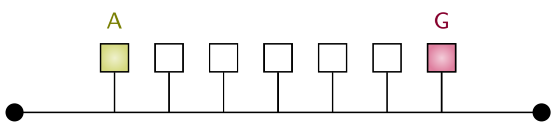


CSMA/CD: Minimal frame size computation

Ethernet ▶ CSMA/CD



$$Min_{frame} = 2.MaxPropagationDelay$$



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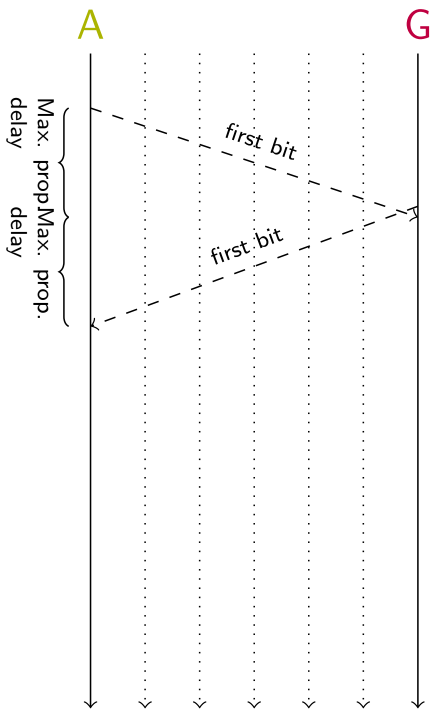
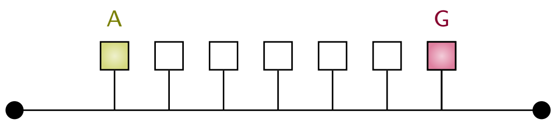
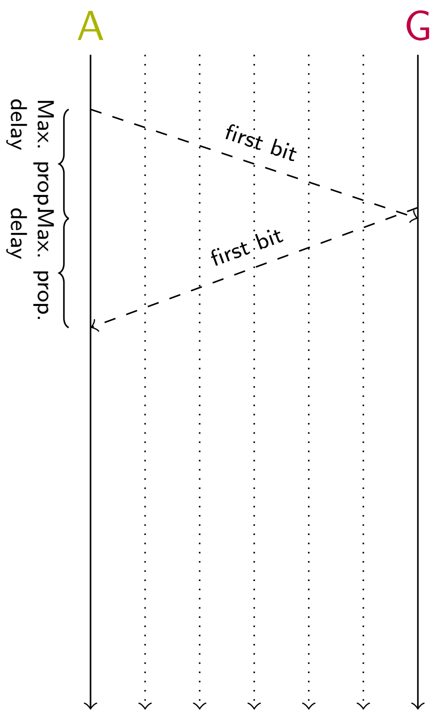


$Min_{frame} = 2.MaxPropagationDelay$

At 10 Mbit/s standard gives:
$MaxPropagationDelay = 51.2\mu s$



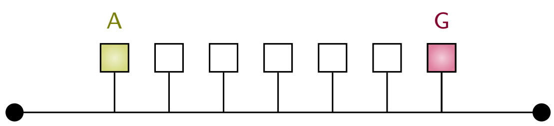
CSMA/CD: Minimal frame size computation
Ethernet ▶ CSMA/CD



$Min_{frame} = 2.MaxPropagationDelay$

At 10 Mbit/s standard gives:
$MaxPropagationDelay = 51.2\mu s$

$Min_{frame} = 64 Bytes$



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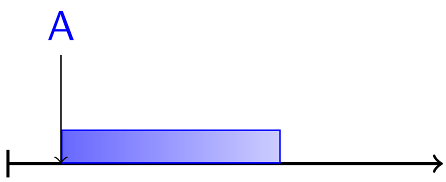
Maximum Frame size

Maximum Frame size

Ethernet ▶ CSMA/CD



- A senses the channel: Idle $\Rightarrow$ send frame

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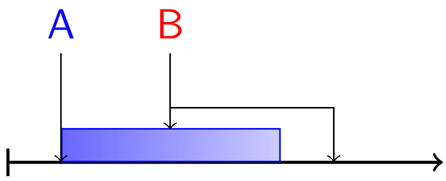
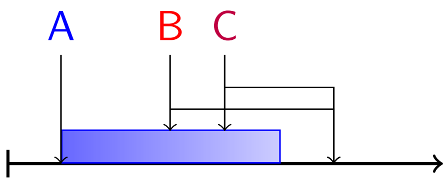


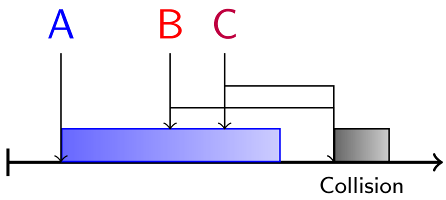
- A senses the channel: Idle ⇒ send frame
- B senses the channel: Busy ⇒ wait until channel becomes Idle

Maximum Frame size
Ethernet ▶ CSMA/CD



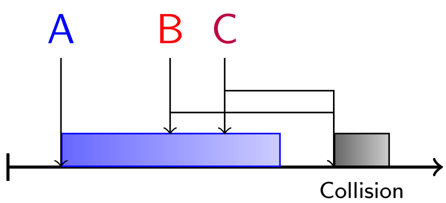
- A senses the channel: Idle ⇒ send frame
- B senses the channel: Busy ⇒ wait until channel becomes Idle
- C senses the channel: Busy ⇒ wait until channel becomes Idle

Maximum Frame size



- A senses the channel: Idle ⇒ send frame
- B senses the channel: Busy ⇒ wait until channel becomes Idle
- C senses the channel: Busy ⇒ wait until channel becomes Idle
- A and C send frame at the same time ⇒ collision

Maximum Frame size



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- C senses the channel: Busy ⇒ wait until channel becomes Idle
- A and C send frame at the same time ⇒ collision

Maximum Frame Size

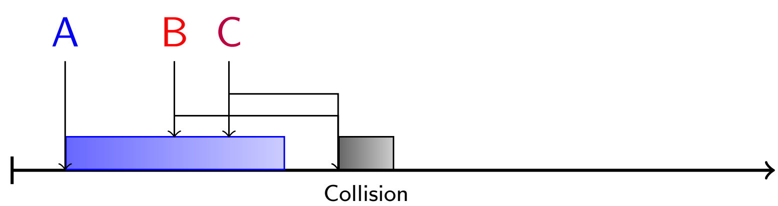
Standard fixes the $Max_{frame} = 1\ 500\ Bytes$.

Frame Length

- Minimum 64 Bytes is given by CSMA/CD propagation delays
  - All versions of the standard impose this limit.
- Maximum 1 500 Bytes is given by the collision propability
  - This value is very small
  - If CSMA/CD is disabled, this value can be up to 9 Kilobyte
    - Jumboframe
  - Can be use either:
    - to increase transmission speed (reduce copy from card to memory)
    - to allow VLAN by adding a value to give a virtual network number
    - to encapsulate Ethernet frame into another Ethernet frame (used by Metro Ethernet)

Binary Exponential Backoff

- Previous slides shows that collisions can occur after the busy period.
- Each equipment must have a different behavior:
  - Otherwise a new collision is generated
- Based on random number
  - First attempt: draw a random number d between [0, 1];
  - Wait $51.2 \cdot d\ \mu s$.



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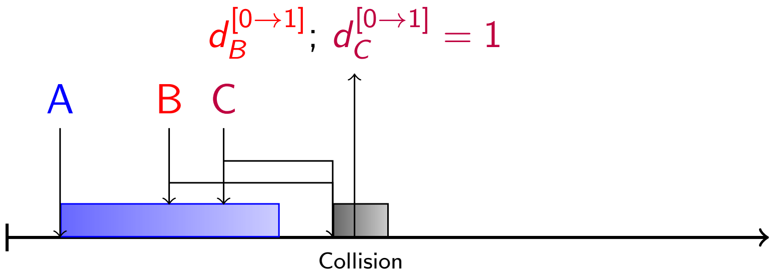

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Ethernet ▶ CSMA/CD

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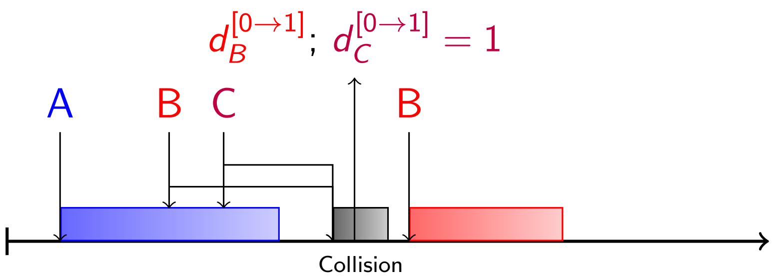

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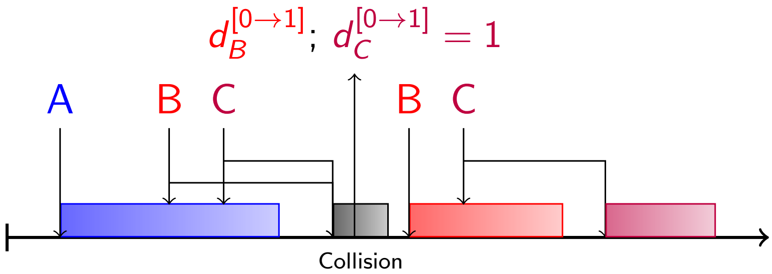
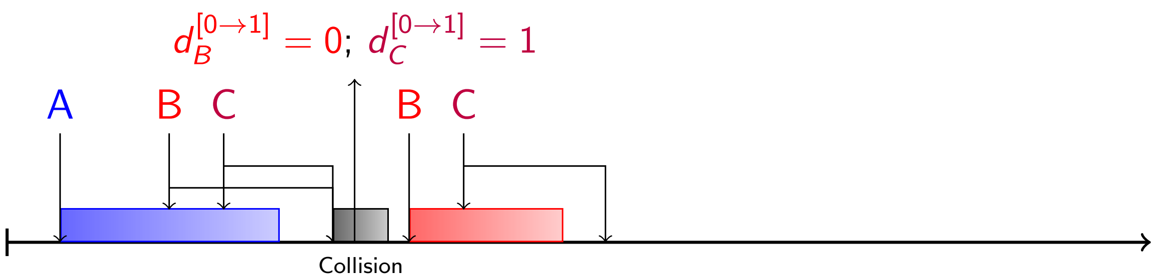


Binary Exponential Backoff (continued)

- In the previous example, if both equipment draws a different random number, the collision is solved
  - if both select the same number, the collision occurs again.
- The space double every attempt until the10th then remains the same until the 16th
  - If after 16 attempts the frame is not sent, the transmission is aborded.
  - No guaranty (and not guaranteed delay) to send a frame.



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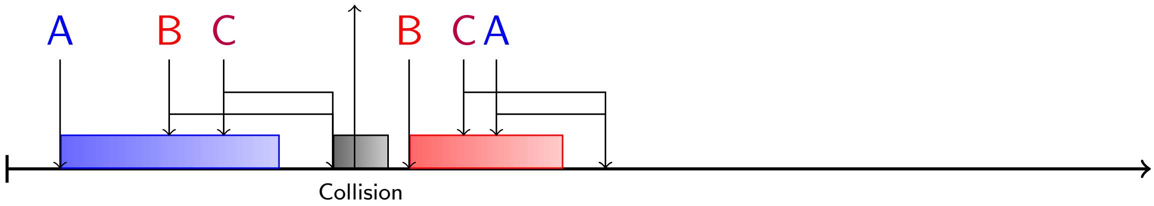
$d_B^{[0\rightarrow 1]} = 0$; $d_C^{[0\rightarrow 1]} = 1$



Ethernet ▶ CSMA/CD

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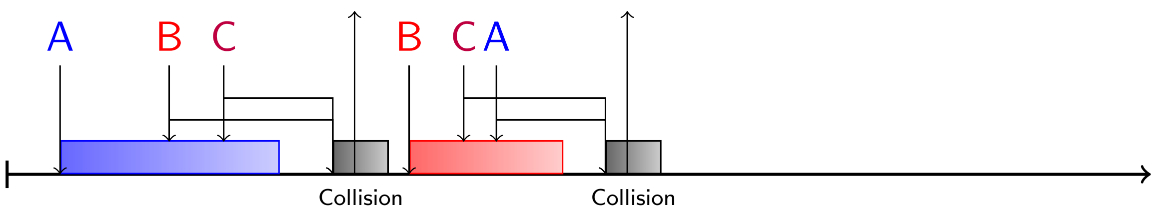
$d_B^{[0\rightarrow 1]} = 0$; $d_C^{[0\rightarrow 1]} = 1$ $d_C^{[0\rightarrow 3]} = 3$; $d_A^{[0\rightarrow 1]} = 1$



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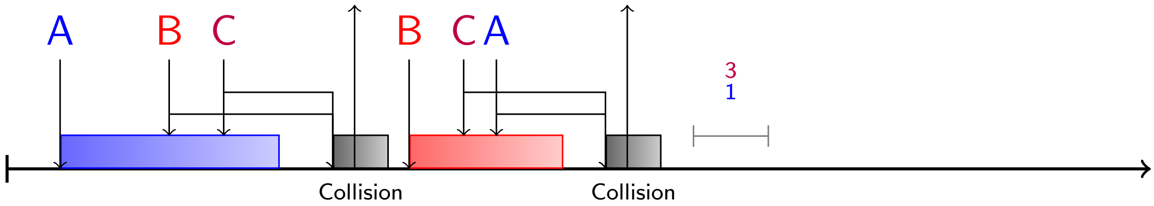

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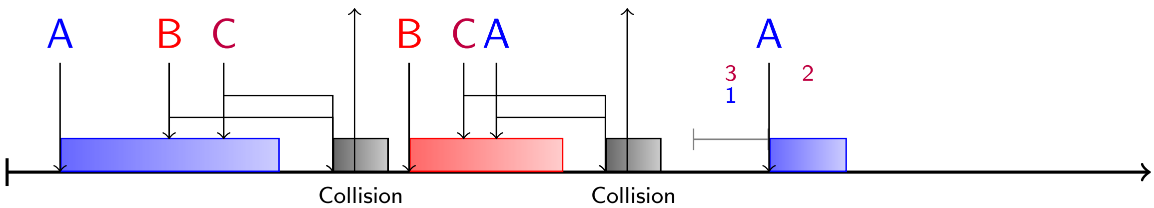

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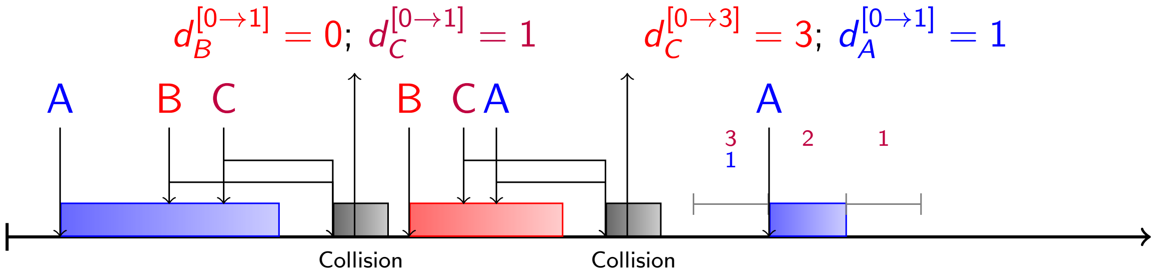

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Ethernet ▶ CSMA/CD

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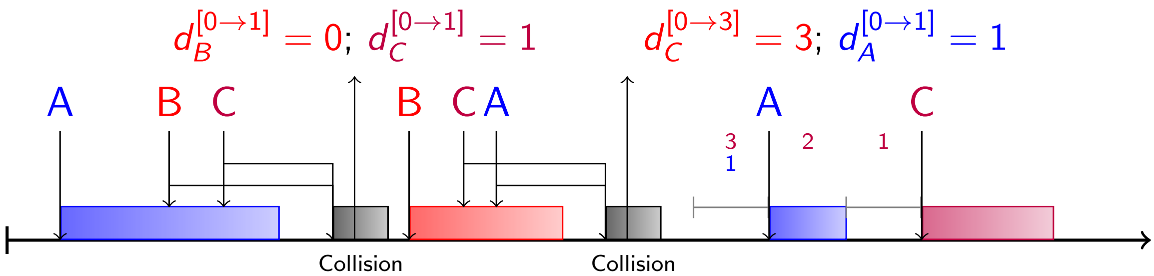

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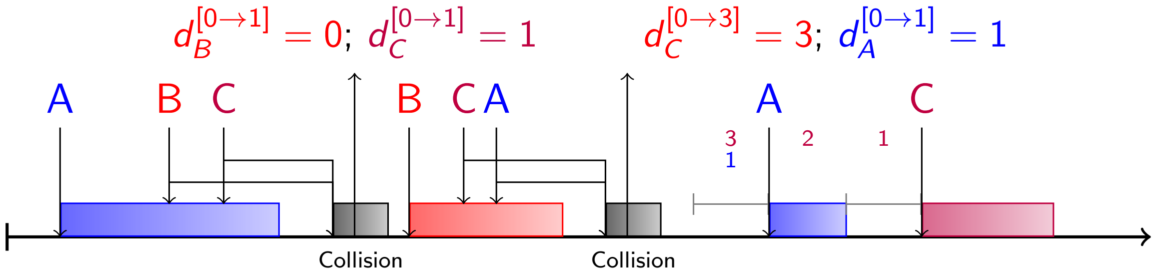


CSMA/CD and 100 Mbit/s

At 10 Mbit/s, standard mandate at minimum duration of 51.2 μs

- or 64 Bytes

At 100 Mbit/s if the same duration is taken, the minimal frame size must be increased to 640 Bytes

- no gain: small frame sending time remains the same (51.2 μs)
- when bridging from 100BASE-TX to 10BASE-T, duration will be increased (512 μs)

So at 100 MBit/s, minimum duration is 5.12 μs

- Minimum size remain compatible with 10 Mbit/s technologies
- Network size must be decreased by a factor 10
  - 10BASE-5 allowed 2.5 km
  - 100BASE-TX allows 250 m
  - Compatible with cabling constraints

Questions

	F	T
An shared Ethernet network can be 10 km long ?	○	○
An shared Ethernet network can be 10 cm long ?	○	○
An switched Ethernet network can be 10 km long ?	○	○
An switched Ethernet network can be 10 cm long ?	○	○
64 Bytes are not necessary in switched mode	○	○
We have the guaranty that a frame is sent in less than 16 attempts	○	○
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer	○	○
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX	○	○

Questions

	F	T
An shared Ethernet network can be 10 km long ?	⊗	○
An shared Ethernet network can be 10 cm long ?	○	○
An switched Ethernet network can be 10 km long ?	○	○
An switched Ethernet network can be 10 cm long ?	○	○
64 Bytes are not necessary in switched mode	○	○
We have the guaranty that a frame is sent in less than 16 attempts	○	○
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer	○	○
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX	○	○

Questions

	F	T
An shared Ethernet network can be 10 km long ?	X	
An shared Ethernet network can be 10 cm long ?		X
An switched Ethernet network can be 10 km long ?		
An switched Ethernet network can be 10 cm long ?		
64 Bytes are not necessary in switched mode		
We have the guaranty that a frame is sent in less than 16 attempts		
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer		
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX		

Questions

	F	T
An shared Ethernet network can be 10 km long ?	X	
An shared Ethernet network can be 10 cm long ?		X
An switched Ethernet network can be 10 km long ?		X
An switched Ethernet network can be 10 cm long ?		
64 Bytes are not necessary in switched mode		
We have the guaranty that a frame is sent in less than 16 attempts		
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer		
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX		

Questions

	F	T
An shared Ethernet network can be 10 km long ?	X	
An shared Ethernet network can be 10 cm long ?		X
An switched Ethernet network can be 10 km long ?		X
An switched Ethernet network can be 10 cm long ?		X
64 Bytes are not necessary in switched mode		
We have the guaranty that a frame is sent in less than 16 attempts		
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer		
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX		

Questions

	F	T
An shared Ethernet network can be 10 km long ?	X	
An shared Ethernet network can be 10 cm long ?		X
An switched Ethernet network can be 10 km long ?		X
An switched Ethernet network can be 10 cm long ?		X
64 Bytes are not necessary in switched mode	X	X
We have the guaranty that a frame is sent in less than 16 attempts		
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer		
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX		

Questions

	F	T
An shared Ethernet network can be 10 km long ?	⊗	○
An shared Ethernet network can be 10 cm long ?	○	⊗
An switched Ethernet network can be 10 km long ?	○	⊗
An switched Ethernet network can be 10 cm long ?	○	⊗
64 Bytes are not necessary in switched mode	⊗	⊗
We have the guaranty that a frame is sent in less than 16 attempts	⊗	○
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer	○	○
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX	○	○

Questions

	F	T
An shared Ethernet network can be 10 km long ?	⊗	○
An shared Ethernet network can be 10 cm long ?	○	⊗
An switched Ethernet network can be 10 km long ?	○	⊗
An switched Ethernet network can be 10 cm long ?	○	⊗
64 Bytes are not necessary in switched mode	⊗	⊗
We have the guaranty that a frame is sent in less than 16 attempts	⊗	○
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer	⊗	○
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX	○	○

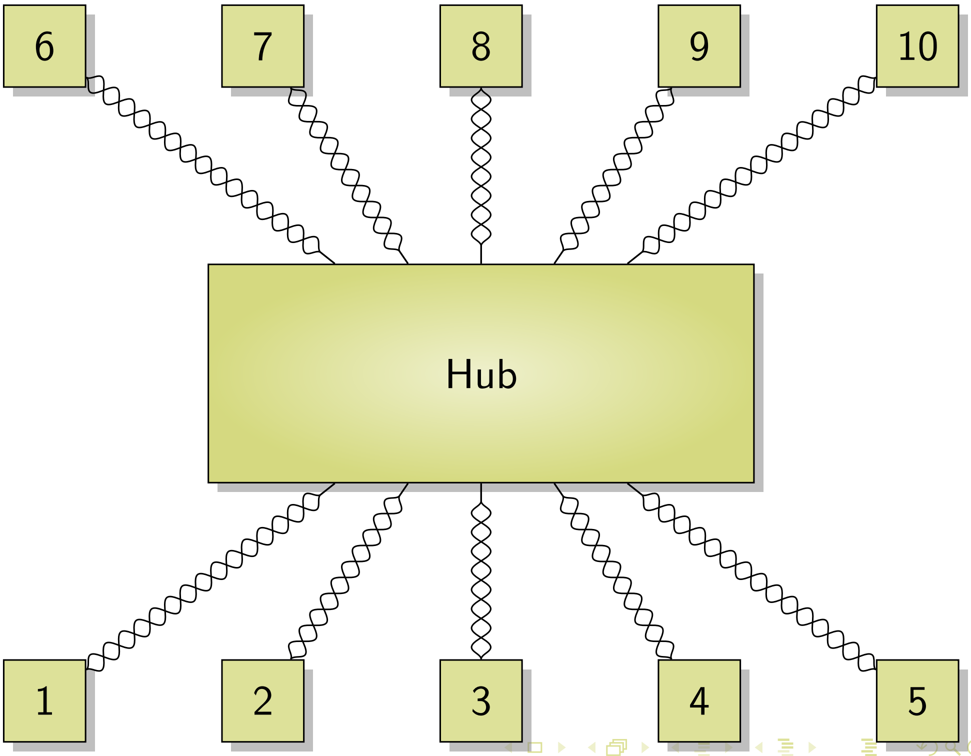
Questions

	F	T
An shared Ethernet network can be 10 km long ?	X	
An shared Ethernet network can be 10 cm long ?		X
An switched Ethernet network can be 10 km long ?		X
An switched Ethernet network can be 10 cm long ?		X
64 Bytes are not necessary in switched mode	X	X
We have the guaranty that a frame is sent in less than 16 attempts	X	
CSMA/CD guaranty that frames are sent is the same order they are submitted to the MAC layer	X	
CSMA/CD can be used with 100BASE-TX and 1GBASE-TX		X

Ethernet

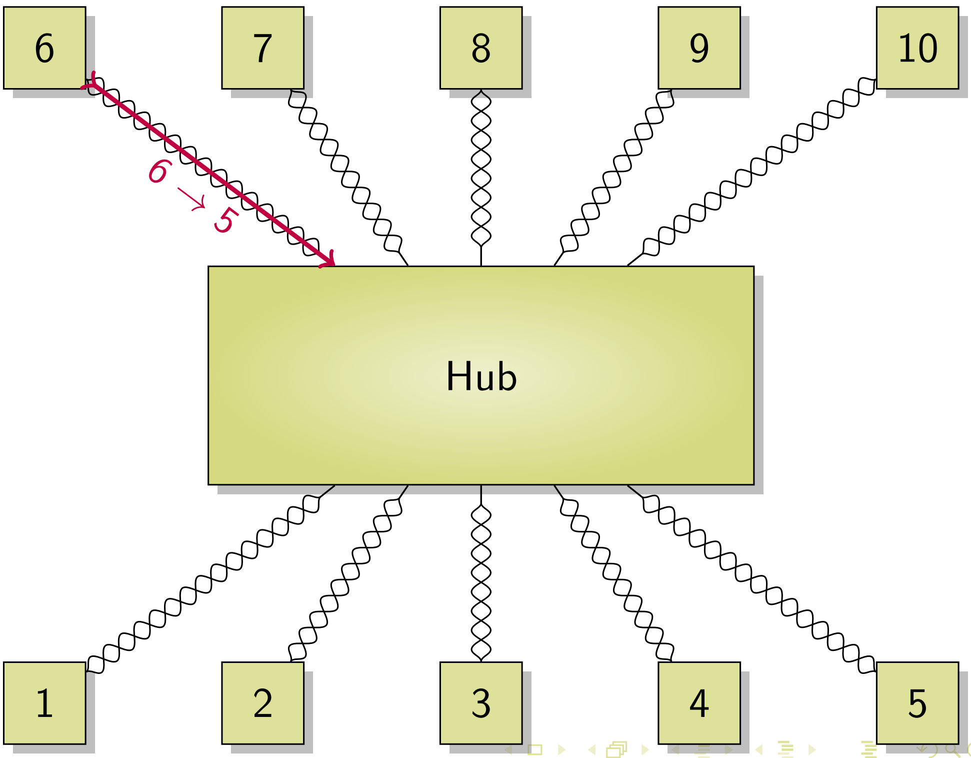
Switching

Switching



Ethernet ▶ Switching

Switching



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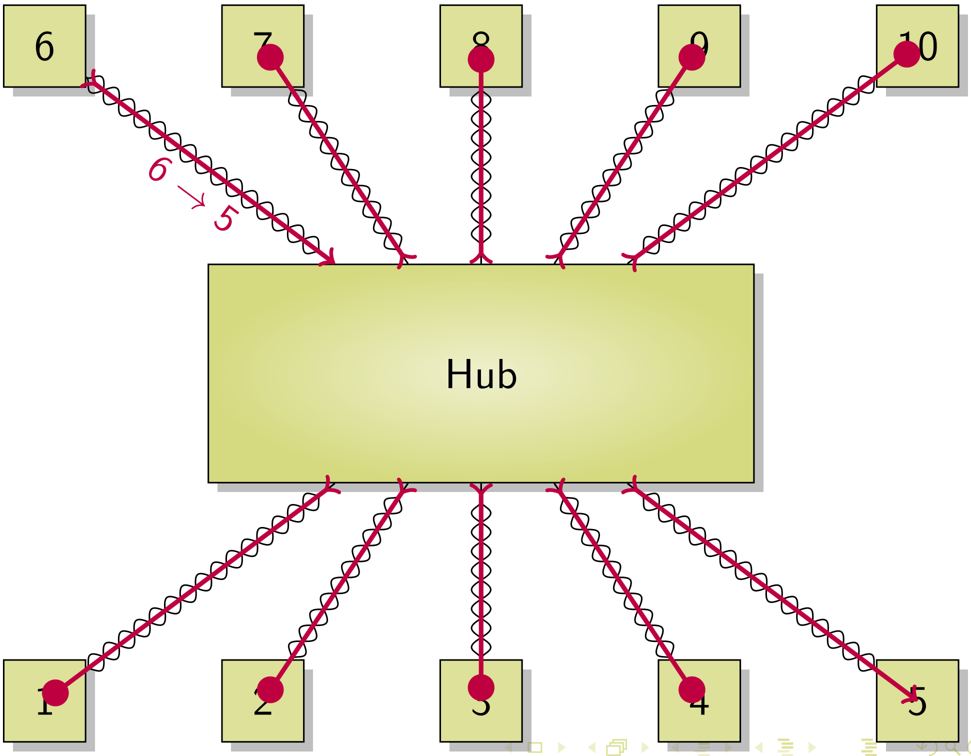
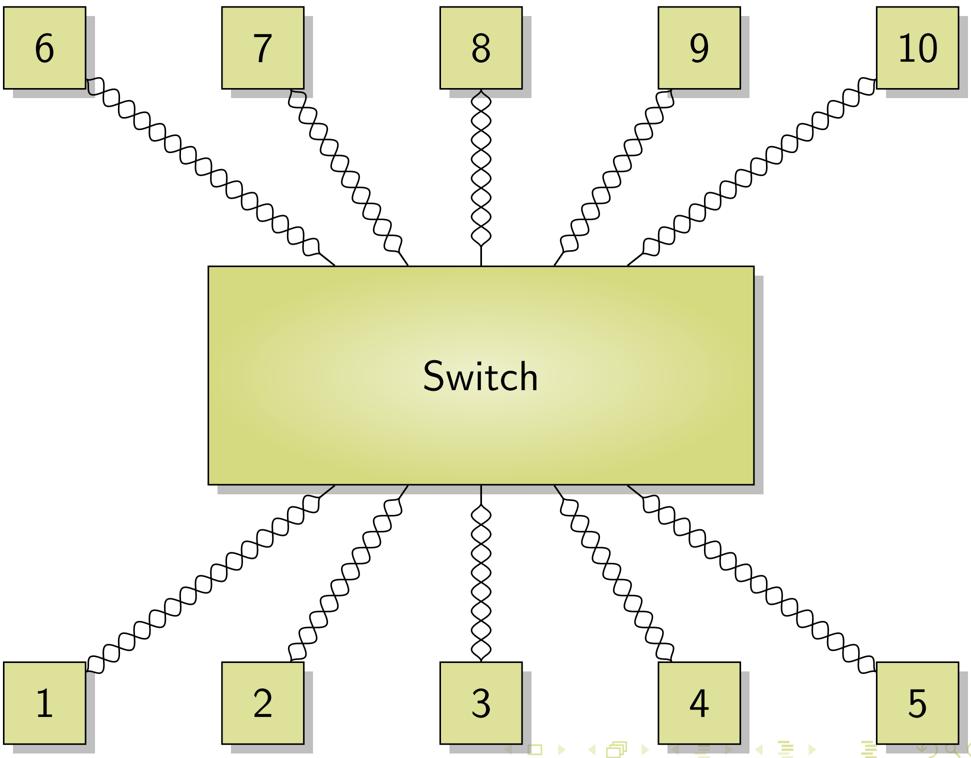
Switching

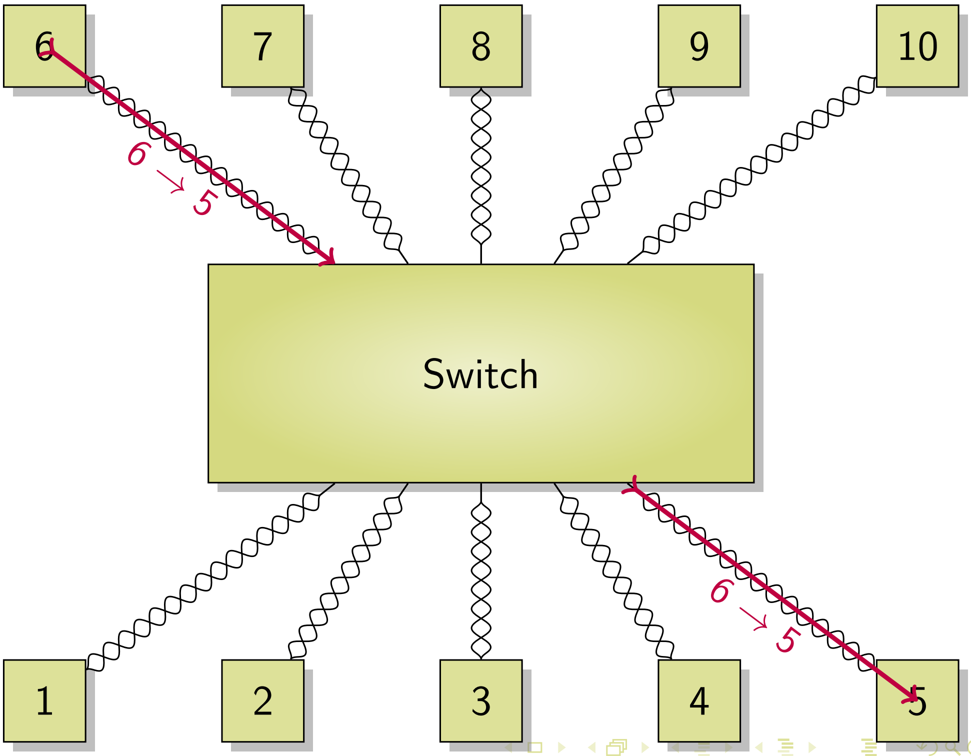


Ethernet ▶ Switching

Switching

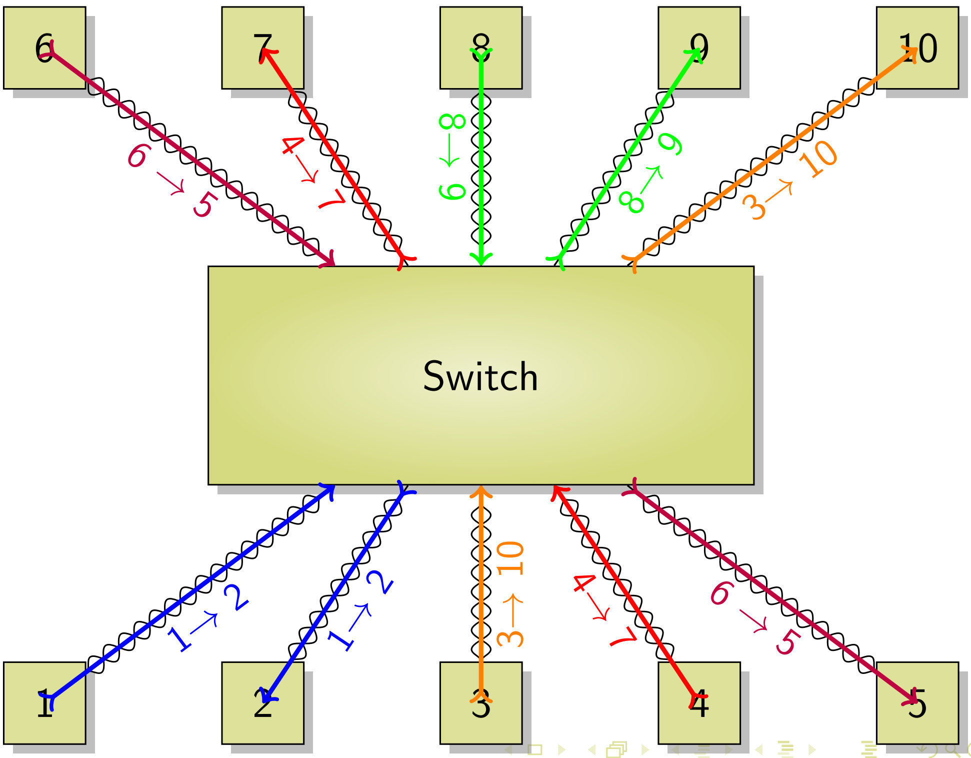


Slide 97 Laurent Toutain RES 301

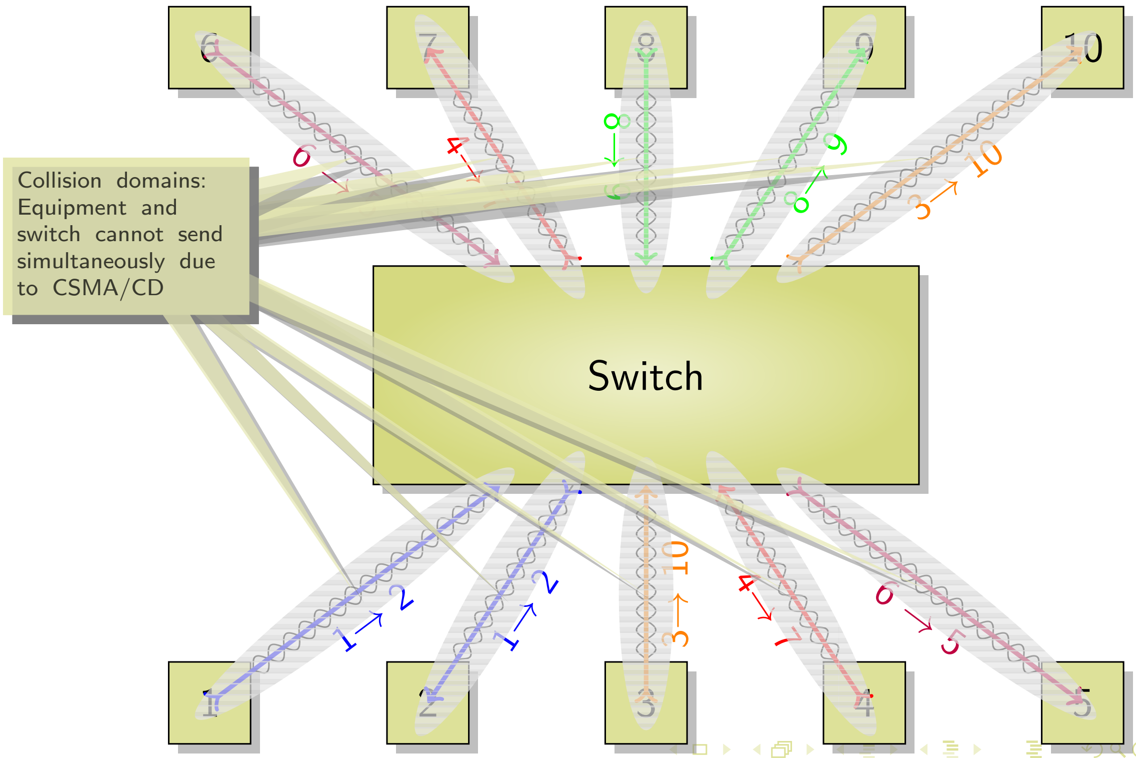


Switching

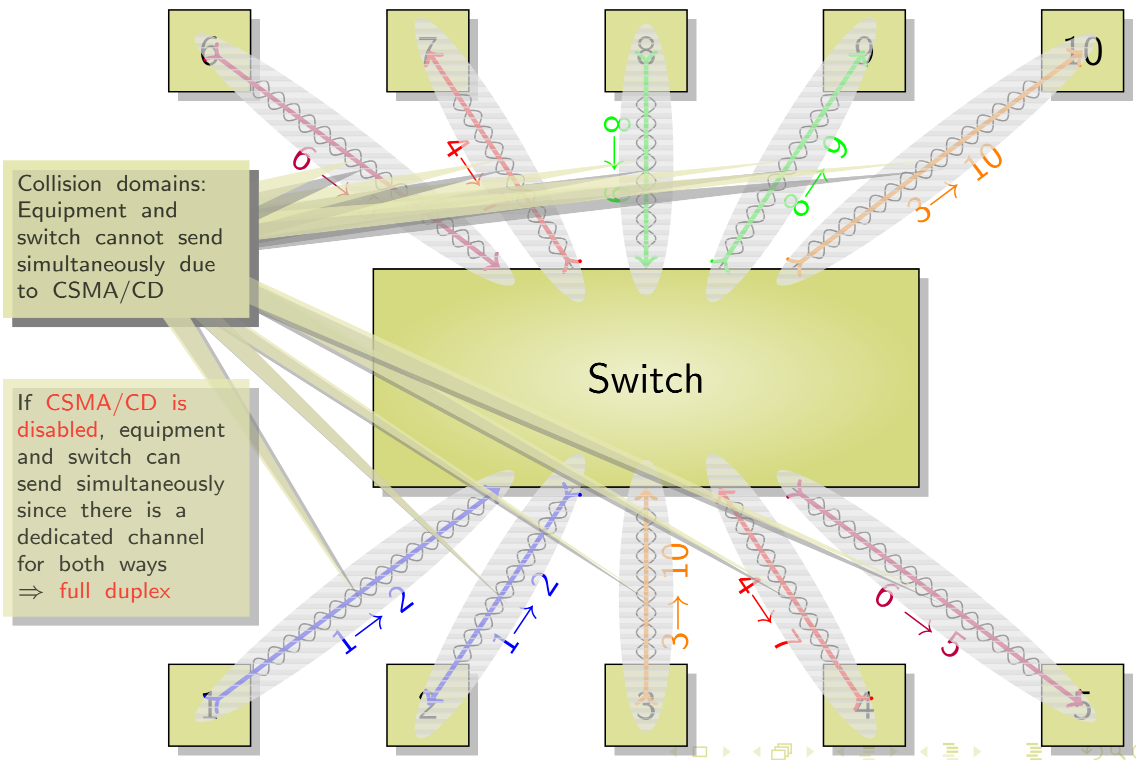
Ethernet ▶ Switching



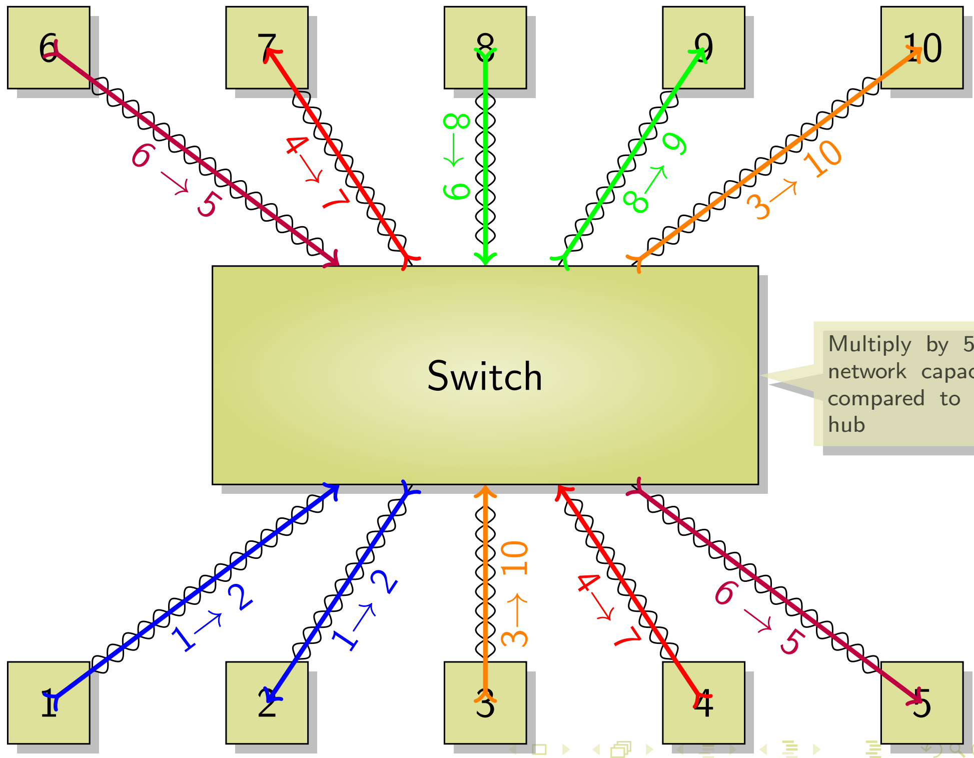
Switching



Switching



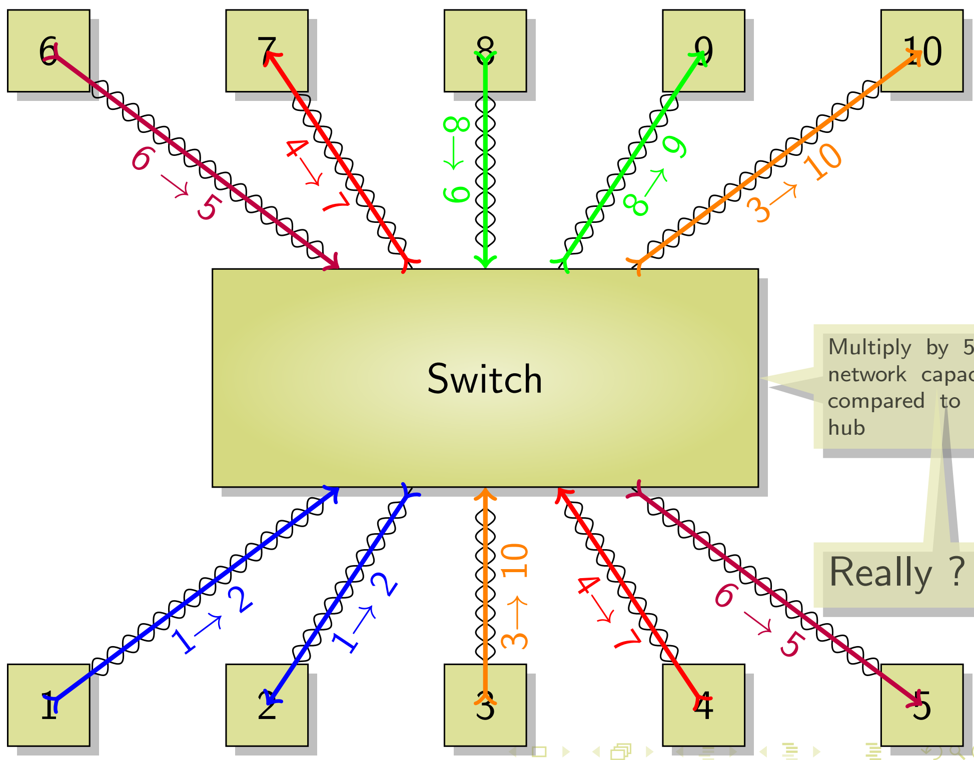
Switching



Multiply by 5 the network capacity compared to an hub

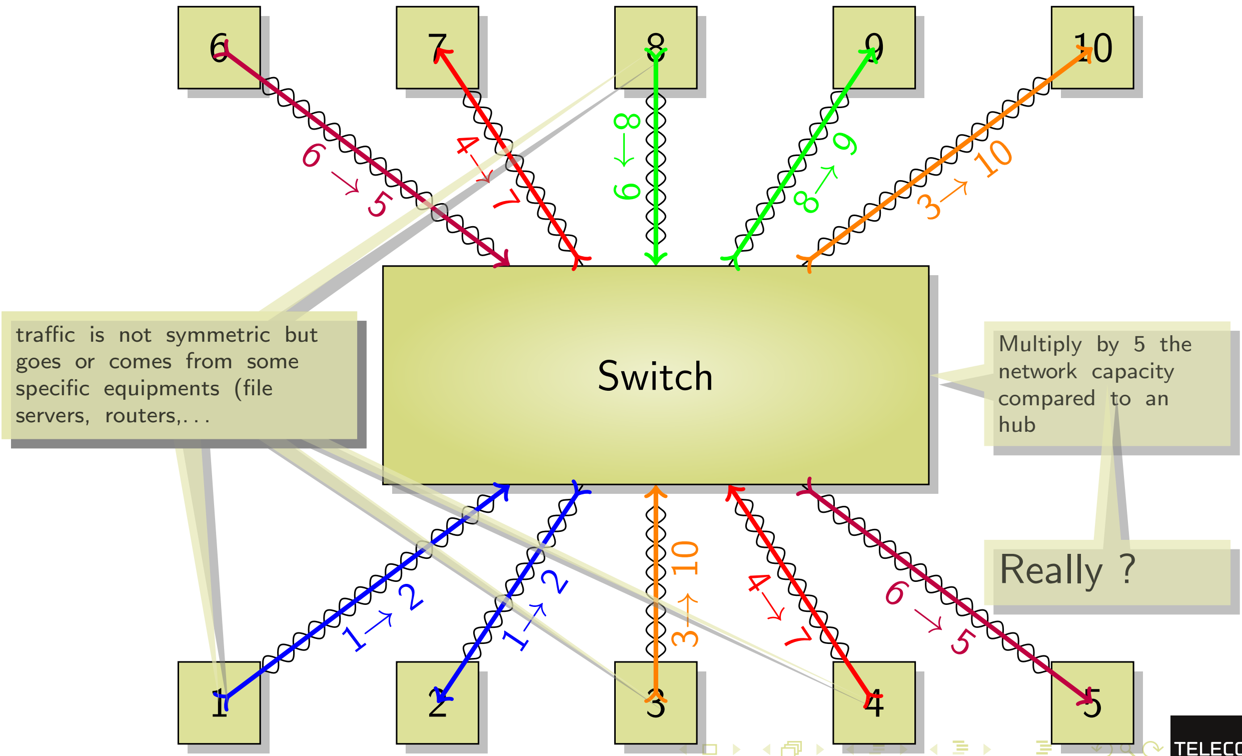
Switching

Ethernet ▶ Switching

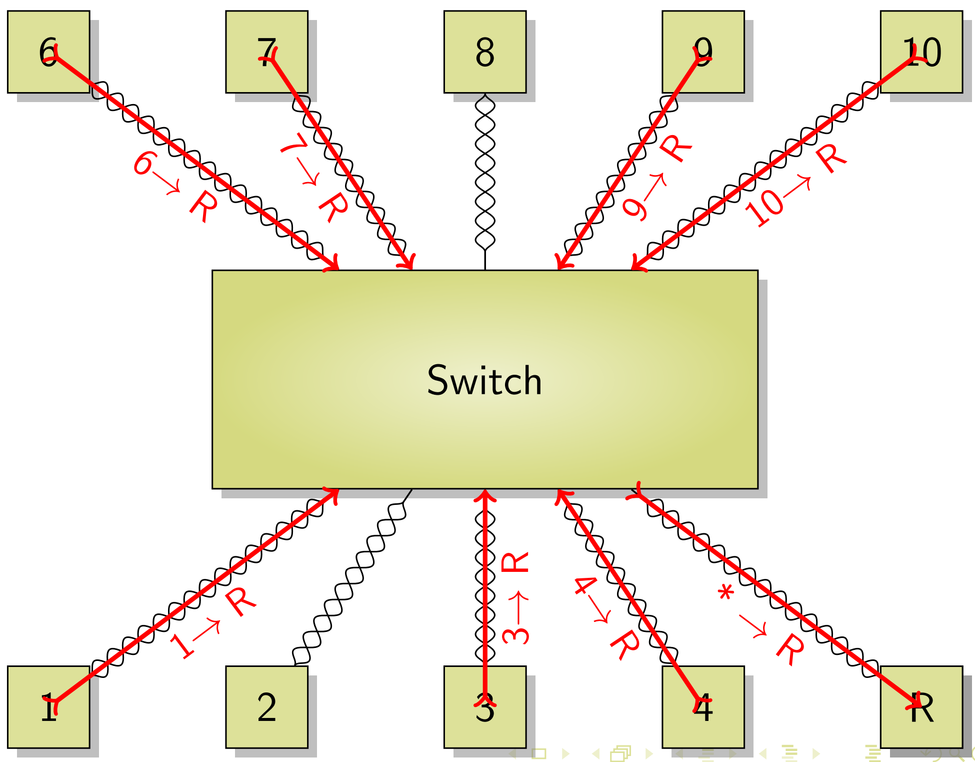


Multiply by 5 the network capacity compared to an hub

Really ?



Switching
Ethernet ▶ Switching



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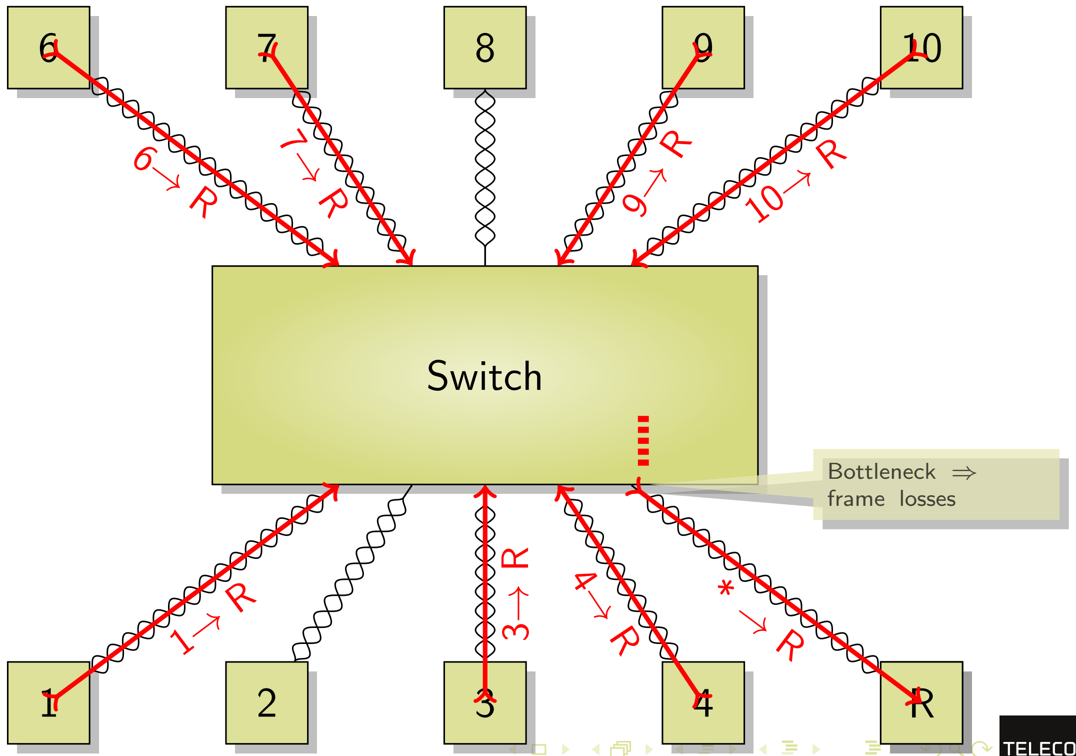
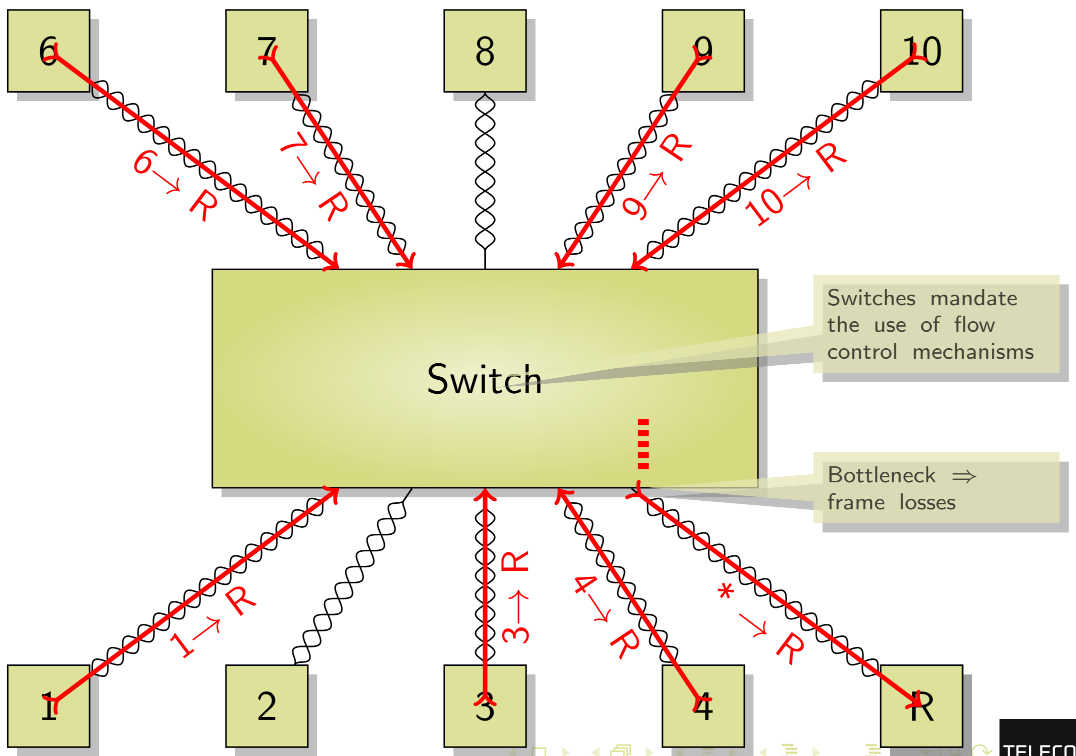
Switching



Ethernet ▶ Switching

Switching



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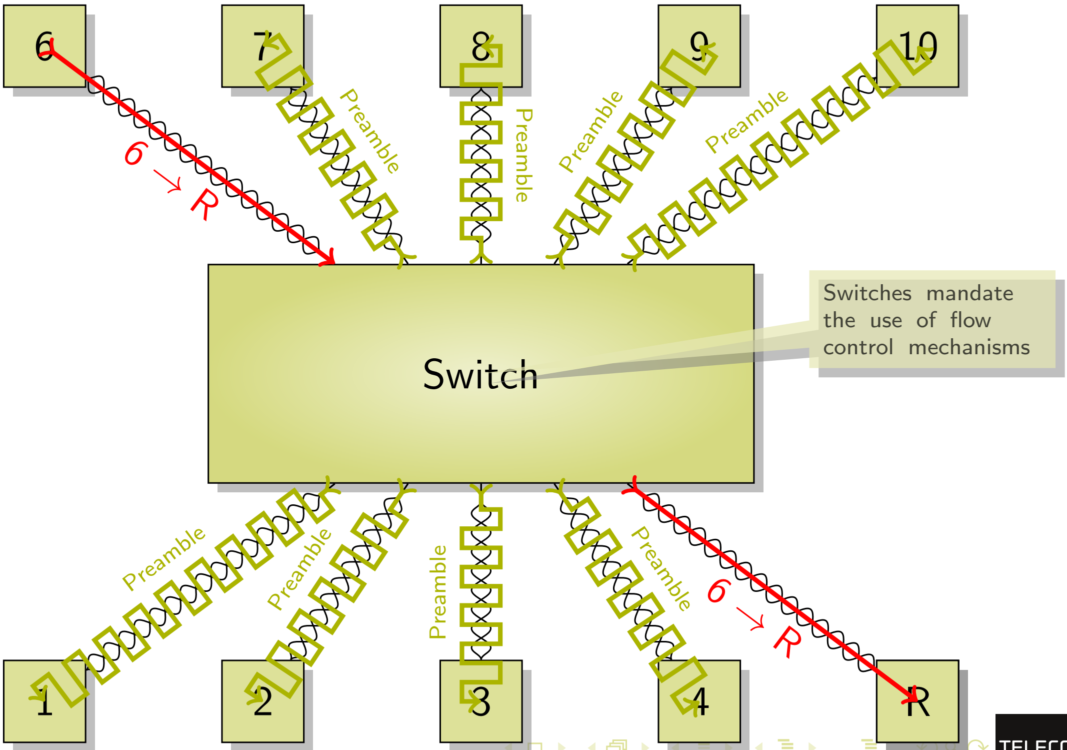
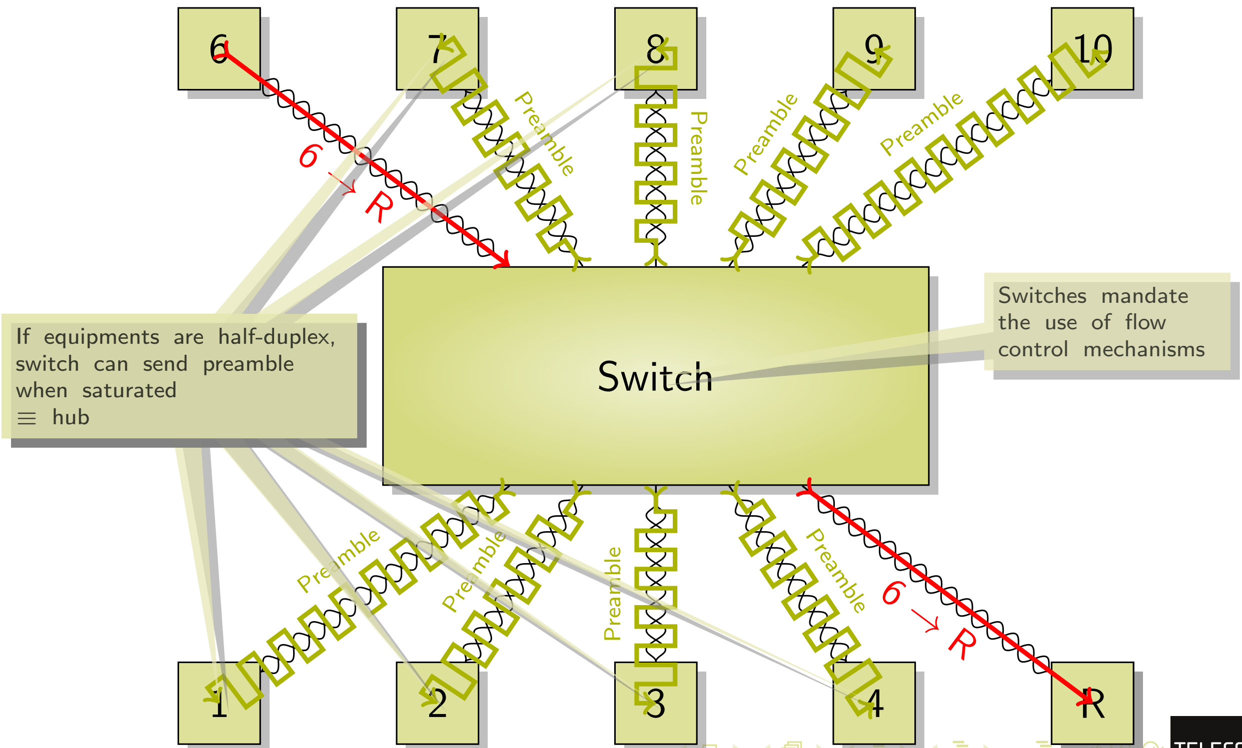
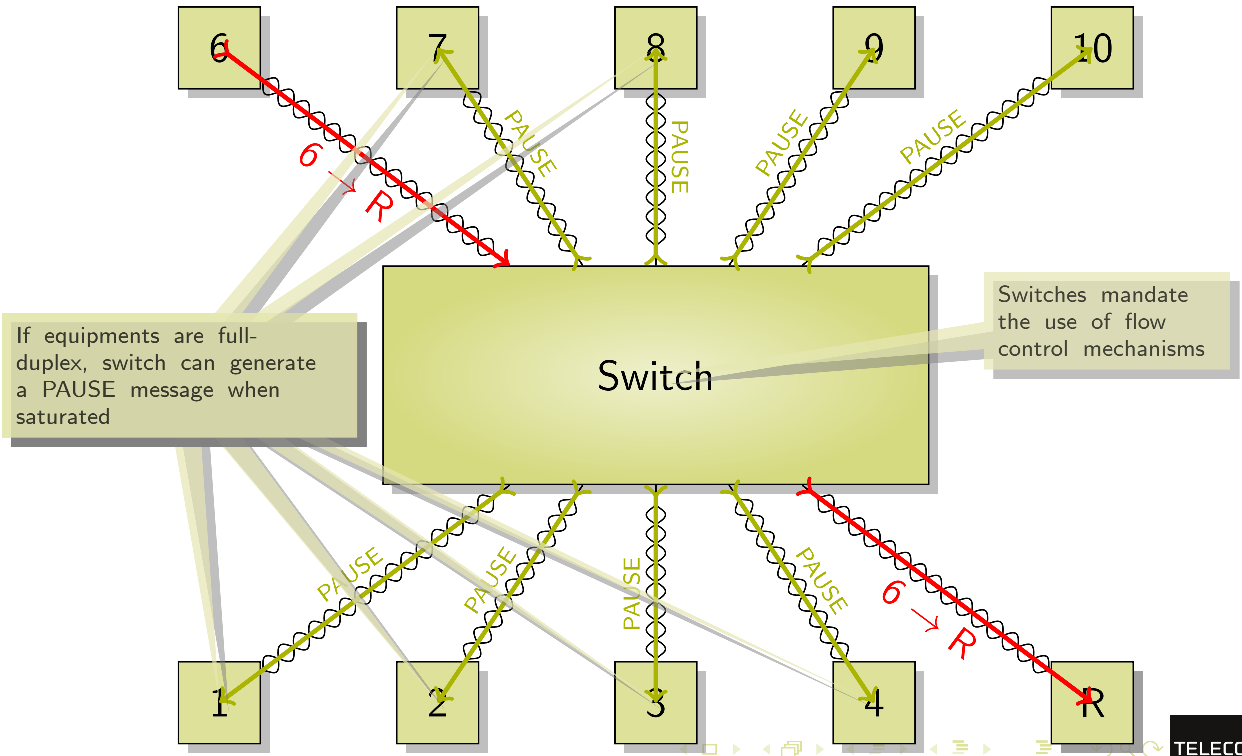
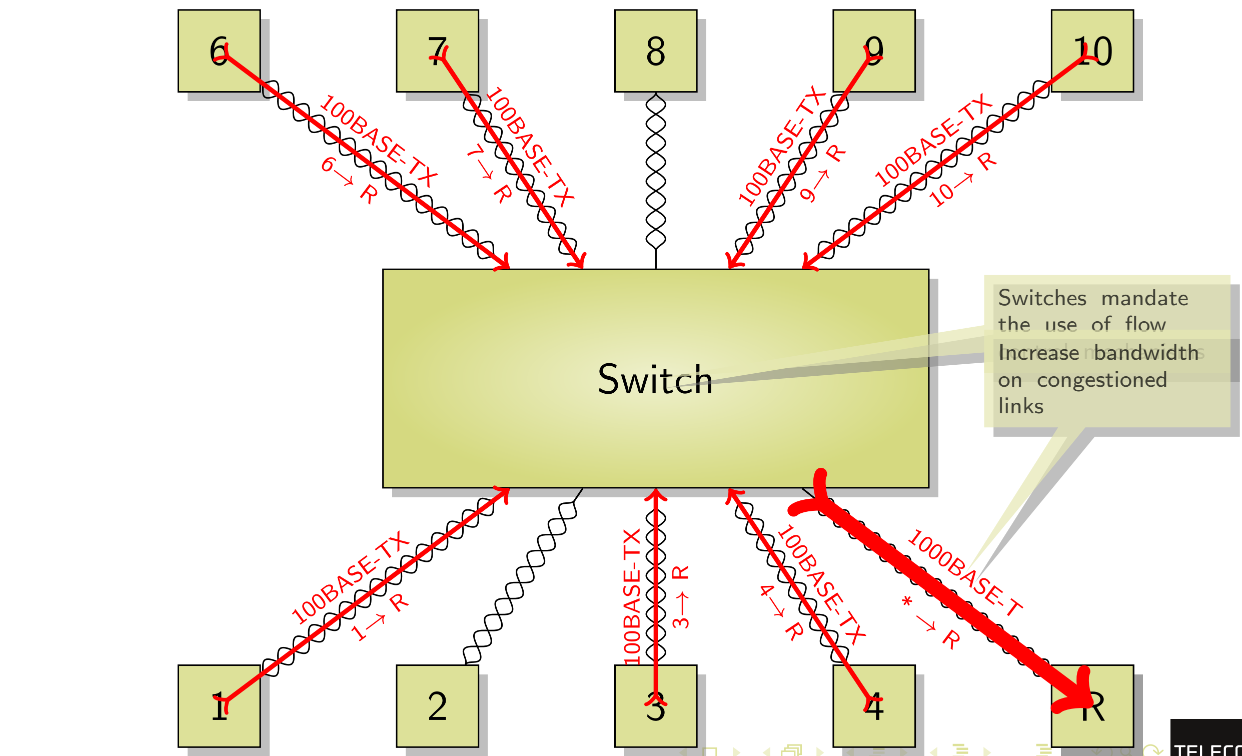

6
7
8
9
10
Preamble
Preamble
Preamble
Preamble
6 → R
Switch
Switches mandate the use of flow control mechanisms
Preamble
Preamble
Preamble
Preamble
6 → R
1
2
3
4
R


6
7
8
9
10
6 → R
Switch
Switches mandate the use of flow control mechanisms
If equipments are half-duplex, switch can send preamble when saturated
≡ hub
6 → R
1
2
3
4
R



Switching

Ethernet ▶ Switching



Ethernet

Auto-Configuration

Auto-Configuration

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Auto-Configuration

What are the switch/hub capabilities: 10BASE-T, 100BASE-TX, 1000BASE-T? Full-duplex, Half-duplex?

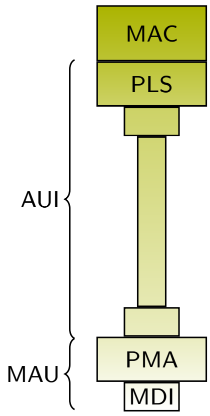
Same question for the equipment connected

Same Media Dependant Interface (RJ-45)
Find the best Ethernet technologies compatible to both ends

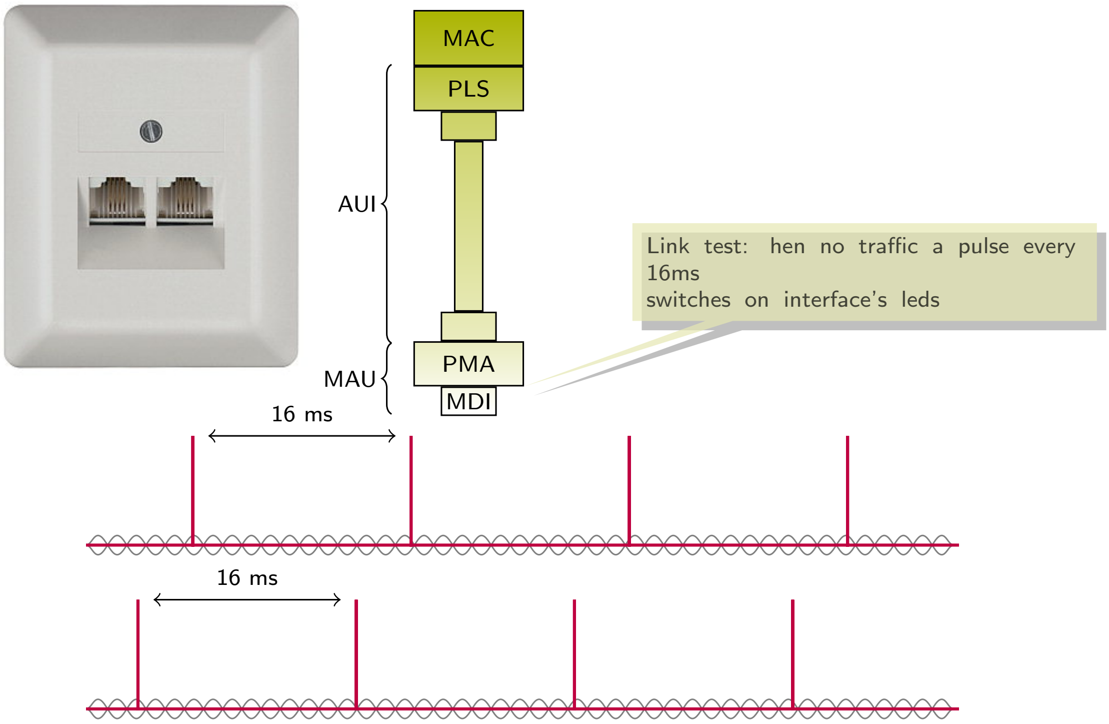
⇒ Auto-negociation

Ethernet ▶ Auto-Configuration

Auto-Configuration

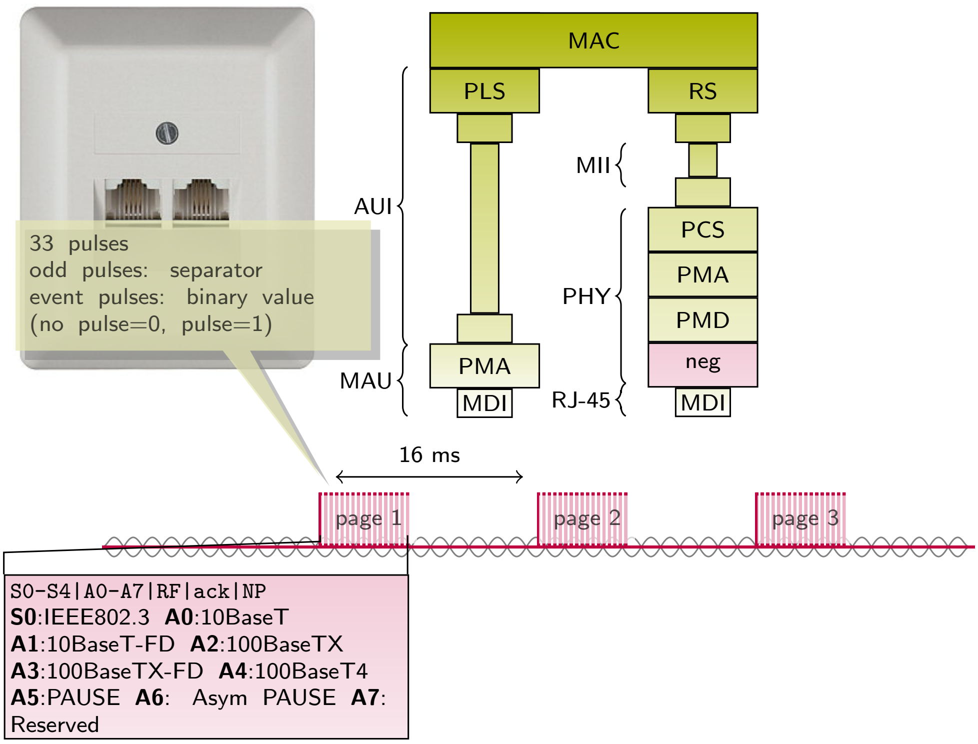


Auto-Configuration

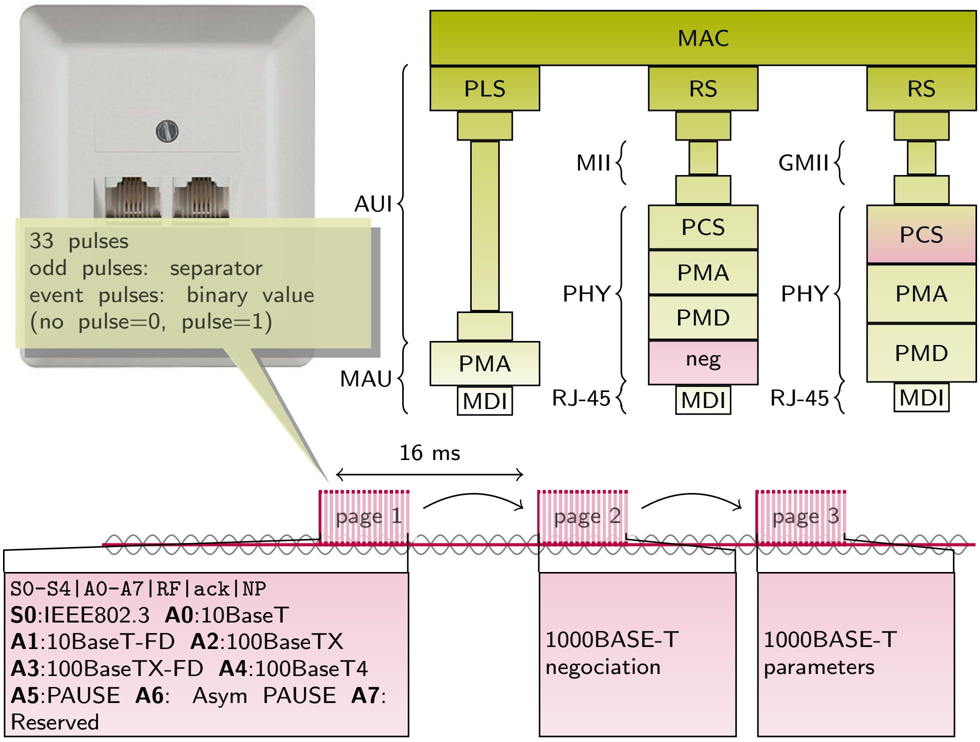


Auto-Configuration

Ethernet ▶ Auto-Configuration



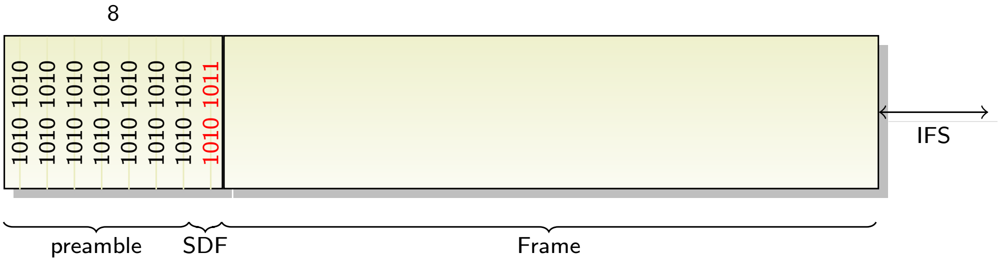
Auto-Configuration



Ethernet

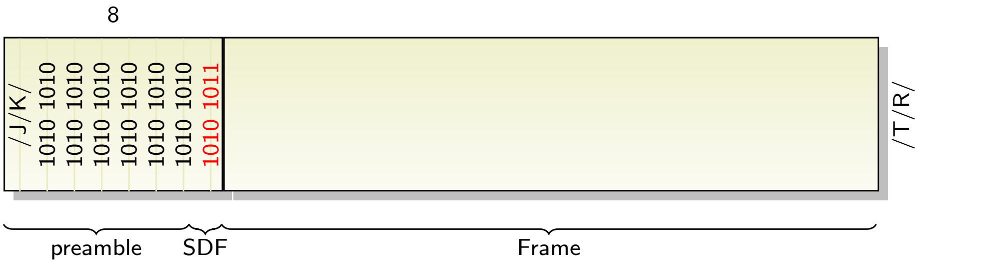
Frame Format

Frame Format

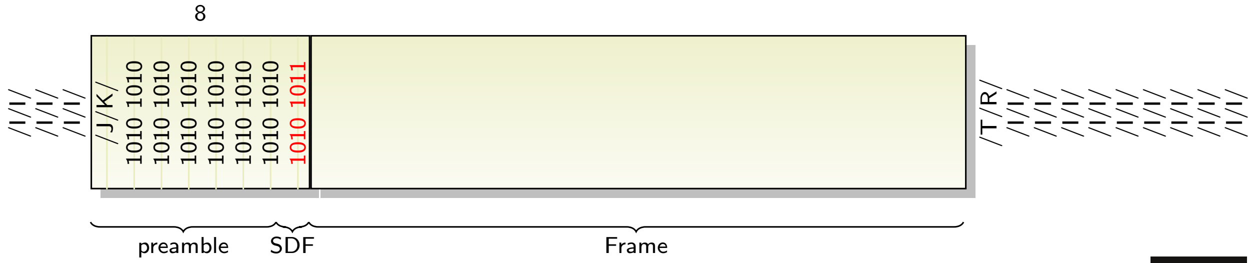


Ethernet ▶ Frame Format

Frame Format

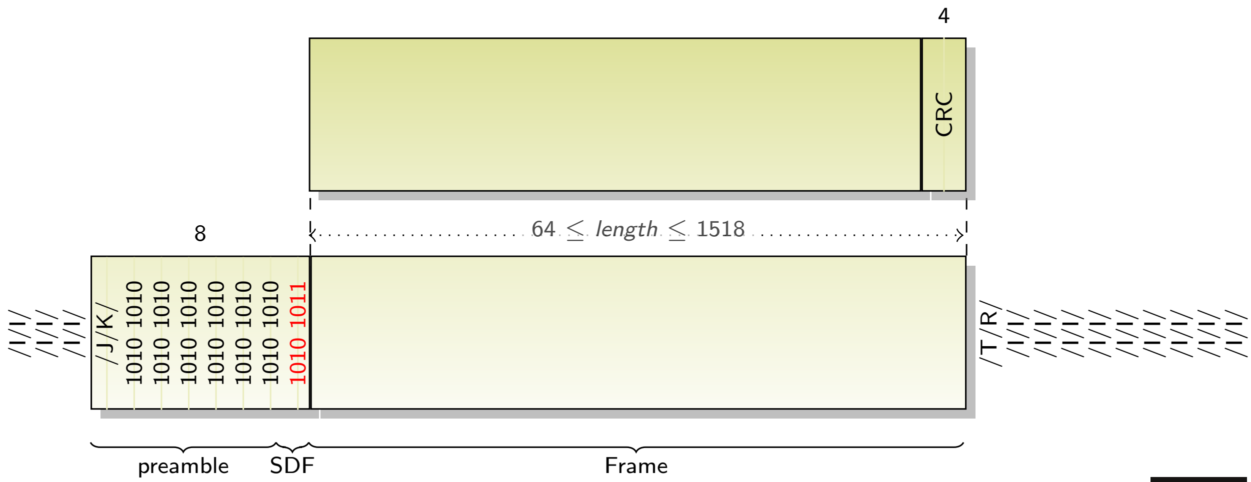


Frame Format



Ethernet ▶ Frame Format

Frame Format



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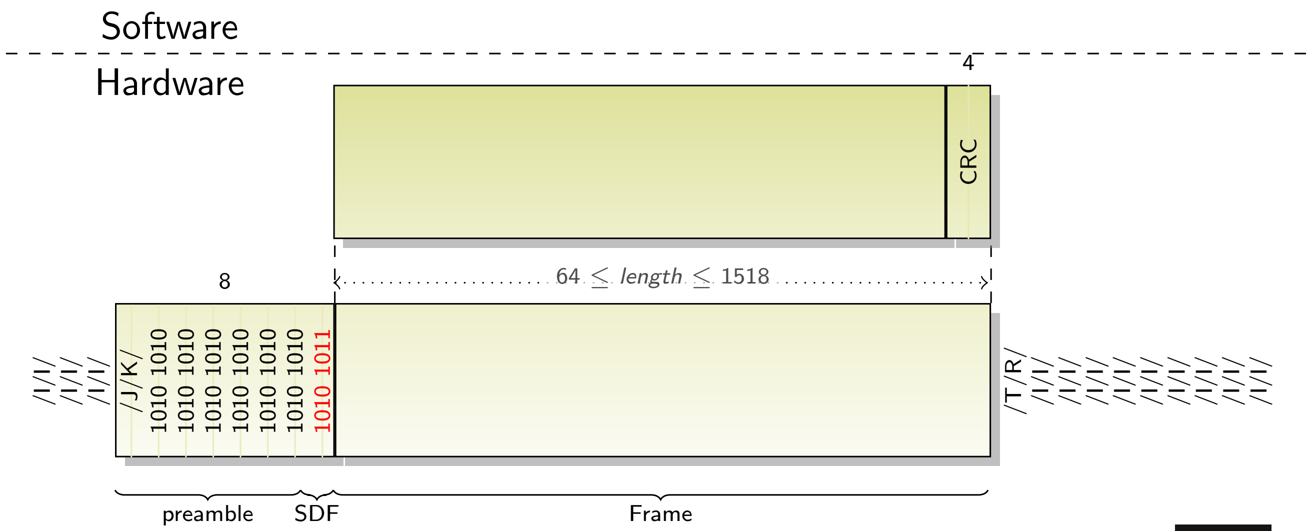
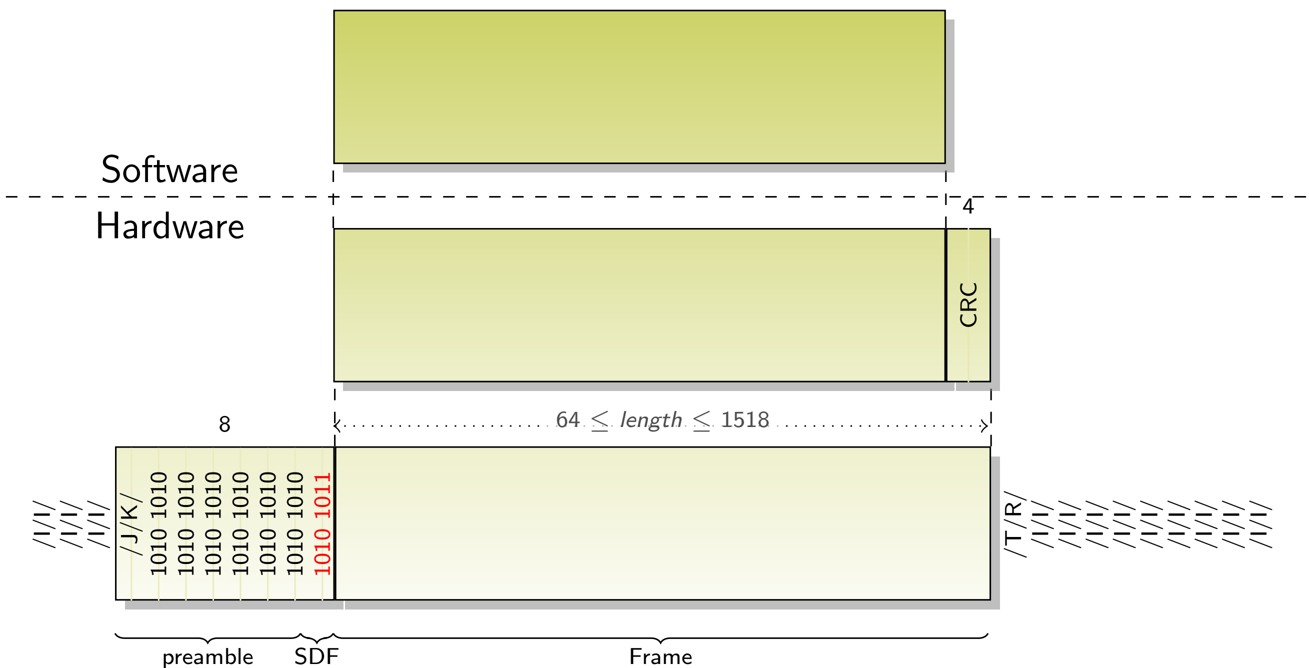
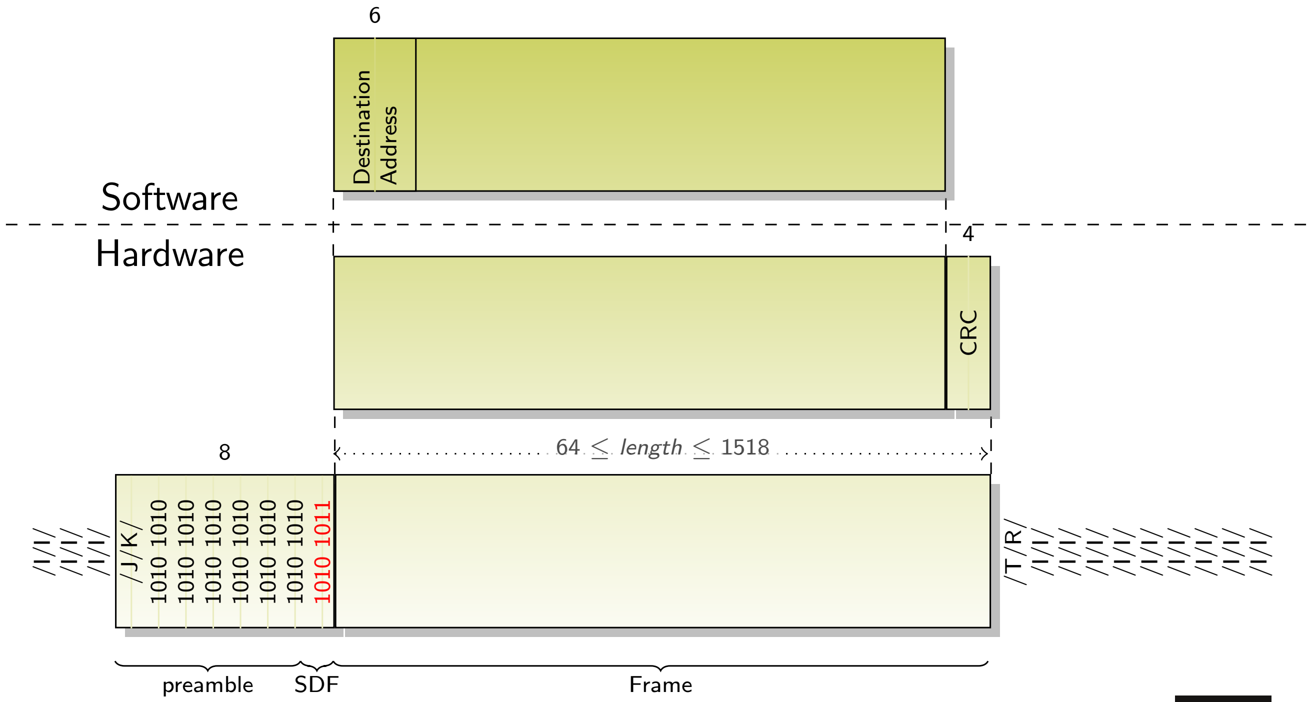
Frame Format



Frame Format

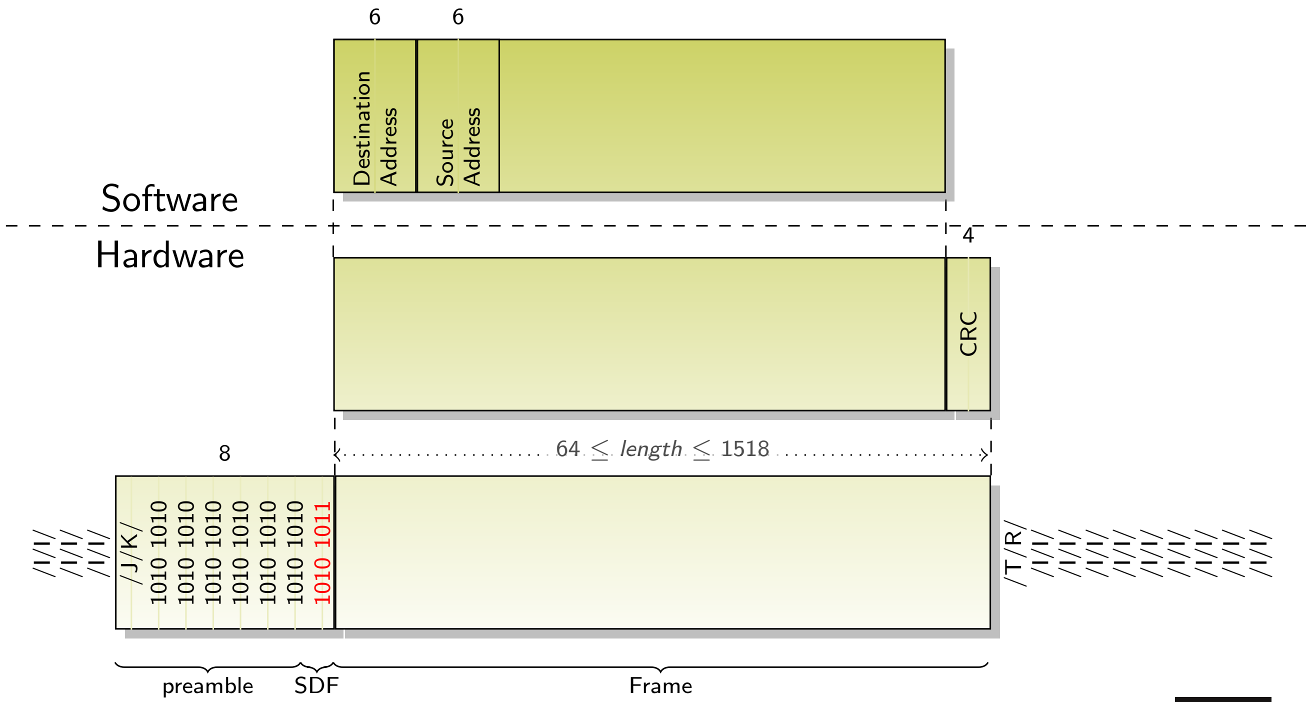


Frame Format

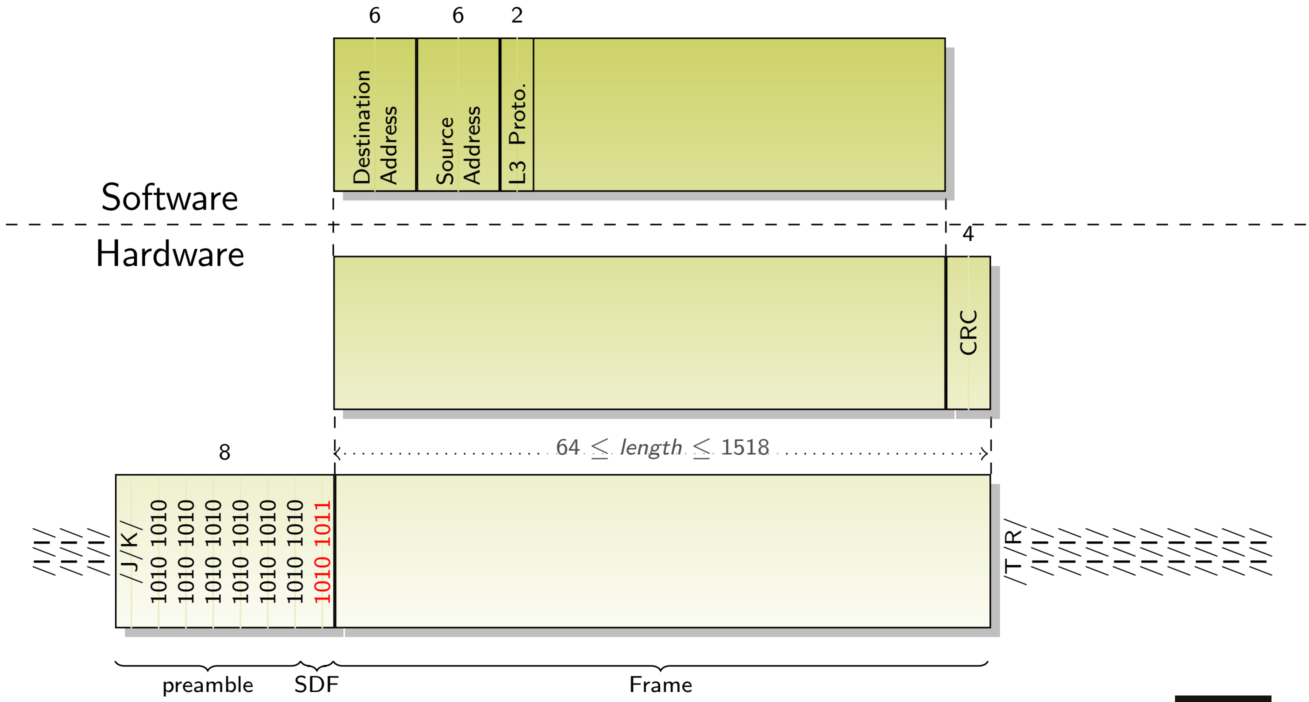


Ethernet ▶ Frame Format

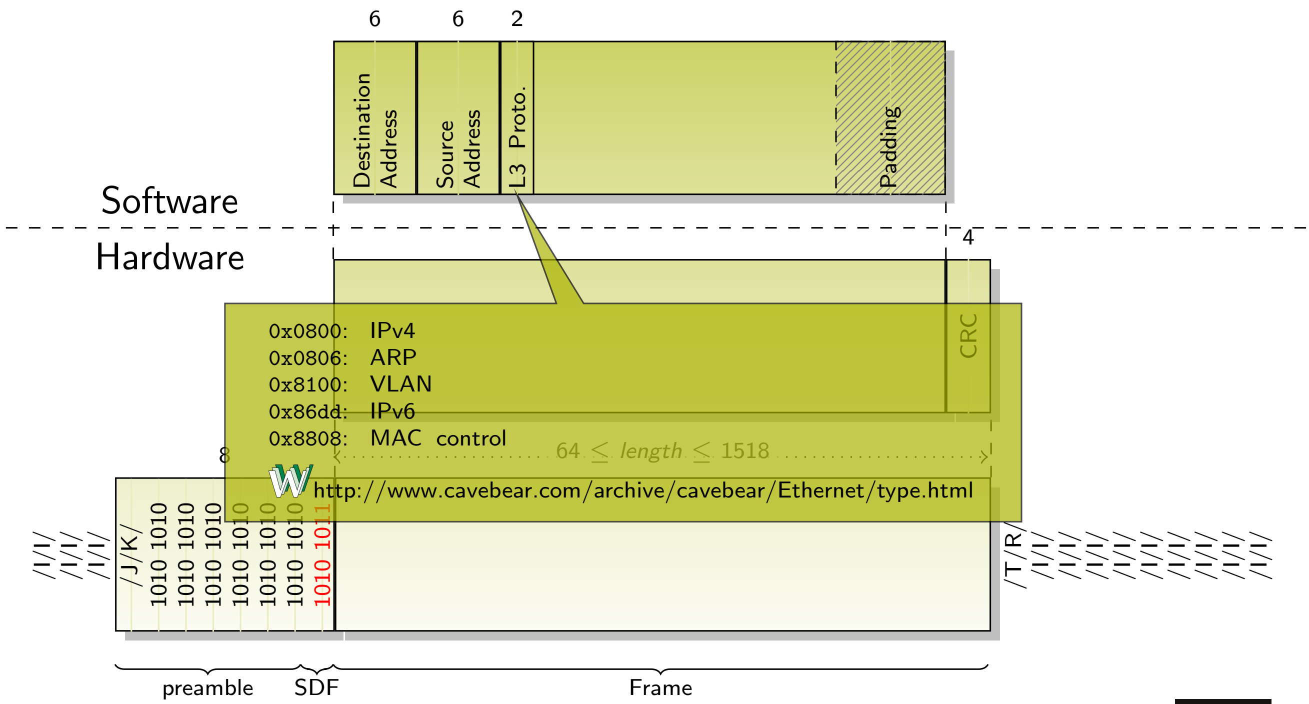
Frame Format



Frame Format



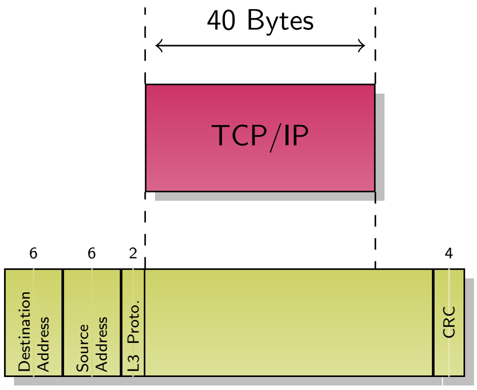
Frame Format



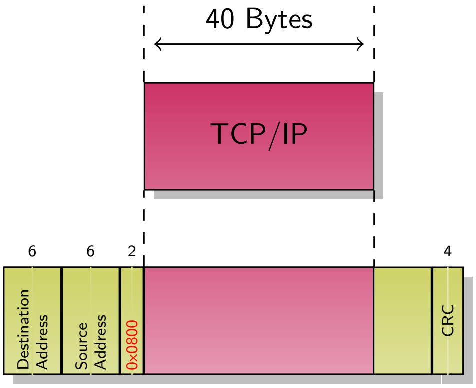
Frame Format

Ethernet ▶ Frame Format

Frame Format

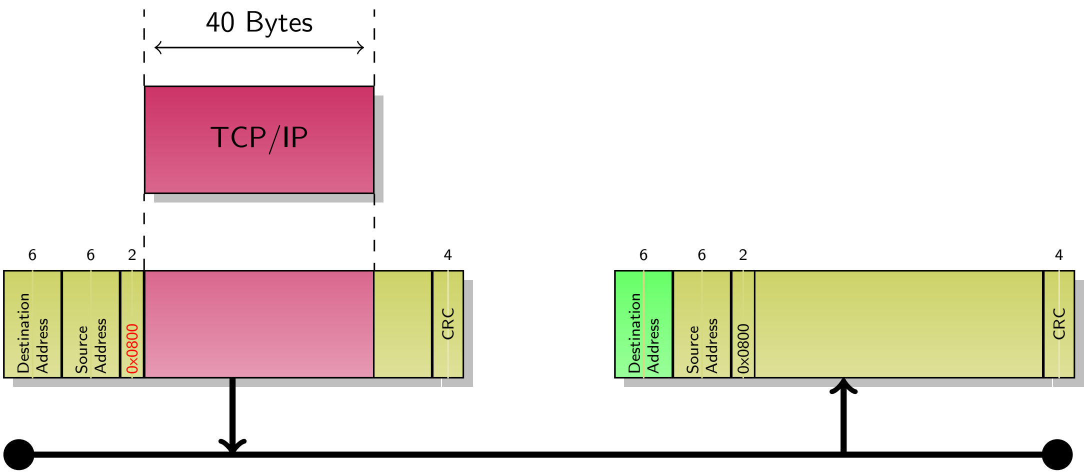


Frame Format



Frame Format

Ethernet ▶ Frame Format



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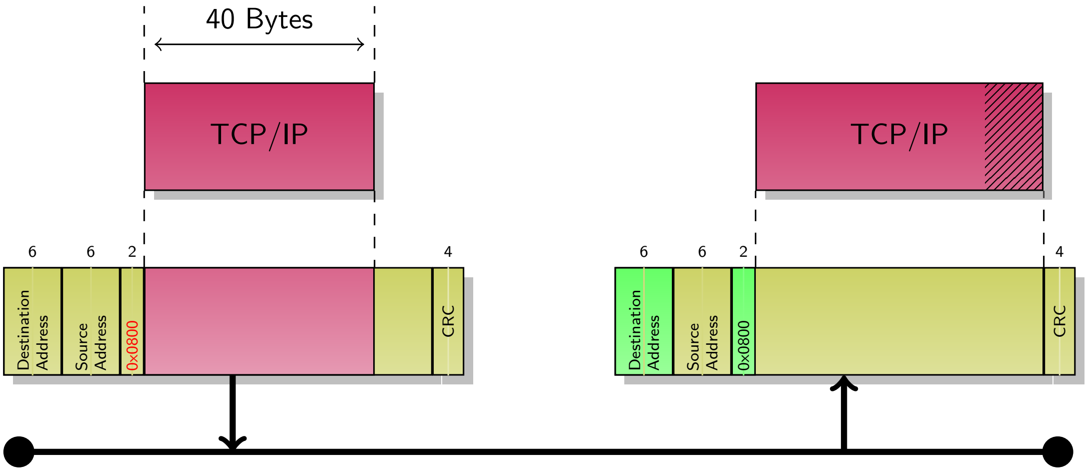
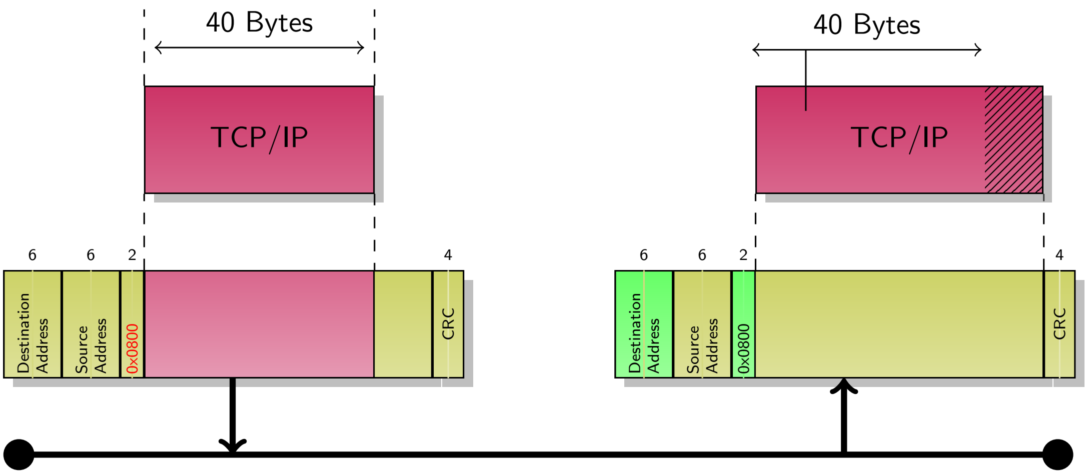
Frame Format

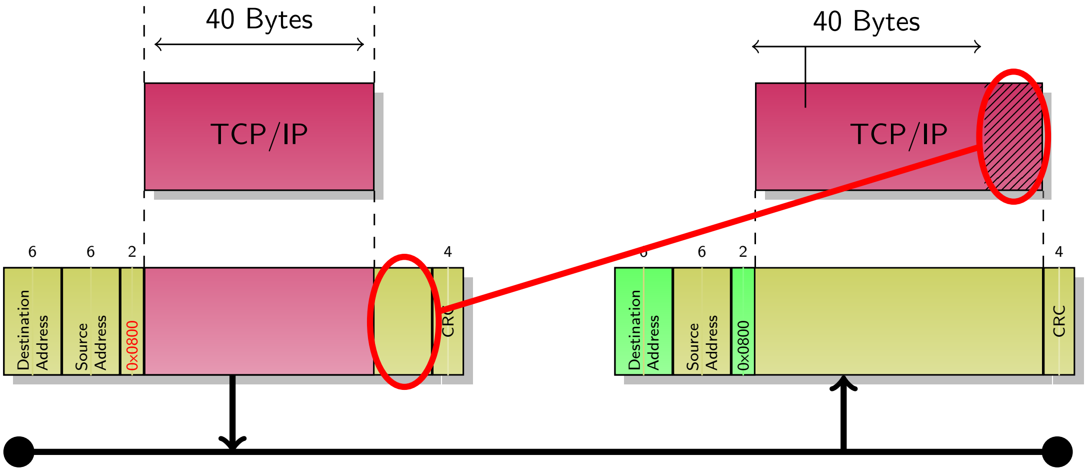


Ethernet ▶ Frame Format

Frame Format

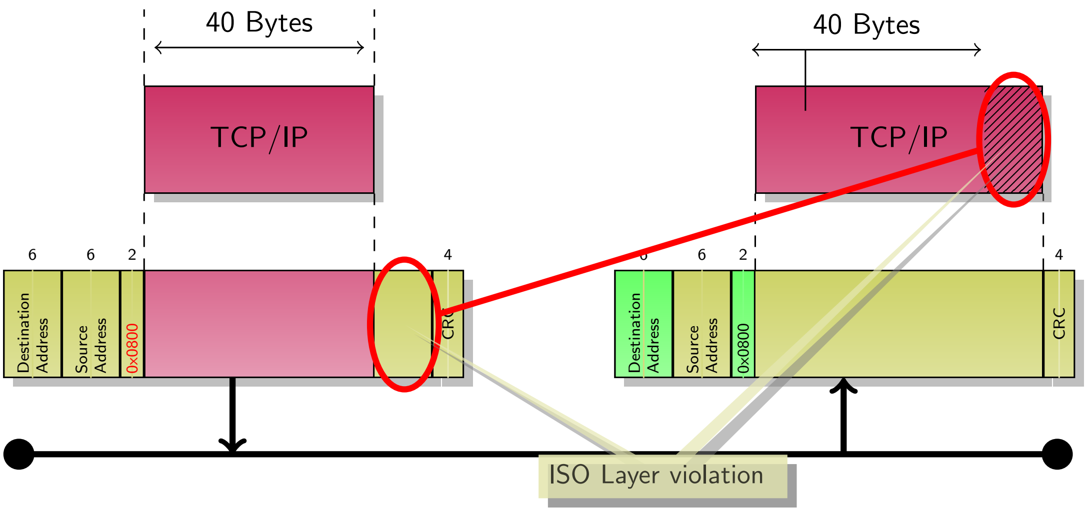


Frame Format



Frame Format

Ethernet ▶ Frame Format



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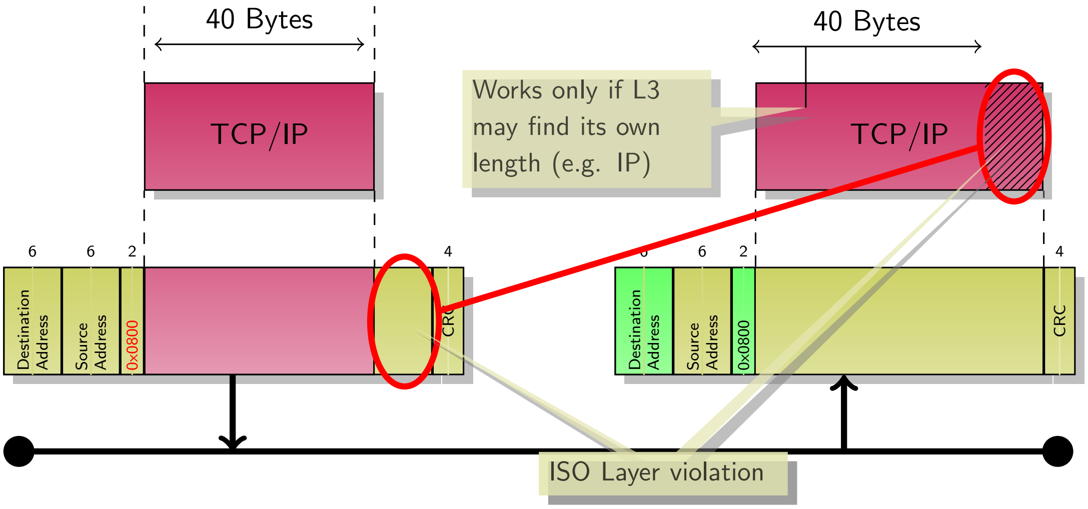
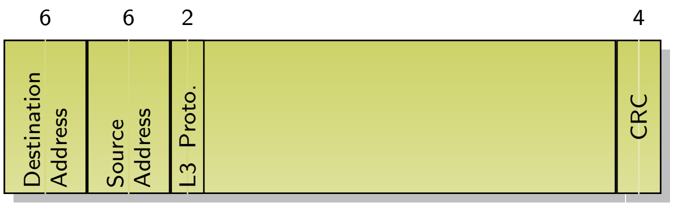
Frame Format

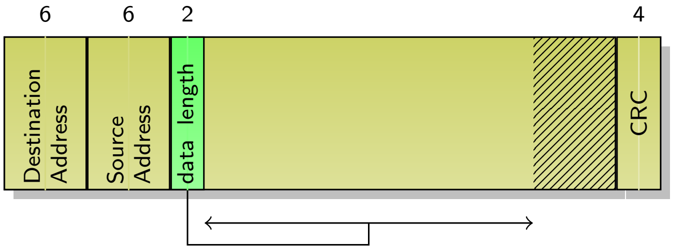


Ethernet ▶ Frame Format

Ethernet vs IEEE 802.3

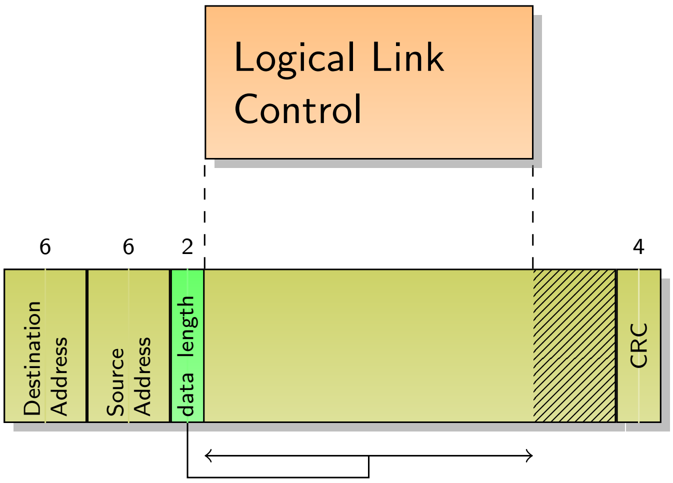


Ethernet vs IEEE 802.3



Ethernet ▶ Frame Format

Ethernet vs IEEE 802.3



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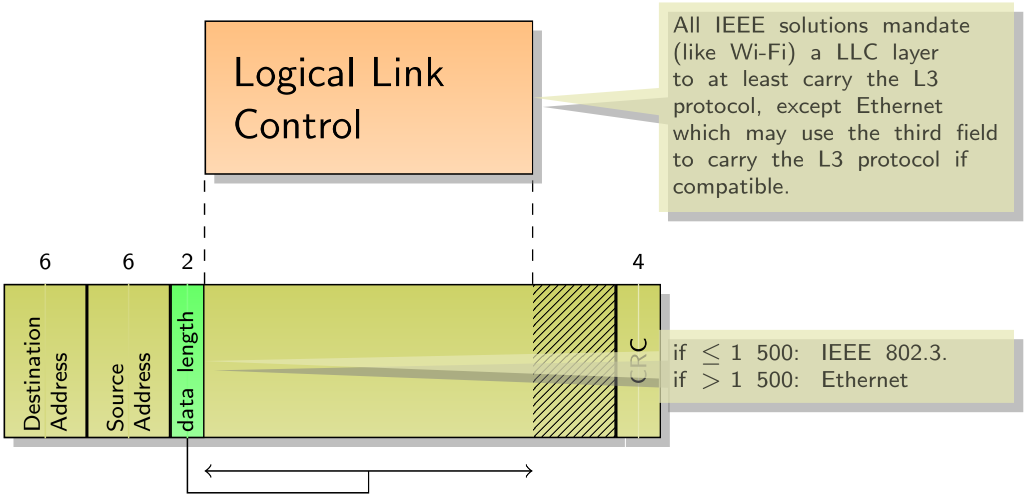
Ethernet vs IEEE 802.3



Questions


```
0x0000: 0180 c200 0000 0019 e79e 1dae 0026 4242
0x0010: 0300 0000 0000 8000 0002 b972 6601 0000
0x0020: 0008 8005 0019 e79e 1d80 802e 0200 1400
0x0030: 0200 0f00 0000 0000 0000 0000
```

This dump gives a IEEE 802.3 frame:

- What is the nature of the destination address ?
- What is the nature of the frame (Ethernet or IEEE 802.3) ?
- Can you identify padding bytes ?
- Can you give the frame CRC ?

Questions

01: 0000 0001

```
0x0000: 0180 c200 0000 0019 e79e 1dae 0026 4242
0x0010: 0300 0000 0000 8000 0002 b972 6601 0000
0x0020: 0008 8005 0019 e79e 1d80 802e 0200 1400
0x0030: 0200 0f00 0000 0000 0000 0000
```

This dump gives a IEEE 802.3 frame:

- What is the nature of the destination address ?
  Multicast (first bit sent = 1)
- What is the nature of the frame (Ethernet or IEEE 802.3) ?
- Can you identify padding bytes ?
- Can you give the frame CRC ?

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Questions

Ethernet ▶ Frame Format

01: 0000 0001

```
0x0000: 0180 c200 0000 0019 e79e 1dae 0026 4242
0x0010: 0300 0000 0000 8000 0002 b972 6601 0000
0x0020: 0008 8005 0019 e79e 1d80 802e 0200 1400
0x0030: 0200 0f00 0000 0000 0000 0000
```

This dump gives a IEEE 802.3 frame:

- What is the nature of the destination address ?
  Multicast (first bit sent = 1)
- What is the nature of the frame (Ethernet or IEEE 802.3) ?

$< 1500 \rightarrow IEEE802.3$

  IEEE 802.3, EtherType is less than 1500

- Can you identify padding bytes ?
- Can you give the frame CRC ?

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Questions

01: 0000 0001

< 1500 → *IEEE*802.3

0x0000: 0180 c200 0000 0019 e79e 1dae 0026 4242
0x0010: 0300 0000 0000 8000 0002 b972 6601 0000
0x0020: 0008 8005 0019 e79e 1d80 802e 0200 1400
0x0030: 0200 0f00 ~~0000 0000 0000 0000~~

This dump gives a IEEE 802.3 frame:

- What is the nature of the destination address ?
  Multicast (first bit sent = 1)
- What is the nature of the frame (Ethernet or IEEE 802.3) ?
  IEEE 802.3, EtherType is less than 1500
- Can you identify padding bytes ?
  Yes: length is 0x26 (2 lines 6 bytes) 8 last bytes are padding
- Can you give the frame CRC ?

Questions

01: 0000 0001

< 1500 → *IEEE*802.3

0x0000: 0180 c200 0000 0019 e79e 1dae 0026 4242
0x0010: 0300 0000 0000 8000 0002 b972 6601 0000
0x0020: 0008 8005 0019 e79e 1d80 802e 0200 1400
0x0030: 0200 0f00 ~~0000 0000 0000 0000~~ XXXX XXXX

Missing CRC

This dump gives a IEEE 802.3 frame:

- What is the nature of the destination address ?
  Multicast (first bit sent = 1)
- What is the nature of the frame (Ethernet or IEEE 802.3) ?
  IEEE 802.3, EtherType is less than 1500
- Can you identify padding bytes ?
  Yes: length is 0x26 (2 lines 6 bytes) 8 last bytes are padding
- Can you give the frame CRC ?
  No: It has been removed by the card

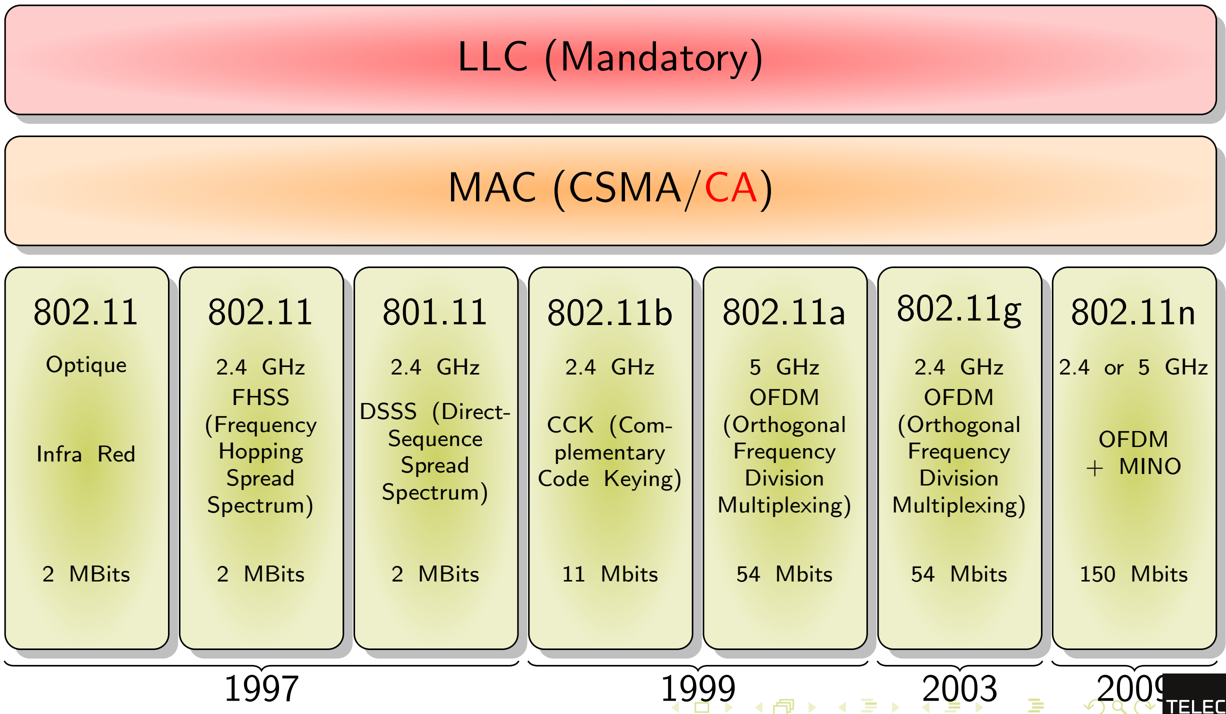
Ethernet: References

- Cisco tutorial:
  http://www.cisco.com/en/US/docs/internetworking/technology/handbook/Ethernet.html#wp1020985
- Auto-configuration: www.ethermanage.com/ethernet/pdf/dell-auto-neg.pdf

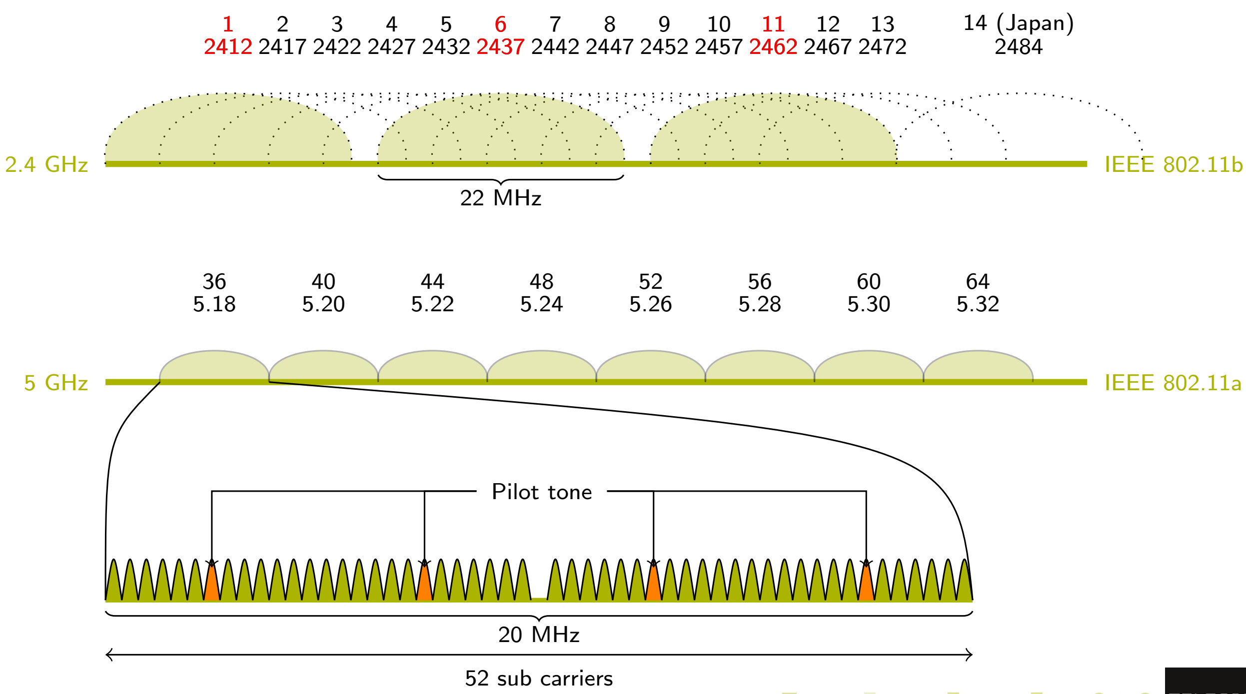
IEEE 802.11

Physical Layer

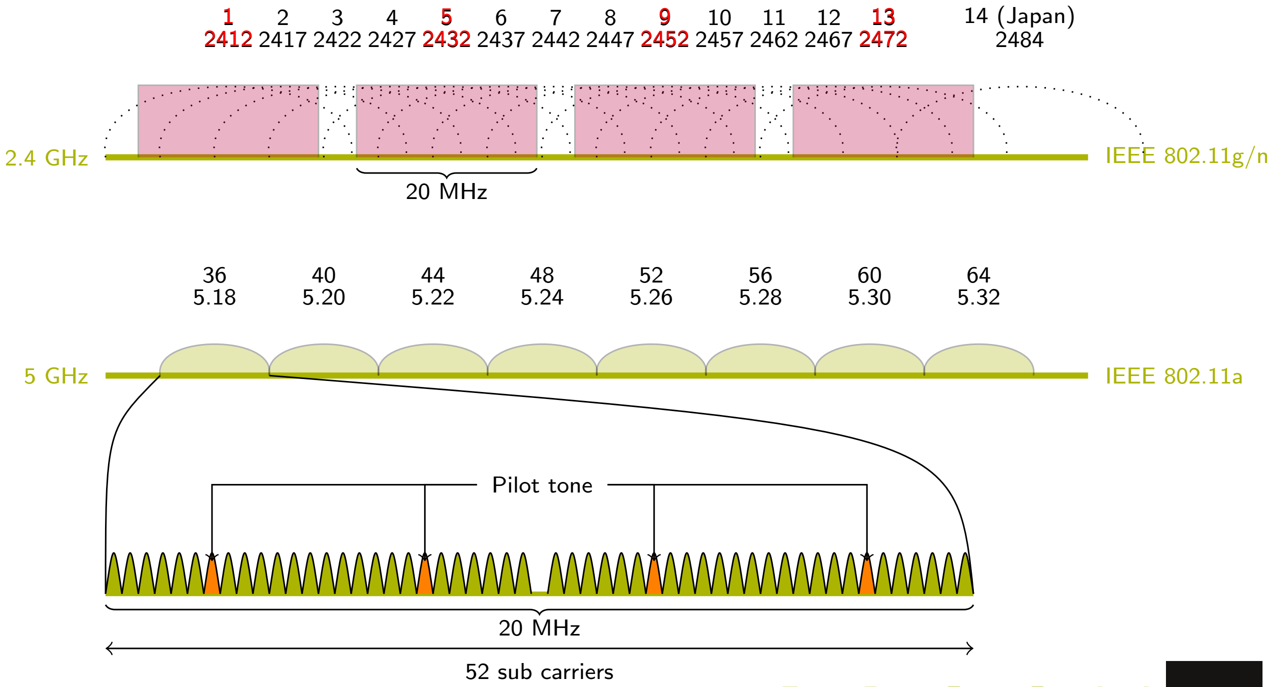
IEEE 802.11 Standards



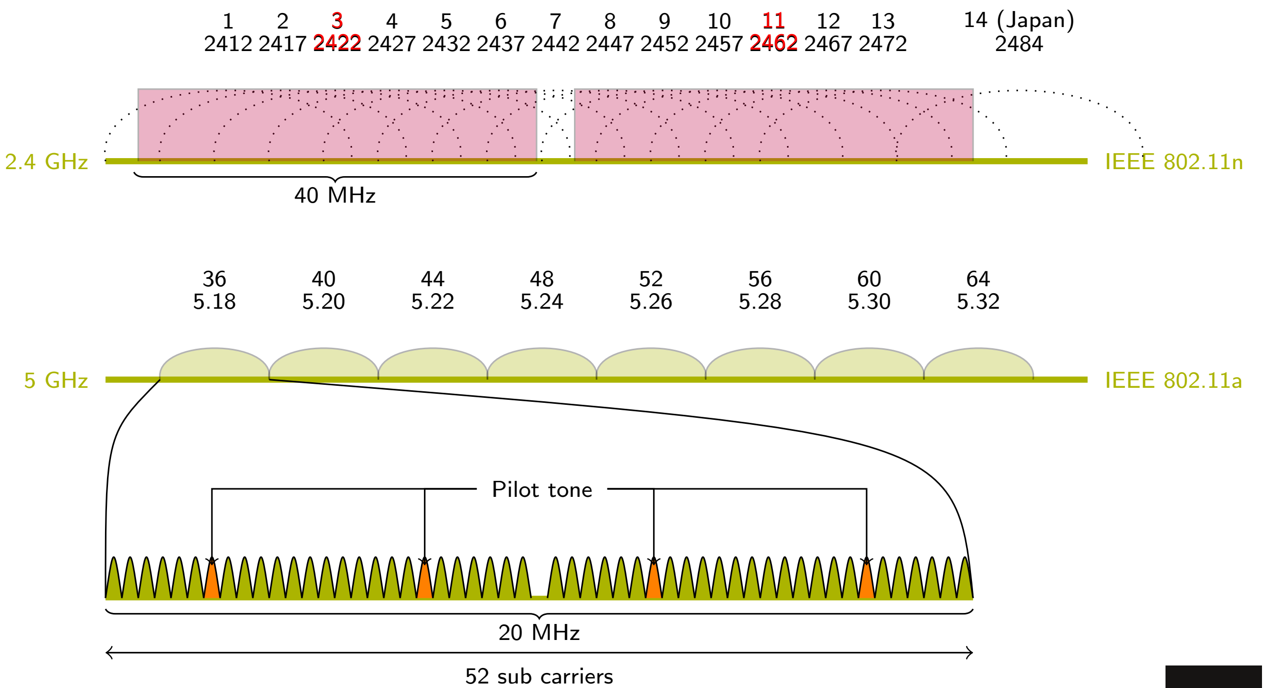
Channels



Channels



Channels



WiFi Throughputs

Data Rate (Mbit/s)	Transmission Type	Modulation Scheme	Standard
1	DSSS	Baker code & BPSK	802.11-1999
2	DSSS	Baker code & QPSK	802.11-1999
5.5	DSSS	CCK & QPSK	802.11b/g
6	OFDM	BPSK	802.11a/g
9	OFDM	BPSK	802.11a/g
12	OFDM	QPSK	802.11a/g
11	DSSS	CCK & QPSK	802.11b/g
18	OFDM	QPSK	802.11a/g
24	OFDM	16 QAM	802.11a/g
36	OFDM	16 QAM	802.11a/g
48	OFDM	64 QAM	802.11a/g
54	OFDM	64 QAM	802.11a/g

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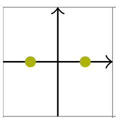
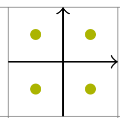
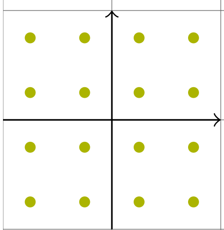
Modulations



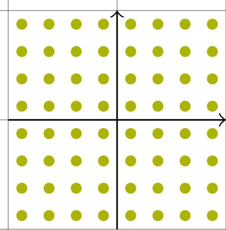
BPSK: Binary Phase Shift Keying (20 MHz)
Coding rate = 1/2 ⇒ 6 Mbit/s
Coding rate = 3/4 ⇒ 9 Mbit/s



QPSK: Quadrature Phase Shift Keying (20 MHz)
Coding rate = 1/2 ⇒ 12 Mbit/s
Coding rate = 3/4 ⇒ 18 Mbit/s



16-QAM: Quadrature Amplitude Modulation (20 MHz)
Coding rate = 1/2 ⇒ 24 Mbit/s
Coding rate = 3/4 ⇒ 36 Mbit/s



64-QAM: Quadrature Amplitude Modulation
Coding rate = 2/3 ⇒ 48 Mbit/s
Coding rate = 3/4 ⇒ 54 Mbit/s

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Versions compatibility

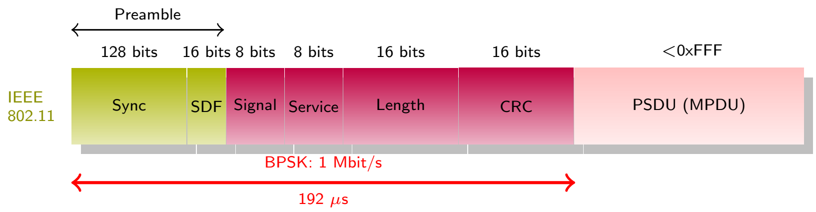
IEEE 802.11b introduces short preamble

- ERP: Extended Rate Physical
- Long preamble: 192 bits or 192 μs
- Short preamble: 120 bits or 96 μs

IEEE 802.11g introduces OFDM

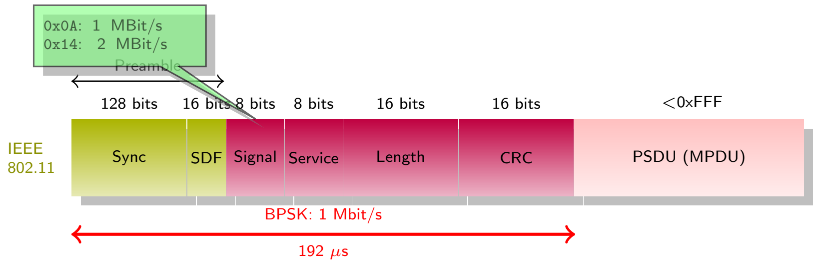
- 3 main physical layers
  - ERP-DSSS/CCK: 1 or 2 Mbit/s legacy physical layer
  - ERP-OFDM: 6 to 54 MBit/s, pure OFDM
    - Invisible from legacy nodes (IEEE 802.11 or IEEE 802.11b)
  - DSSS-OFDM: Start in DSSS and continue with OFDM
    - Ensure compatibility with IEEE 802.11 and IEEE 802.11b

Physical format



http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.8843&rep=rep1&type=pdf

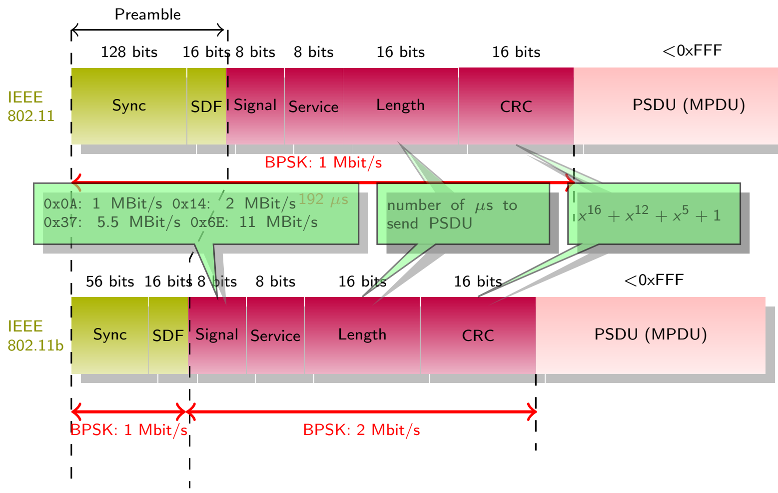
Physical format



http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.8843&rep=rep1&type=pdf

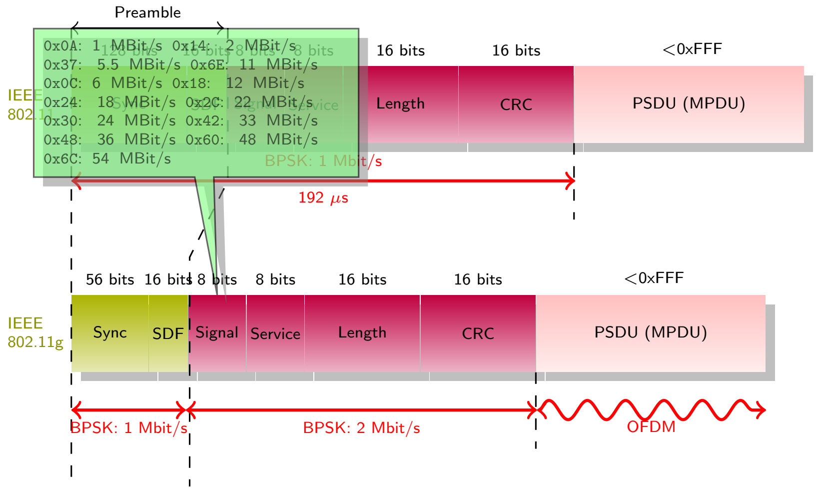
Physical format

IEEE 802.11 ▶ Physical Layer



http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.8843&rep=rep1&type=pdf

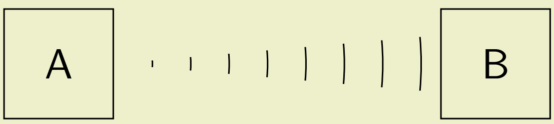
Physical format



http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.8843&rep=rep1&type=pdf

Questions

Is there compatibility problems between IEEE 802.11a and IEEE 802.11g ?



A= B	IEEE 802.11	IEEE 802.11b	IEEE 802.11g
IEEE 802.11			
IEEE 802.11b			
IEEE 802.11g			

Questions

Is there compatibility problems between IEEE 802.11a and IEEE 802.11g ?

No since they do not use the same frequencies

A B

A= B	IEEE 802.11	IEEE 802.11b	IEEE 802.11g
IEEE 802.11			
IEEE 802.11b			
IEEE 802.11g			

Questions

Is there compatibility problems between IEEE 802.11a and IEEE 802.11g ?

No since they do not use the same frequencies

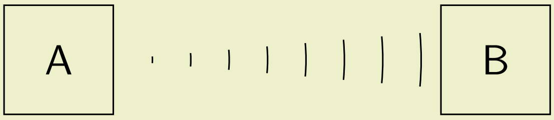
A B

A= B	IEEE 802.11	IEEE 802.11b	IEEE 802.11g
IEEE 802.11	Long		
IEEE 802.11b	Long		
IEEE 802.11g	Long		

Questions

Is there compatibility problems between IEEE 802.11a and IEEE 802.11g ?

No since they do not use the same frequencies



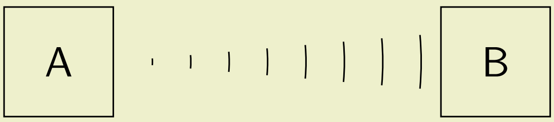
A= B	IEEE 802.11	IEEE 802.11b	IEEE 802.11g
IEEE 802.11	Long	Long	
IEEE 802.11b	Long	Short	
IEEE 802.11g	Long	Short	

IEEE 802.11 ▶ Physical Layer

Questions

Is there compatibility problems between IEEE 802.11a and IEEE 802.11g ?

No since they do not use the same frequencies



A= B	IEEE 802.11	IEEE 802.11b	IEEE 802.11g
IEEE 802.11	Long	Long	Long DSSS-OFDM
IEEE 802.11b	Long	Short	Short DSSS-OFDM
IEEE 802.11g	Long	Short	OFDM

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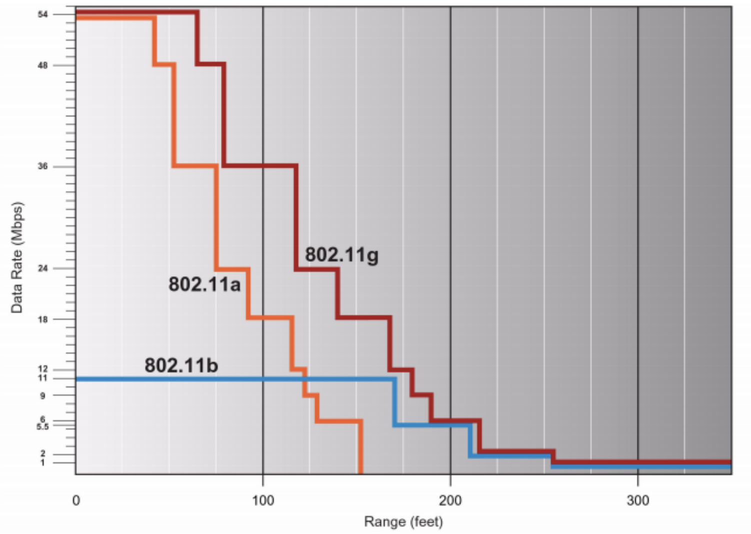
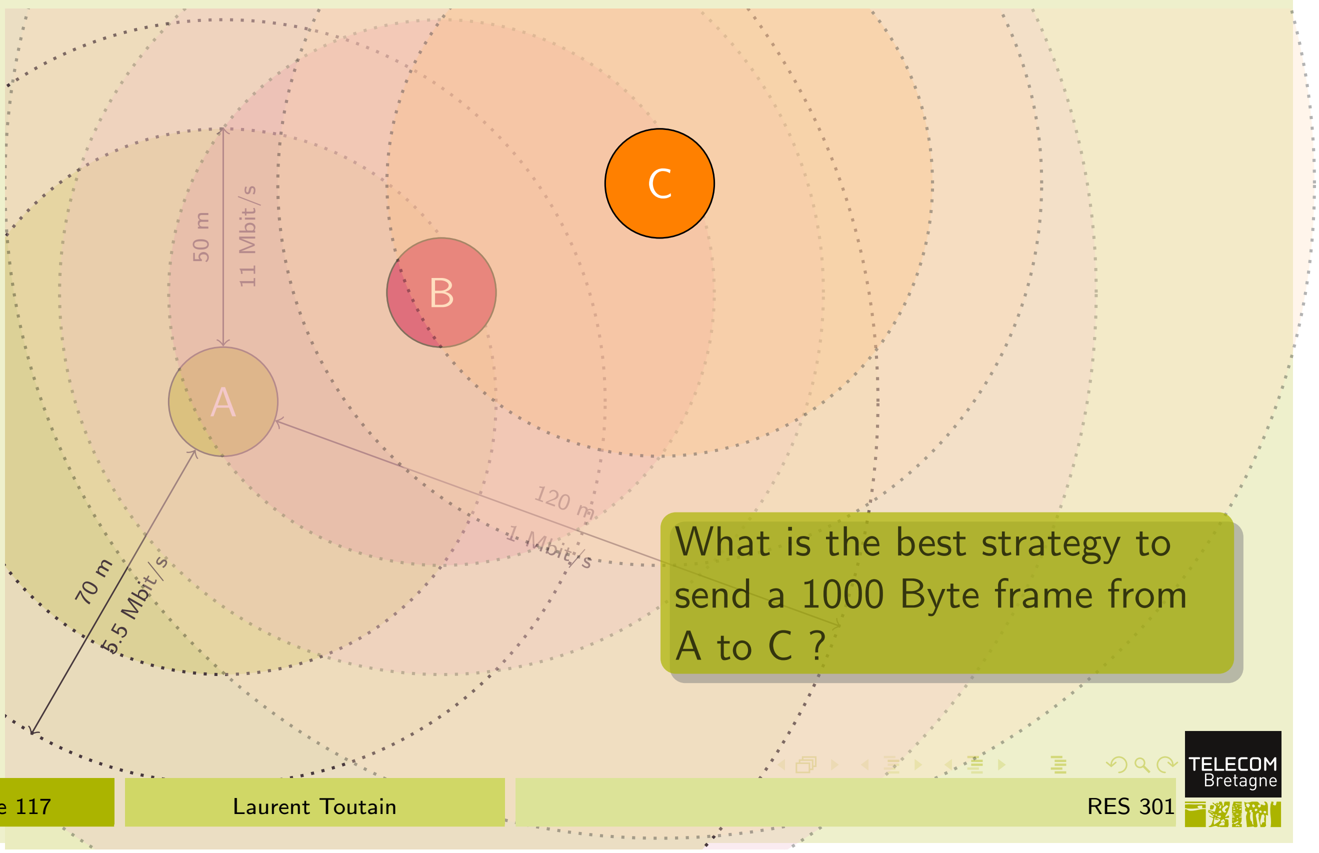
Speed versus Distance



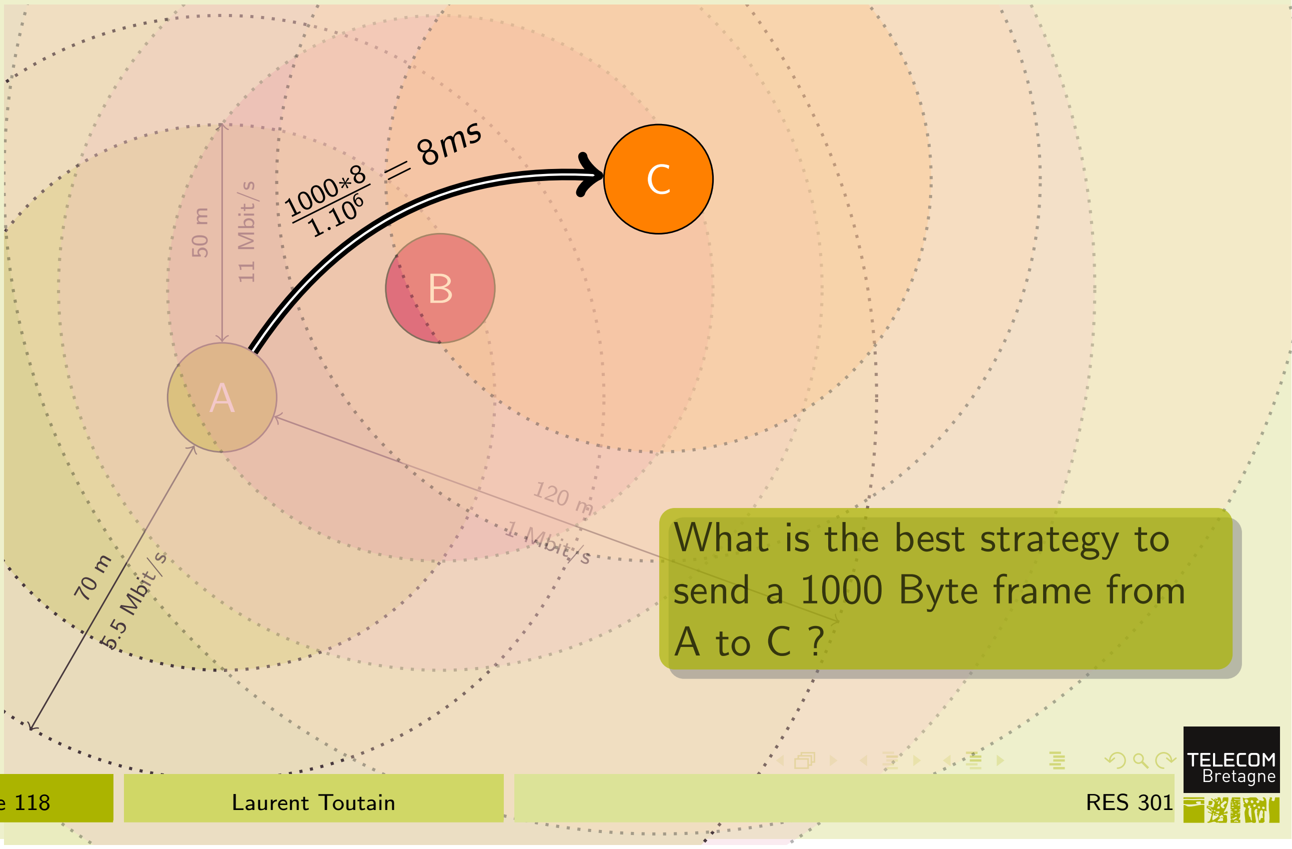
http://www.dell.com/downloads/global/shared/broadcom_802_11_g.pdf

Questions



What is the best strategy to send a 1000 Byte frame from A to C ?

Questions



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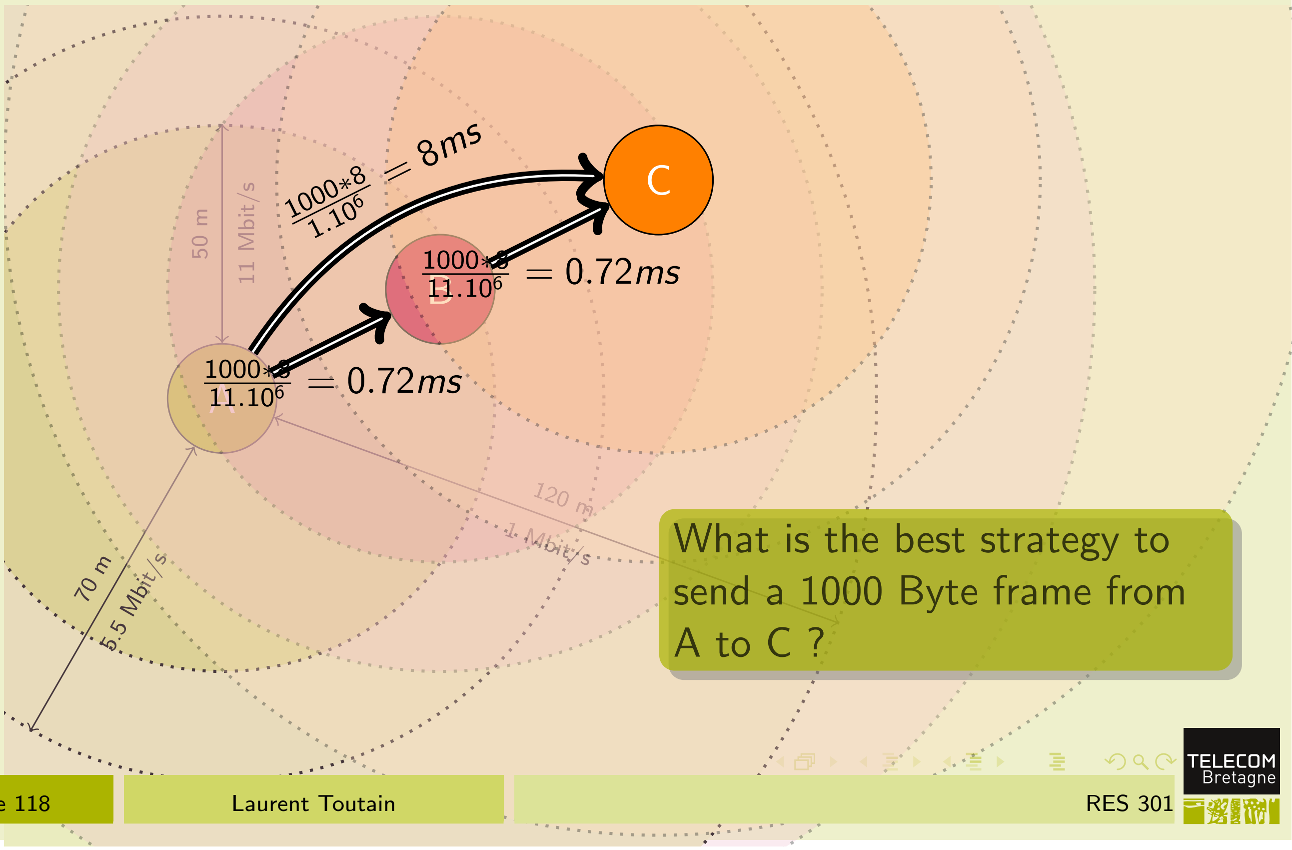

What is the best strategy to send a 1000 Byte frame from A to C ?

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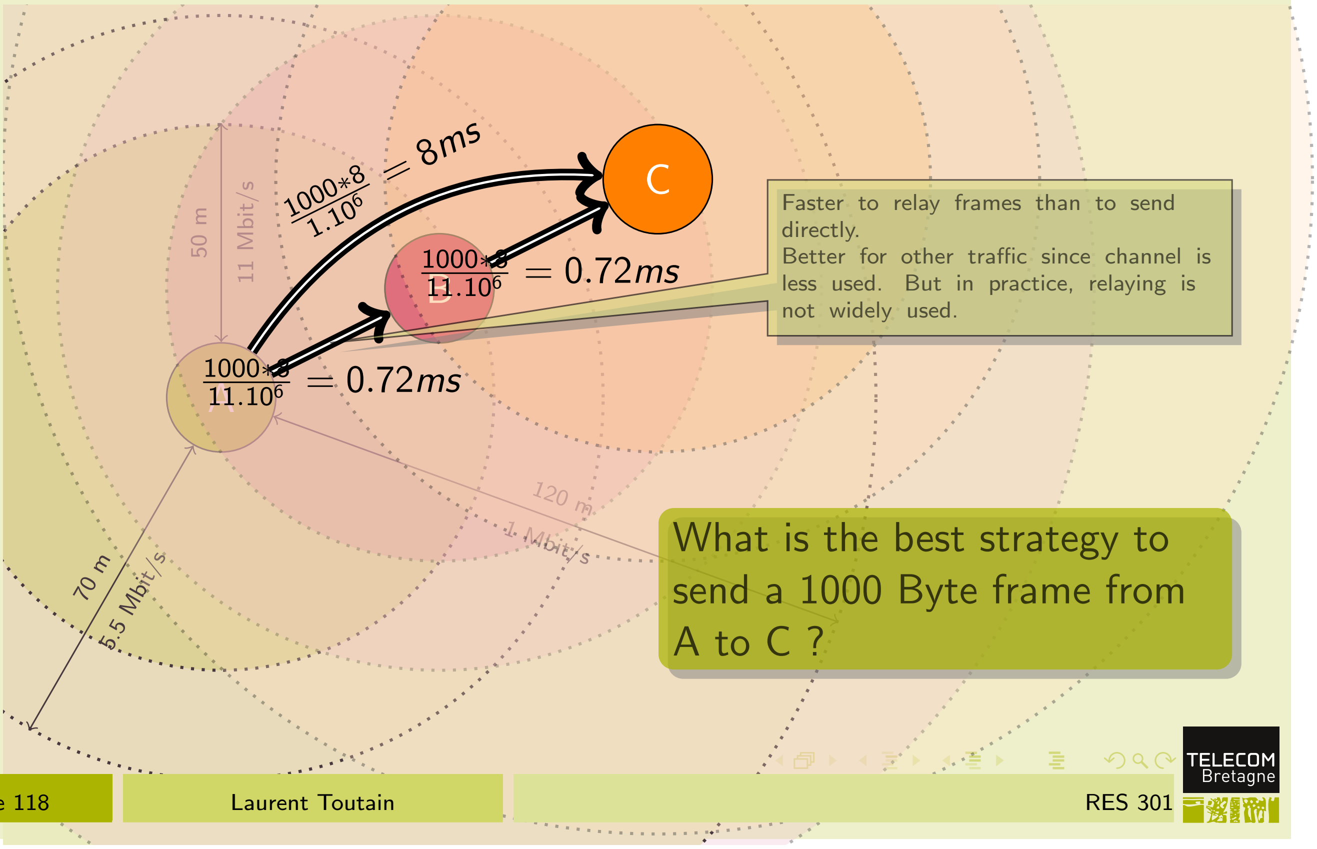

What is the best strategy to send a 1000 Byte frame from A to C ?

IEEE 802.11n

- OFDM: 48 $\rightarrow$ 52 subcarriers
  - $\Rightarrow$ 54 Mbit/s $\rightarrow$ 58.5 Mbit/s
- FEC: 3/4 $\rightarrow$ 5/6
  - $\Rightarrow$ 58.5 Mbit/s $\rightarrow$ 65 Mbit/s
- Guard Interval: 800 ns $\rightarrow$ 400 ns
  - $\Rightarrow$ 65 Mbit/s $\rightarrow$ 72.2 Mbit/s
- Channel Bounding: 20 Mhz $\rightarrow$ 40 MHz
  - $\Rightarrow$ 72.2 Mbit/s $\rightarrow$ 150 Mbit/s
- 4 spacial streams
  - $\Rightarrow$ 150 Mbit/s $\rightarrow$ 600 Mbit/s

http://www.wireshark.ch/download/Cisco_PSE_Day_2009.pdf

IEEE 802.11

CSMA/CA

CSMA/CA

- Ethernet uses Carrier Sense Multiple Access/Collision Detect
  - Wait for free channel, if collision stop sending and try later
  - Collision is detected either because received intensity is higher than maximum sending intensity
  - or generated by the Hub
  - work only on wired network
- On radio channel, received signal intensity is small compared to sending intensity.
  - Instead of detecting collision: try to avoid collision and
  - Solution: Acknowledge frames

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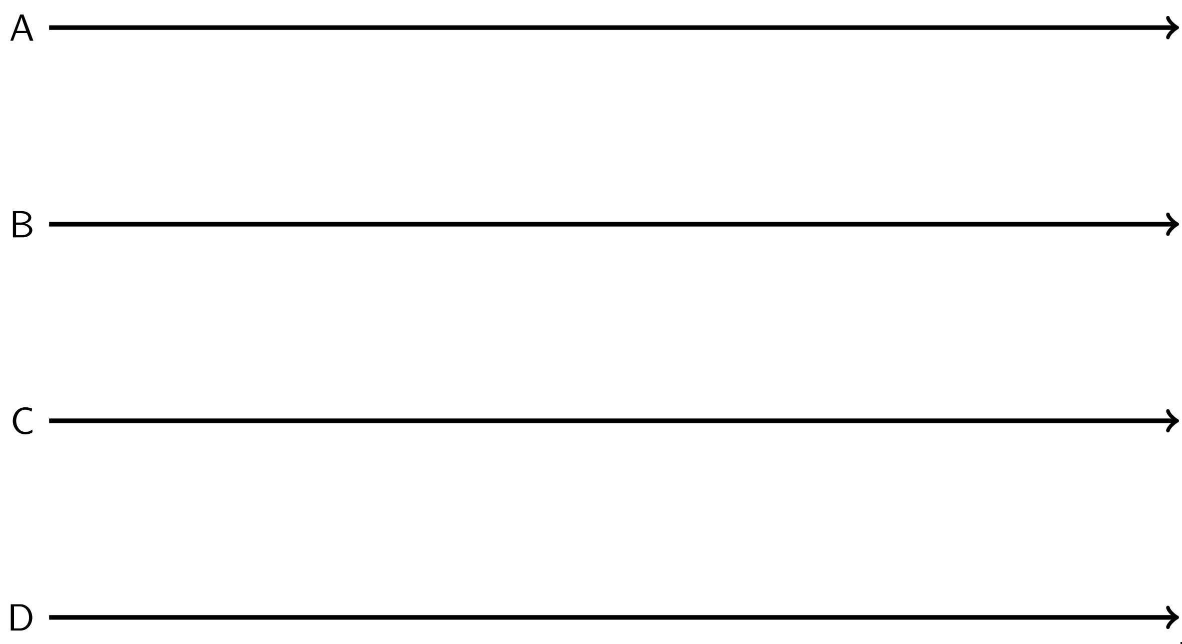
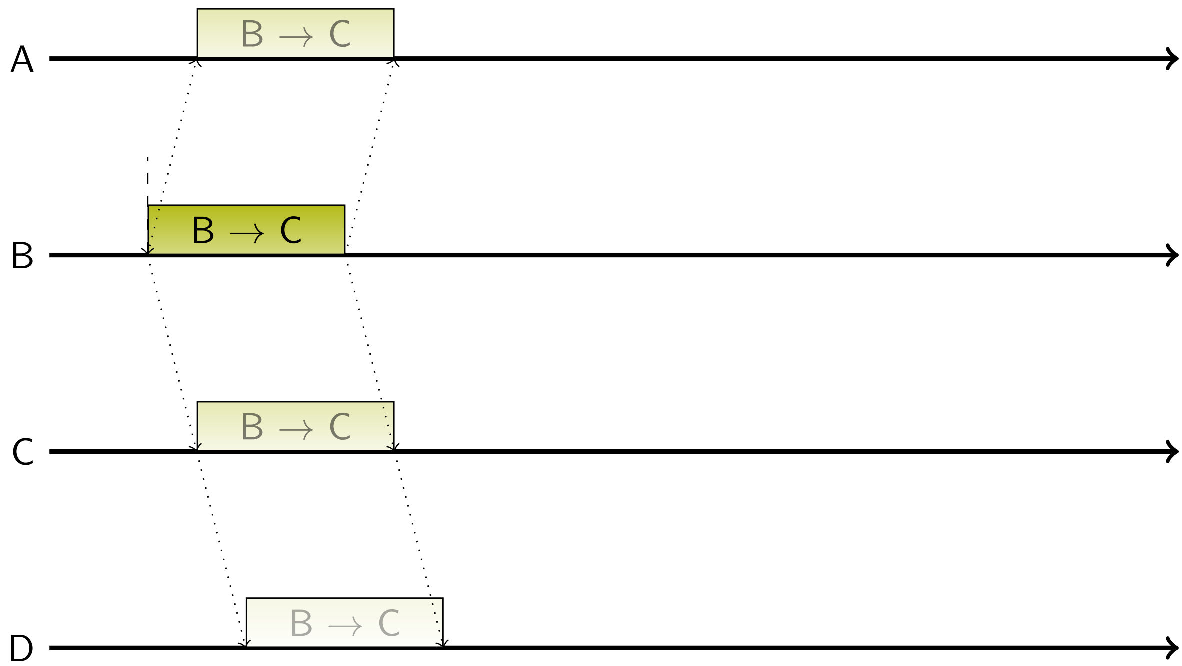
Acknowledgment: what does it change?



Acknowledgment: what does it change?

IEEE 802.11 ▶ CSMA/CA



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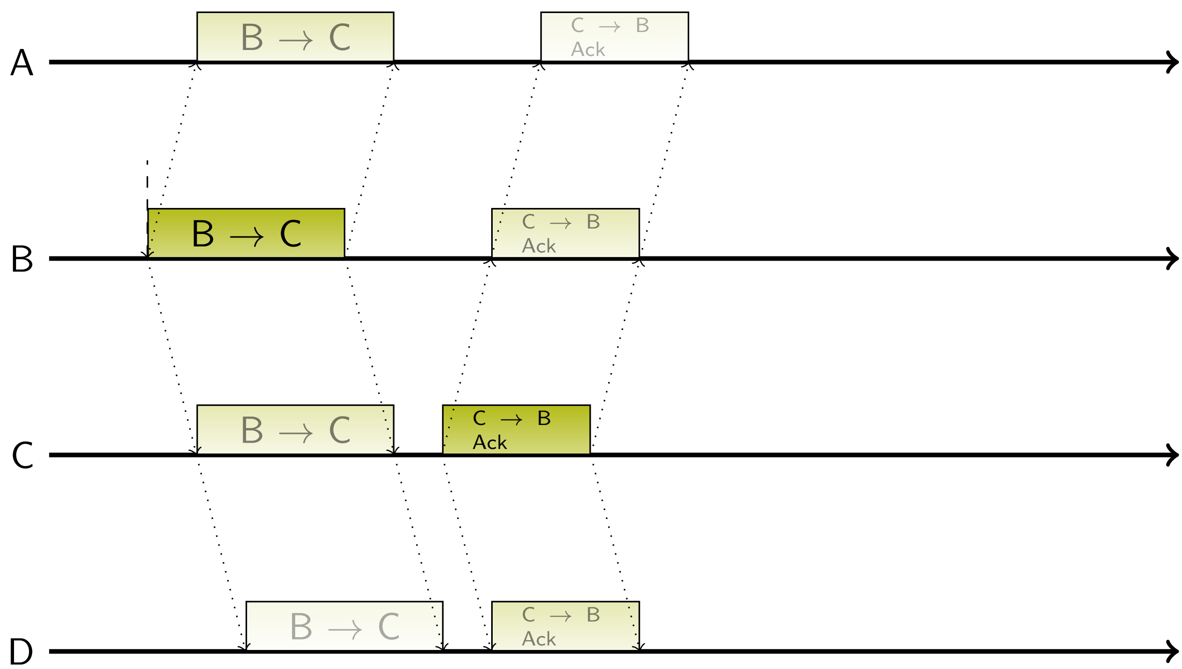
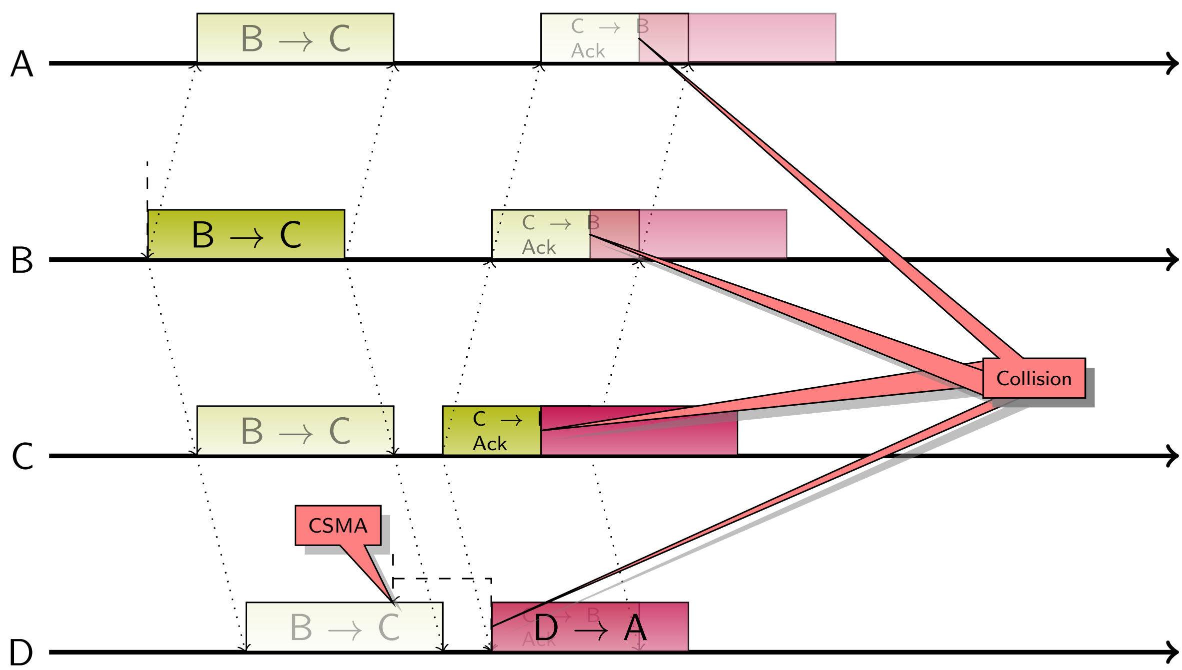
Acknowledgment: what does it change?



Acknowledgment: what does it change?

IEEE 802.11 ▶ CSMA/CA



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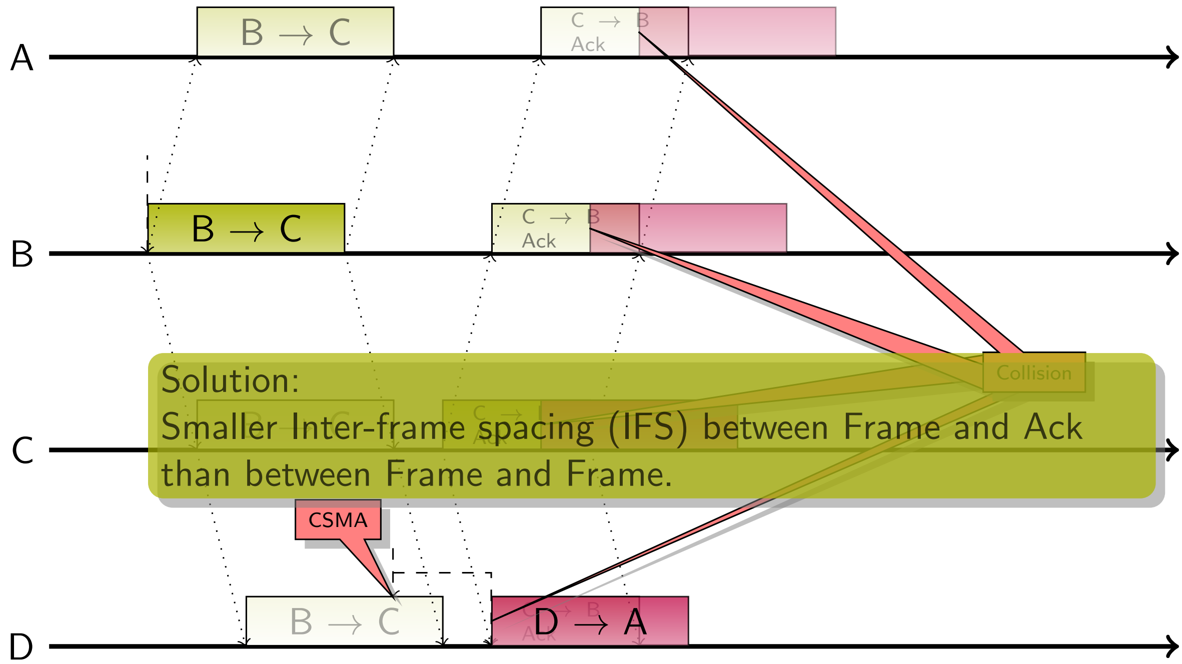
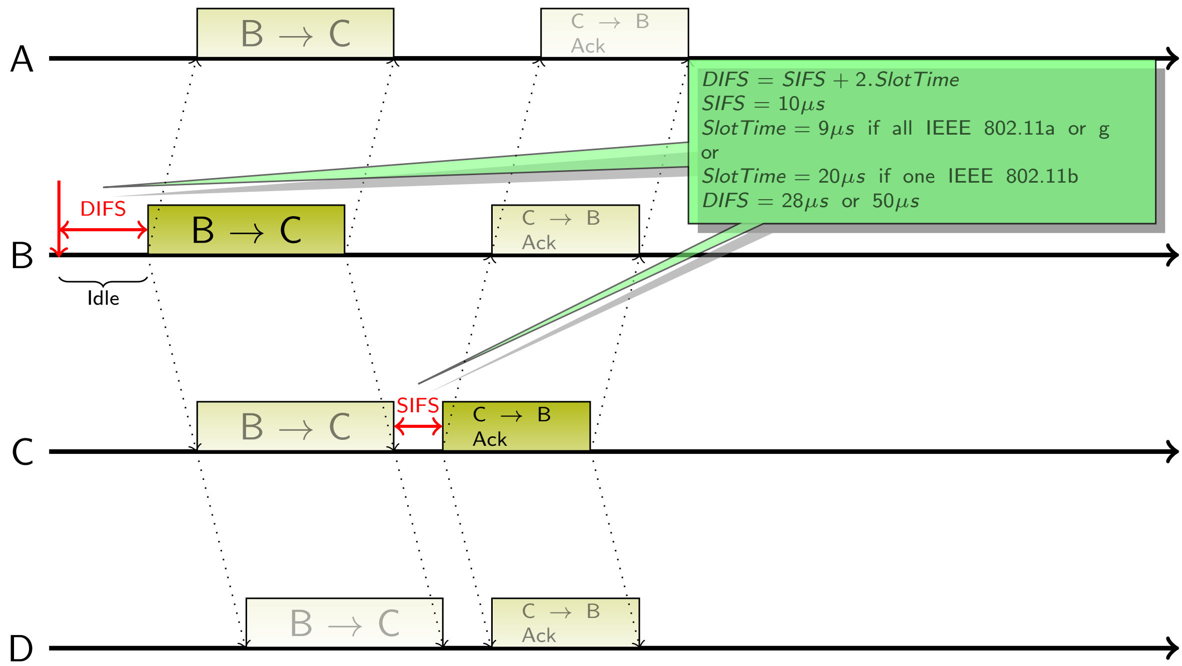
Acknowledgment: what does it change?



Solution:
Smaller Inter-frame spacing (IFS) between Frame and Ack than between Frame and Frame.

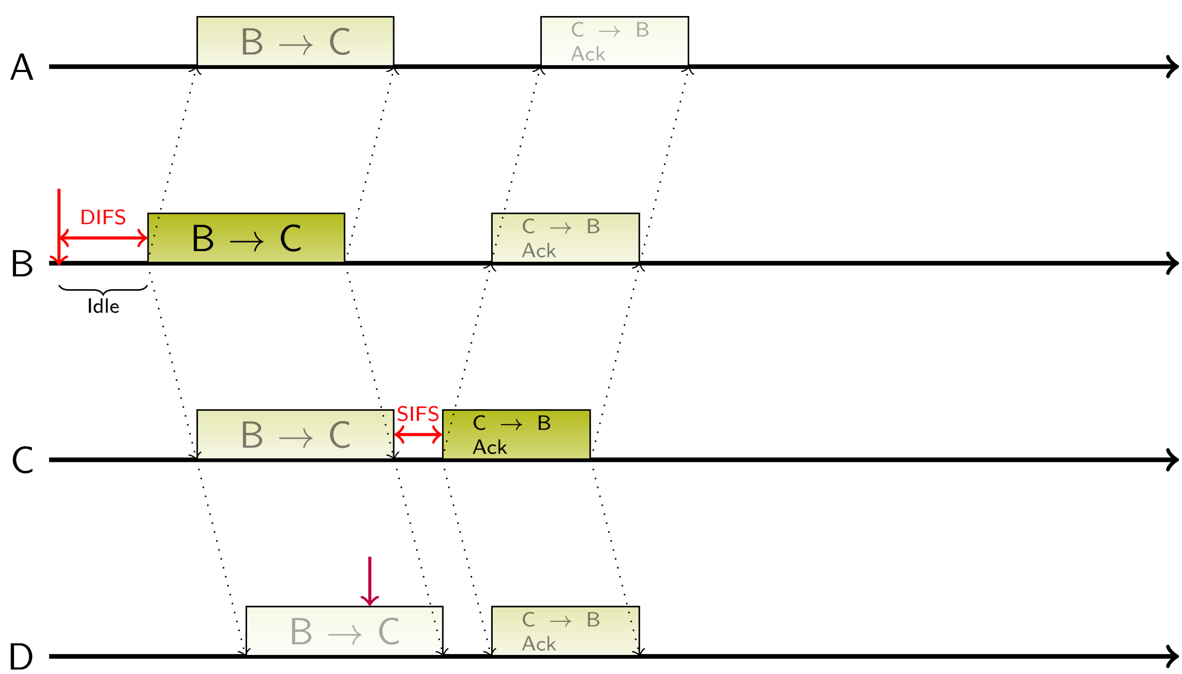
IEEE 802.11 ▶ CSMA/CA

Acknowledgment: what does it change?



$DIFS = SIFS + 2.SlotTime$
$SIFS = 10\mu s$
$SlotTime = 9\mu s$ if all IEEE 802.11a or g or
$SlotTime = 20\mu s$ if one IEEE 802.11b
$DIFS = 28\mu s$ or $50\mu s$

Acknowledgment: what does it change?



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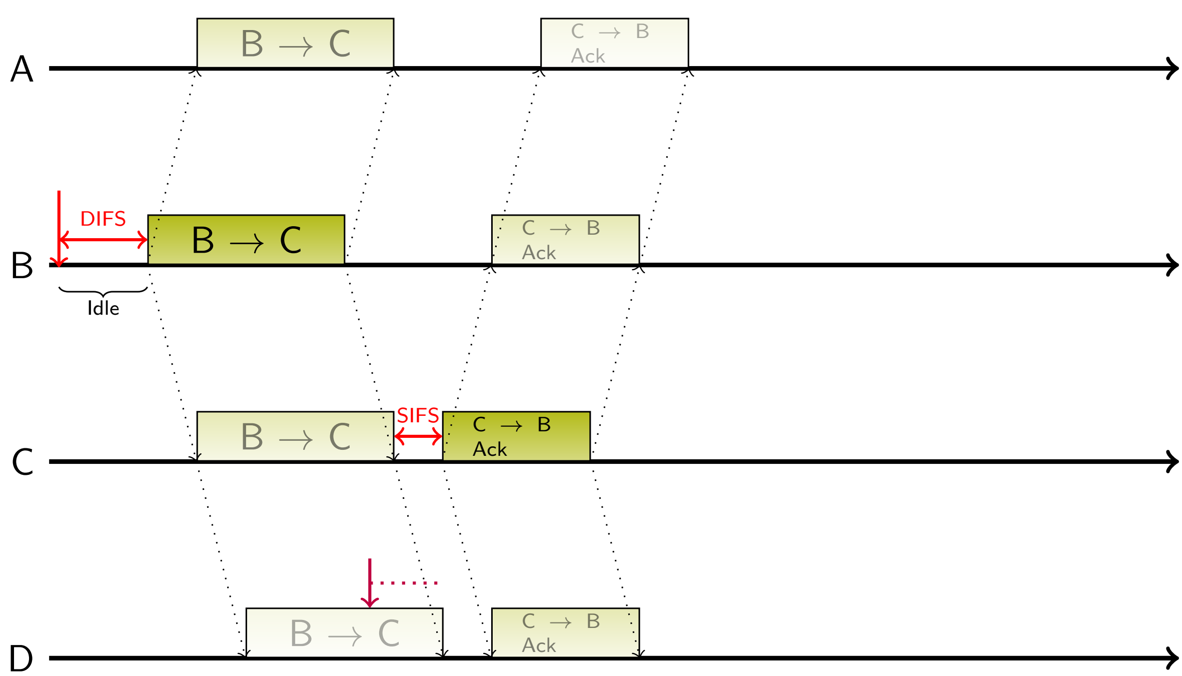

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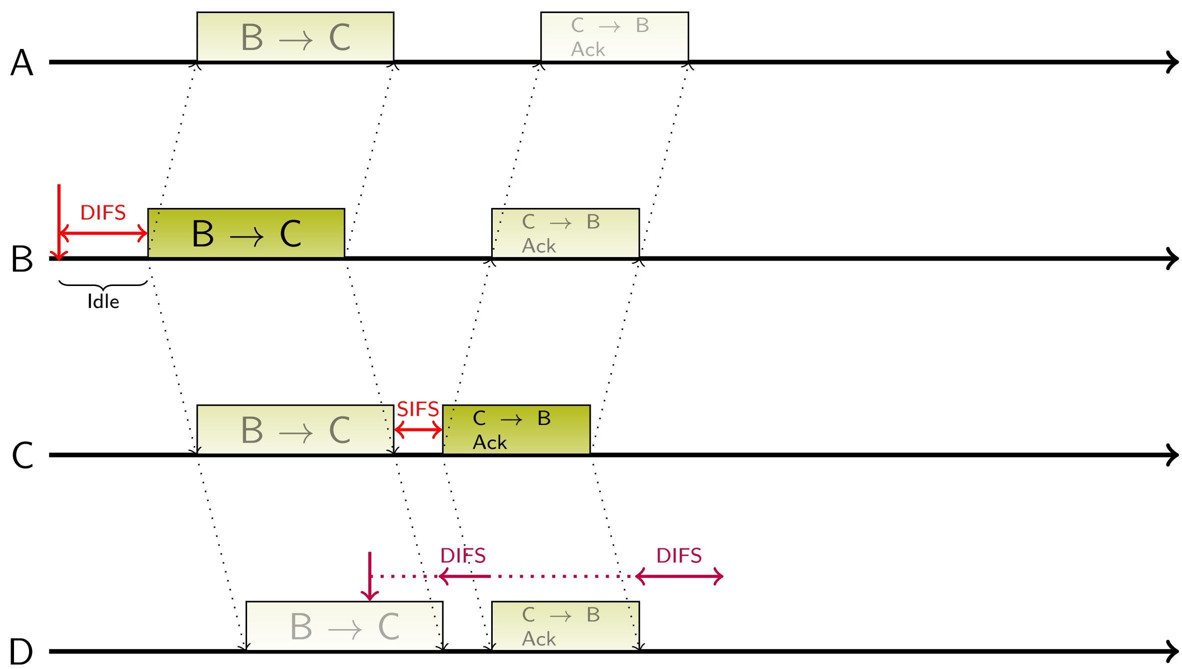

IEEE 802.11 ▶ CSMA/CA

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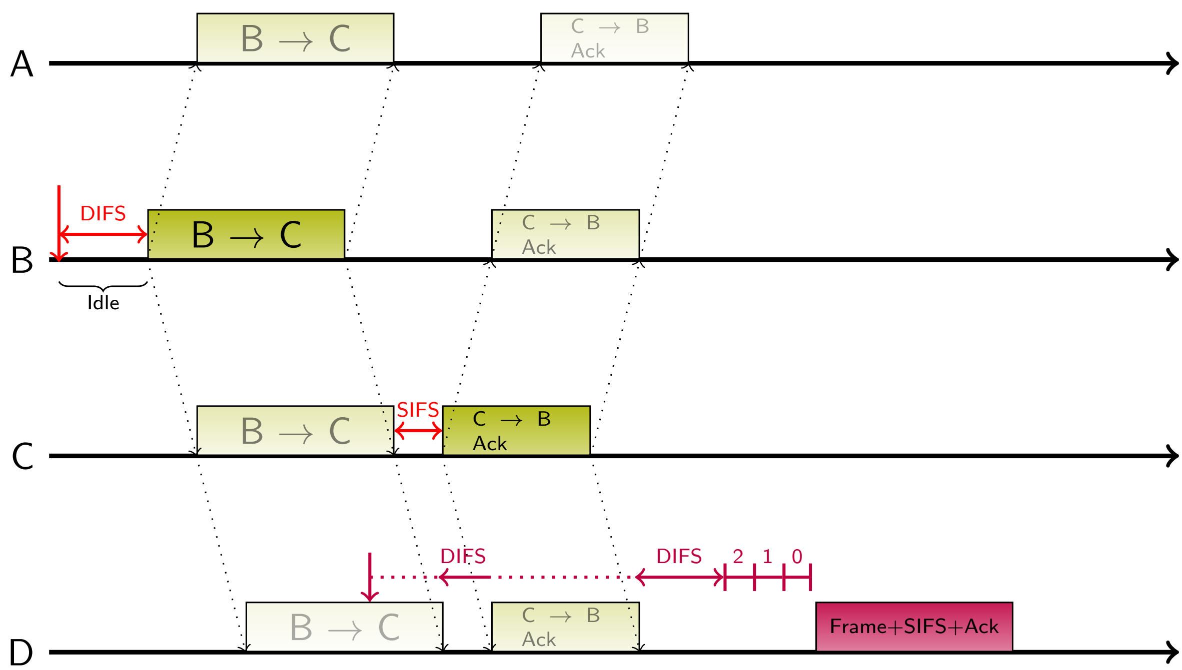

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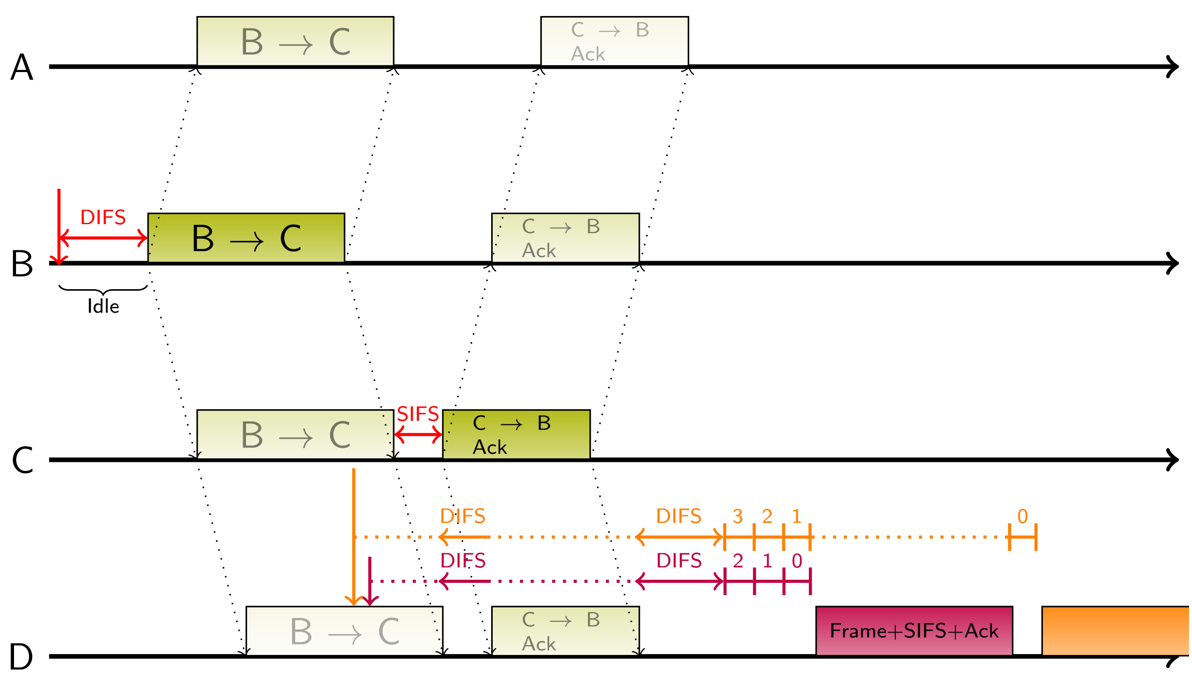

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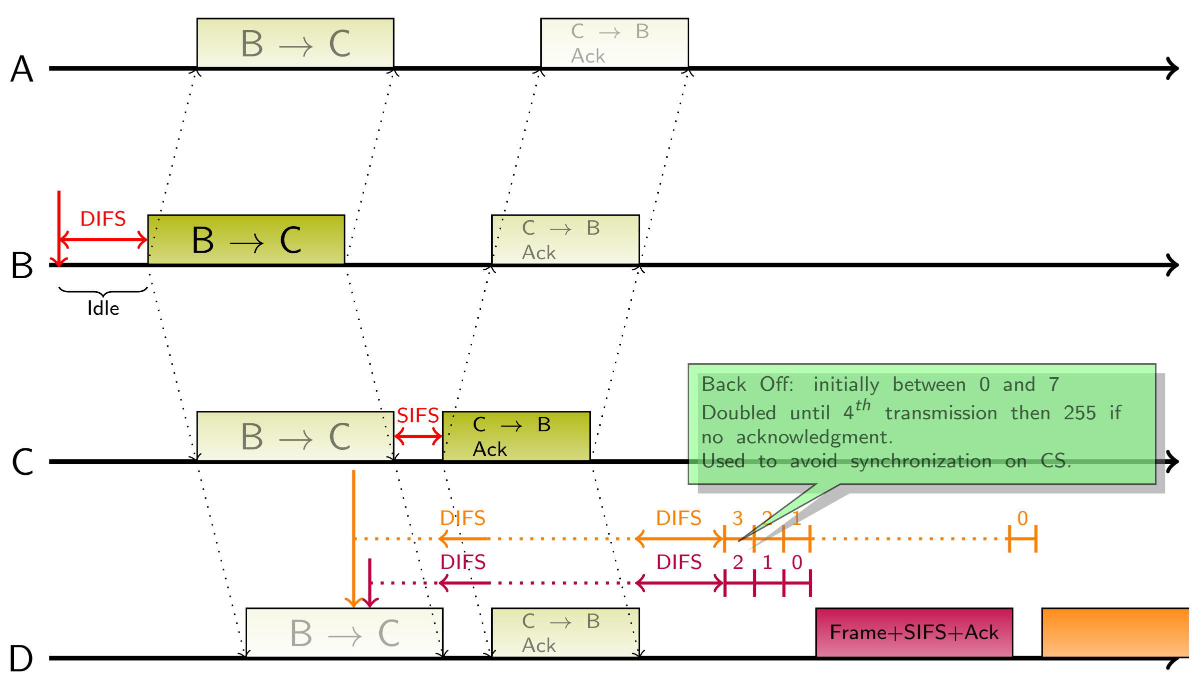
IEEE 802.11 ▶ CSMA/CA



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Questions

What is the real speed of an empty channel with IEEE 802.11g?
Suppose largest values of DIFS and frame size of 1000 Bytes (Ack frame is 14 Byte long)

IEEE 802.11 ▶ CSMA/CA

Questions

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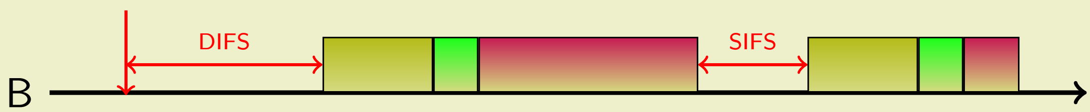
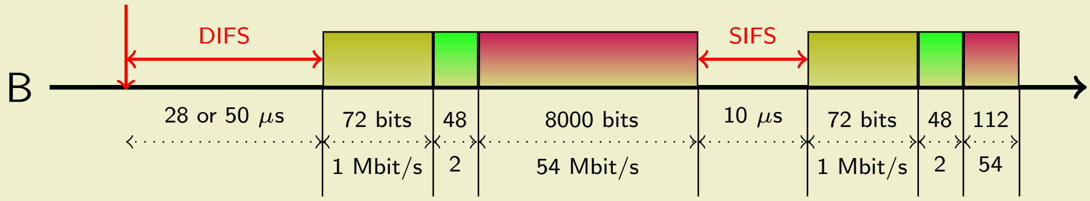
Suppose largest values of DIFS and frame size of 1000 Bytes (Ack frame is 14 Byte long)



What is the real speed of an empty channel with IEEE 802.11g?
Suppose largest values of DIFS and frame size of 1000 Bytes (Ack frame is 14 Byte long)



Questions

IEEE 802.11 ▶ CSMA/CA

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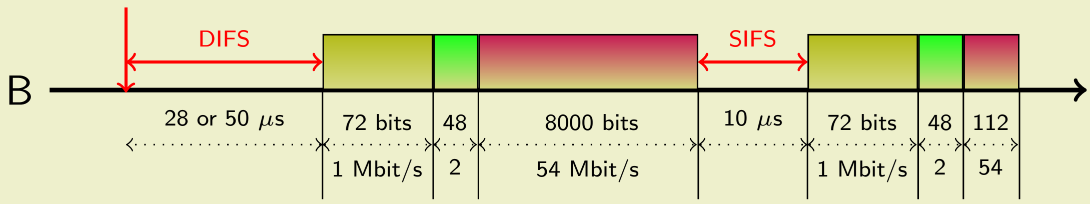
Suppose largest values of DIFS and frame size of 1000 Bytes (Ack frame is 14 Byte long)



$$T_{20\mu s\_1000B} = 50.10^{-9} + 72.10^{-6} + 24.10^{-6} + 148.10^{-6} + 10^{-9} + 72.10^{-6} + 24.10^{-6} + 2.10^{-6}$$

$$= 342,06.10^{-6}\mu s$$

$$Throughput = \frac{8000 bits}{34210^{-6}\mu s} = 23 Mbit/s$$

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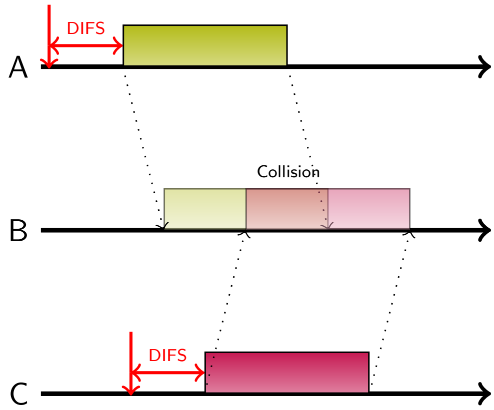
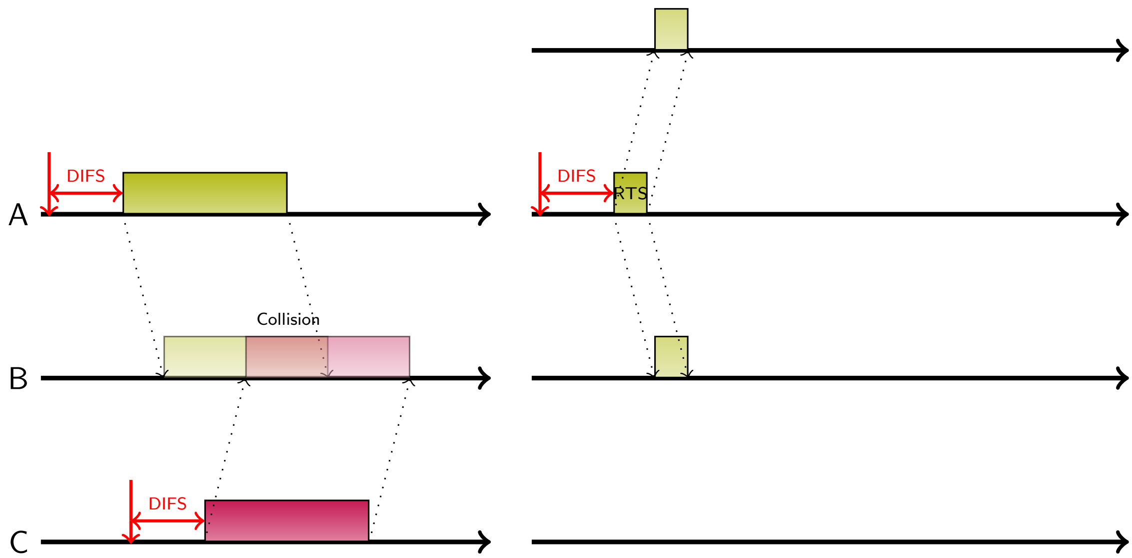
Hidden hosts



Hidden hosts

IEEE 802.11 ▶ CSMA/CA



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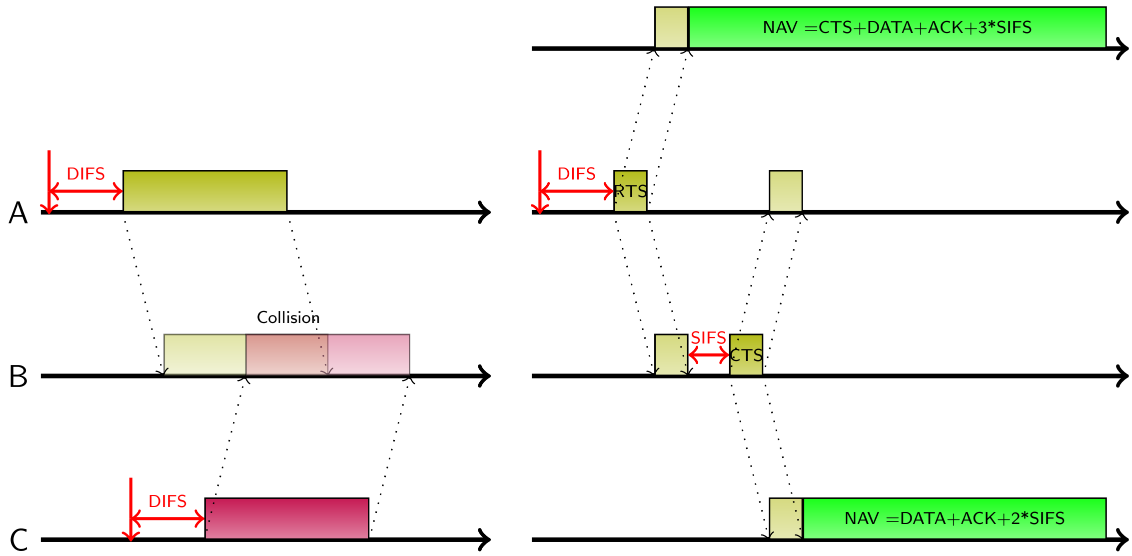
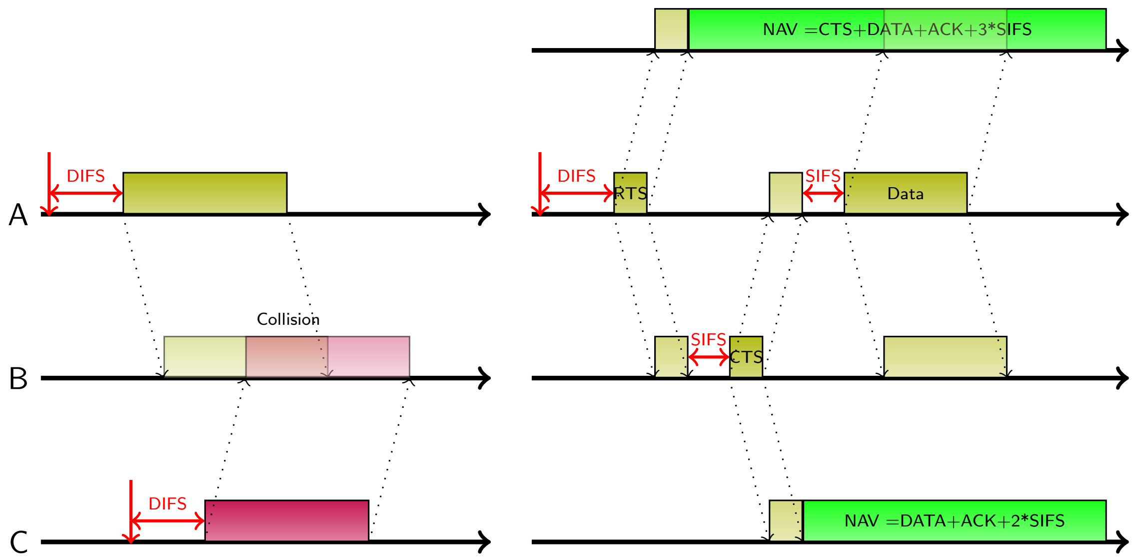


IEEE 802.11 ▶ CSMA/CA

Hidden hosts



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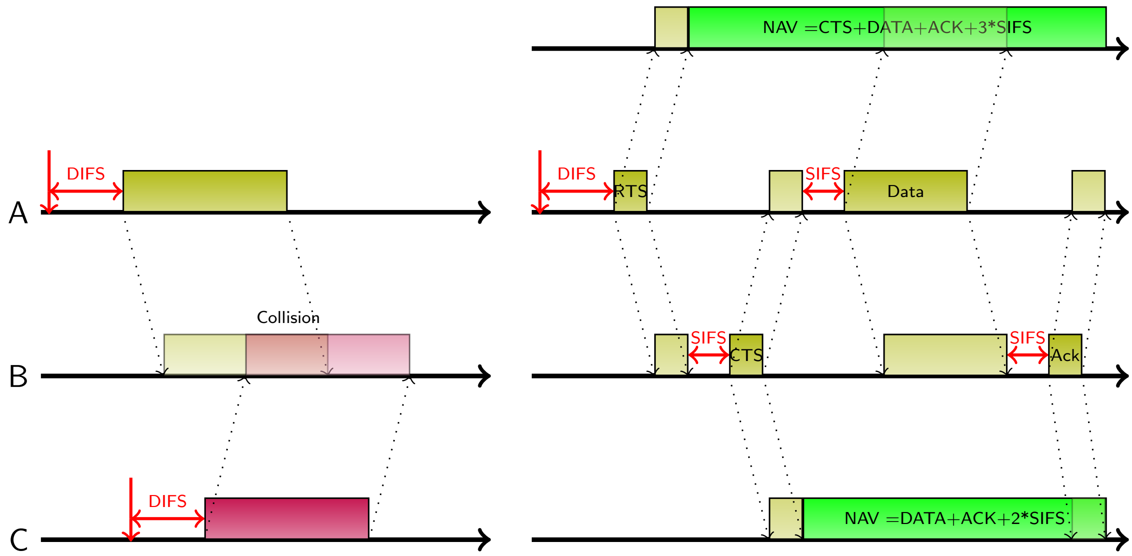

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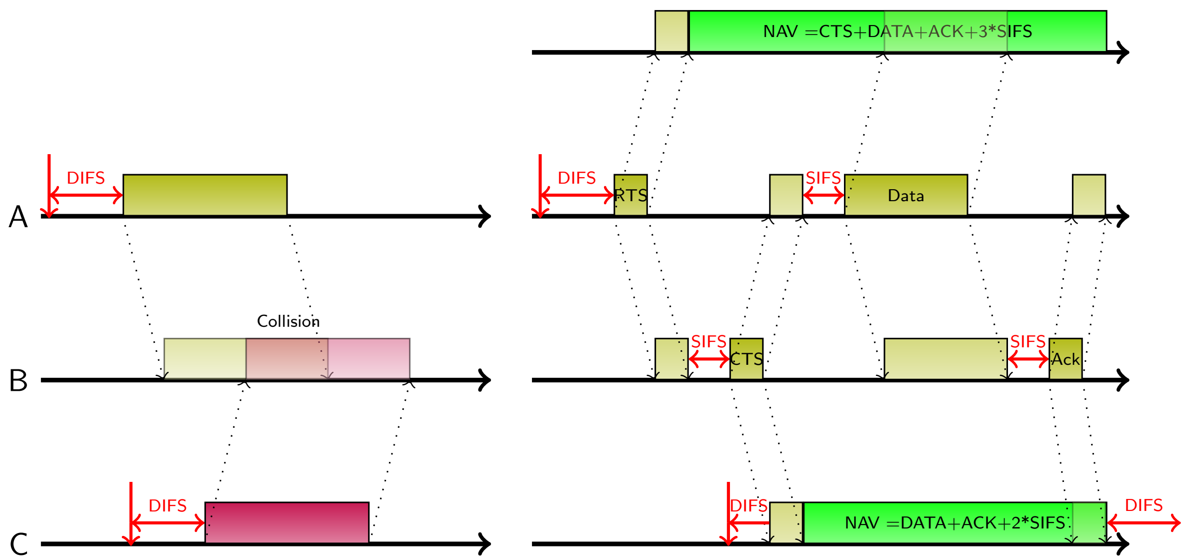
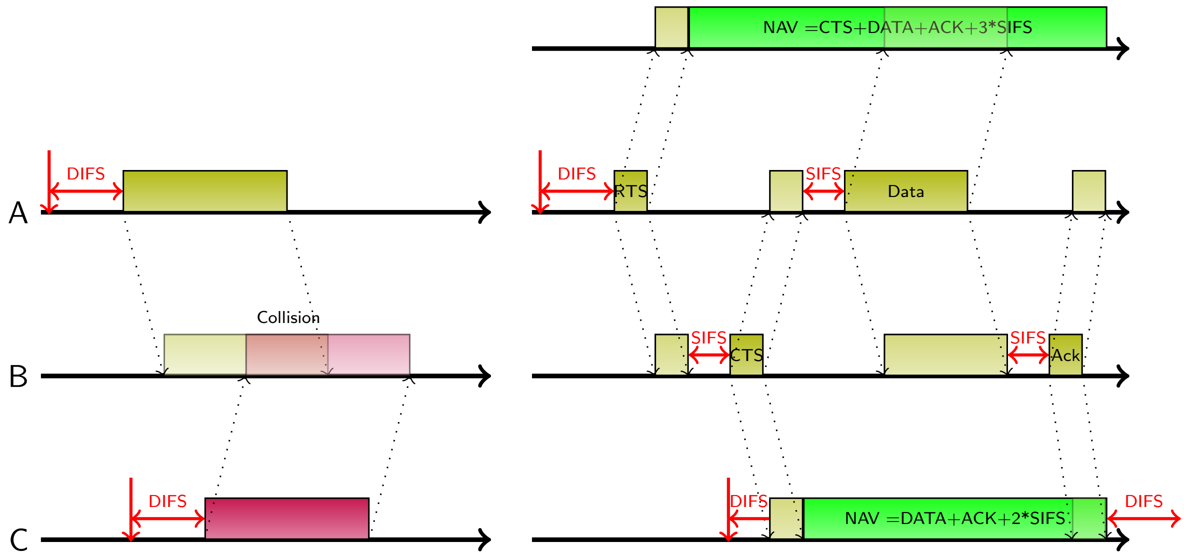
IEEE 802.11 ▶ CSMA/CA



Hidden hosts

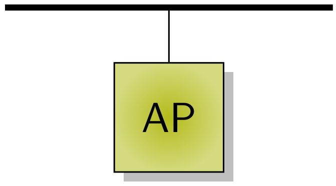


Disabled by default. If collision rate is too high, activate for frame larger than 500 Bytes. Not implemented on every IEEE 802.11 cards.

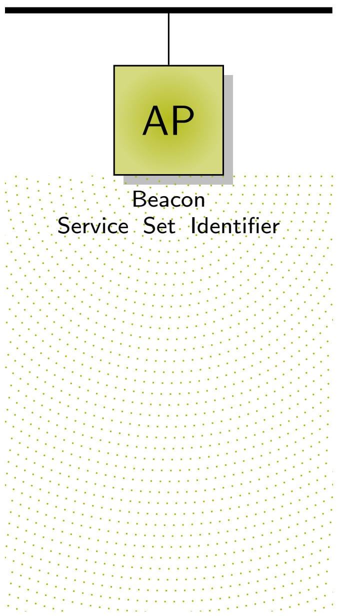
IEEE 802.11

Architecture and Frames

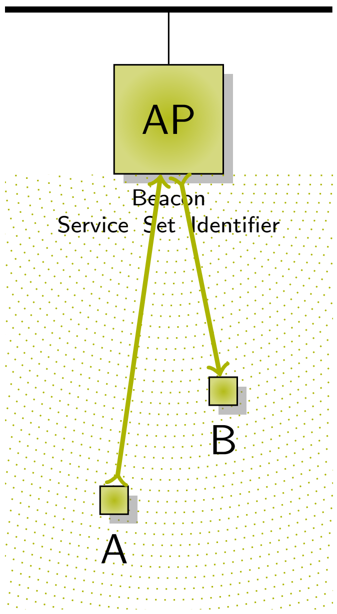
Architectures (infrastructure)



Architectures (infrastructure)

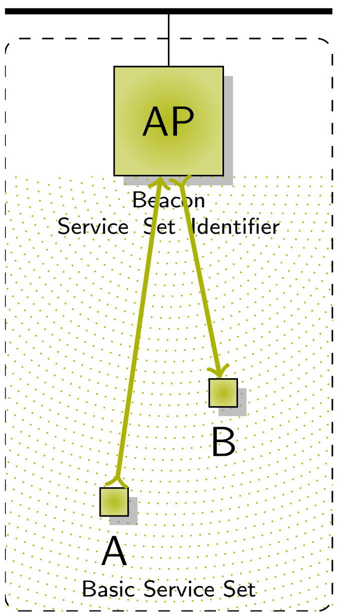


Architectures (infrastructure)

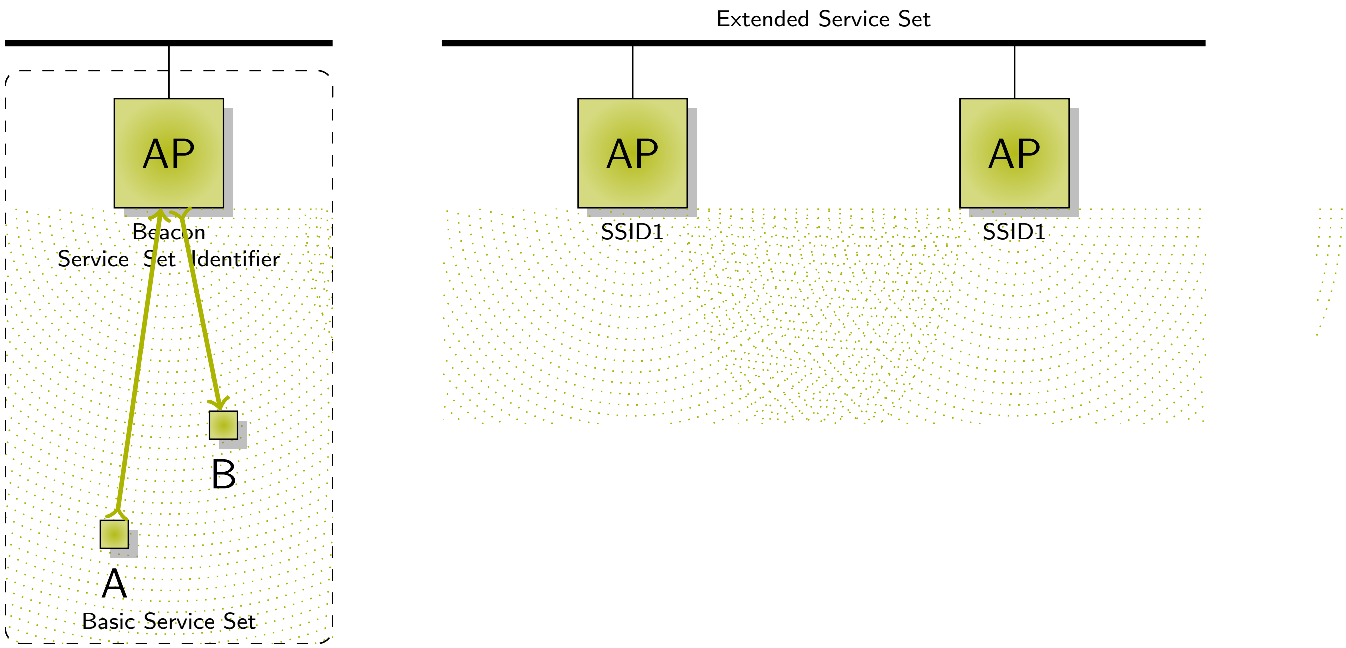


Architectures (infrastructure)

IEEE 802.11 ▶ Architecture and Frames

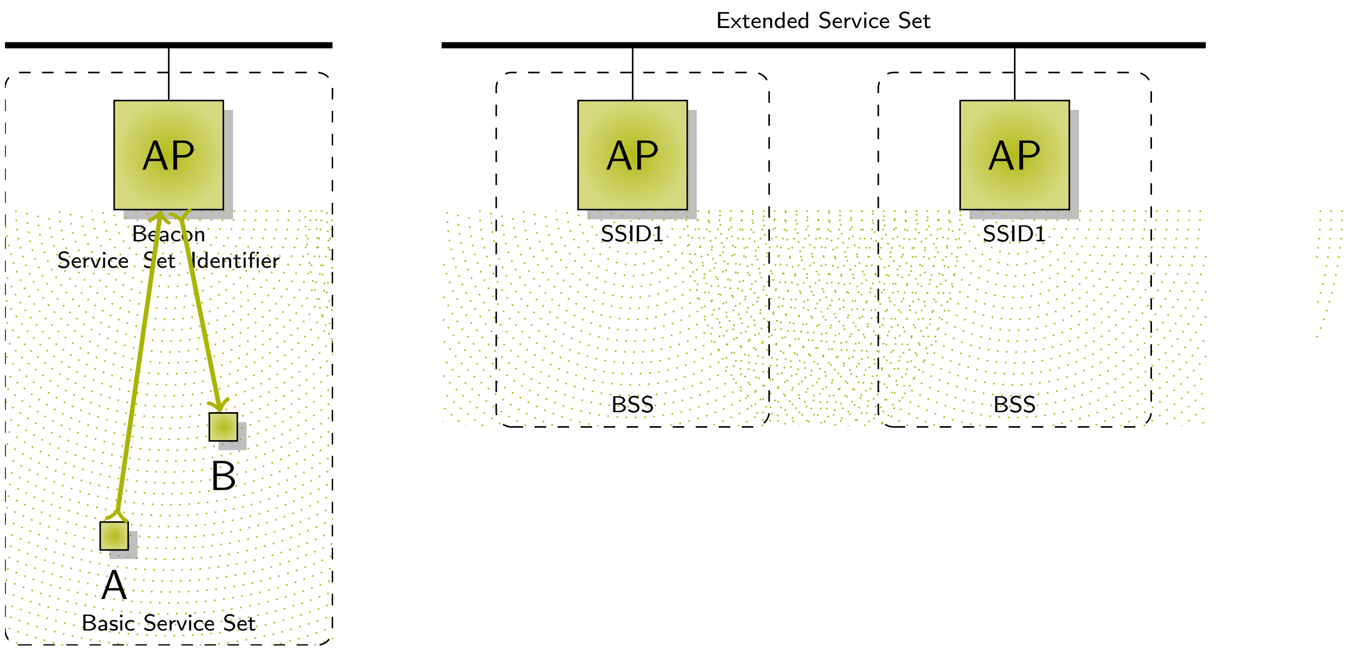


Architectures (infrastructure)

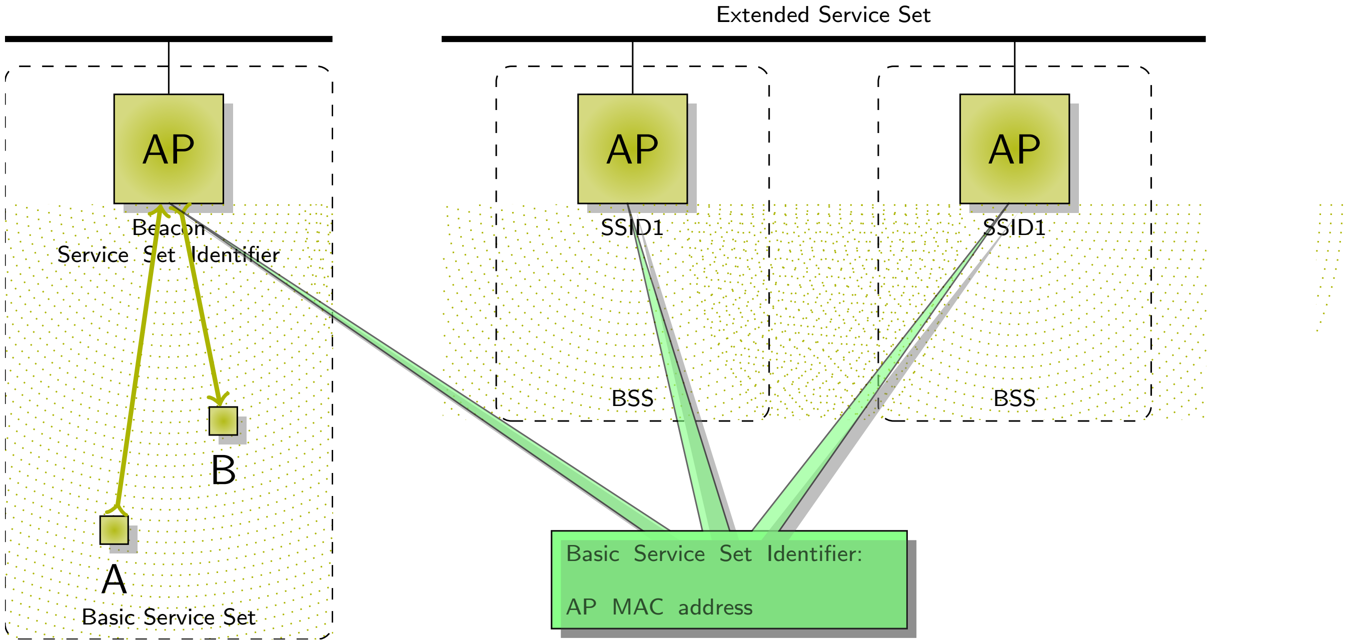


Architectures (infrastructure)

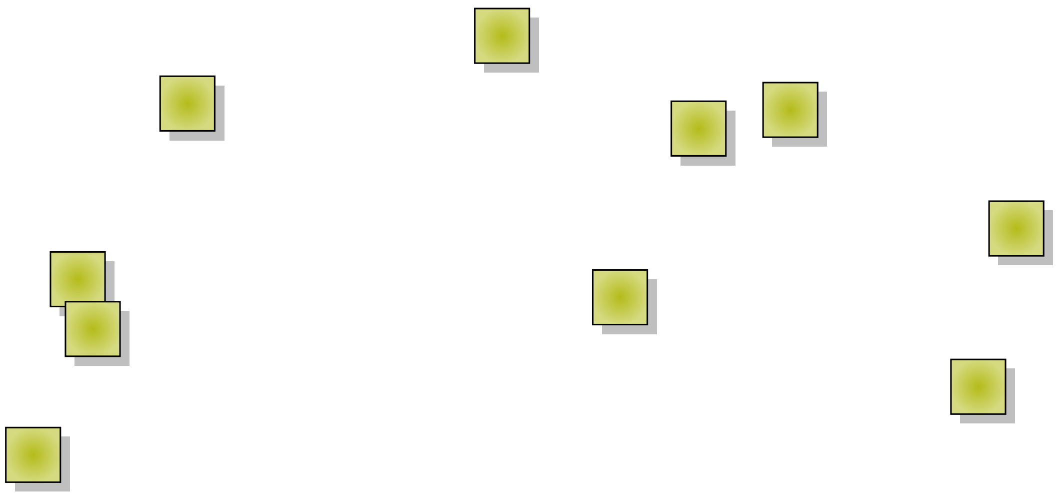
IEEE 802.11 ▶ Architecture and Frames



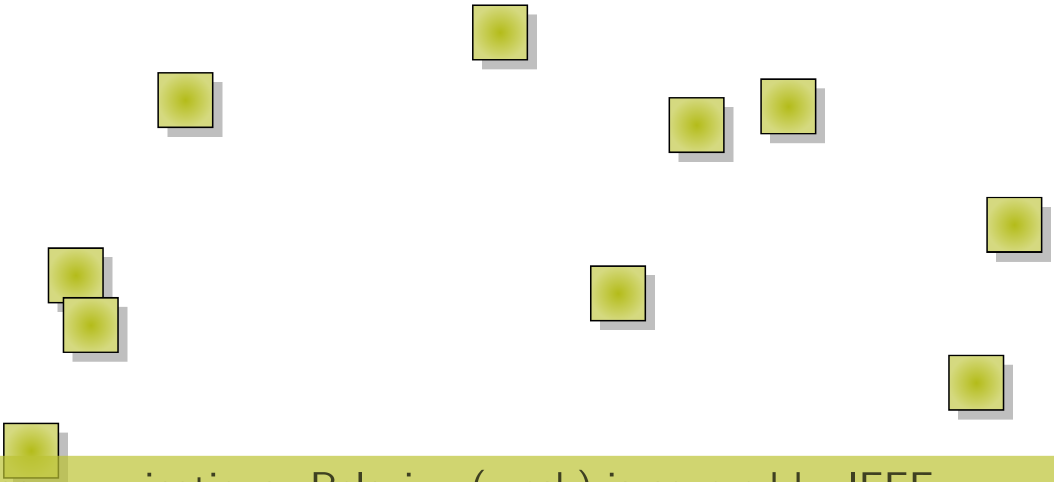
Architectures (infrastructure)



Architectures (Ad Hoc)



Architectures (Ad Hoc)

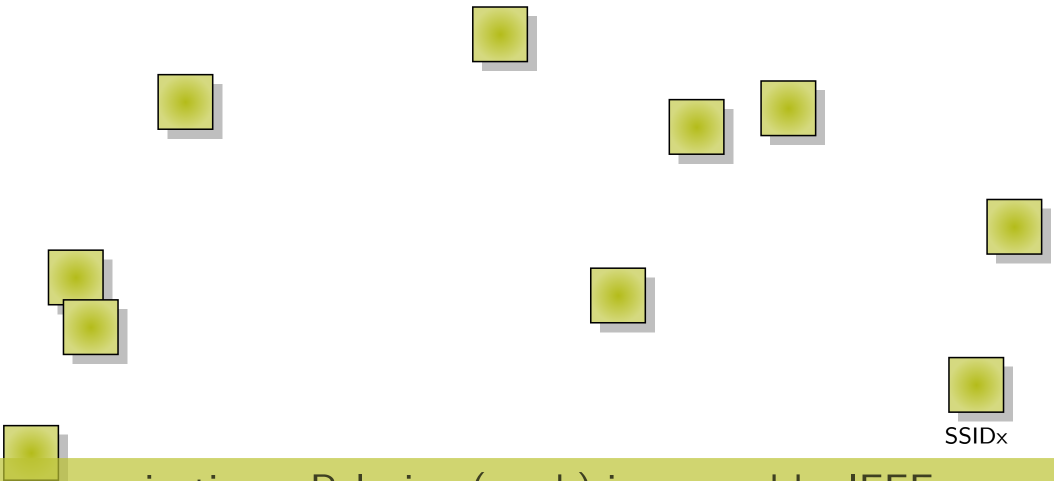


Direct communications. Relaying (mesh) is covered by IEEE 802.11s or with OLSR

All node mot be manually configured, or use iBSS

Architectures (Ad Hoc)

IEEE 802.11 ▶ Architecture and Frames



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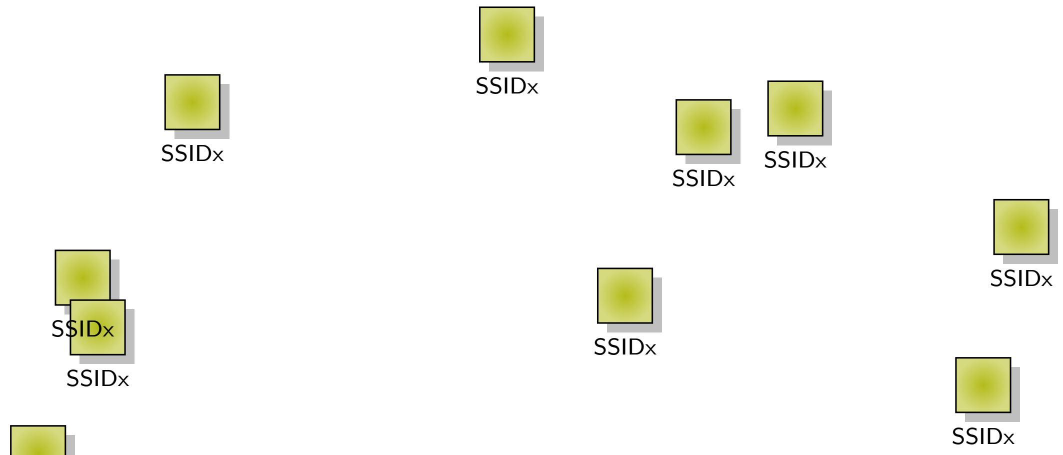
Architectures (Ad Hoc)



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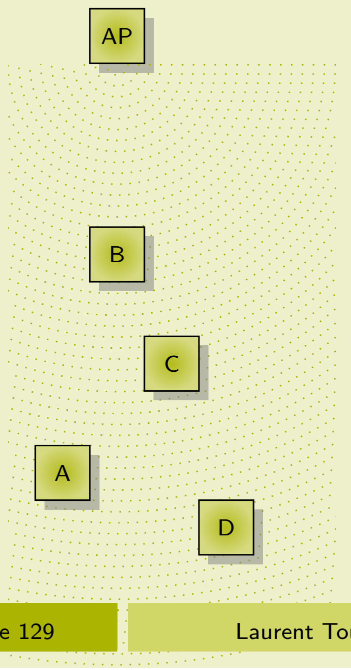
IEEE 802.11 ▶ Architecture and Frames

Questions



What happen if B send a broadcast Frame ?

Do we have a guaranty that all receivers got the frame ?

Can RTS/CTS be used ?

At which rate should be sent the multicast frame ?

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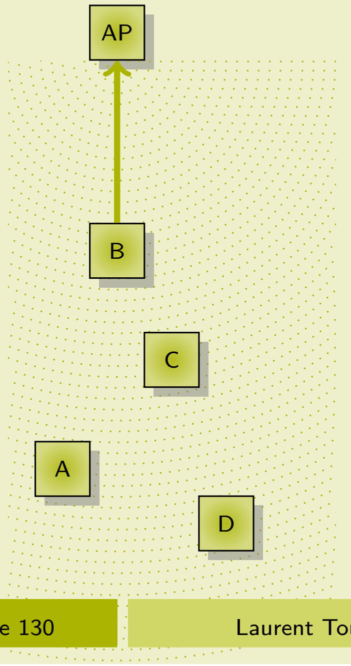

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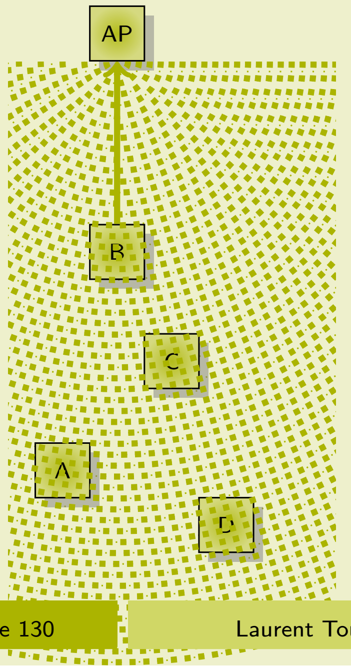

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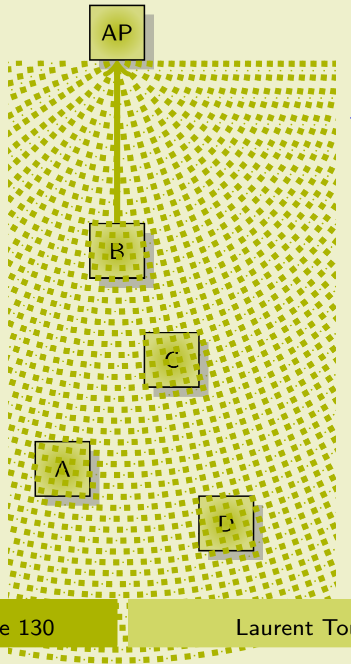


What happen if B send a broadcast Frame ?
B send to AP and AP broadcast the frame

Do we have a guaranty that all receivers got the frame ?
No, there is no ack for Broadcast frame, if a collision occurs there is no way to detect it.

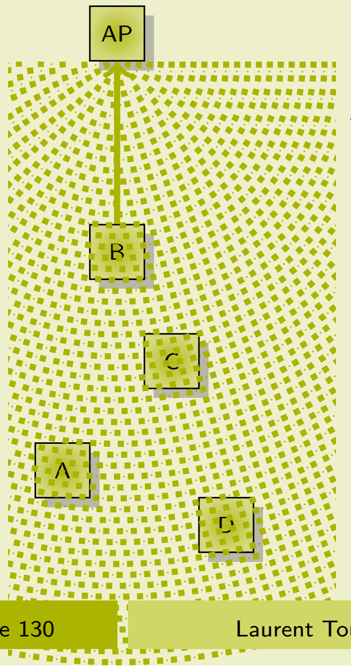
Can RTS/CTS be used ?

At which rate should be sent the multicast frame ?

TELECOM Bretagne

Questions

IEEE 802.11 ▶ Architecture and Frames



What happen if B send a broadcast Frame ?
B send to AP and AP broadcast the frame

Do we have a guaranty that all receivers got the frame ?
No, there is no ack for Broadcast frame, if a collision occurs there is no way to detect it.

Can RTS/CTS be used ?
No, since it is a multicast frame AP cannot request to a specific destination

At which rate should be sent the multicast frame ?
Lowest rate among Stations associated to the AP.

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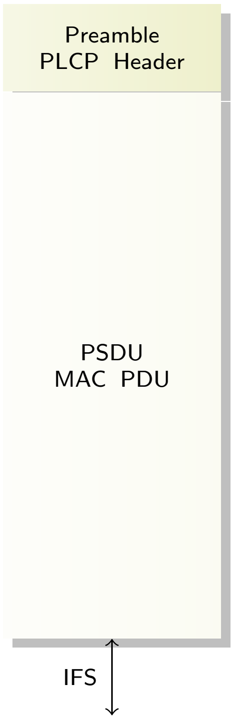
MAC Frame Format



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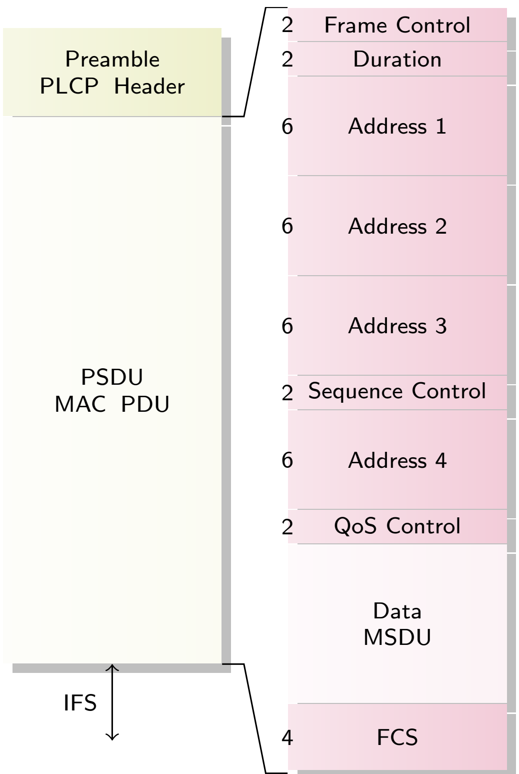

MAC Frame Format

Preamble PLCP Header
PSDU MAC PDU
IFS

Size	MAC field
2	Frame Control
2	Duration
6	Address 1
6	Address 2
6	Address 3
2	Sequence Control
6	Address 4
2	QoS Control
	Data MSDU
4	FCS

Frame Control field	Size
Proto Vers = 00	2
Control	2
Sub Type	4
to DS	1
from DS	1
More Fragments	1
Retry	1
Power Mgt.	1
More data	1
Protected Frame	1
Order	1

MAC Frame Format

IEEE 802.11 ▶ Architecture and Frames

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00 xxxx : Management
00 0001: Association request
00 0010: Association response
00 1000: Beacon

01 xxxx: Control
01 1011: RTS
01 1100: CTS
01 1101: Ack

10 0000: data

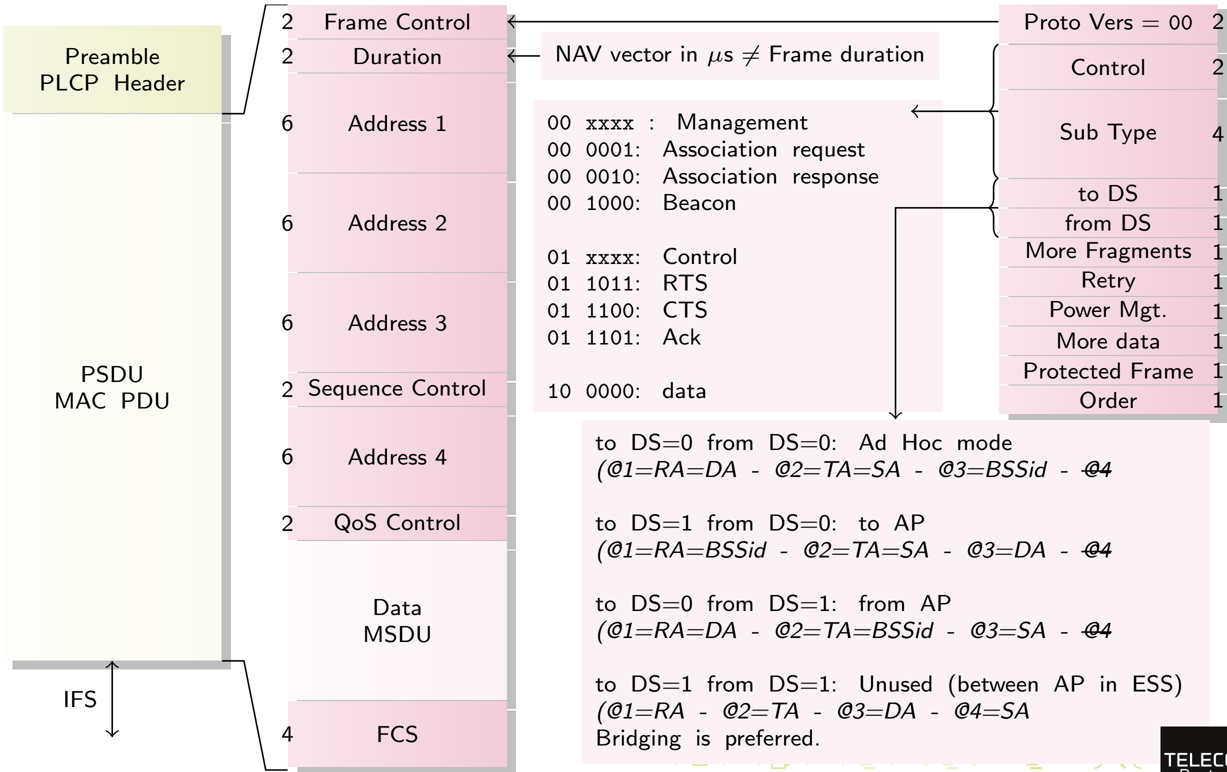
to DS=0 from DS=0: Ad Hoc mode
(@1=RA=DA - @2=TA=SA - @3=BSSid - ~~@4~~

to DS=1 from DS=0: to AP
(@1=RA=BSSid - @2=TA=SA - @3=DA - ~~@4~~

to DS=0 from DS=1: from AP
(@1=RA=DA - @2=TA=BSSid - @3=SA - ~~@4~~

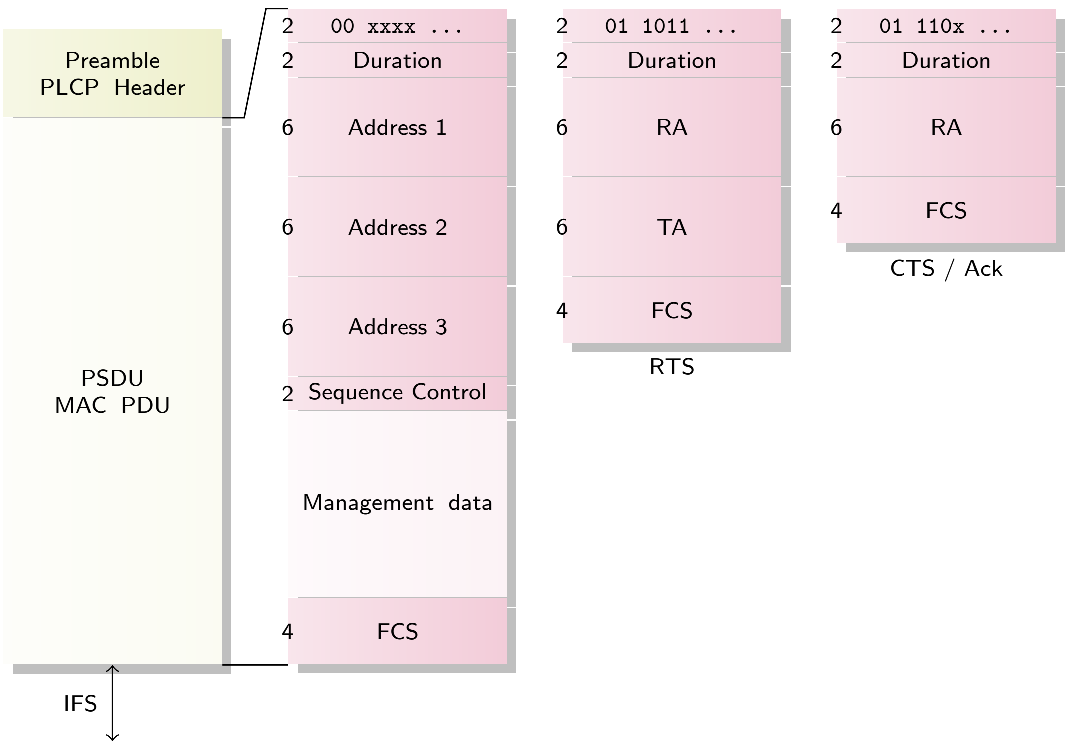
to DS=1 from DS=1: Unused (between AP in ESS)
(@1=RA - @2=TA - @3=DA - @4=SA
Bridging is preferred.

MAC Frame Format



MAC Frame Format

IEEE 802.11 ▶ Architecture and Frames



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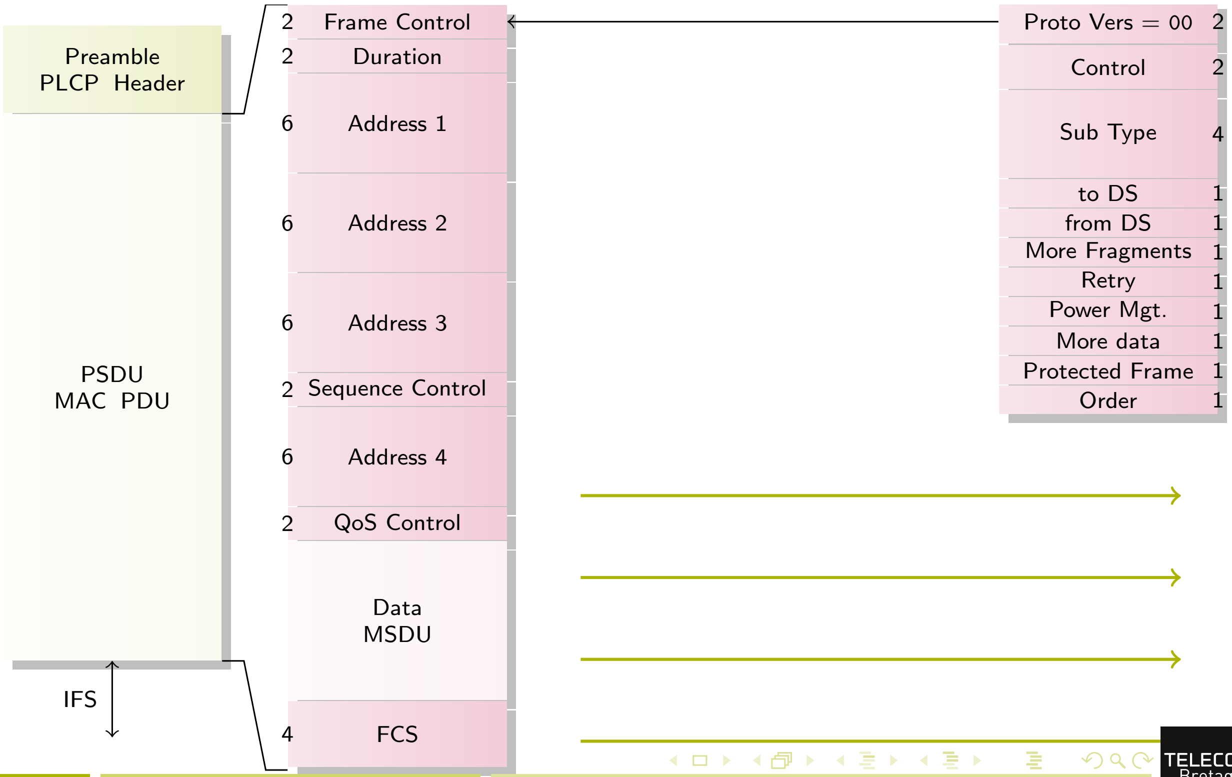
MAC Fragmentation



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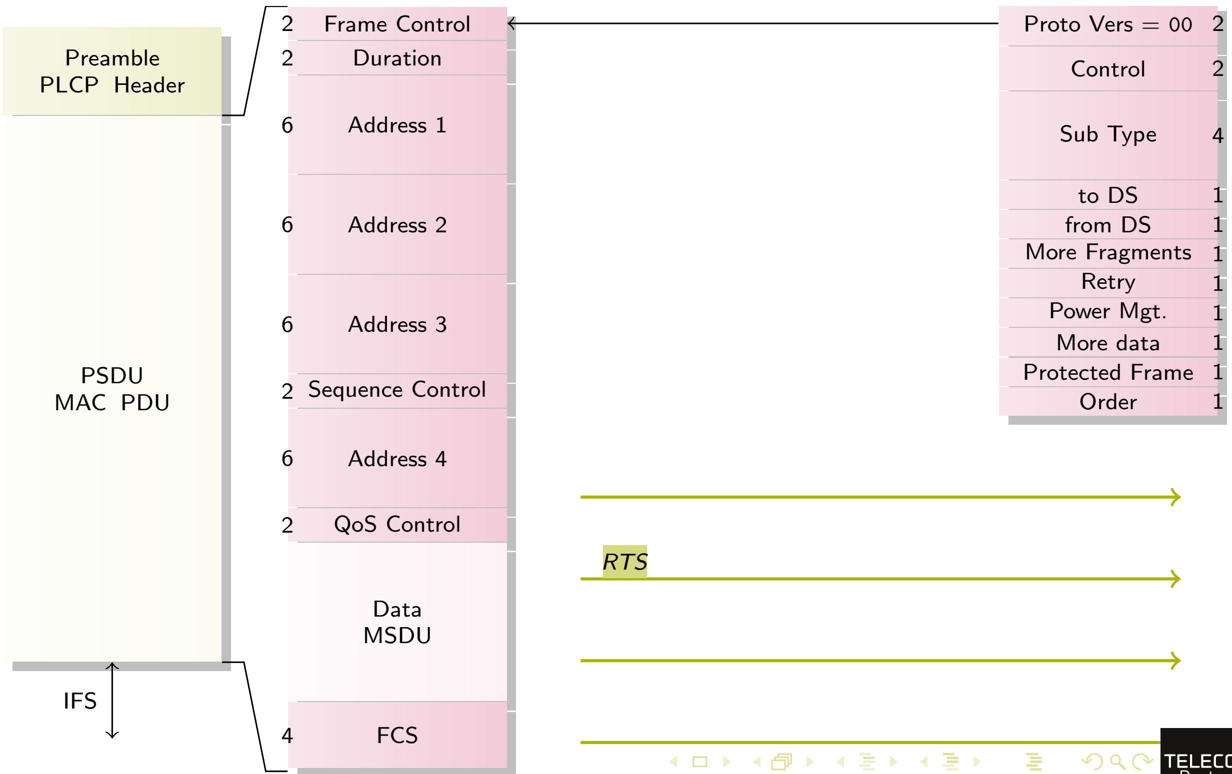
IEEE 802.11 ▶ Architecture and Frames



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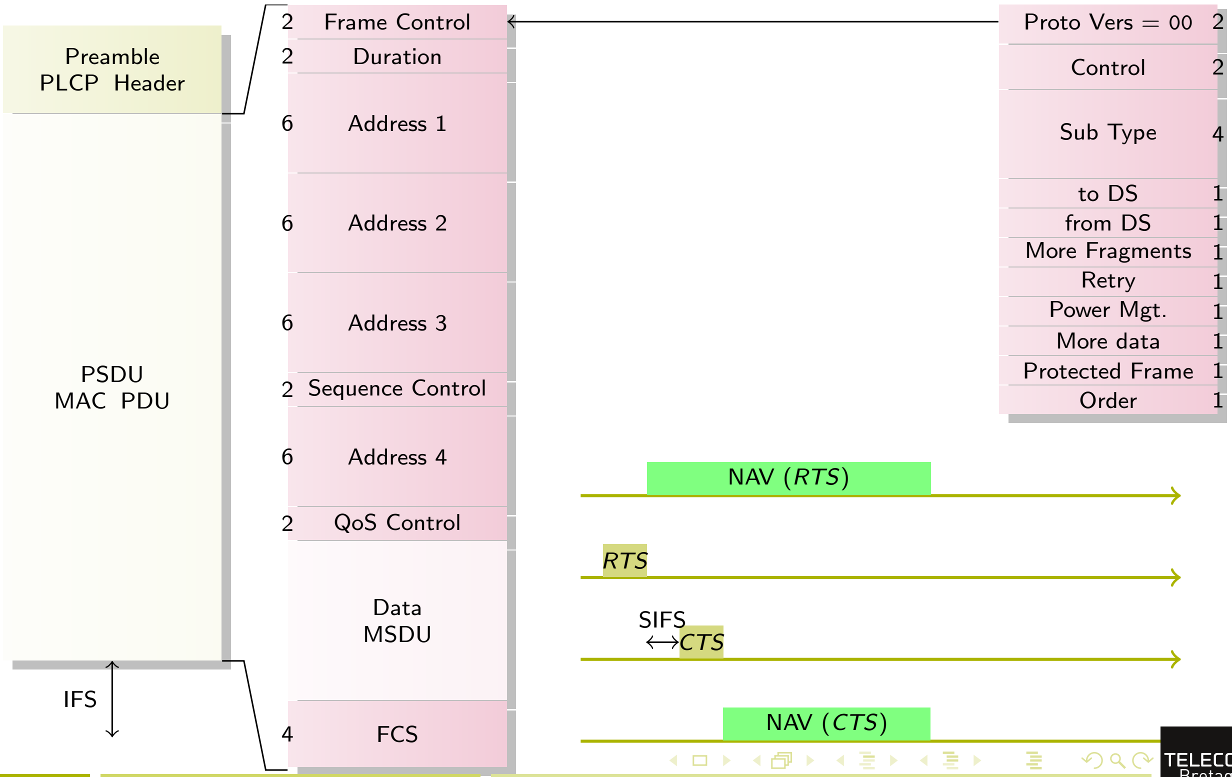

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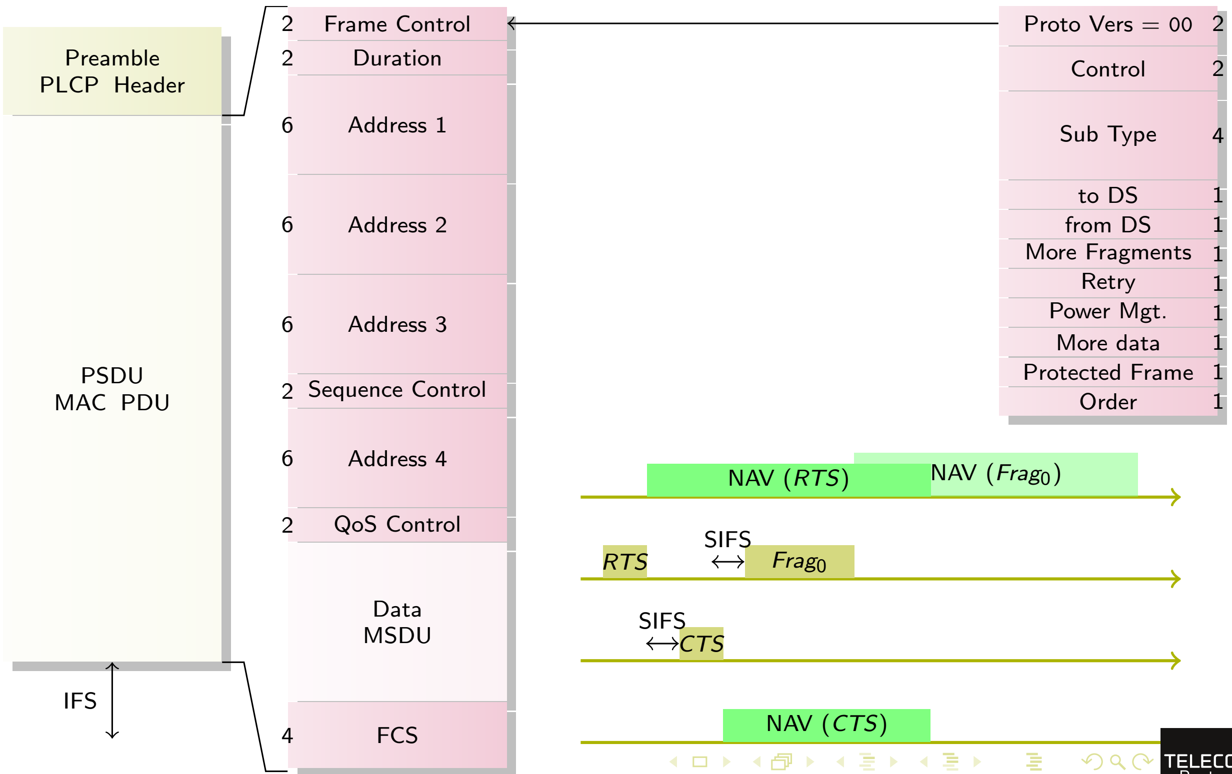

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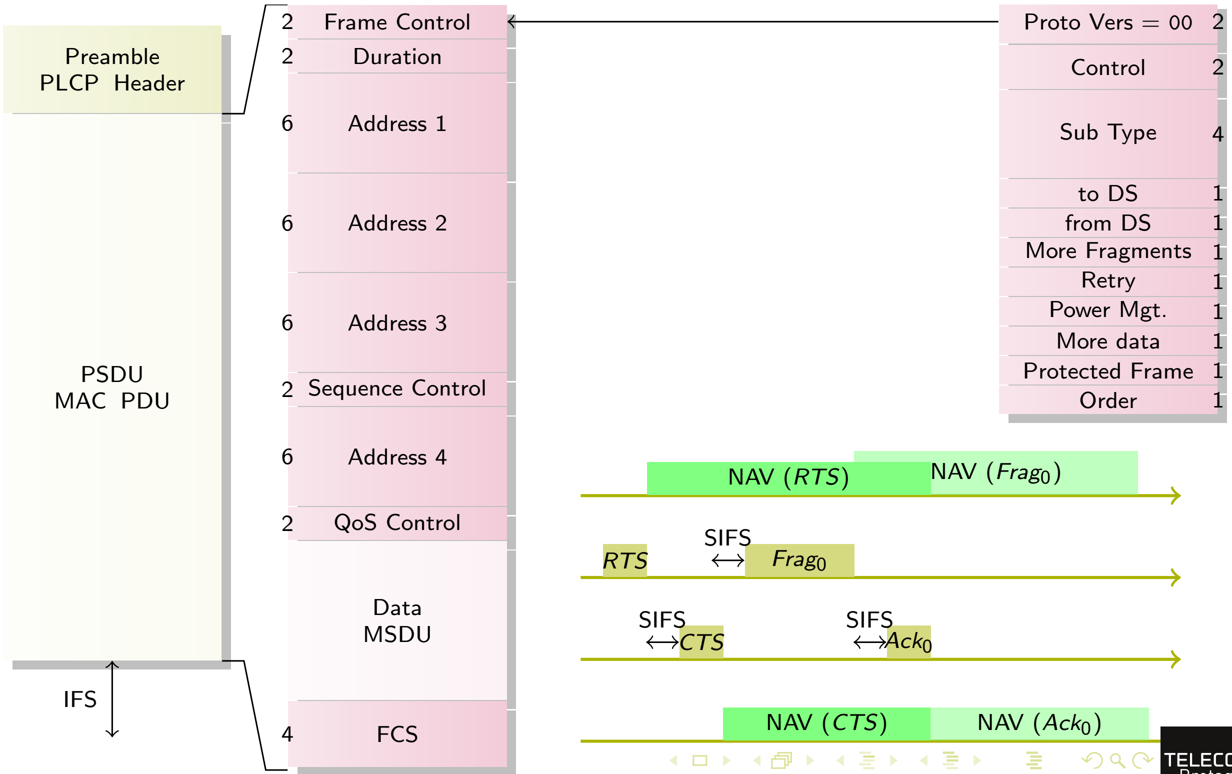

IEEE 802.11 ▶ Architecture and Frames

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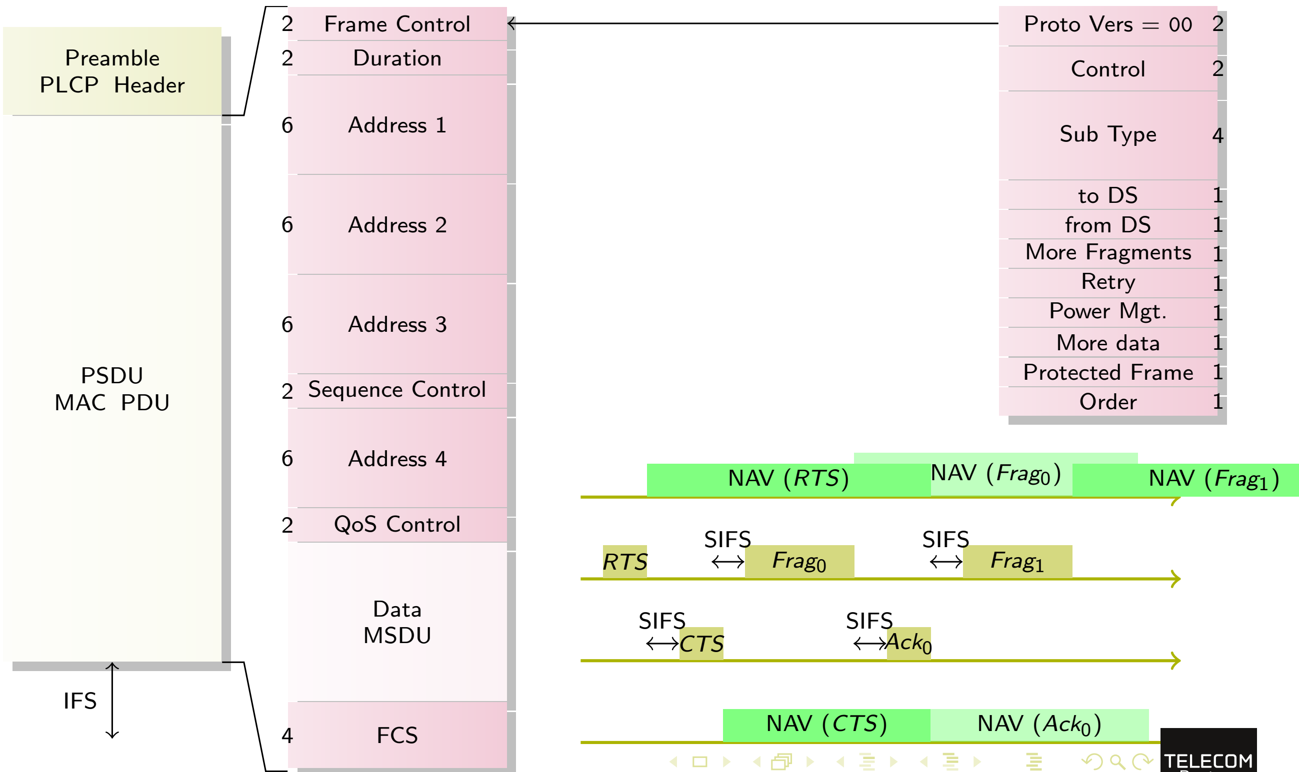

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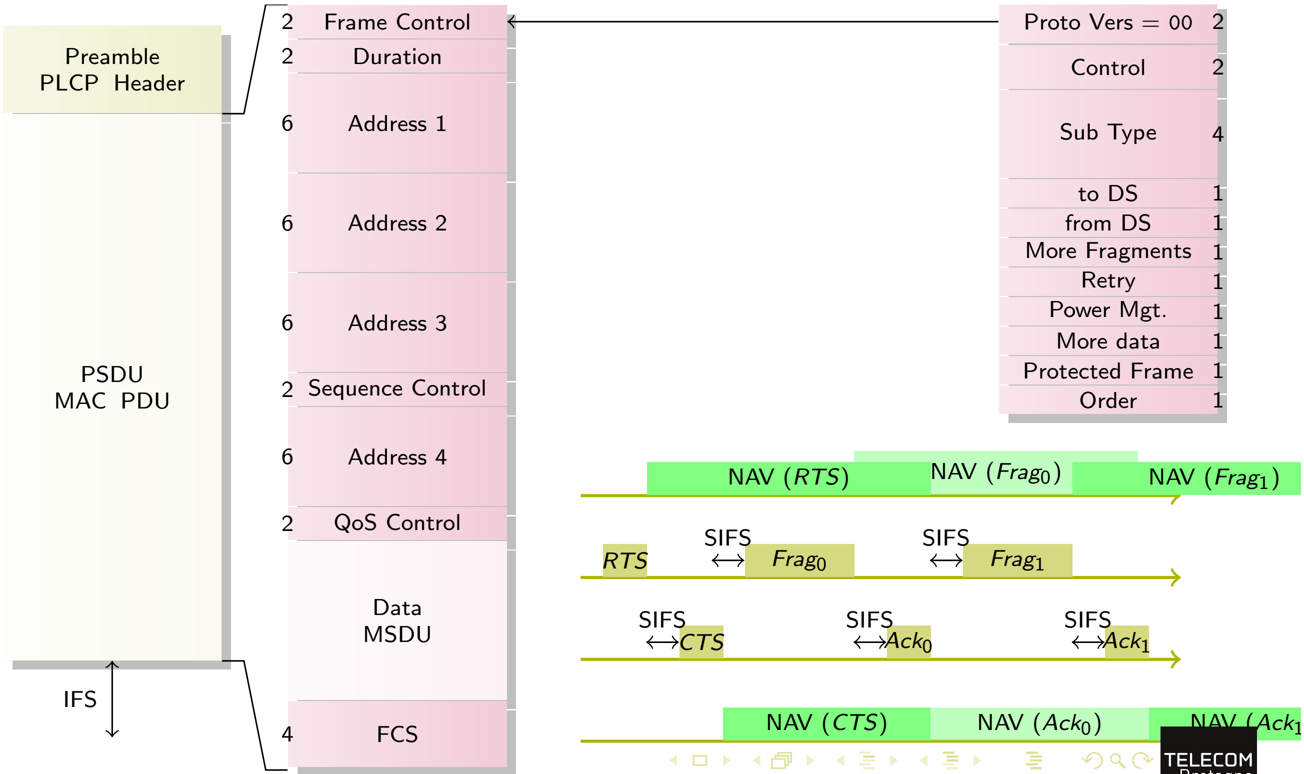

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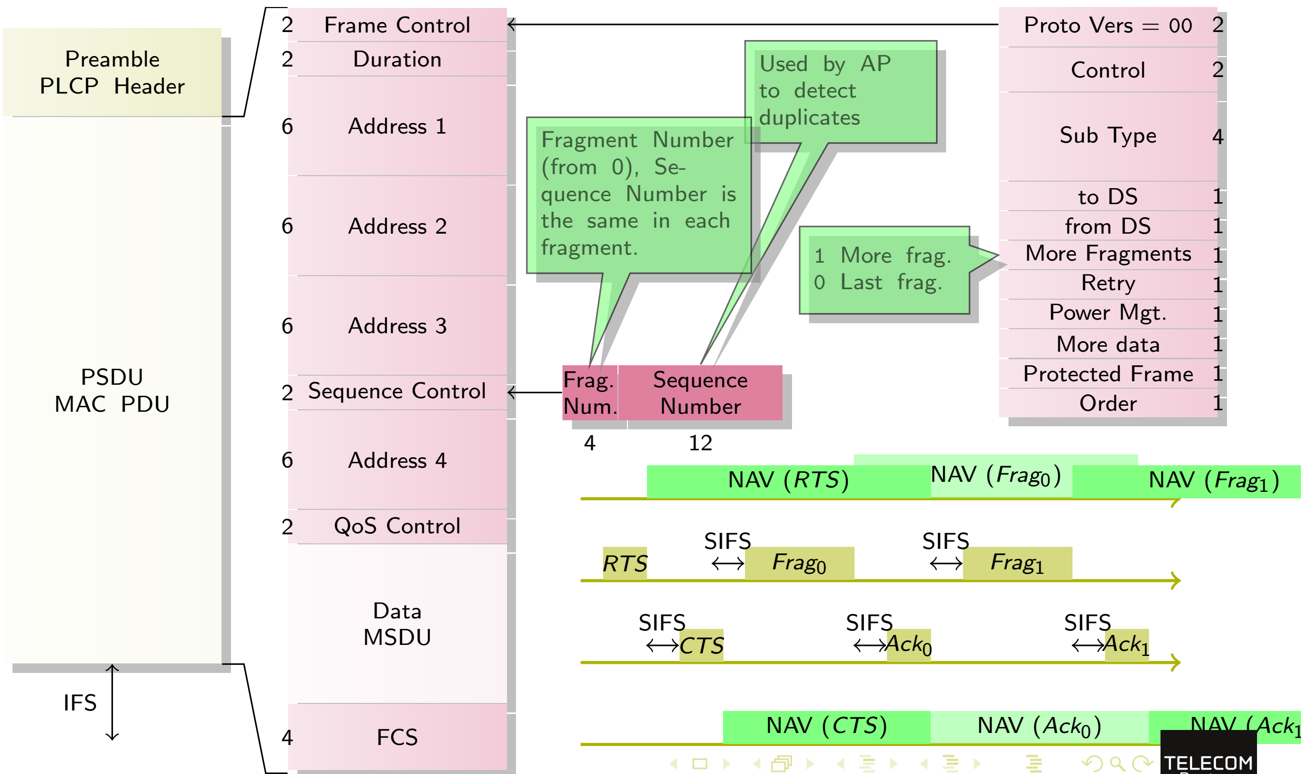
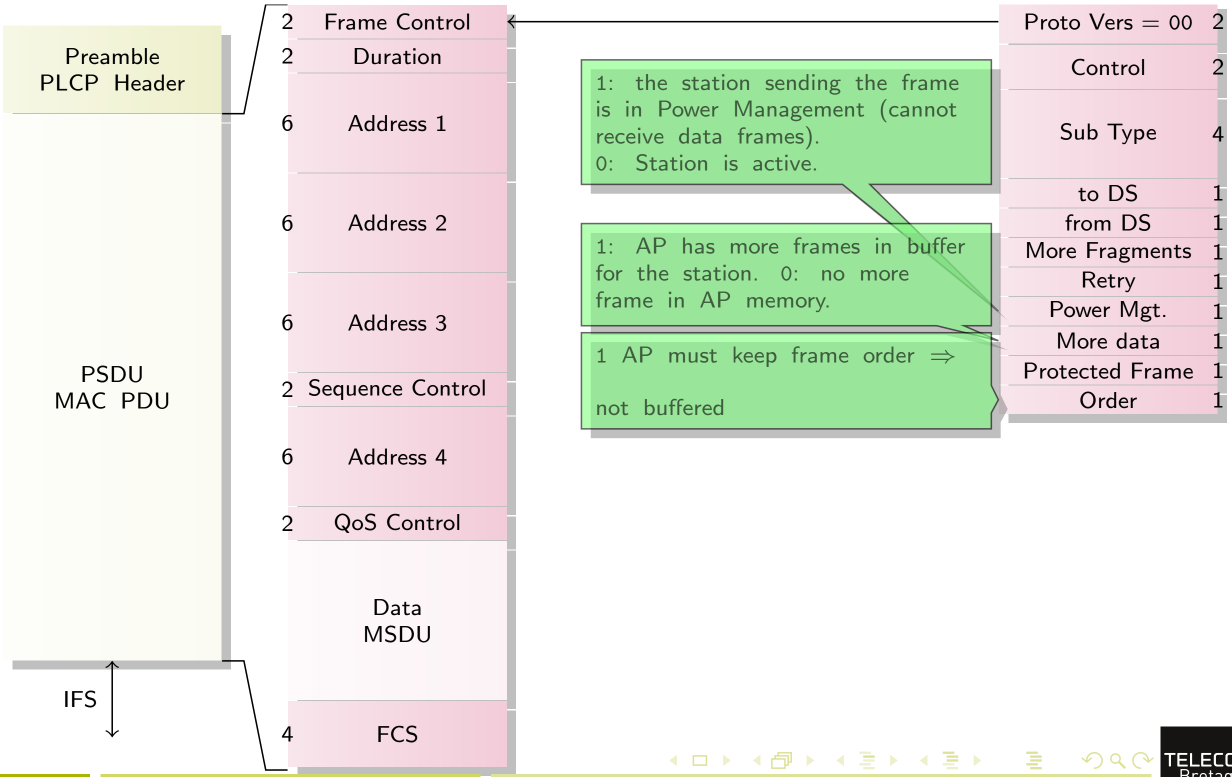
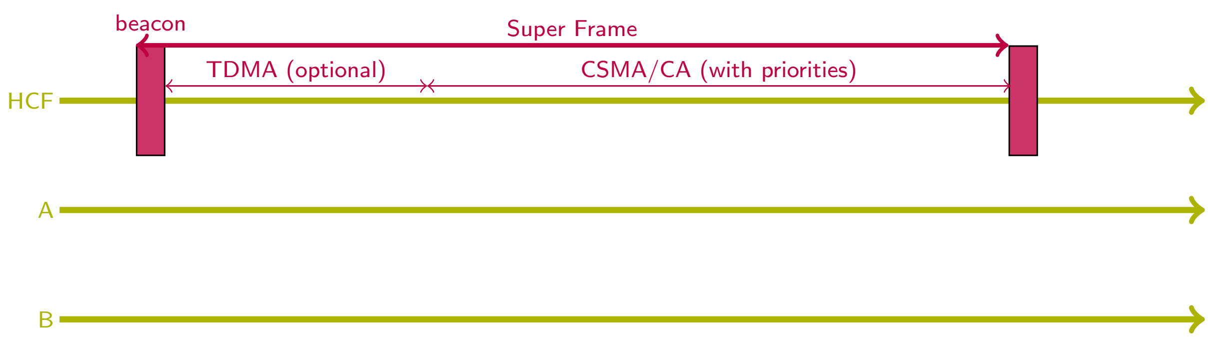


Energy Management



QoS: IEEE 802.11e



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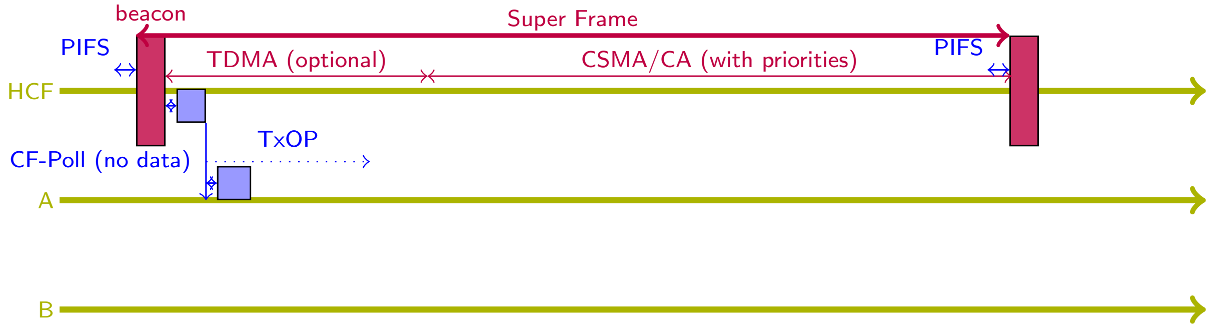
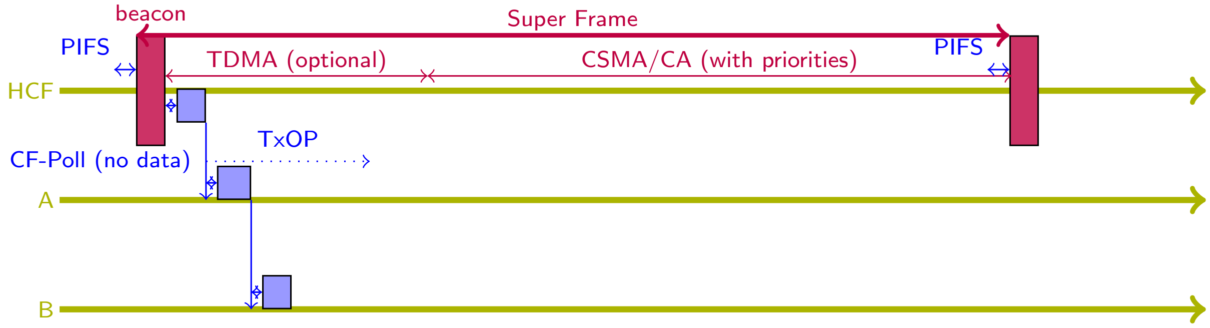


IEEE 802.11 ▶ Architecture and Frames

QoS: IEEE 802.11e



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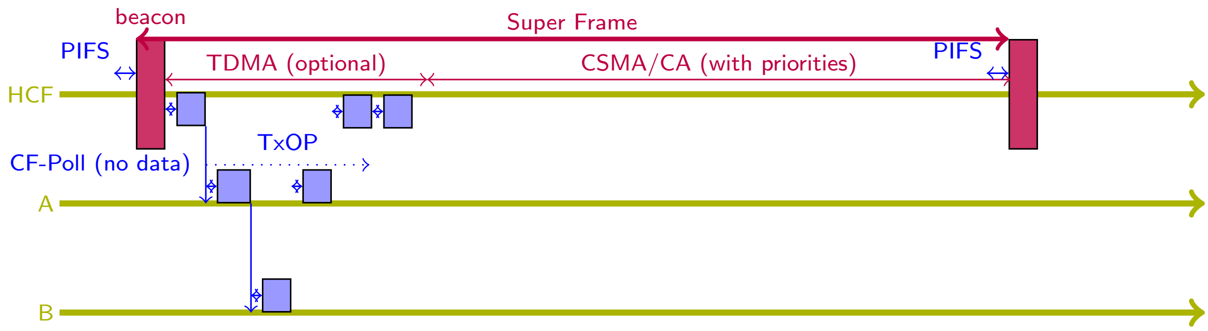

IEEE 802.11 ▶ Architecture and Frames

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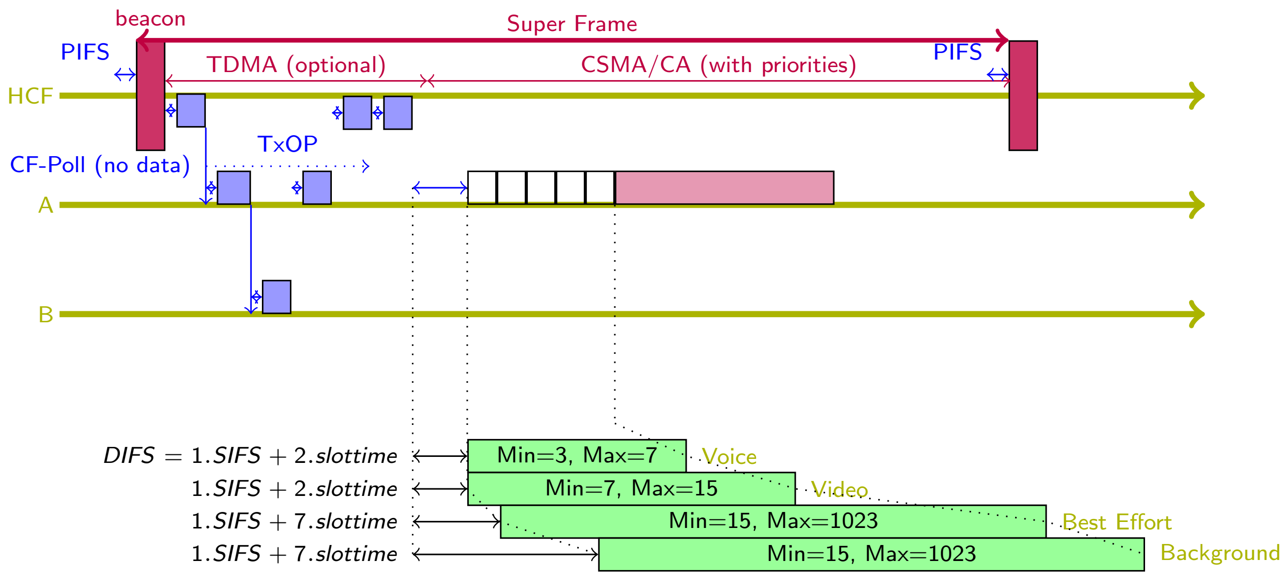

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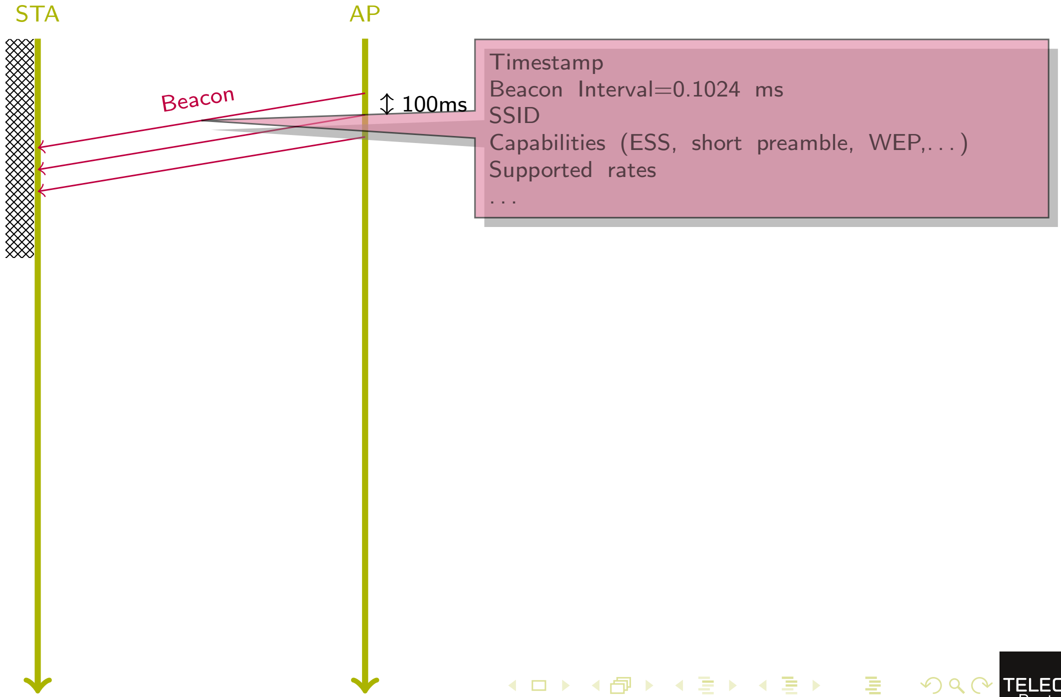
Laurent Toutain
RES 301

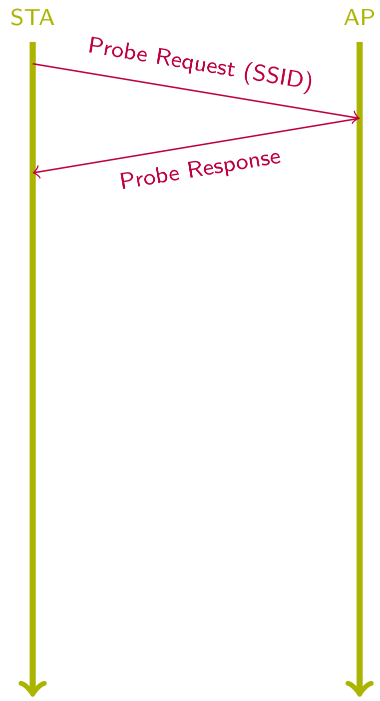
Connecting to an AP

Passive Scanning:
-Scanning all channels
-Record SSID
-Select AP with the best signal



IEEE 802.11 ▶ Architecture and Frames

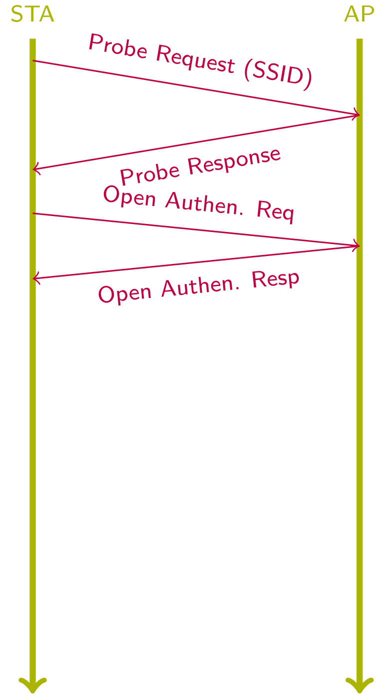
Connecting to an AP



State1: Unassociated/Unauthenticated

CTS, RTS, Ack
Probe Req/Resp, Beacon, Auth., Deauth.,
Data (fromDS=toDS=0)

Connecting to an AP



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CTS, RTS, Ack
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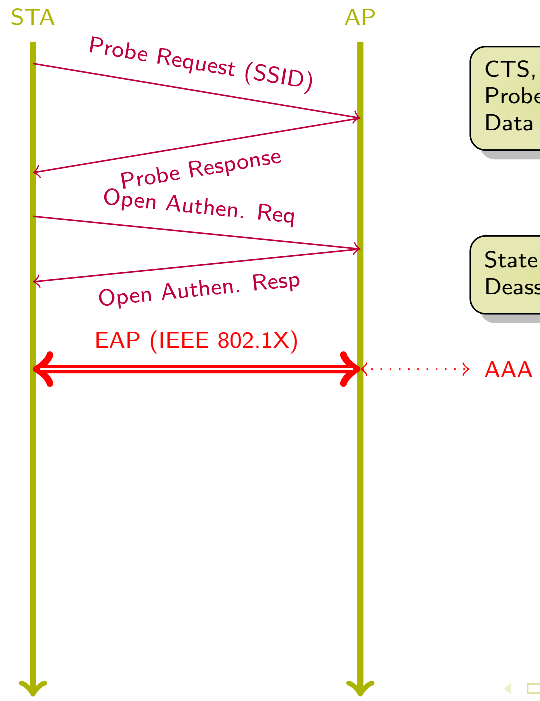
State2: Unassociated/Authenticated

State 1 frame + Association / Reassociation / Deassociation Req/Resp

Connecting to an AP

IEEE 802.11 ▶ Architecture and Frames



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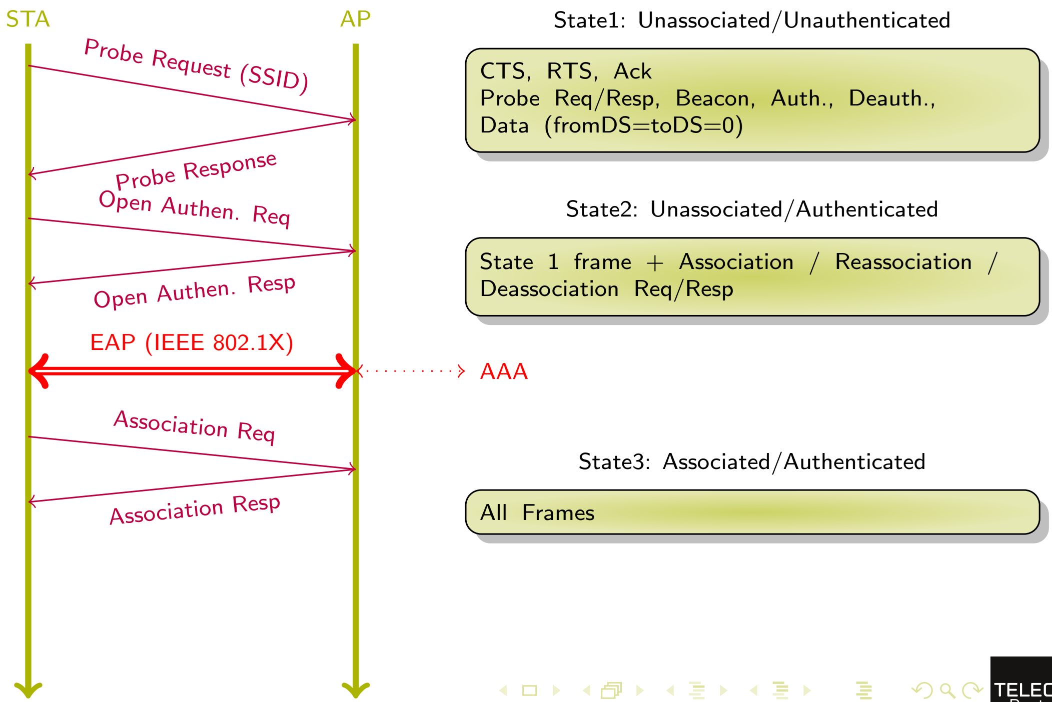
Connecting to an AP



IEEE 802.11 ▶ Architecture and Frames

References

- Channels a/b/g/b :
  ˜jian/Course_mc_files/802.11n.pdf -o qrcode9.png"
  pgflastimage http://users.cecs.anu.edu.au/˜jian/Course_mc_files/802.11n.pdf
-

LLC Layer

Introduction

LLC: Logical Link Control

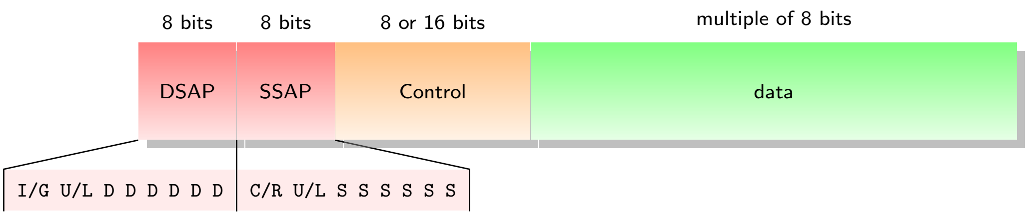
- MAC Layer emulate a point-to-point network
  - MAC algorithm: one sender
  - Destination address: one receiver
- LLC Layer plays the role of the Link Layer in OSI model
  - Detect and correct transmission errors
  - Identify Layer 3 protocol
- LLC has three types:
  - Type 1: Datagram
  - Type 2: Connection oriented
  - Type 3: Acknowledged datagram
- In practice, only type 1 is used
  - Error rate in LAN/MAN/WAN is very low, connection oriented mode is too complex to manage compared to the benefits

LLC Layer

Frame Format

LLC framing

Based on HDLC framing:



- DSAP: Destination Service Access Point
  - The address of the L3 service that must process the PDU
    - First bit indicates Individual (=0) or group (=1)
    - U=1: standardized by ISO; L=0 local to the LAN
    - in practice only individual are currently used
- SSAP: Destination Service Access Point
  - The address of the L3 service that sends the PDU
    - First bit indicates command (=0) or respond (=1)
    - in practice only individual are currently used
- In practice DSAP=SSAP

SAP Values

hexa	dec.	binary	protocol
0x00	0	0000 0000	Null SAP
0x02	2	0000 0010	LLC Management
0x06	6	0000 0110	reserved to IPv4
0x0A	10	0000 1010	Secure Data Exchange PDU (IEEE 802.10)
0x42	66	0100 0010	Spanning Tree Protocol
0x7E	126	0111 1110	X.25
0xAA	170	1010 1010	SNAP
0xE0	224	1110 0000	IPX
0xFE	254	1111 1110	ISO, CLNP
0xFF	255	1111 1111	All entities

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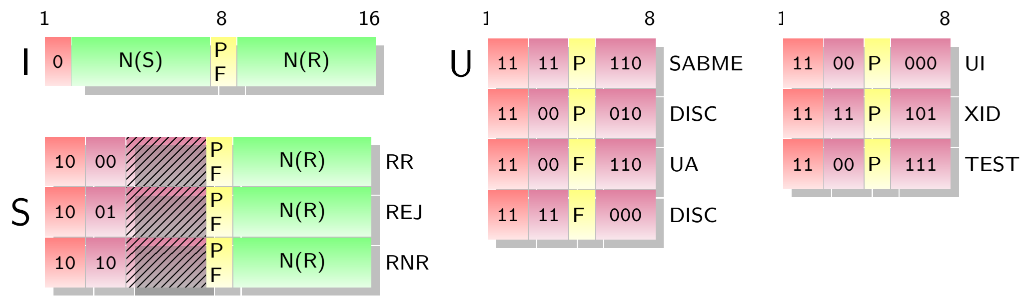
0xE0	224	1110 0000	IPX
0xFE	254	1111 1110	ISO, CLNP
0xFF	255	1111 1111	All entities

- Value `0x06` for IP is forbidden by IETF
- Most common values are STP (`0x42`) and SNAP (`0xAA`)

- As for HDLC, LLC control field defines 3 types of frames:
  - Information Frames: used to carry LLC type 2 data
  - Supervision Frames: used to acknowledge I frames
  - Unnumbered Frames: used to open, close connection and for LLC type 1 and 3.
- Counters are on 7 bits: I and S frames are 2 byte long, U frame 1 byte long



Control field
LLC Layer ▶ Frame Format

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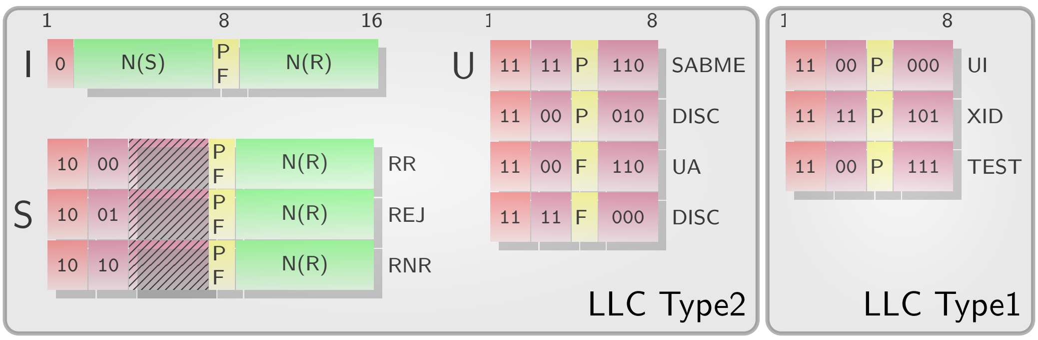

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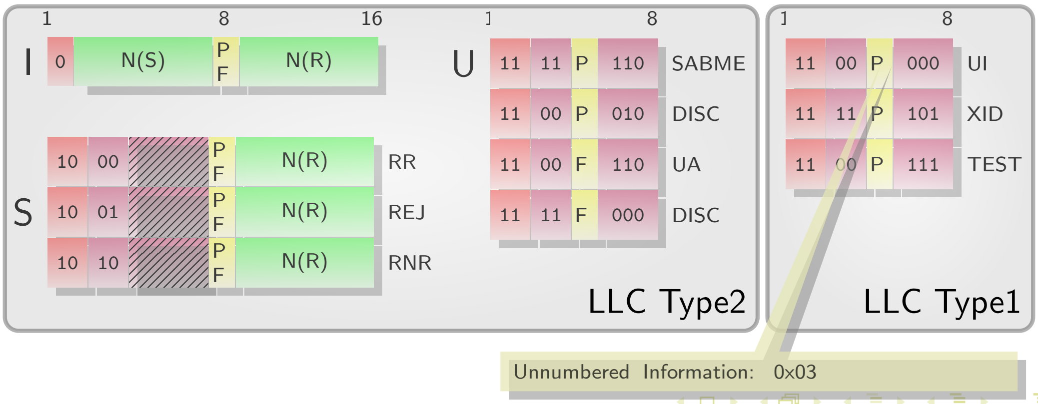

Questions

How many L3 protocol ISO can standardize ?

How many L3 protocol Ethernet can identify ?

What is the length of a LLC type1 header ?

Does Ethernet require LLC encapsulation ?

```
0x0000: 0180 c200 0000 0019 e79e 1dae 0026 4242
0x0010: 0300 0000 0000 8000 0002 b972 6601 0000
0x0020: 0008 8005 0019 e79e 1d80 802e 0200 1400
0x0030: 0200 0f00 0000 0000 0000 0000
```

What is the L3 protocol ?

Which type of LLC ?

Questions

How many L3 protocol ISO can standardize ? $2^6 = 64$

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Questions
LLC Layer ▶ Frame Format

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Which type of LLC ?

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```
0x0000:  0180 c200 0000 0019 e79e 1dae 0026 4242
0x0010:  0300 0000 0000 8000 0002 b972 6601 0000
0x0020:  0008 8005 0019 e79e 1d80 802e 0200 1400
0x0030:  0200 0f00 0000 0000 0000 0000
```

What is the L3 protocol ? DSAP=SSAP=0x42: Spanning Tree Protocol

Which type of LLC ?

Questions

LLC Layer ▶ Frame Format

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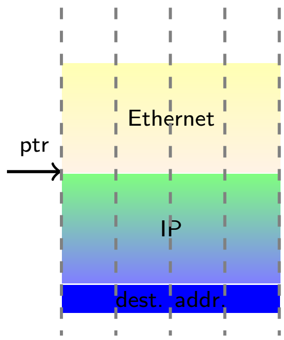
0x0030: 0200 0f00 0000 0000 0000 0000

What is the L3 protocol ? DSAP=SSAP=0x42: Spanning Tree Protocol

Which type of LLC ? 03=0000 0011 : UI ⇒ Type 1

LLC Drawbacks

- IEEE mandate LLC in its archtecture, but :
  - protocols are not named the same way by Ethernet and LLC
    - and Ethernet is the dominant protocol.
  - LLC type 1 breaks memory alignment
    - 3 byte long
    - IP relies on memory alignment to speed up address processing




```
#put dest
#addr into CPU
#register
#
read A, ptr+36
```


LLC Drawbacks

LLC Layer ▶ Frame Format

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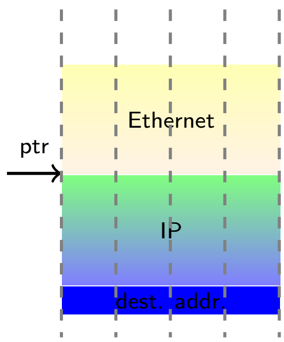


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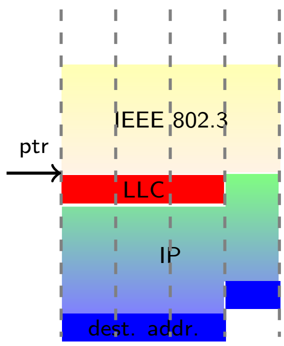


```
#put dest
#addr into CPU
#register
#
read A, ptr+36
shift left A, 24
read B, ptr+40,
shift right B, 8
add A B
```

LLC Drawbacks

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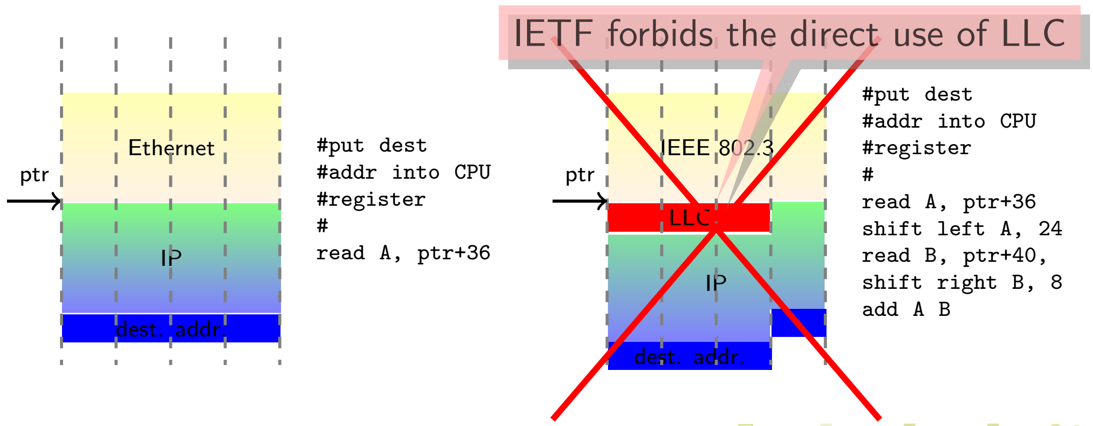
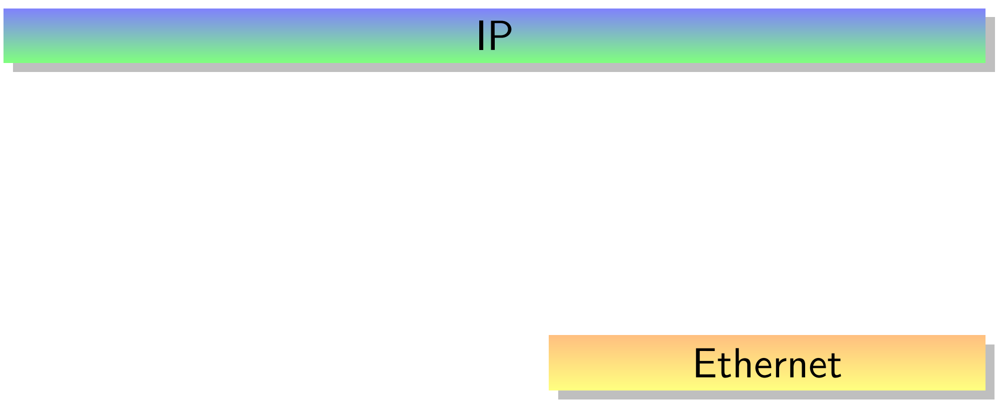
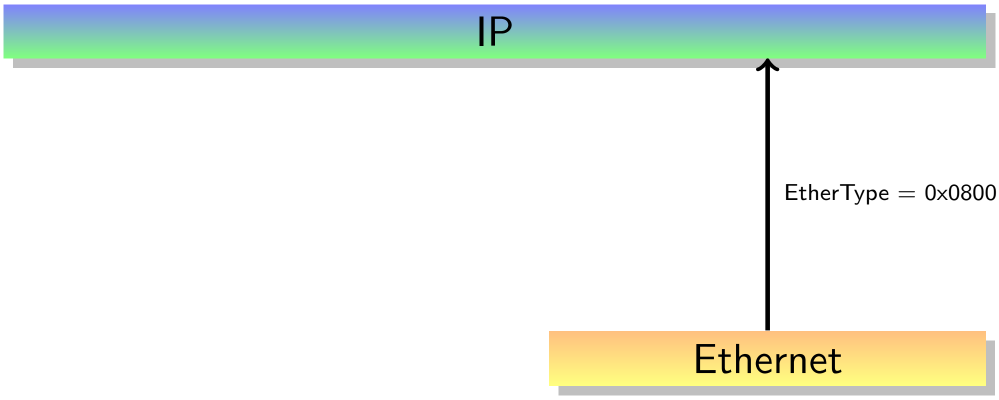


LLC: dead end ?



LLC: dead end ?



LLC Layer ▶ Frame Format

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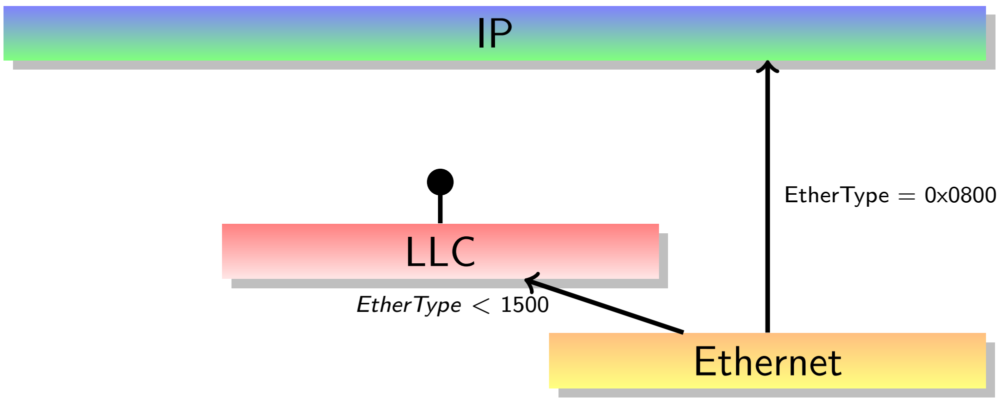

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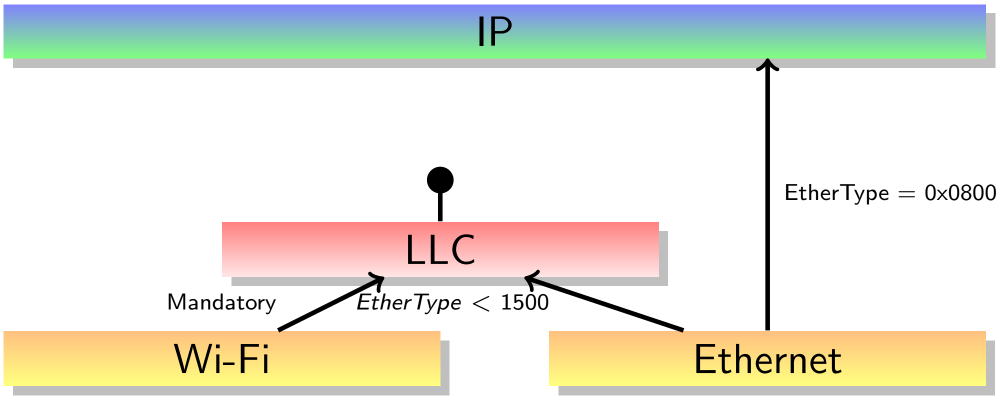

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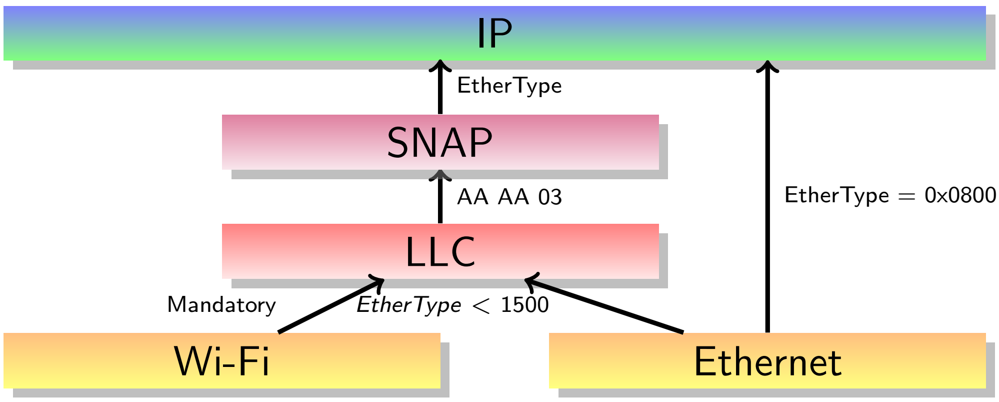

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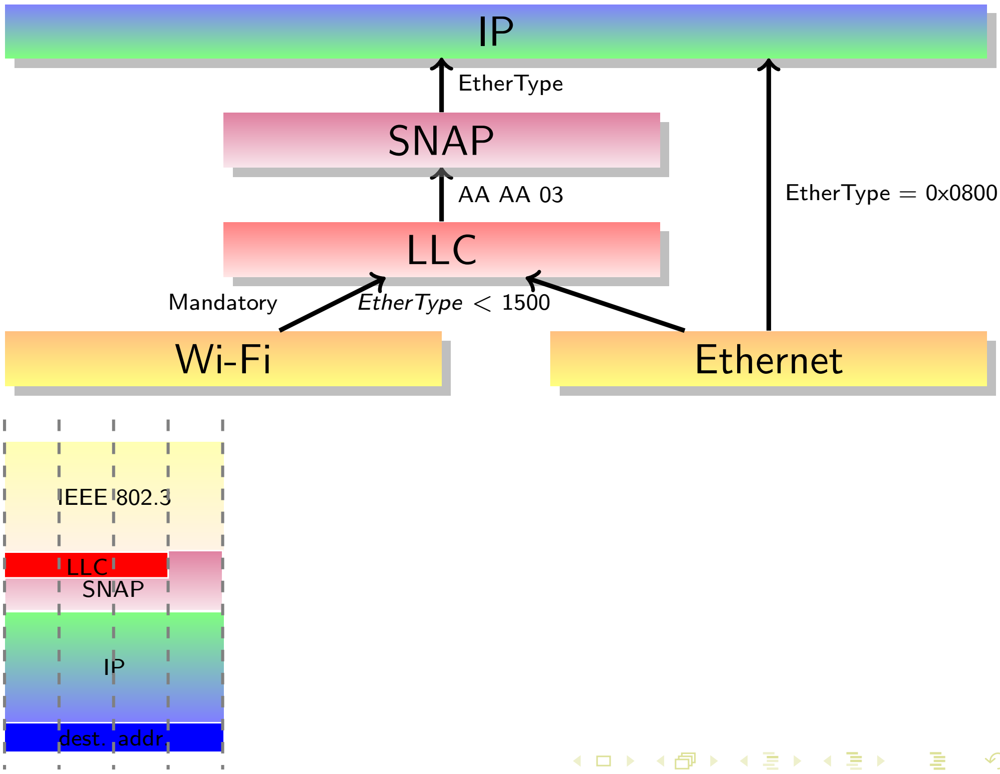

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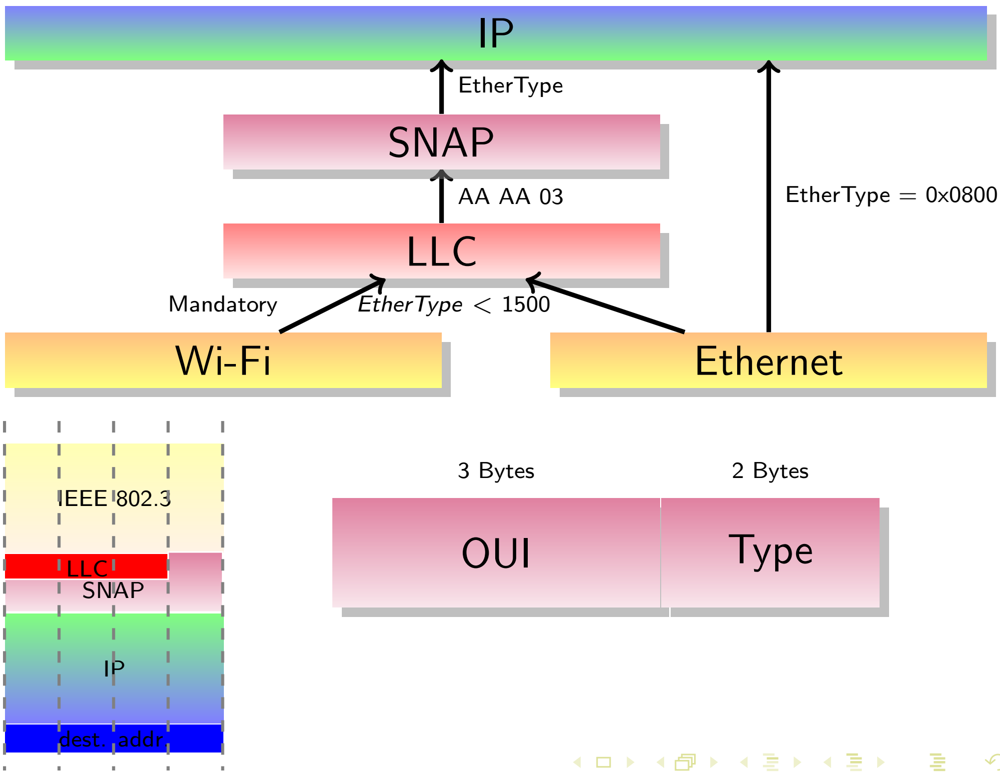
LLC Layer ▶ Frame Format



LLC Layer

SNAP

SNAP RFC 1042

- Sub-Network Access Protocol
- Mainly used to maintain alignment in equipment memory
  - 5 Byte long + LLC (3 Bytes) = 8 Bytes
- If OUI = 00−00−00 then the last two bytes contains the EtherType
  - Facilitate bridging since protocols are identified the same in Ethernet and LLC networks.
  - Make Ethernet EtherType universal
- OUI can be used by its owner to develop proprietary protocols
  - Cisco Discovery Protocol: OUI `0x00000C` protocol ID `0x2000`.

Questions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0x0000: 000c 295d 3a94 0011 43aa f48b 86dd 600c
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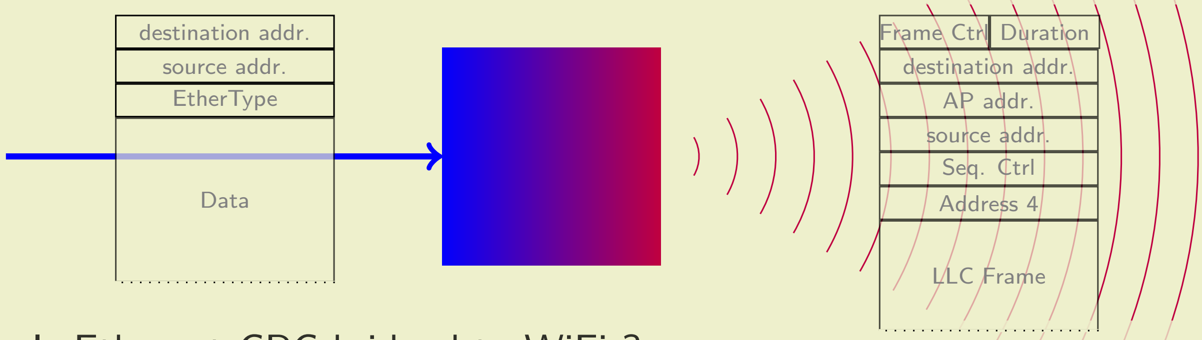

Is Ethernet CRC bridged to WiFi ?

Can Ethernet padding be bridged to the WiFi ?

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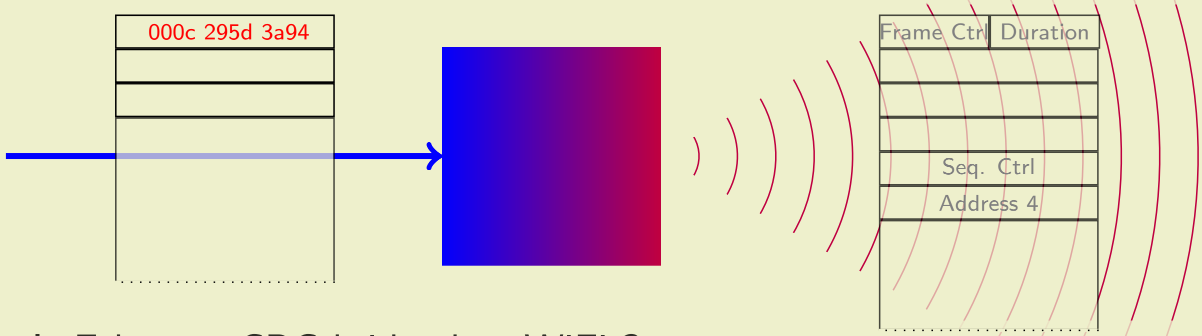

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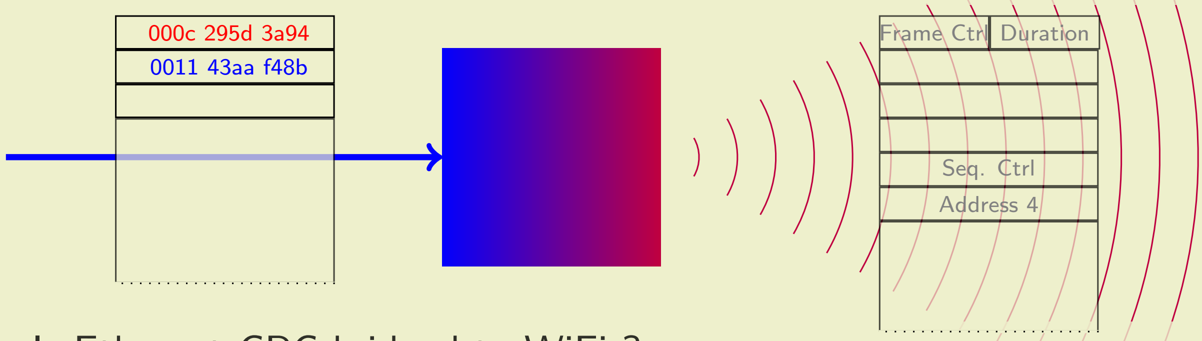

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LLC Layer ▶ SNAP

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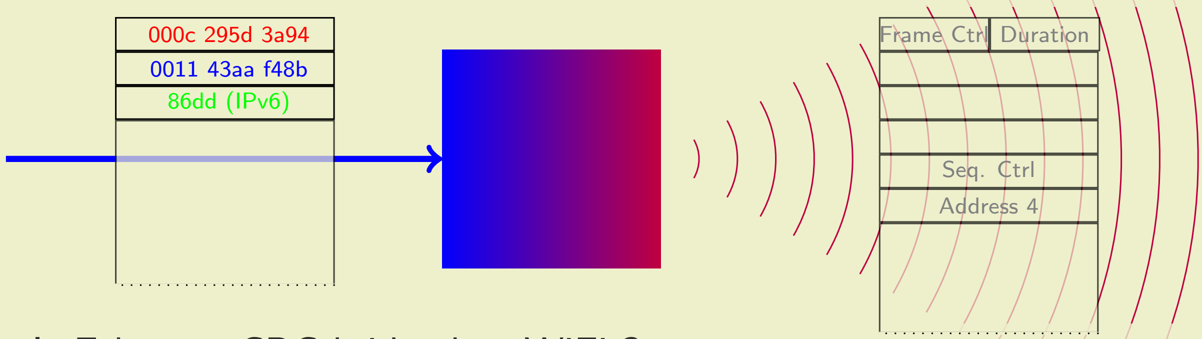

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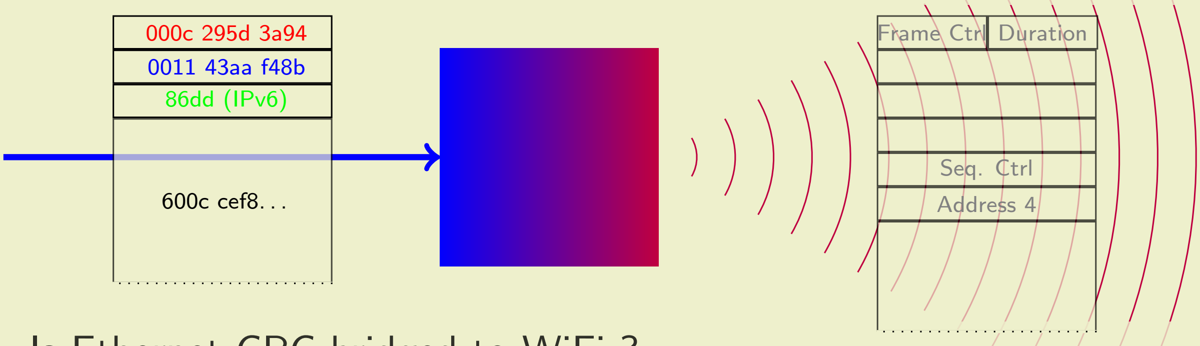

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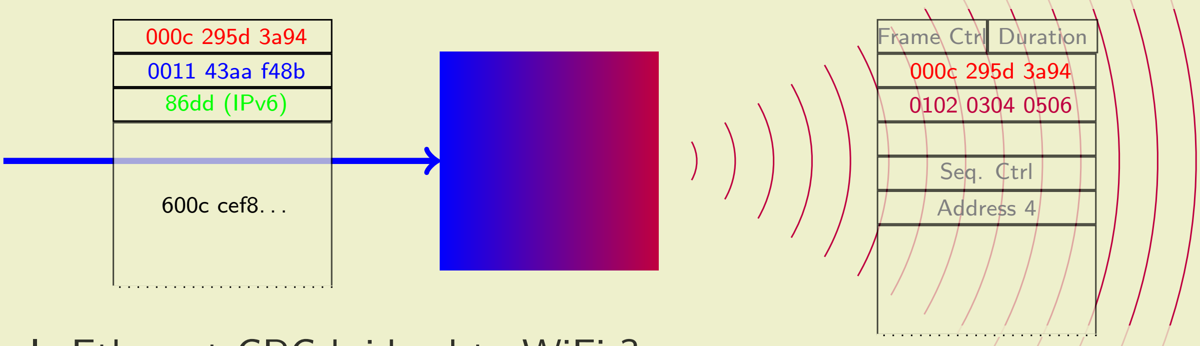

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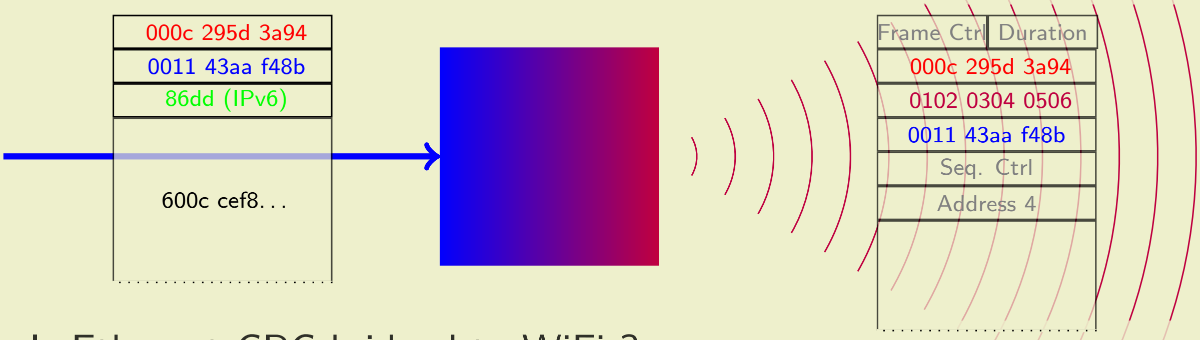

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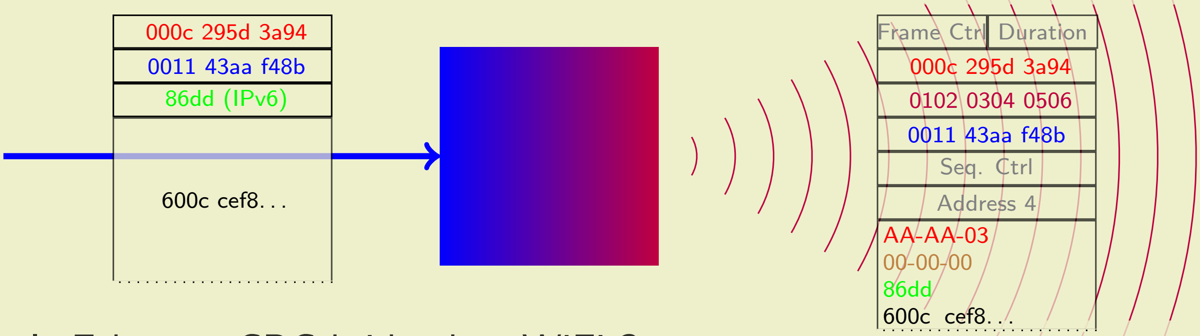

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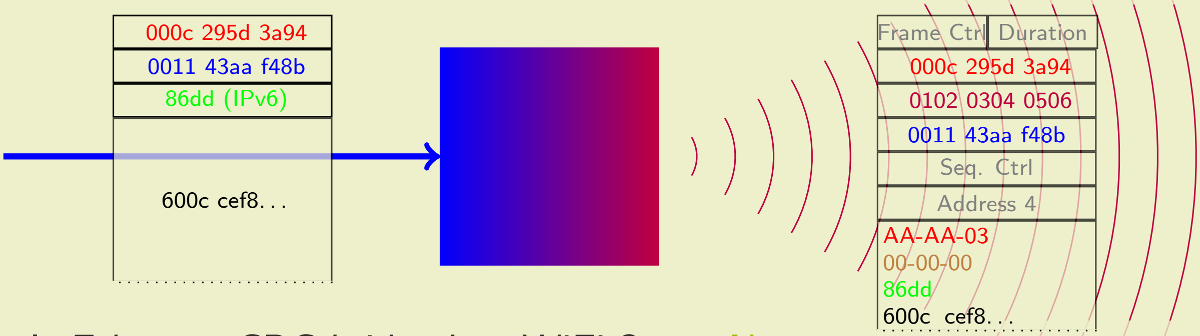

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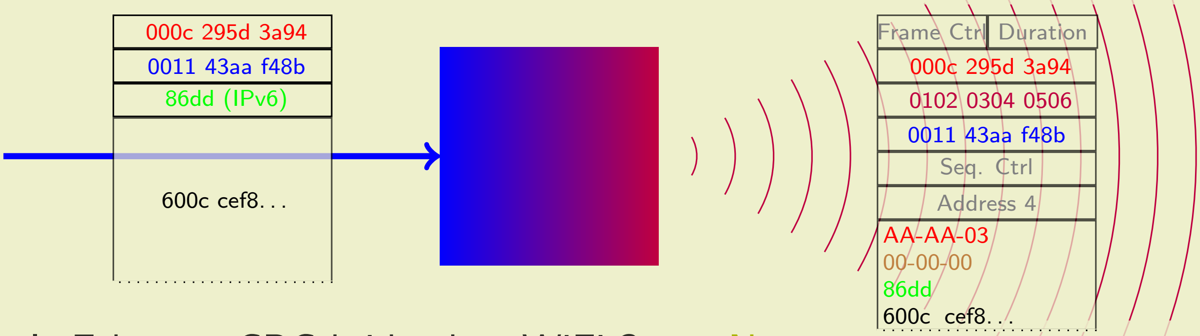


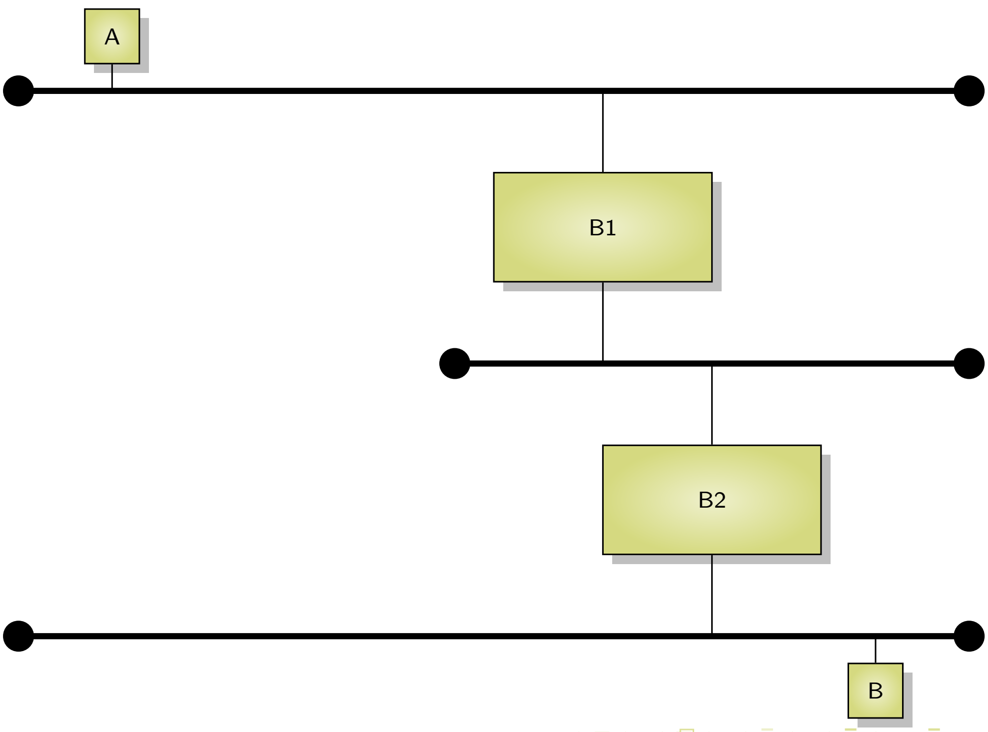
Is Ethernet CRC bridged to WiFi ? No

Can Ethernet padding be bridged to the WiFi ? Yes

Spanning Tree

Bridge loops

Several bridges in a network



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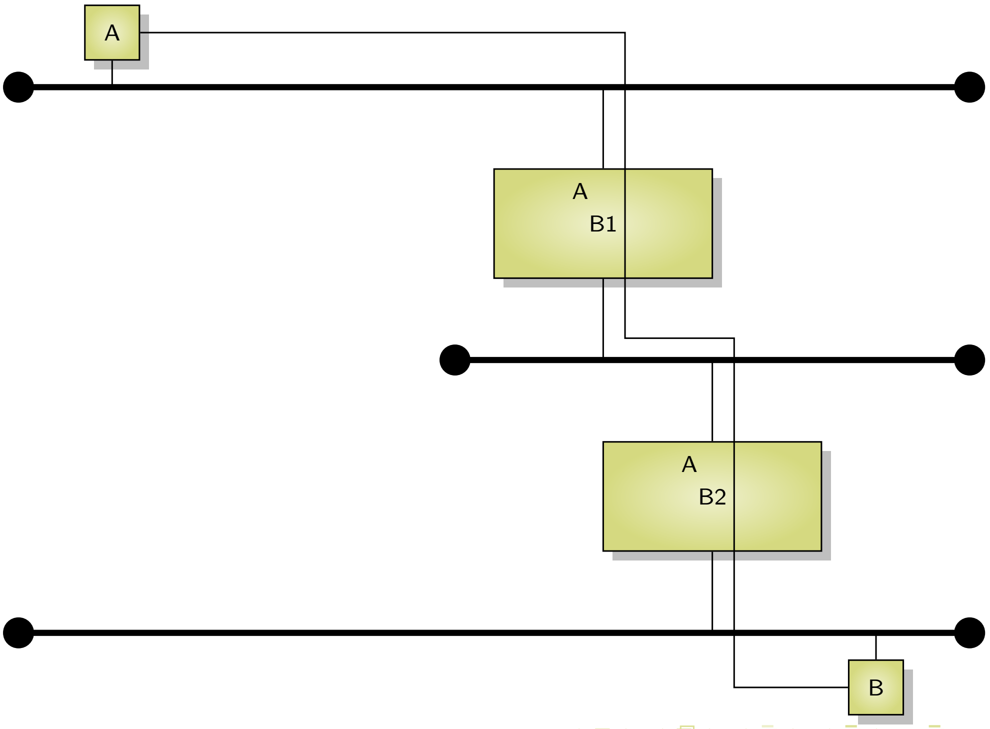

Spanning Tree ▶ Bridge loops

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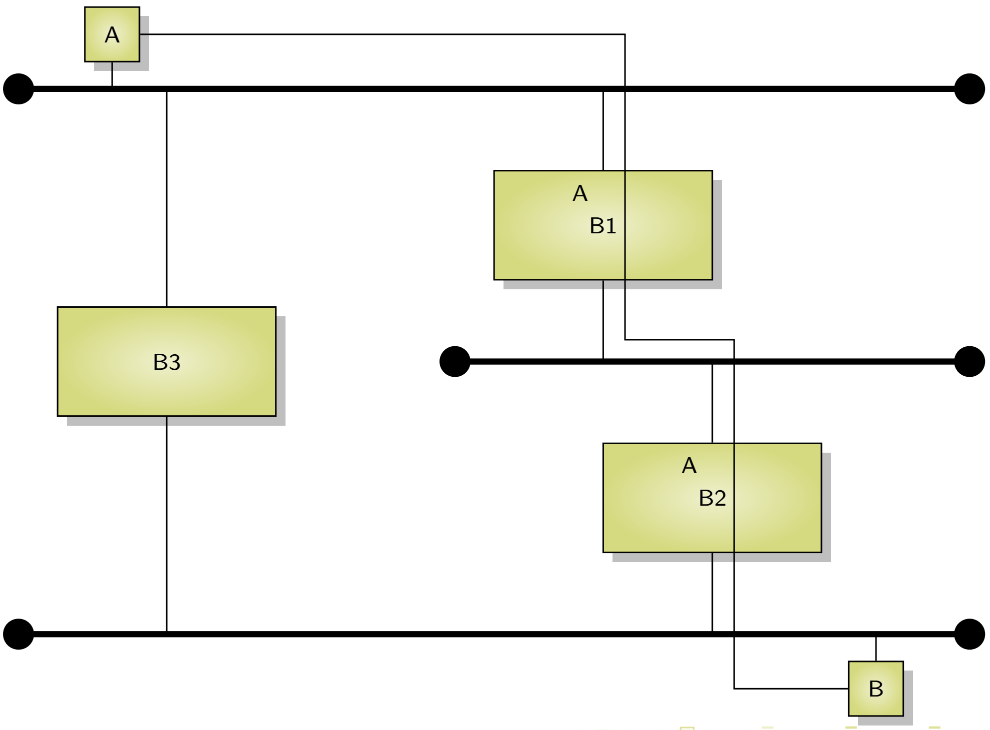

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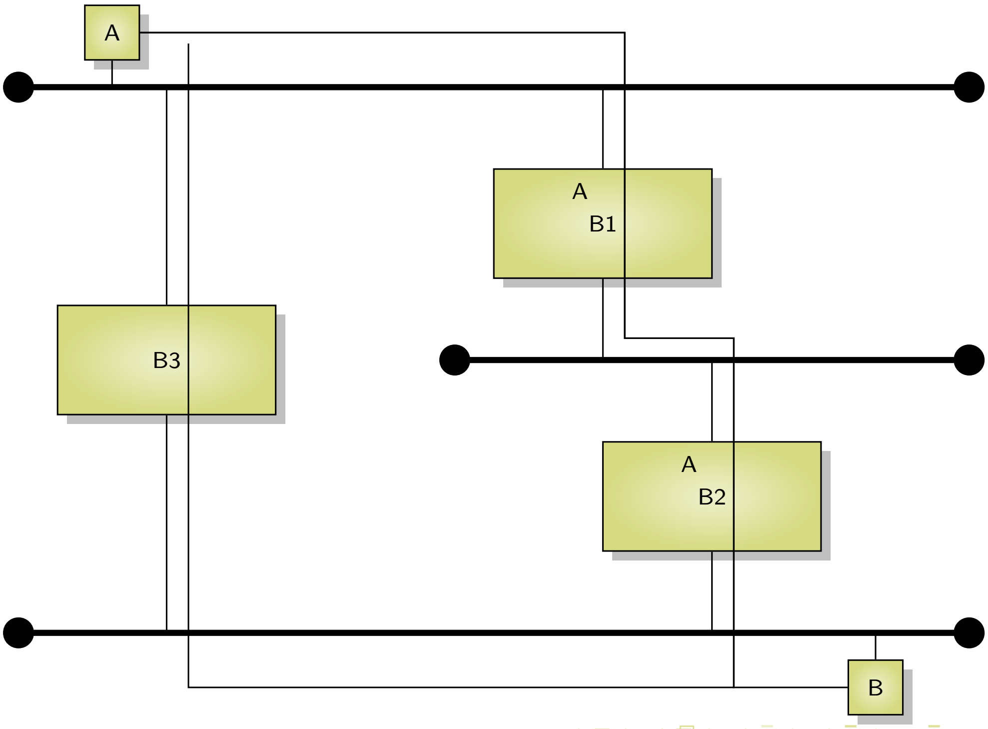

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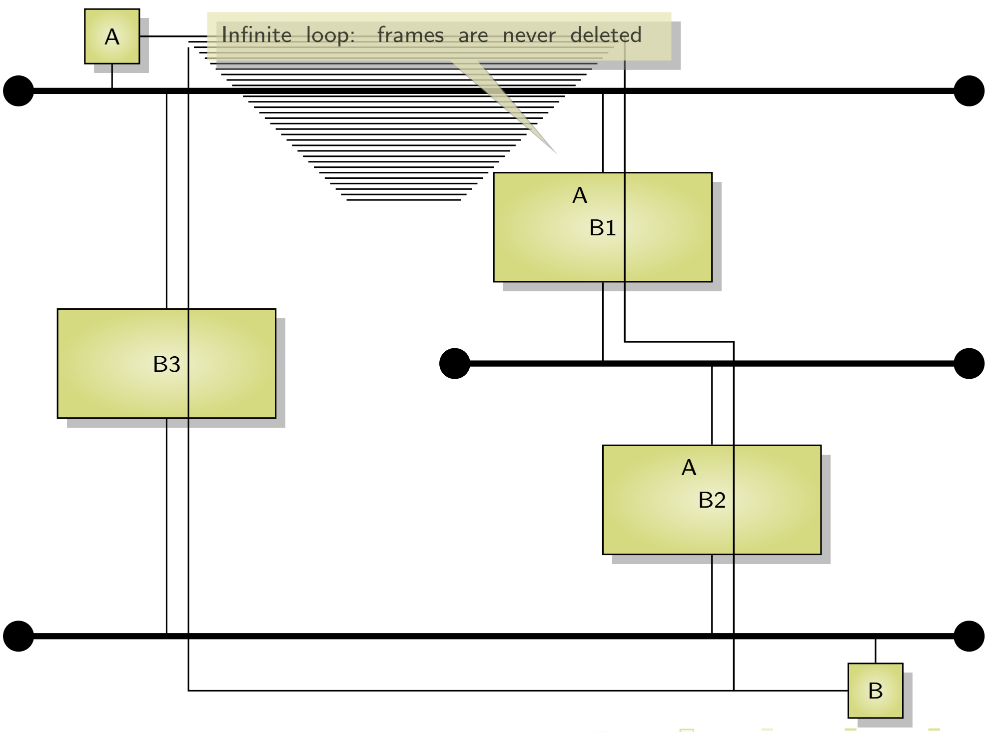
Spanning Tree ▶ Bridge loops



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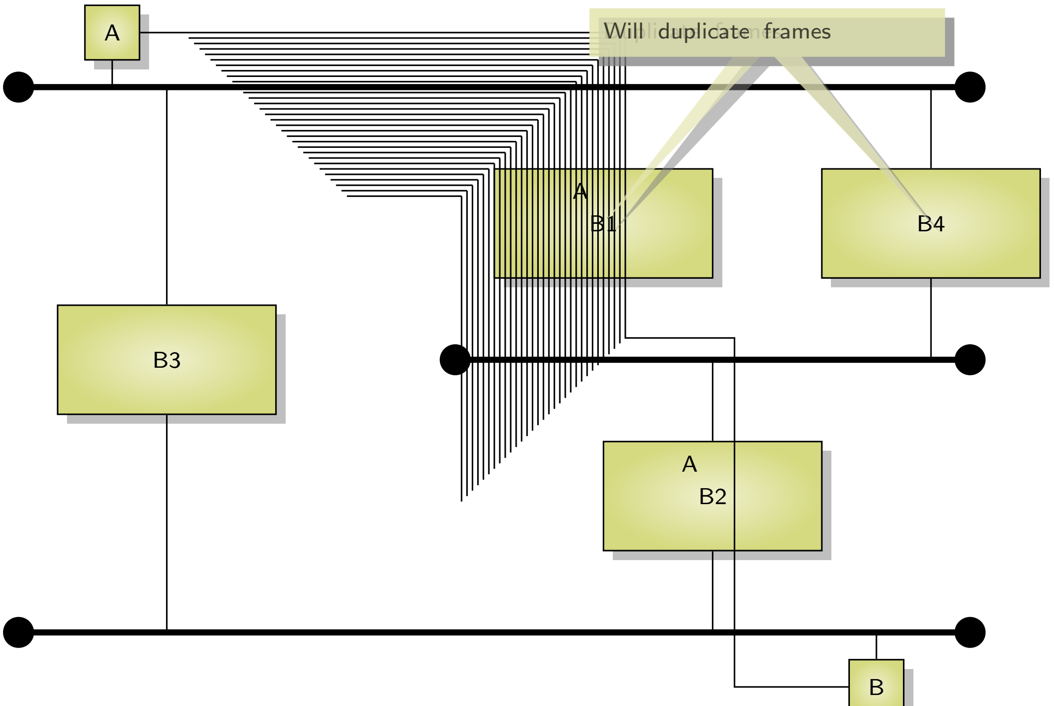

Spanning Tree ▶ Bridge loops

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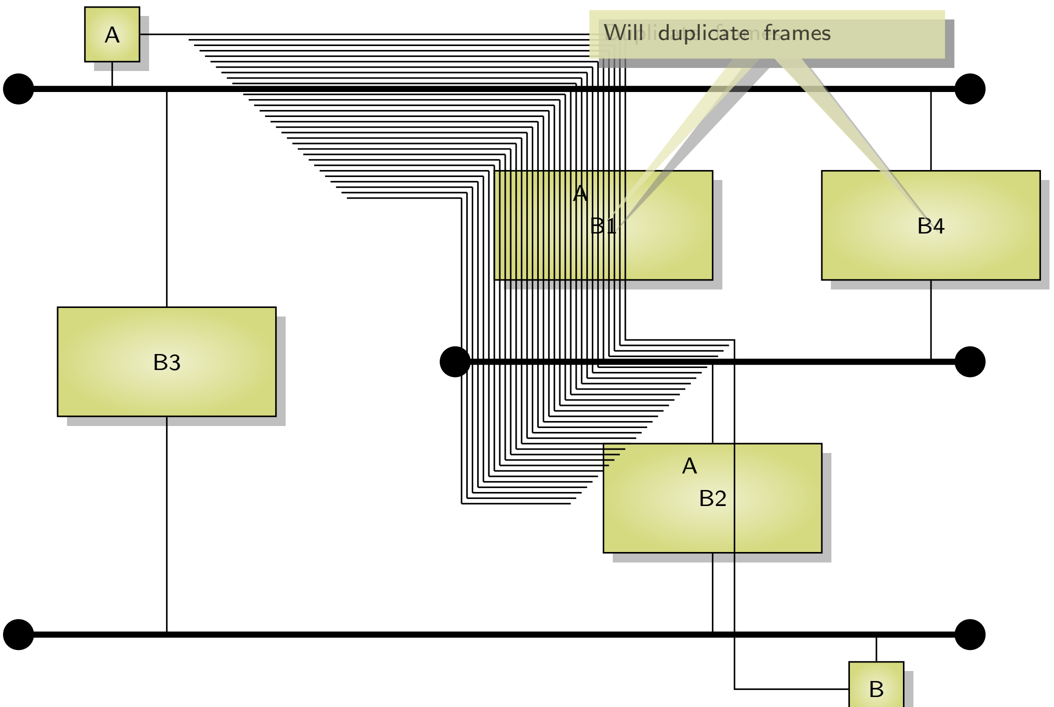

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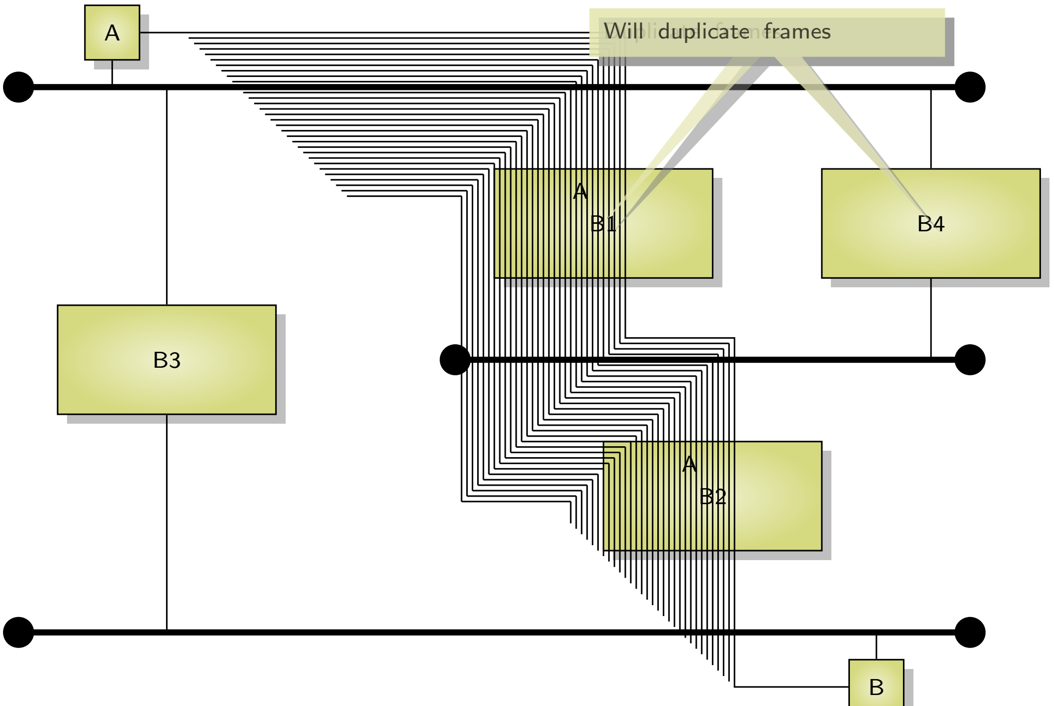

Spanning Tree ▶ Bridge loops

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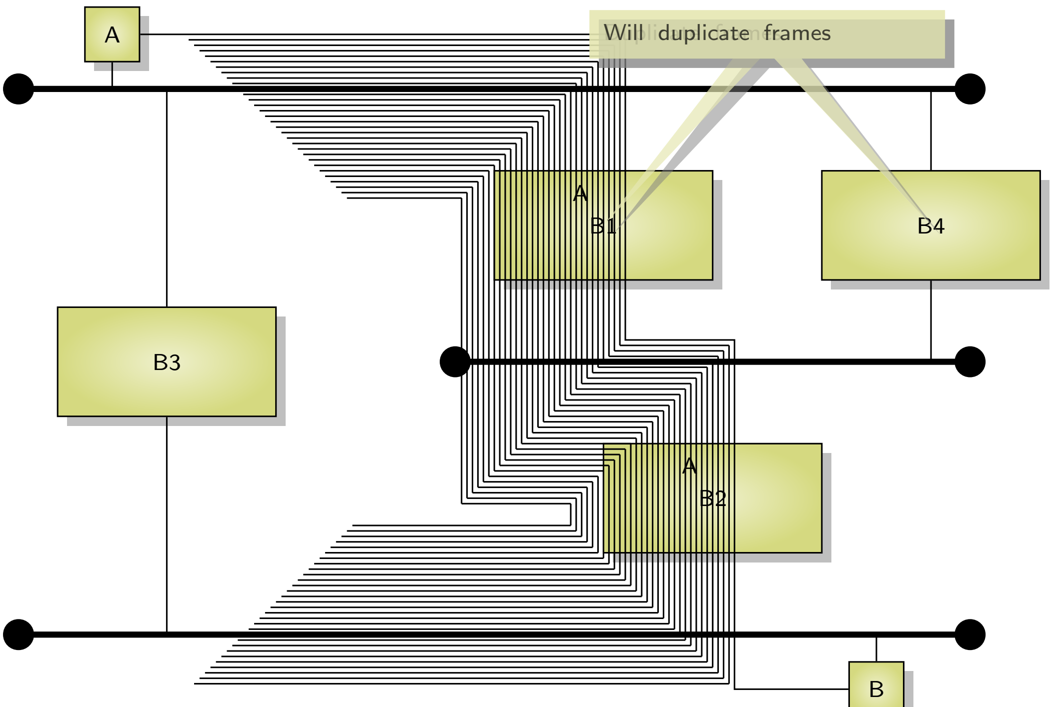

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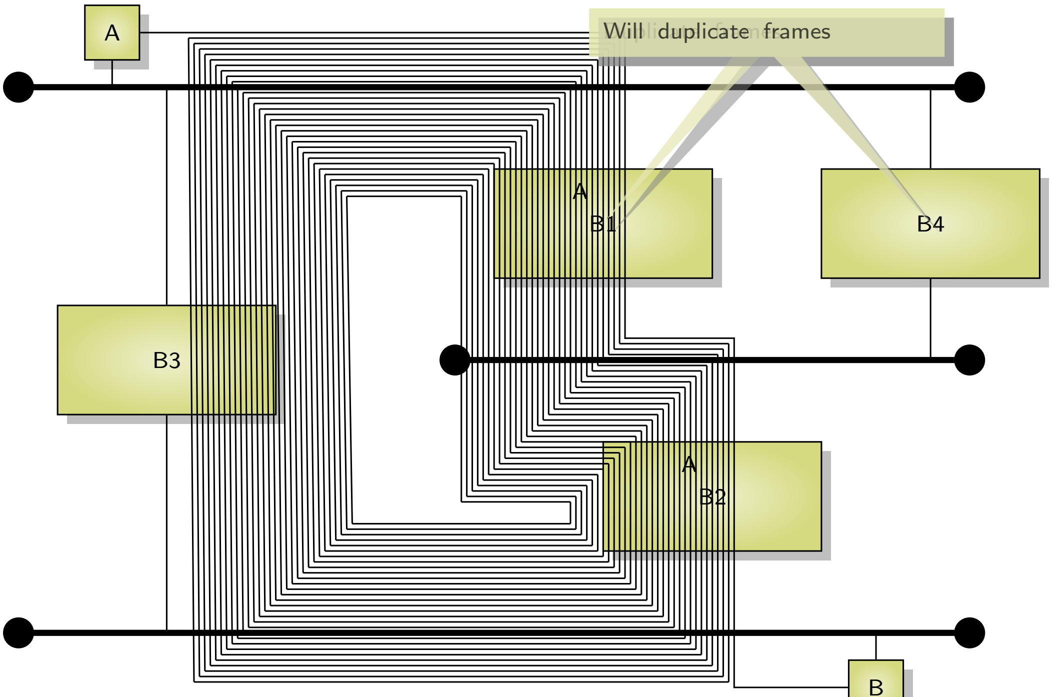


Spanning Tree

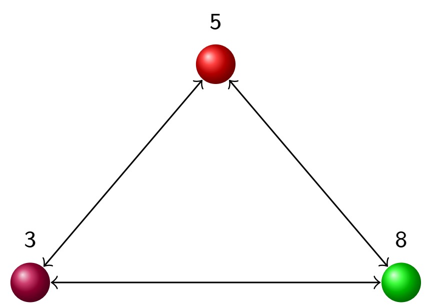
- Bridging works well, if there is a single path to go from one point to another
- When there is several way to go to the same destination, there is a loop.
- Frame will turn forever in the network
  - Since frame are not modified by bridging it is not possible to stop them
  - If several paths, frame can also be duplicated
  - Network will collapse by overloading
- Several possible path = a graph
- Single path = a tree
- The goal is to disable some bridge interfaces to get back to a tree structure
- The tree must cover all the graph: Spanning Tree

Spanning Tree

Algorithm

Main idea

- Compute a root (shortest value)
- Take the shortest path to the root
  - Guaranty that all costs will be different
- Disable interfaces leading to a larger cost



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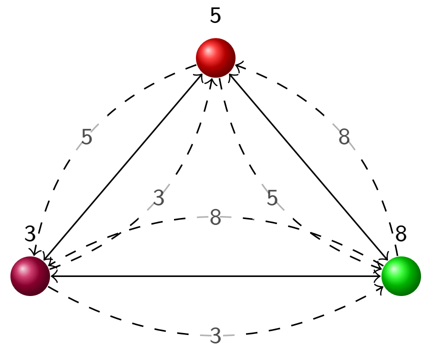

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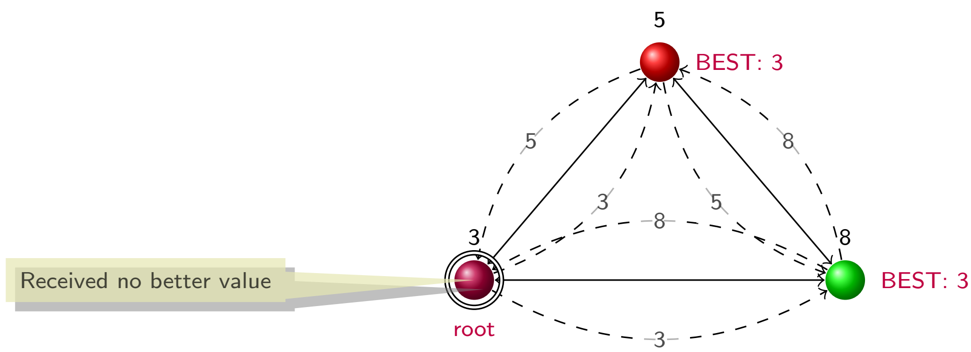

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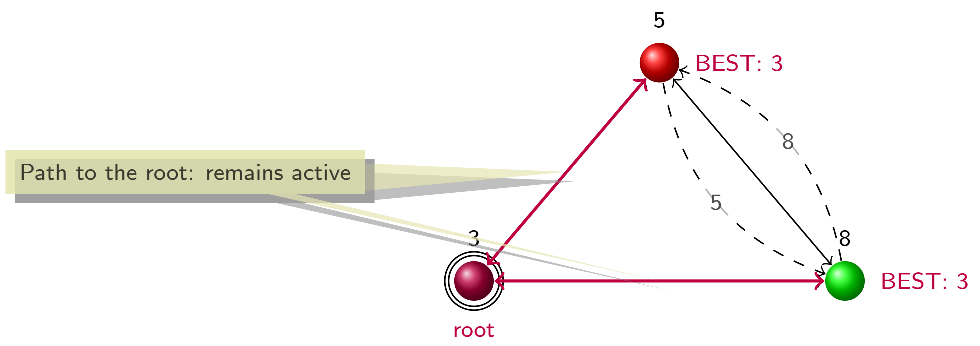

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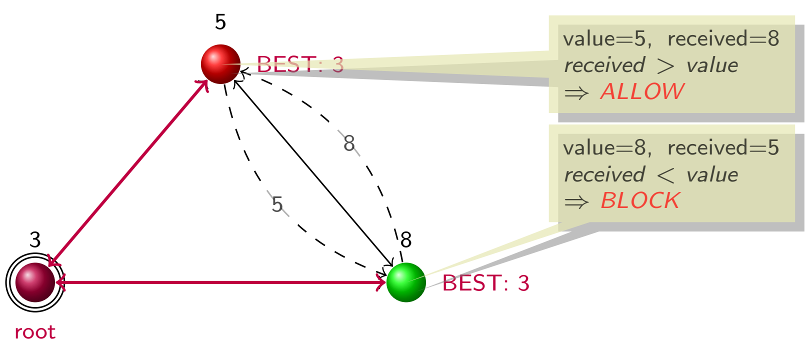

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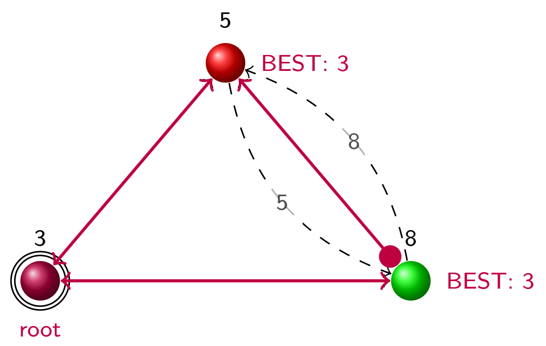

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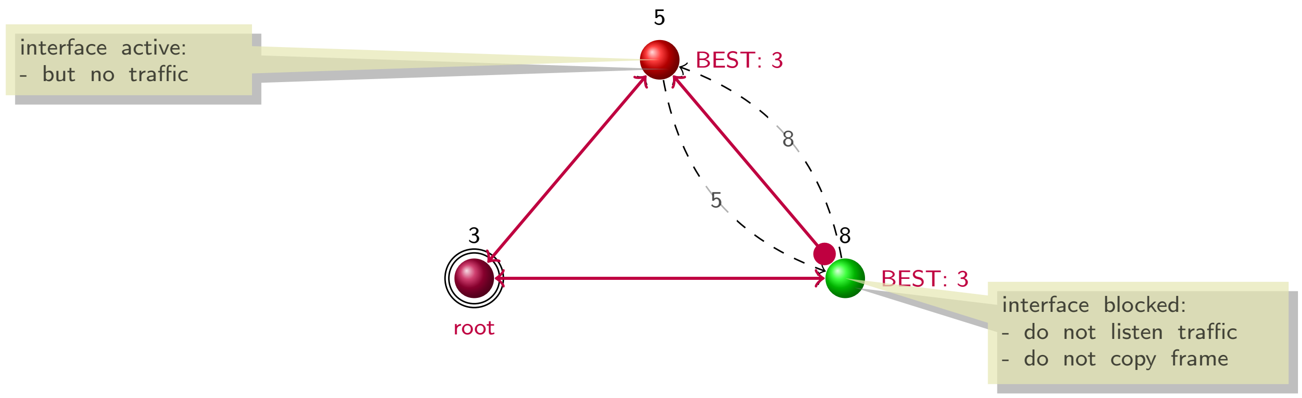


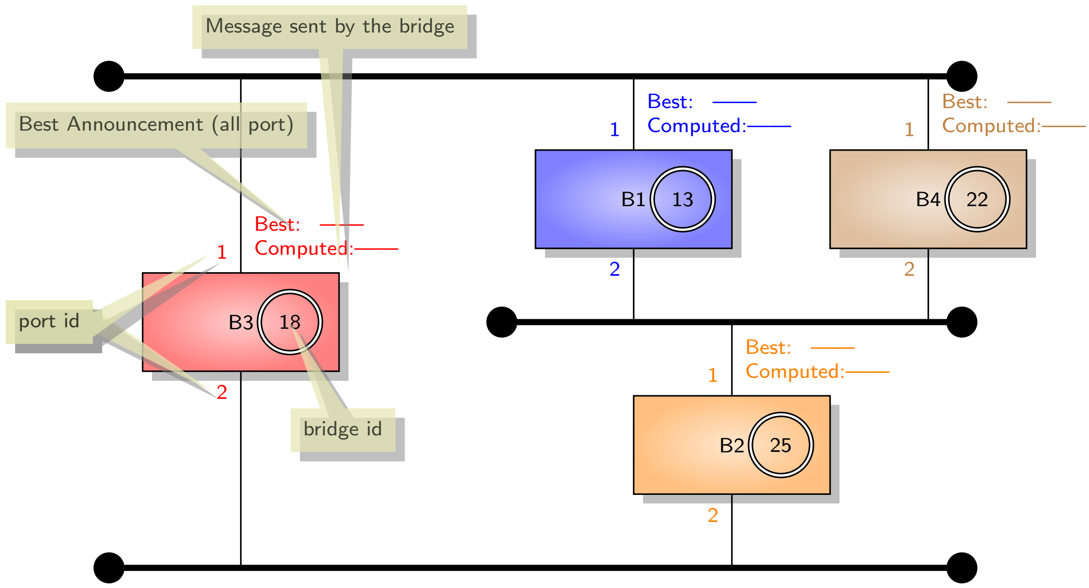
Cost vector

- Each bridge must have an unique id:
  - by construction id are not equal
  - MAC address of one of the interface can be used.
- Cost vector announced by bridge is composed of 4 values
  - Root id: the lowest value the bridge received
    - if no smaller value are received, root id = bridge id
  - Cost to the root: used to select the smallest path to the root
  - Bridge id
  - Port number or interface number
- $V = \langle V_1, V_2, V_3, V_4 \rangle < U = \langle U_1, U_2, U_3, U_4 \rangle$
  - if $V_1 < U_1$ or
  - if $V_1 = U_1$; $V_2 < U_2$ or
  - if $V_1 = U_1$ and $V_2 = U_2$; $V_3 < U_3$ or
  - if $V_1 = U_1$ and $V_2 = U_2$ and $V_3 = U_3$; $V_4 < U_4$

Algorithm overview

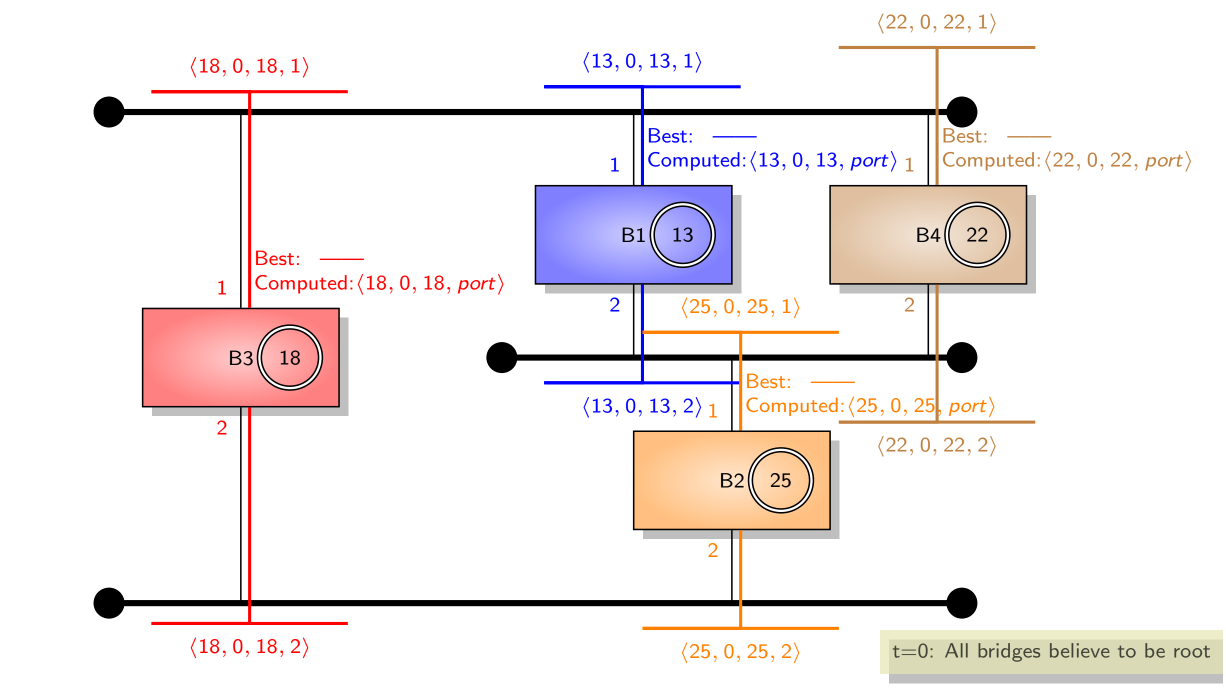
1. Each bridge/switch believes to be the root
2. When receiving a message smaller all the bridges except one will not be the root
   2.1 The port on which the smallest (best) message is received becomes the root port
   2.2 Other port must be active (Designated) or passive (no forwarding: Alternate) ports
      - if a smaller message than the one generated by be bridge is receive the port is alternate
      - if the bridge generate the best message for the link, the port is designated.
3. if the topology changes, the bridge informs the root:
   3.1 the root informs all the bridges of a topology change
   3.2 all bridges discard their forwarding table (i.e. MAC address location)
   3.3 all bridges start again learning process (and continue to forward).

Example



Spanning Tree ▶ Algorithm

Example



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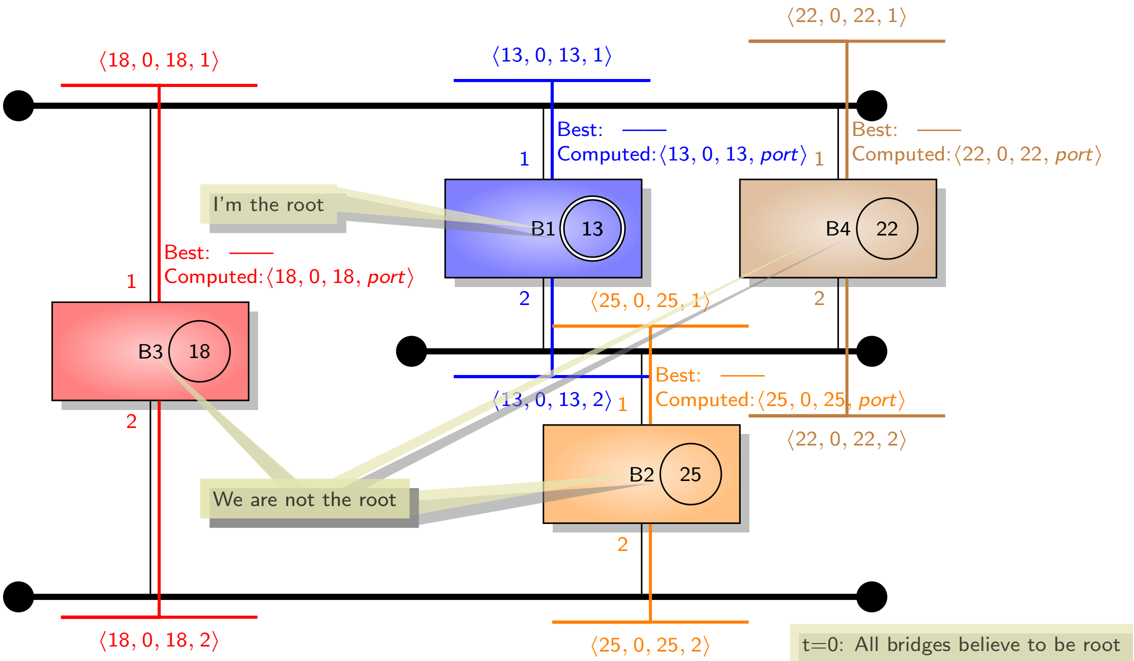
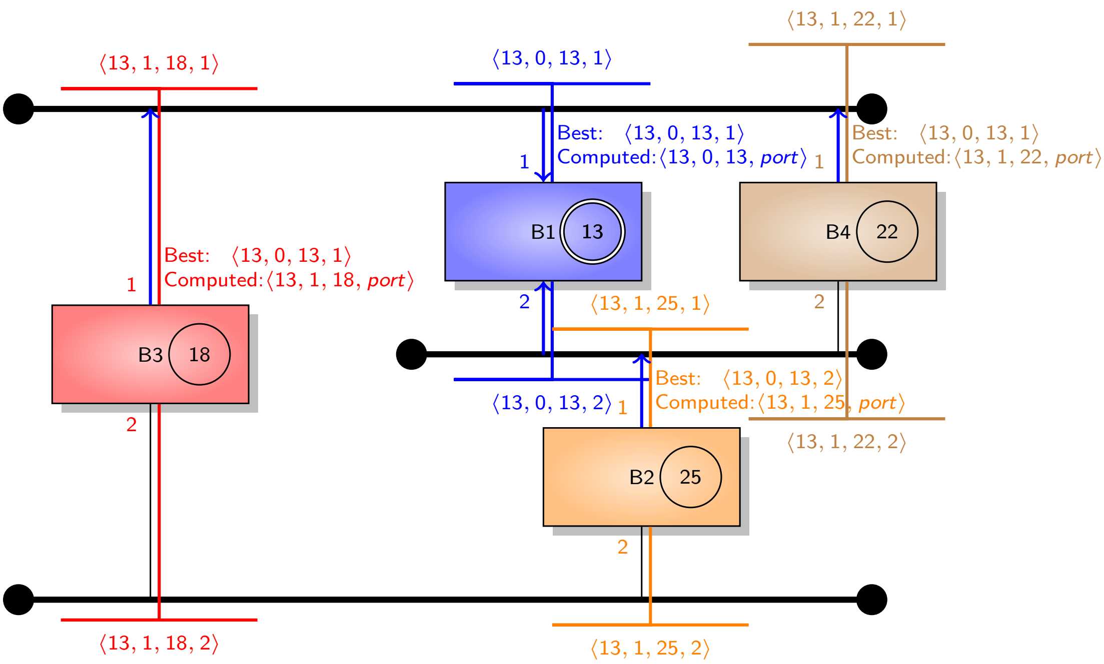
Example



t=0: All bridges believe to be root

Example

Spanning Tree ▶ Algorithm



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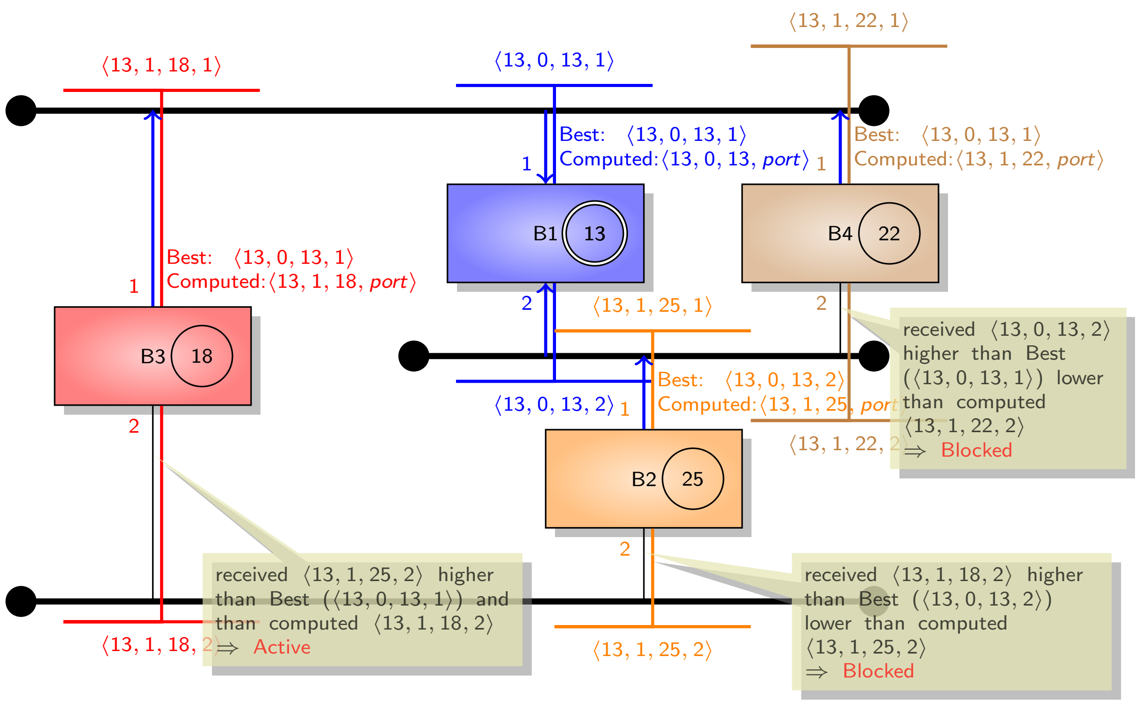

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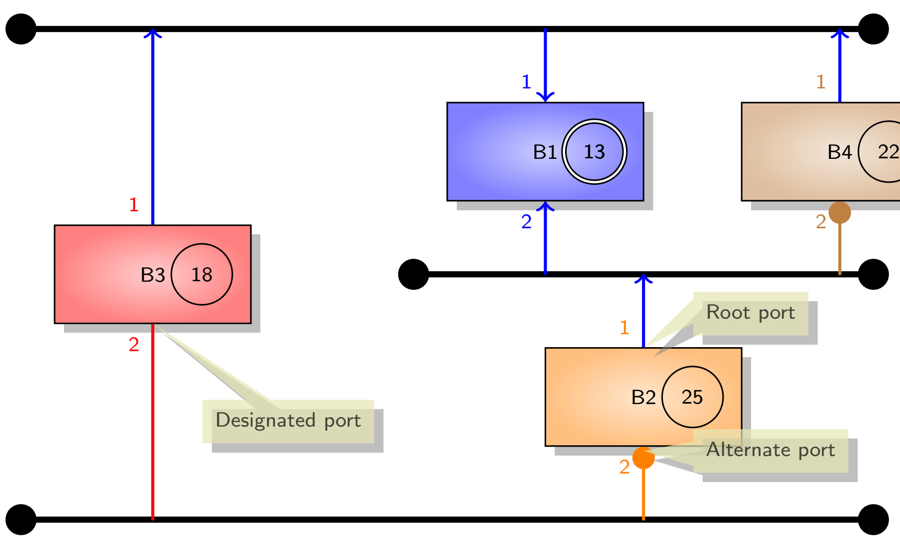

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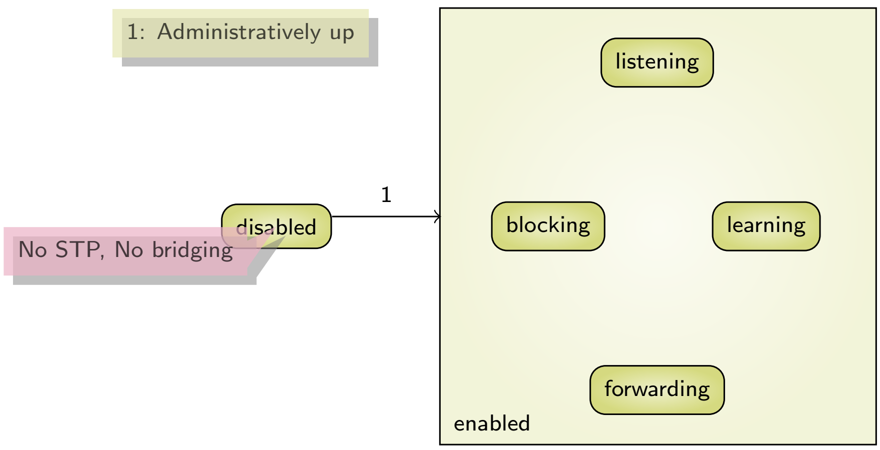
TELECOM Bretagne

Spanning Tree

Rapid STP

Interface states

In STP, an interface may have different states:



Timer 5 is about 15 sec + up to 40 sec to detect failure ⇒ more than 1 minute to forward frames.

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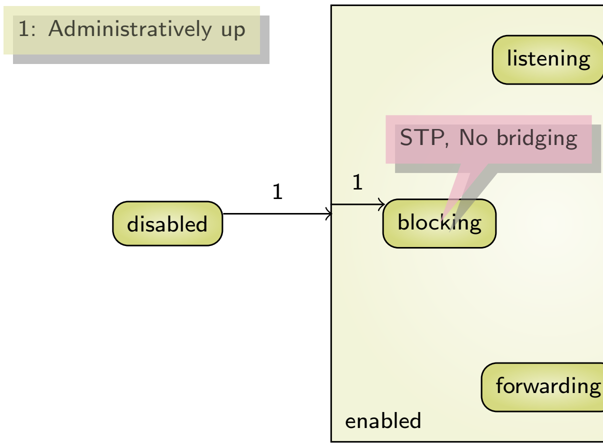

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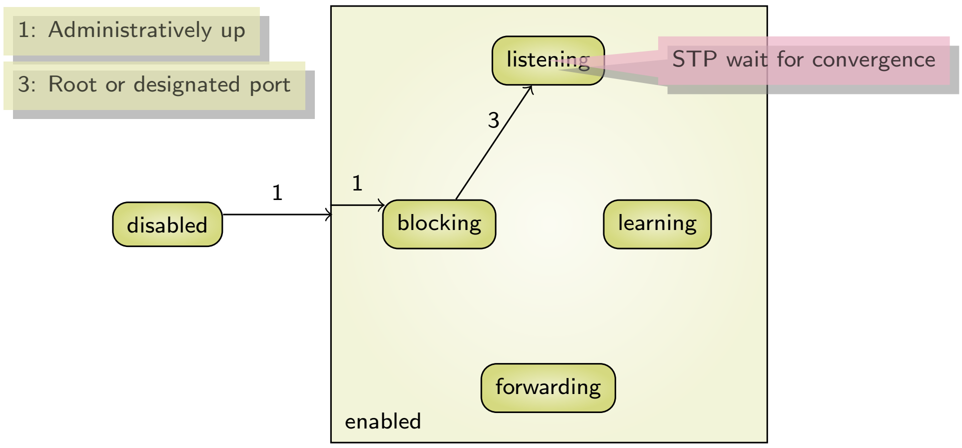

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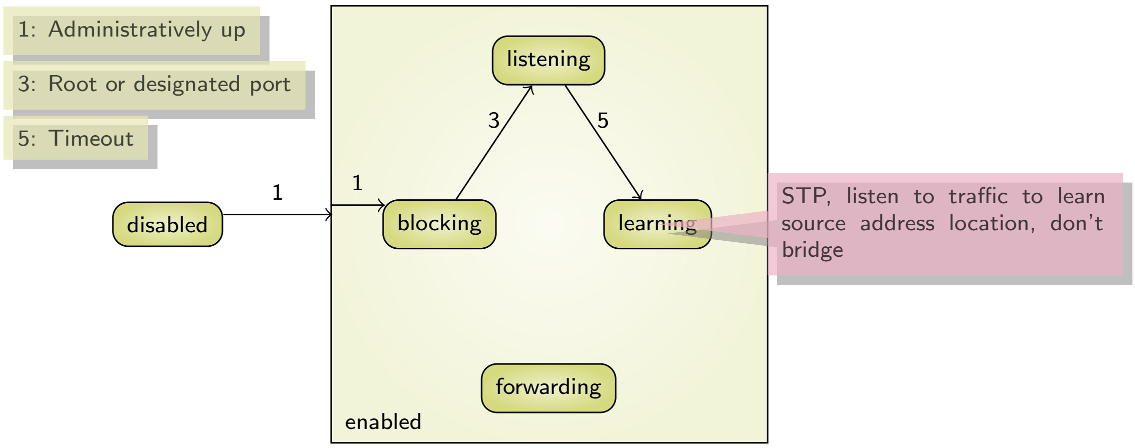

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Interface states

Spanning Tree ▶ Rapid STP

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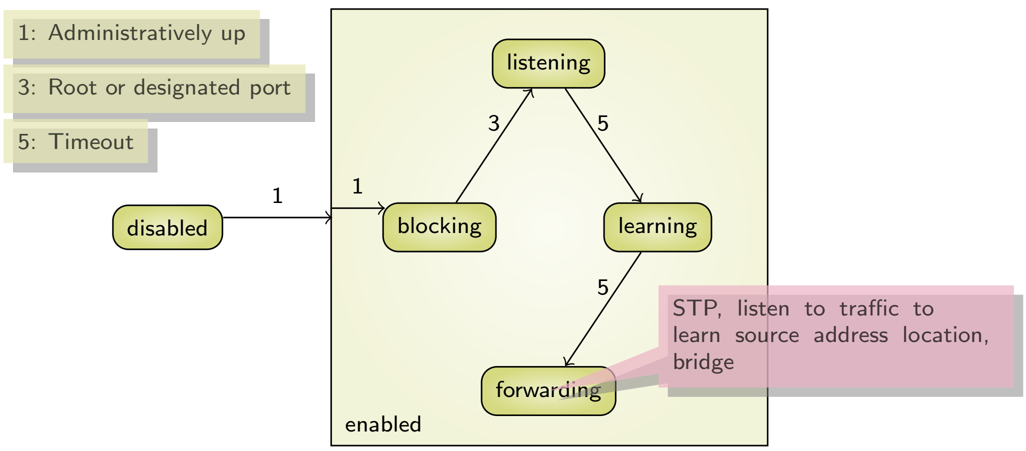

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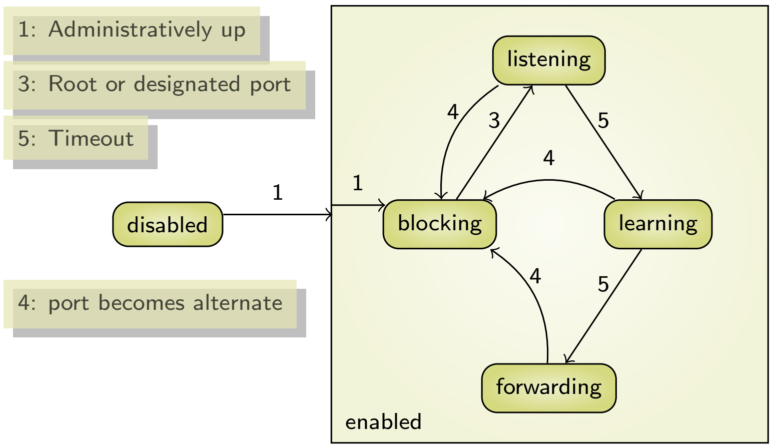

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Spanning Tree ▶ Rapid STP

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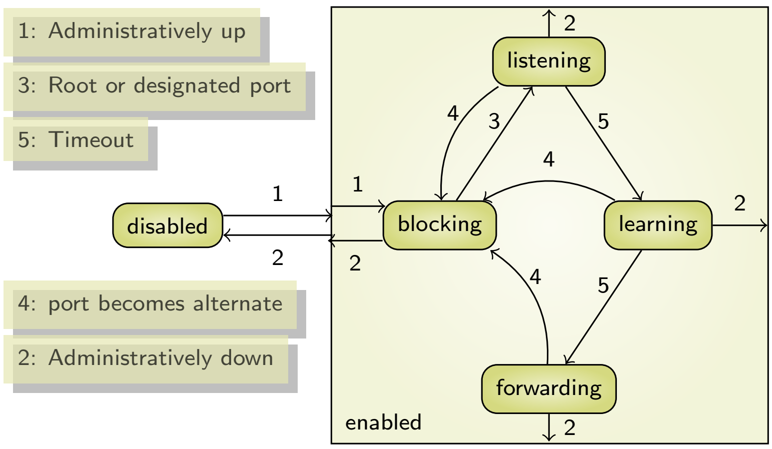

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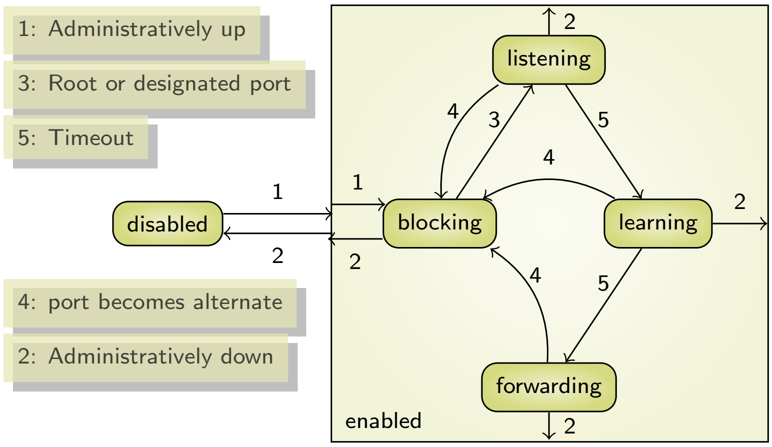

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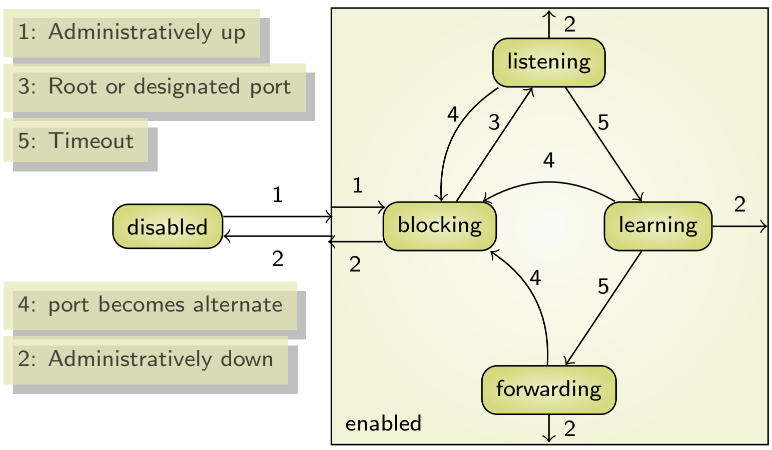
Interface states

In STP, an interface may have different states:



Timer 5 is about 15 sec + up to 40 sec to detect failure ⇒ more than 1 minute to forward frames.

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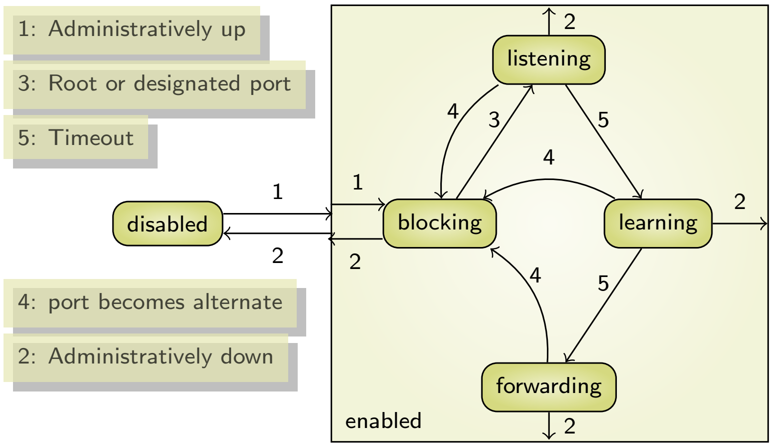


Timer 5 is about 15 sec + up to 40 sec to detect failure ⇒ more than 1 minute to forward frames.

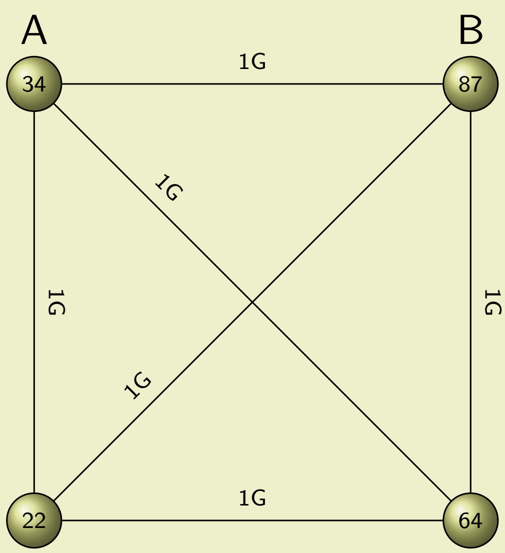
Network recovery

- Each bridge send periodically a ST message
  - interval: between 1s and 10s (recommended: 2s)
- Each message contains an age field giving the time the root has been seen.
- If age reach a limit (between 6s and 40s (recommended 20s)), this implies a connectivity problem between the bridge and the root.
  - Spanning Tree construction is restarted (start in the blocking state)
  - new root may be selected.
- Network may take about 1mn to recover:
  - Up to 20s to detect a path to root failure
  - 15s to move from learning
  - 15s to move to forwarding state.

Slow Convergence

- When SPT has been developed, preventing loops was more important than time to recover when a bridge or a link fails.
  - File transfer, mail,. . . are not real time
  - It may take more than a minute to recover
- Nowadays with real time protocol such as VoIP or streaming these delays are not acceptable
- Rapid Spanning Tree Protocol developed by IEEE 802.1w is backward compatible with STP.
  - if 3 consecutive ST messages are lost, ST topology is restarted
    - up to 6s to restart Spanning Tree construction
- Adapt to switched technologies
  - Link to other switches
  - Link to hosts (No Bridge PDU).

Questions



Which router becomes root?

Which ports are root ports?

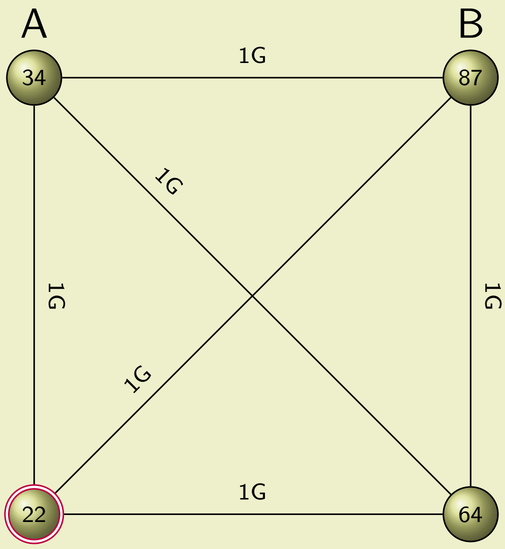
Which ports are alternate ports?

Will a frame from A to B follows the optimal path?

Are all the link used ?

What happen if root bridge links were 10 Mbit/s links? How to solve this?

Questions



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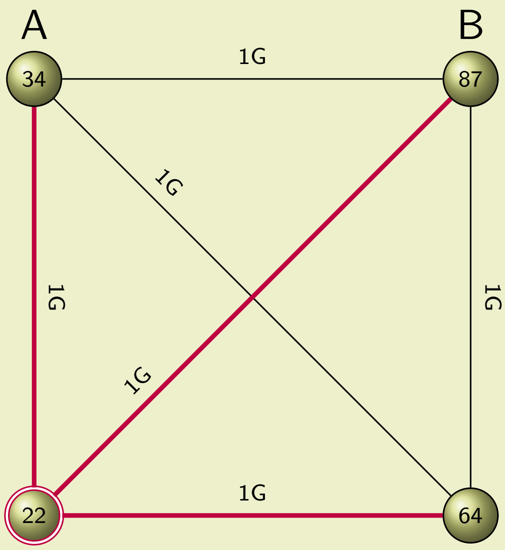

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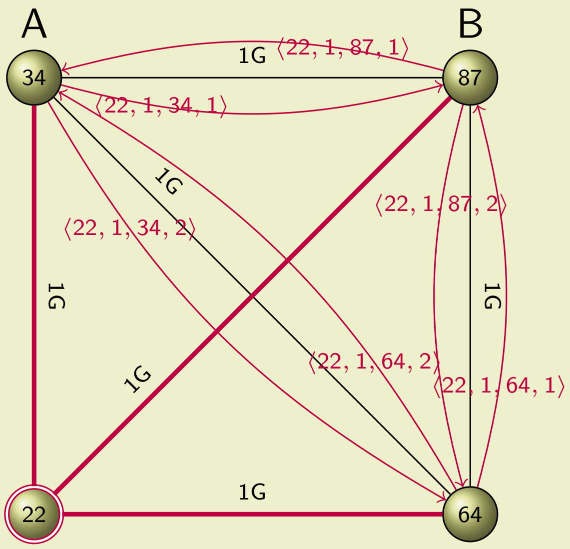

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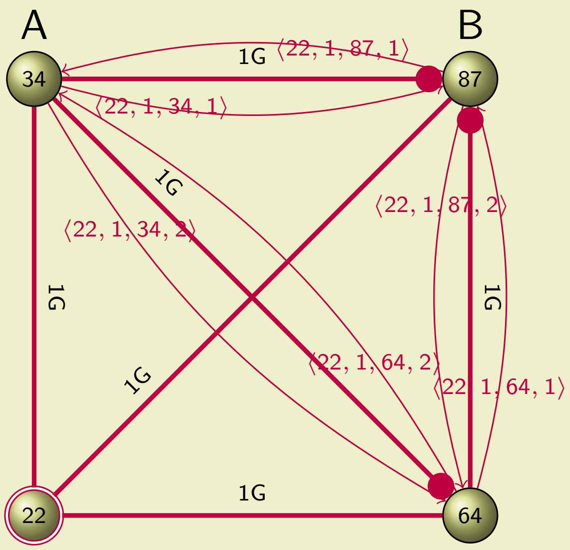
Spanning Tree ▶ Rapid STP

Questions



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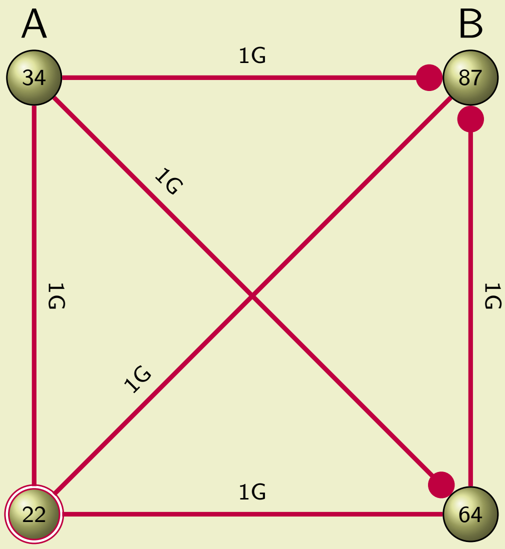

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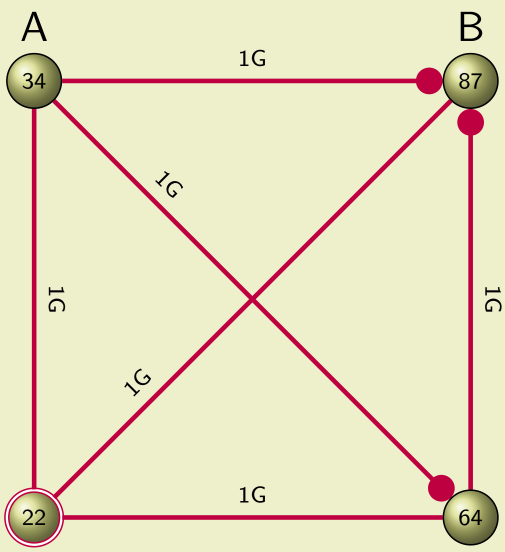
Spanning Tree ▶ Rapid STP



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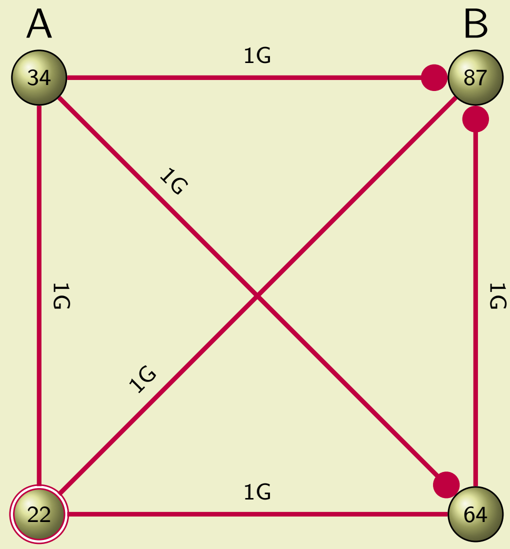

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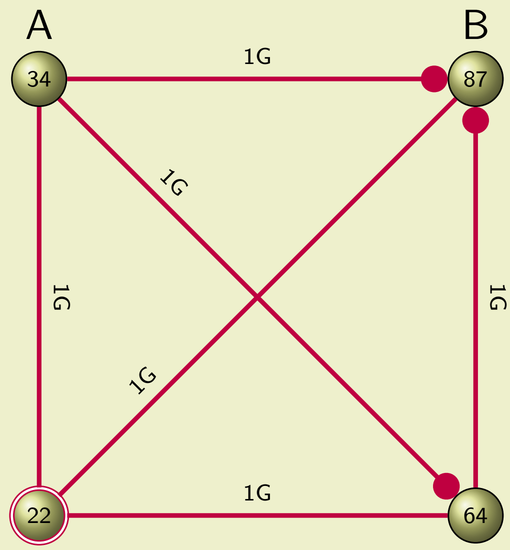

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What happen if root bridge links were 10 Mbit/s links? How to solve this?

Bad performances. Change root bridge id.

Alternatives to Spanning Tree

- Spanning Tree can be viewed as a fuse to protect network but
  - Traffic Engineering is quite complex
  - The shortest path is not always used
  - Some links are not used
- Alternatives based on routing protocol are currently standardized:
  - IETF TRILL (Transparent Interconnection of Lots of Links)
    http://datatracker.ietf.org/wg/trill/
  - Shortest Path Bridging (SPB) (IEEE 802.1aq)
    http://www.ieee802.org/1/pages/802.1aq.html

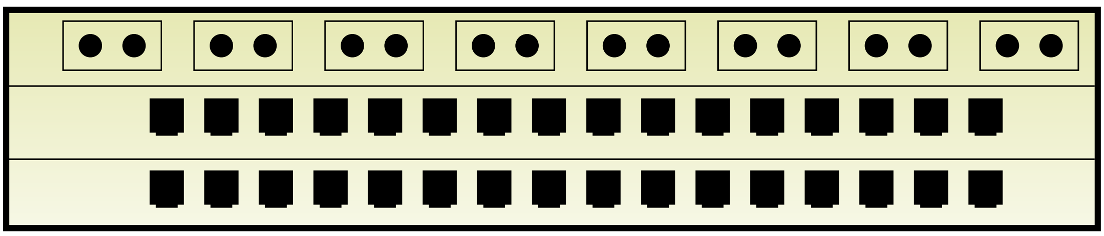
VLAN

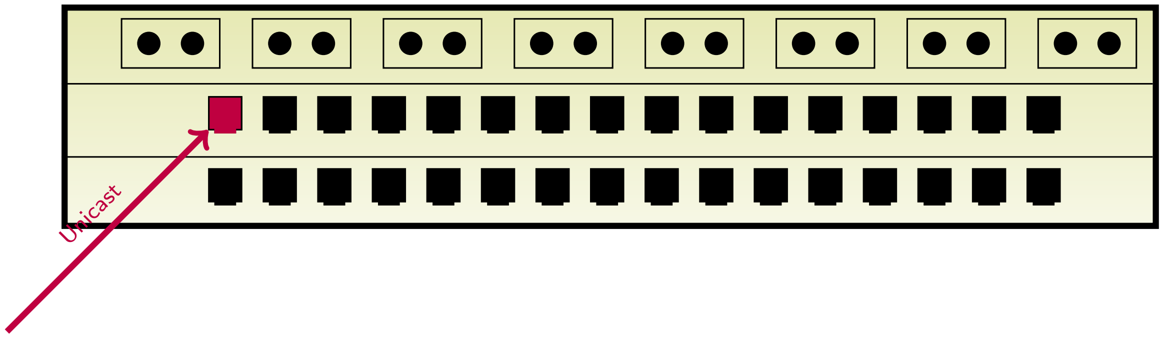
Introduction

Virtual Local Area Network

- LAN allows a simple management:
  - No address allocation procedures
  - Simple interconnection with bridges
- But suffers from some scalability and security problems
  - Address list must be construct for each port
  - Traffic cannot be filtered
  - Broadcast or Multicast frames flood the network
  - Cabling constraints: Moving one equipment from one network to another implies modifying the topology.
- VLAN solves this problem separating the physical infrastructure into logical (virtual) ones.
  - Physical: Links, switches
  - Logical: Configure switches to assign a virtual network to a group of ports.

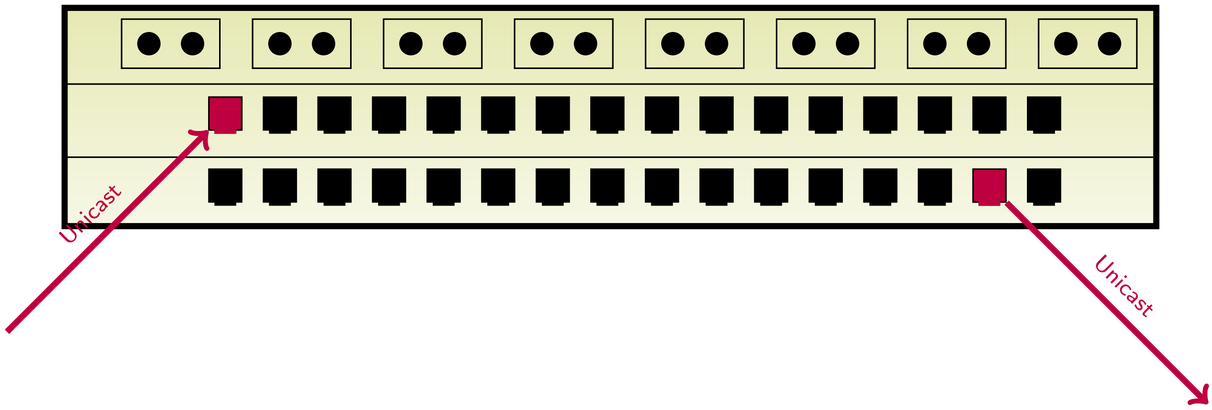
VLAN on a switch





VLAN on a switch

VLAN ▶ Introduction



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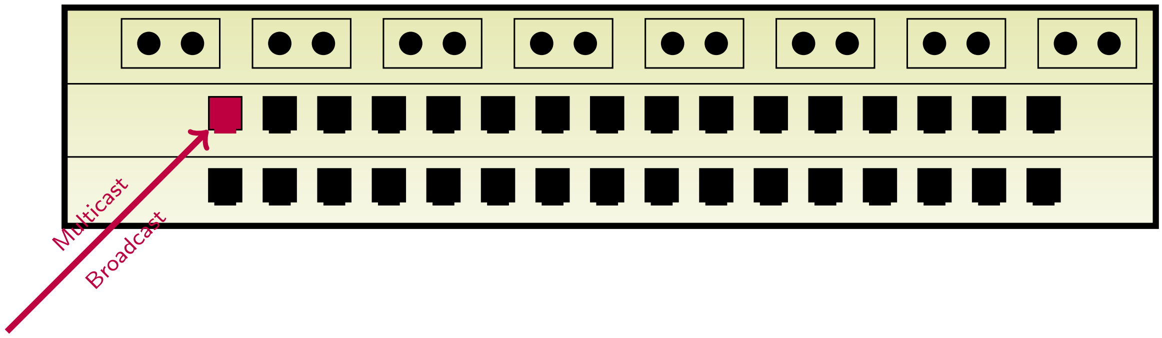
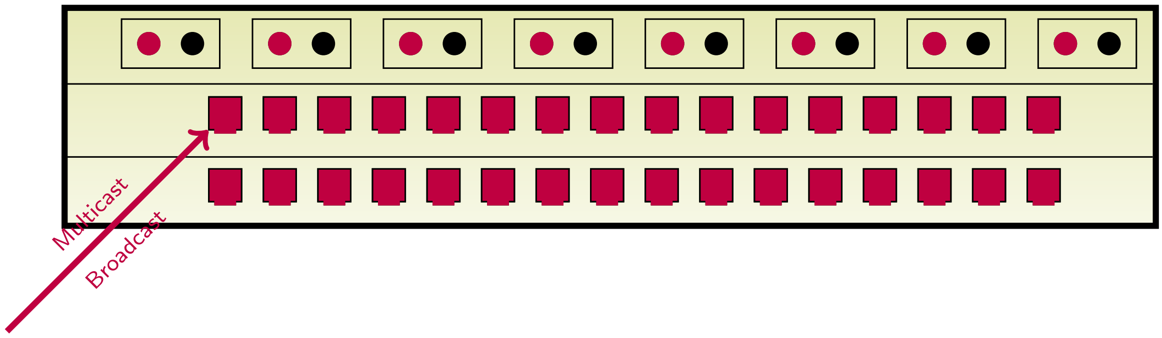


VLAN on a switch

VLAN ▶ Introduction



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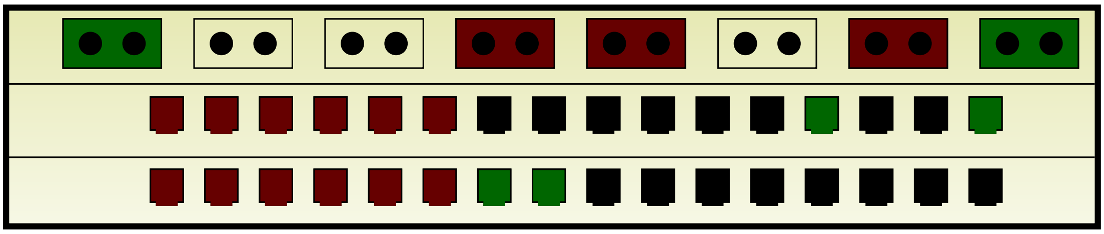
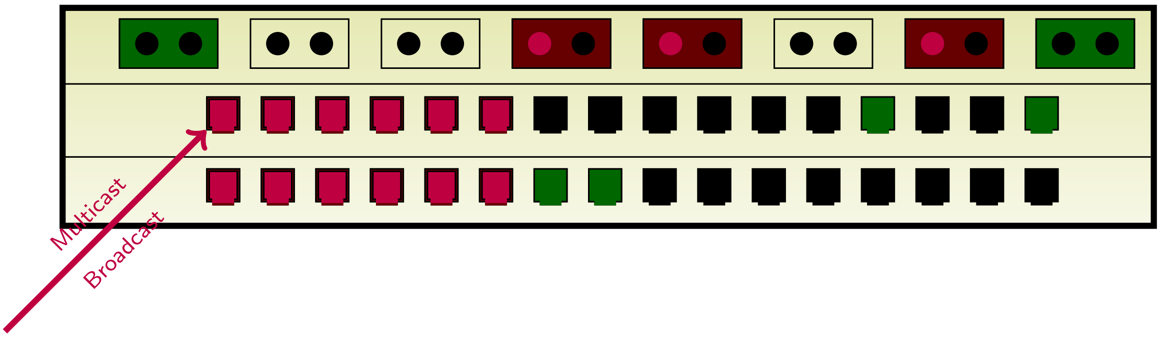


VLAN on a switch
VLAN ▶ Introduction



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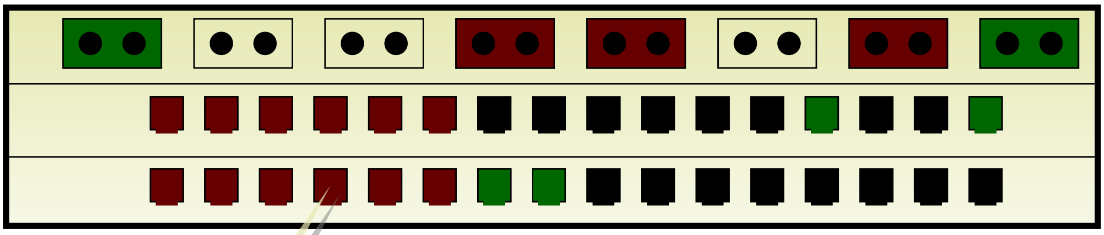
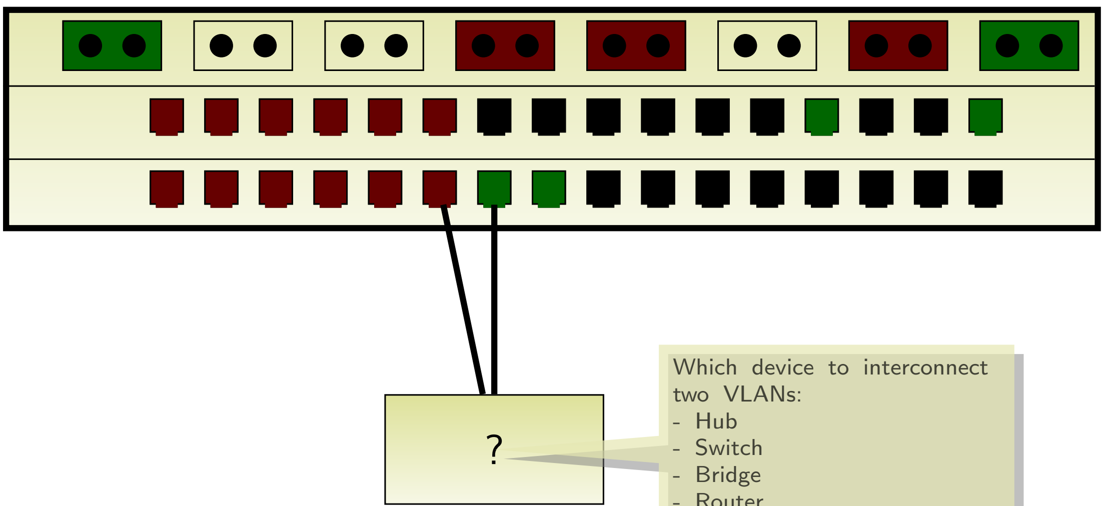
VLAN on a switch



Assign by configuration a VLAN number to some ports
Can be different technologies (optical fiber, twisted pair)
Similar to different separated switches

VLAN on a switch

VLAN ▶ Introduction



Which device to interconnect two VLANs:
- Hub
- Switch
- Bridge
- Router
- Gateway

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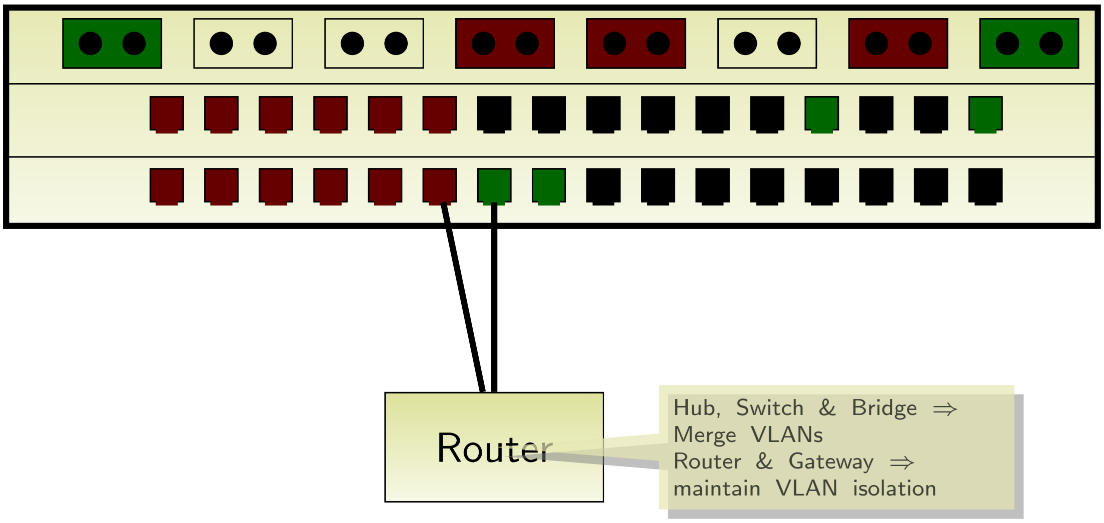
VLAN on a switch



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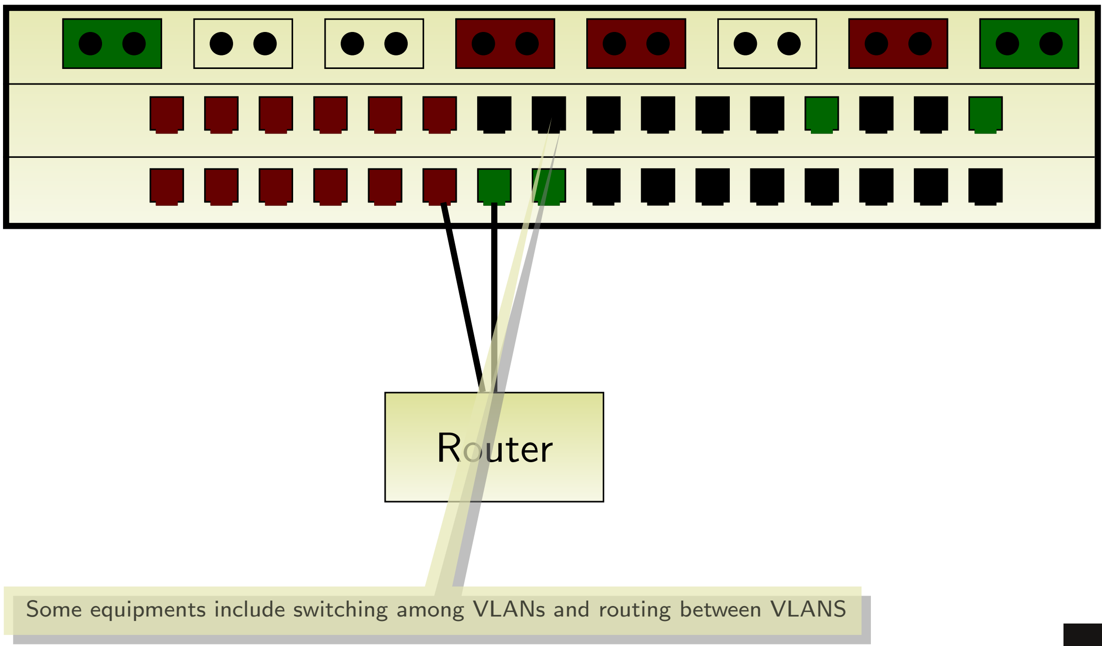
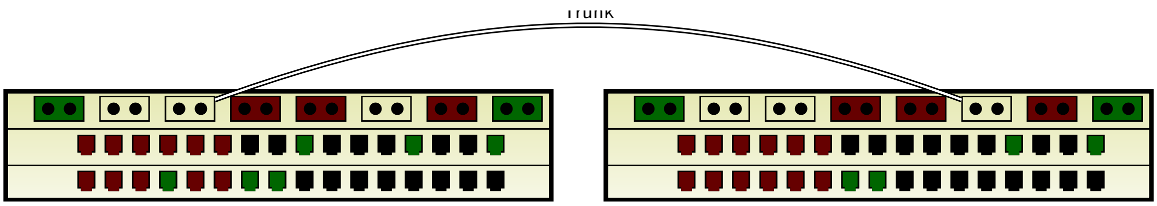


VLAN

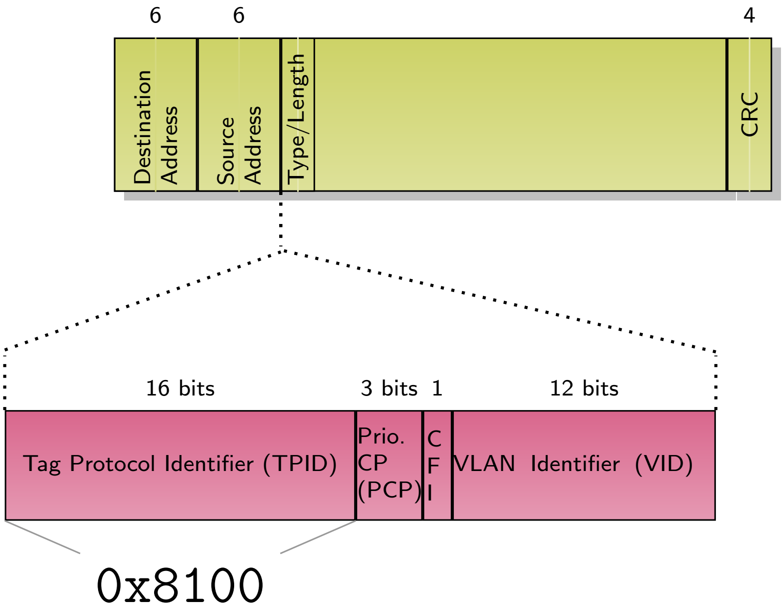
IEEE 802.1p/Q

Tags IEEE 802.1p/Q



- When several switches are involved, VLAN value must be carried between equipments.
- Switches add a tag in the frame containing the VLAN number.
- IEEE 802.1p/Q defines tag format for VLAN and priority.

Ethernet vs IEEE 802.3



VLAN ▶ IEEE 802.1p/Q

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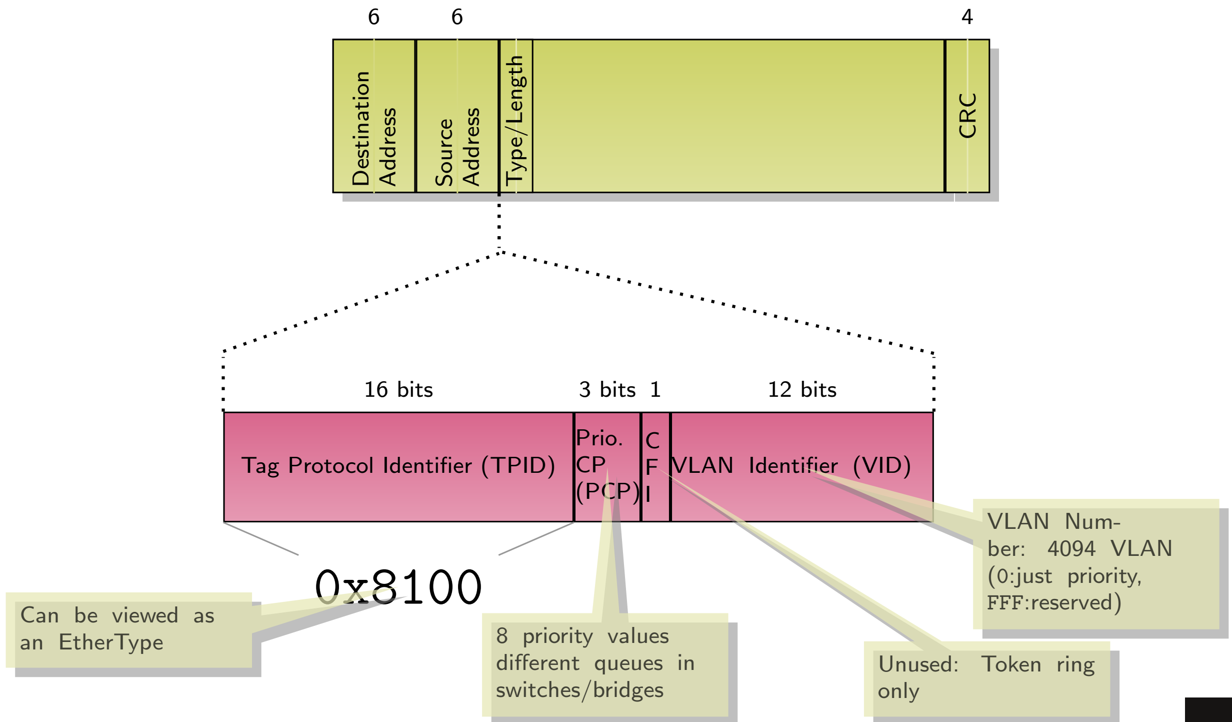

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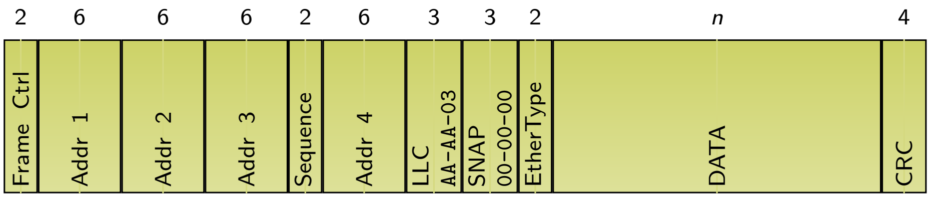
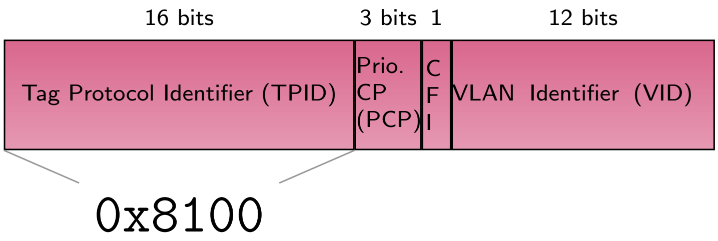
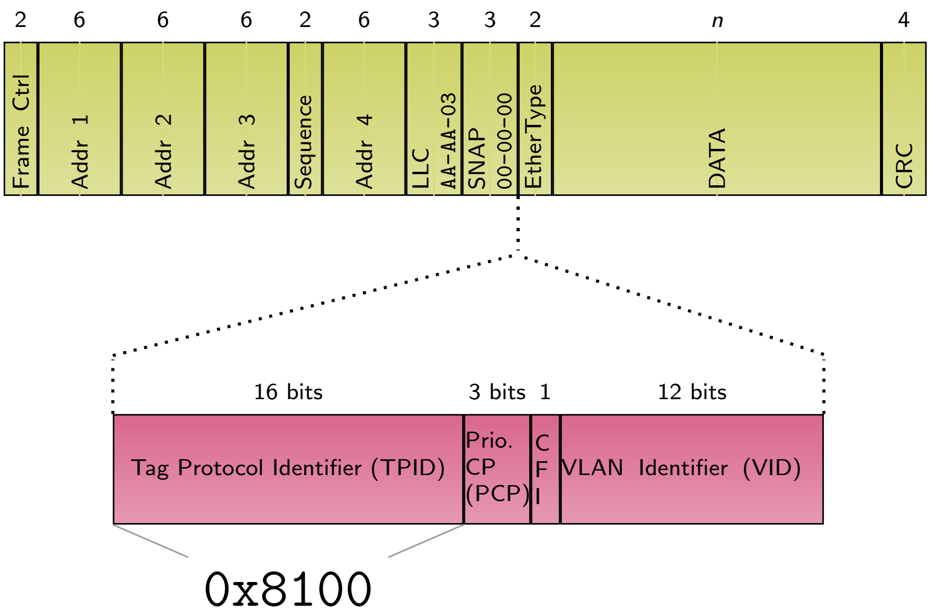




Ethernet vs IEEE 802.3
VLAN ▶ IEEE 802.1p/Q



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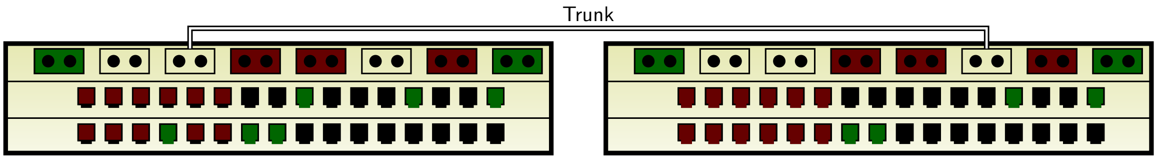
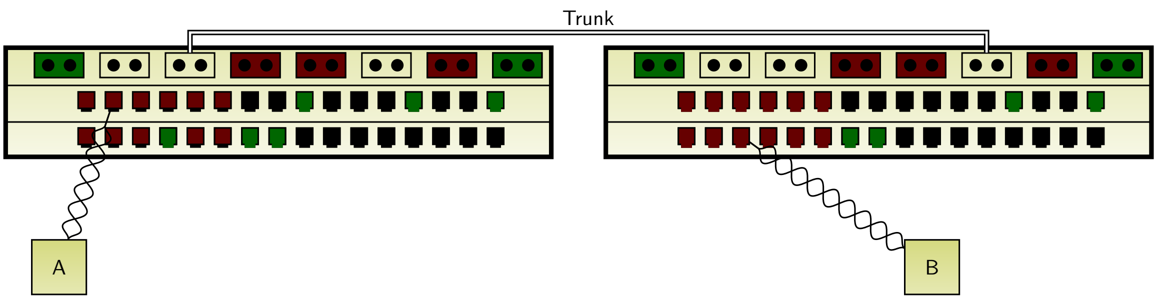


- VLAN tag is added between switches:
  - Host generally do not tag frames
  - Maximum frame size can be exceeded when tag is added
    - not a problem with jumboframe (9 KB)
    - IEEE 802.3ac also allow Ethernet frame with up to 1522 Bytes
- There is a default VLAN without tagging, switch can be configured to associate internally a VLAN value.

Tags IEEE 802.1p/Q

VLAN ▶ IEEE 802.1p/Q



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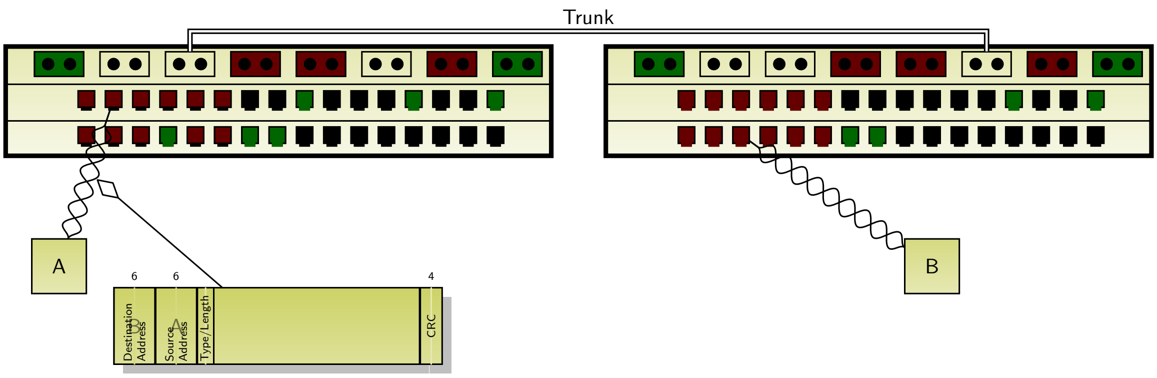

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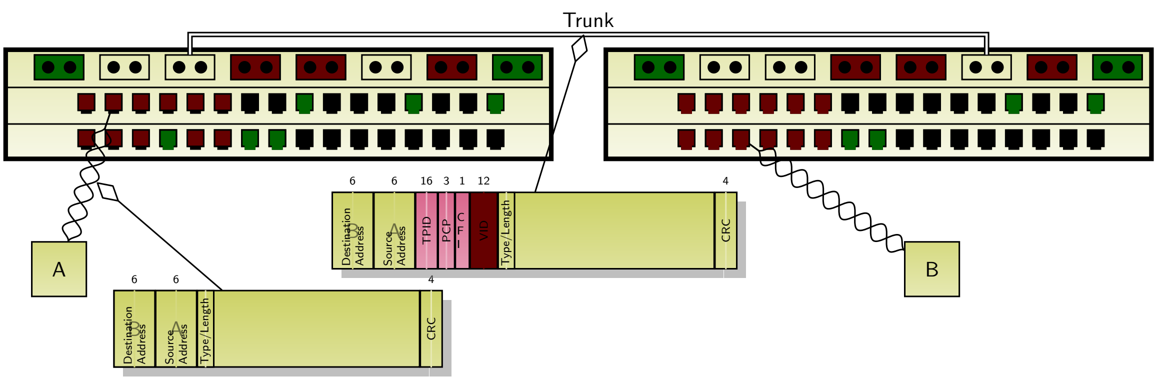

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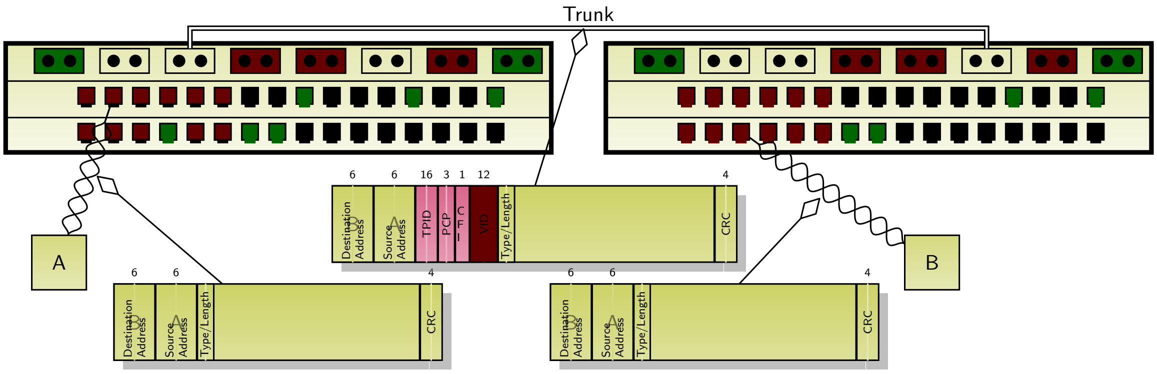

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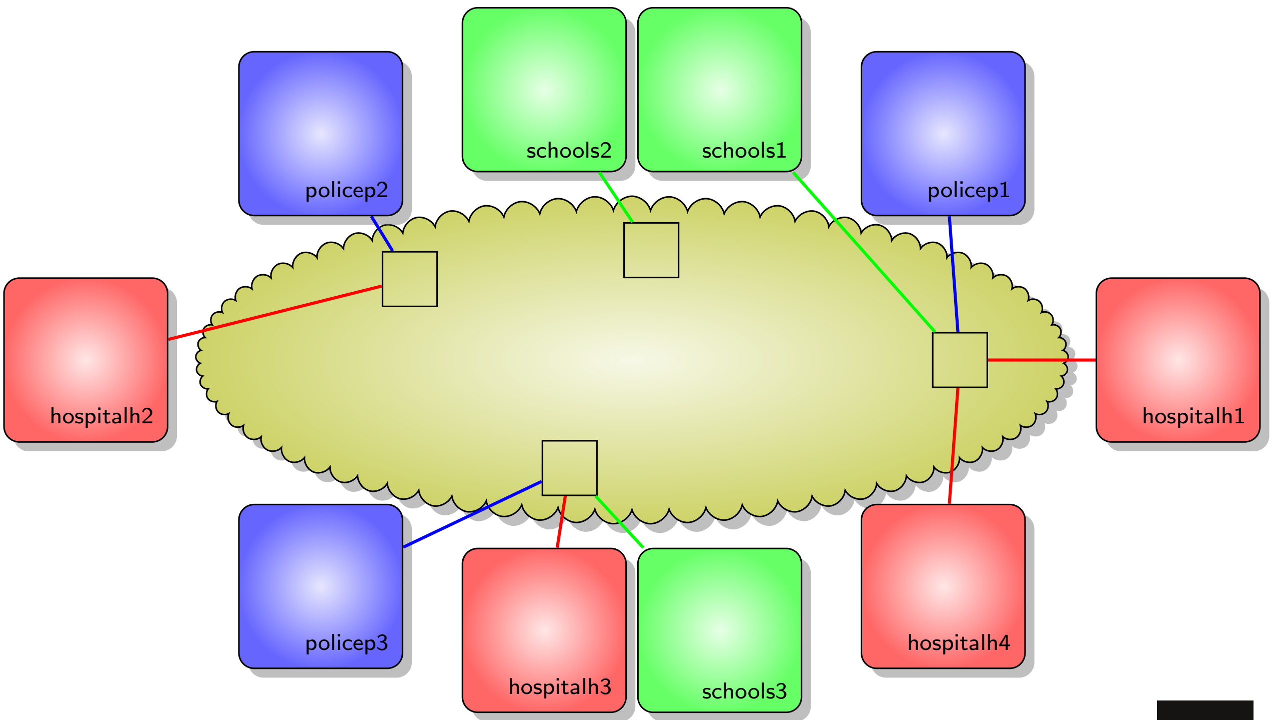
Metropolitan Networks

QinQ

Metropolitan Ethernet

- Switched networks with VLAN are particularly powerful:
  - frame switching is efficient
  - distance is no more a limitation (no CSMA/CD)
  - OPEX is reduced (equipments automatically configure themselves)
- But scalability and security are limited:
  - Switches must learn all the MAC address
  - An attacker may inject fake addresses
  - VLAN numbers must be globally unique
- QinQ allows to stack VLAN tag
- MACinMAC(IEEE 802.1ah) allows to encapsulate Ethernet frame into Ethernet frame.

IEEE 802.1ad (QinQ)



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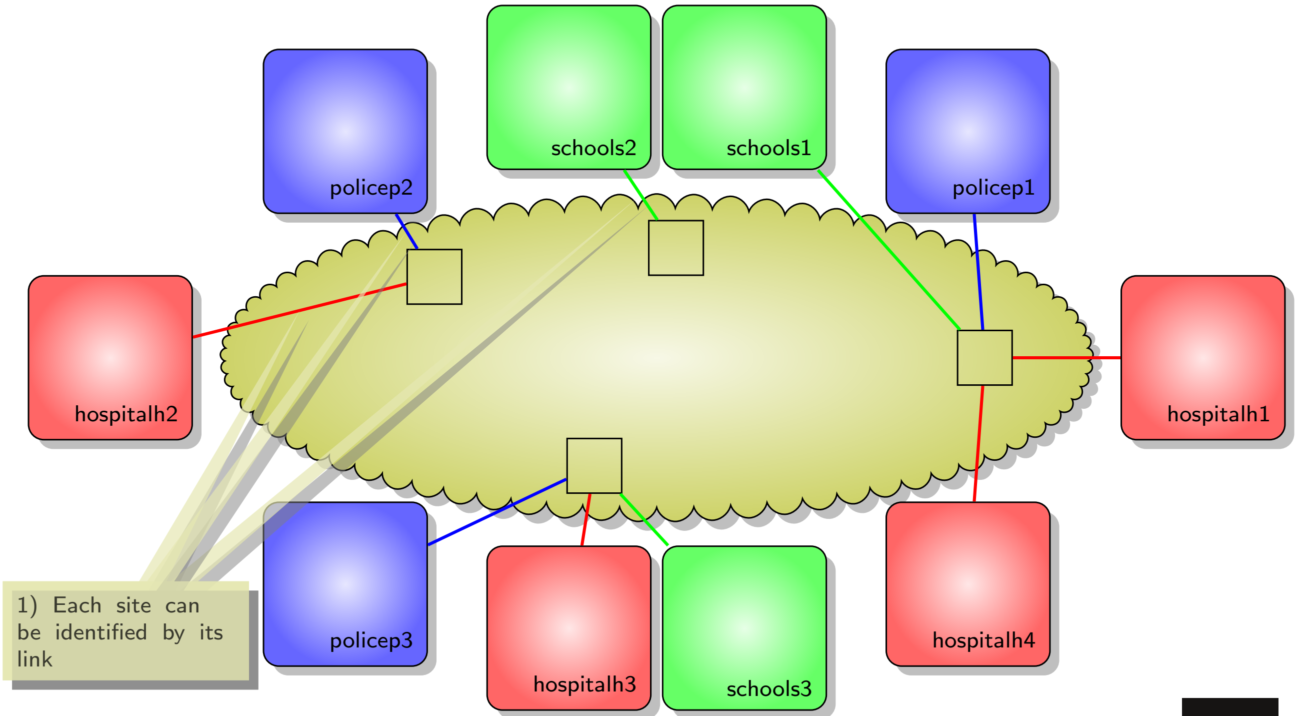
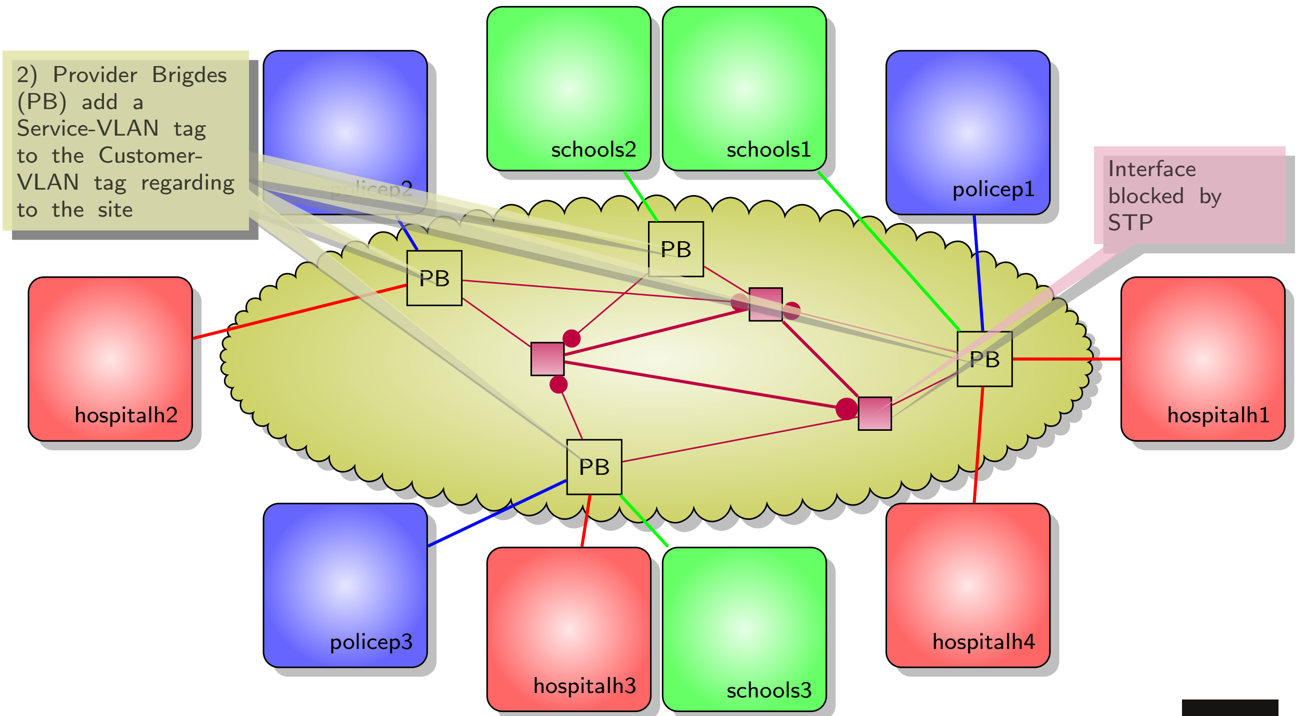


IEEE 802.1ad (QinQ)

Metropolitan Networks ▶ QinQ



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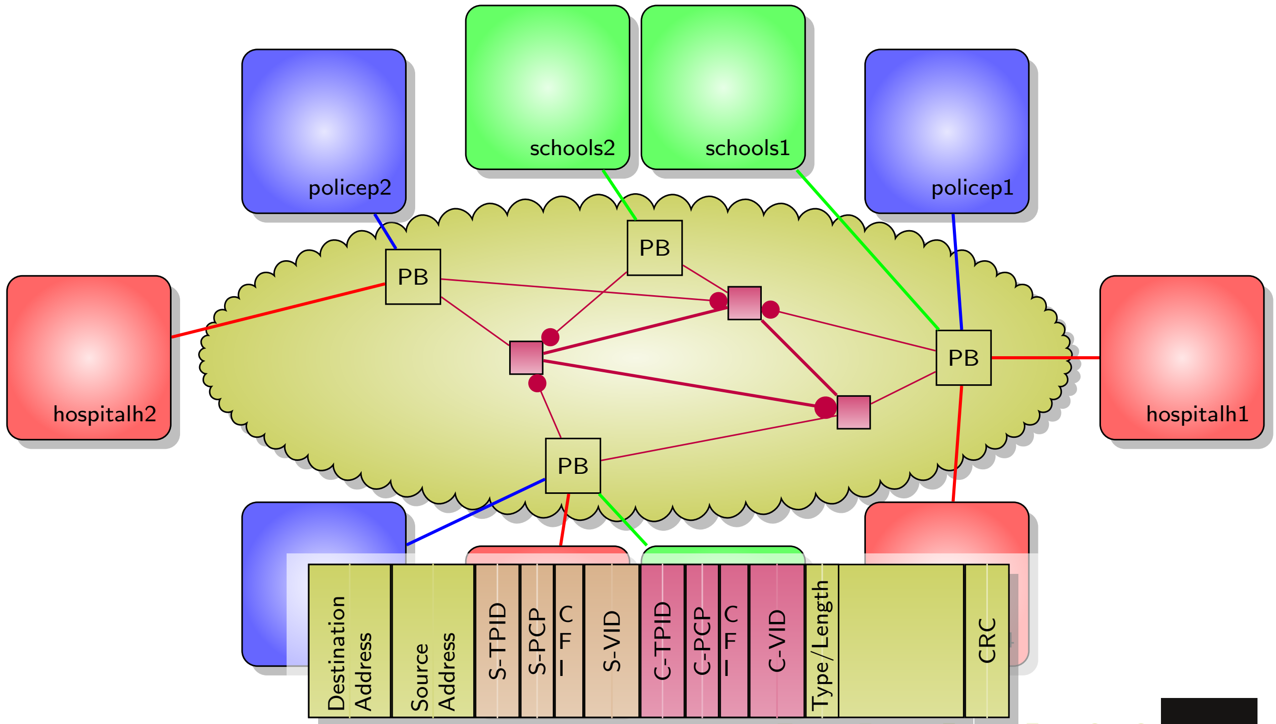
IEEE 802.1ad (QinQ)



IEEE 802.1ad (QinQ)

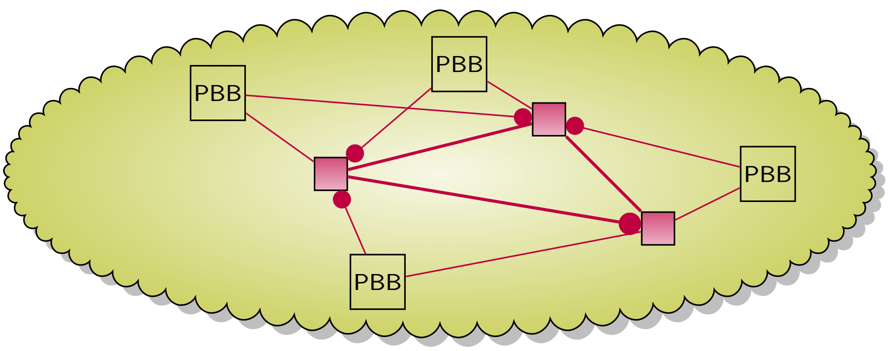
Metropolitan Networks ▶ QinQ

- IEEE 802.1ad defines two categories of VLAN tags:
  - Customer VLAN (or C-VLAN) generated by the customer switches
  - Service VLAN (or S-VLAN) added by the provider.
    - S-VID are chosen by the provider to link a group of sites.
    - S-VID designates a customer.
- S-VLAN guaranty unicity between two customers
  - if two independent company select the same VLAN number, traffic will not be merged
- S-VLAN guaranty security
  - A company cannot access to another company traffic.
- S-LAN are defined by the value 88a8 in the S-TPID
- More simple to manage than Layer 2 VPN based on IP routing and MPLS.

Metropolitan Networks

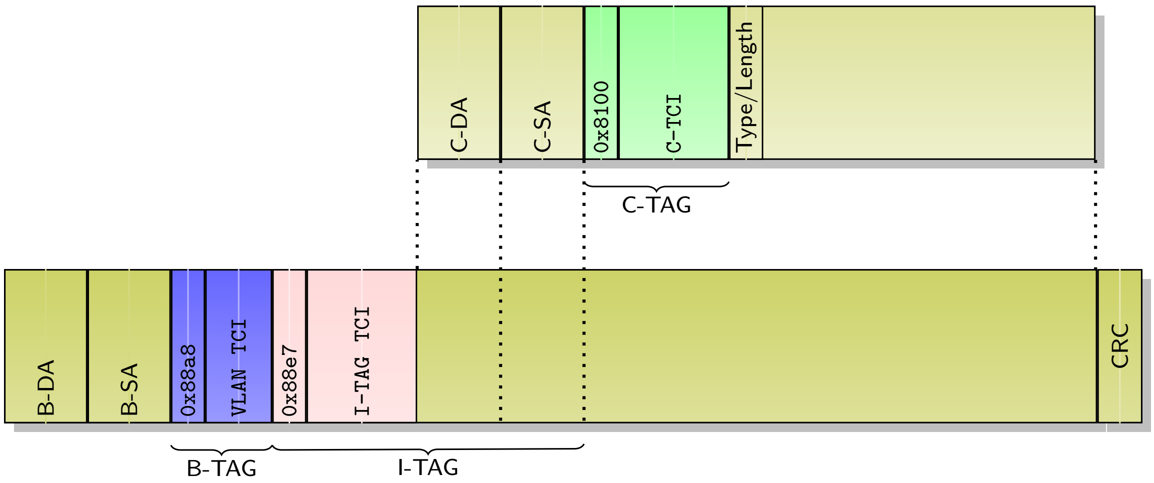
Mac In Mac

IEEE 802.1ah (MACinMAC)



- Switches in the provider network have to memorize all the MAC addresses
  - require a lot of memory.
- an attacker forging the source mac address may:
  - slow down the network saturating core tables,
  - make some equipments unreachable using their MAC address.
- Provider Backbone Bridge adds an Ethernet header.

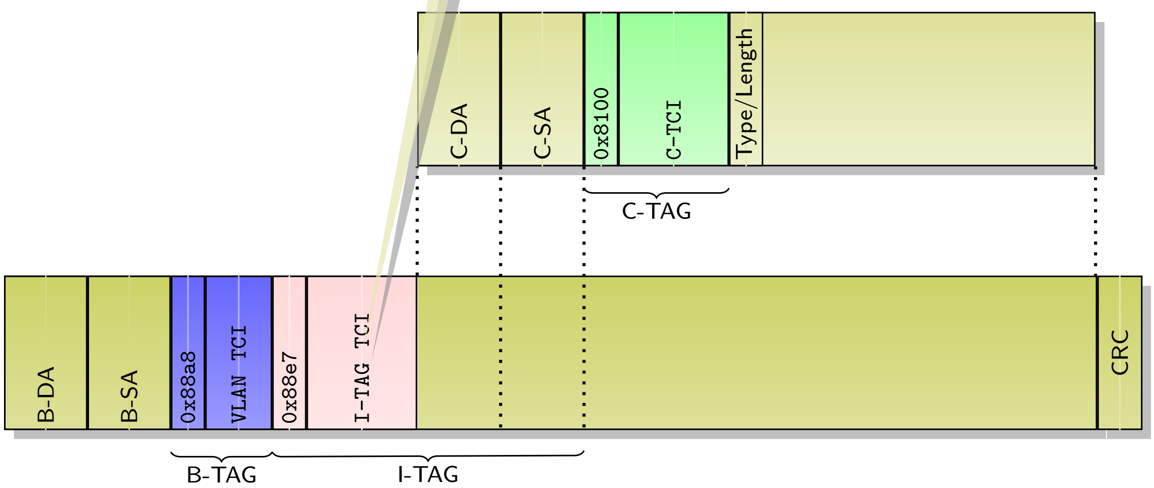
IEEE 802.1ah (MACinMAC)



Metropolitan Networks ▶ Mac In Mac

IEEE 802.1ah (MACinMAC)

Information for Traffic Engineering



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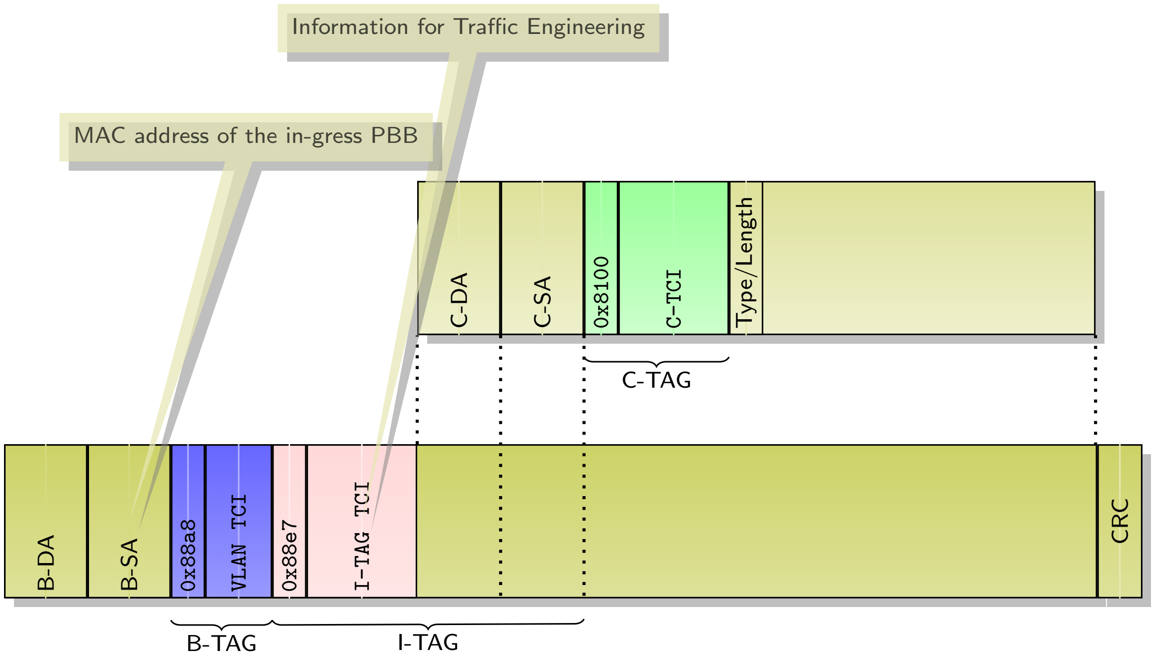
IEEE 802.1ah (MACinMAC)



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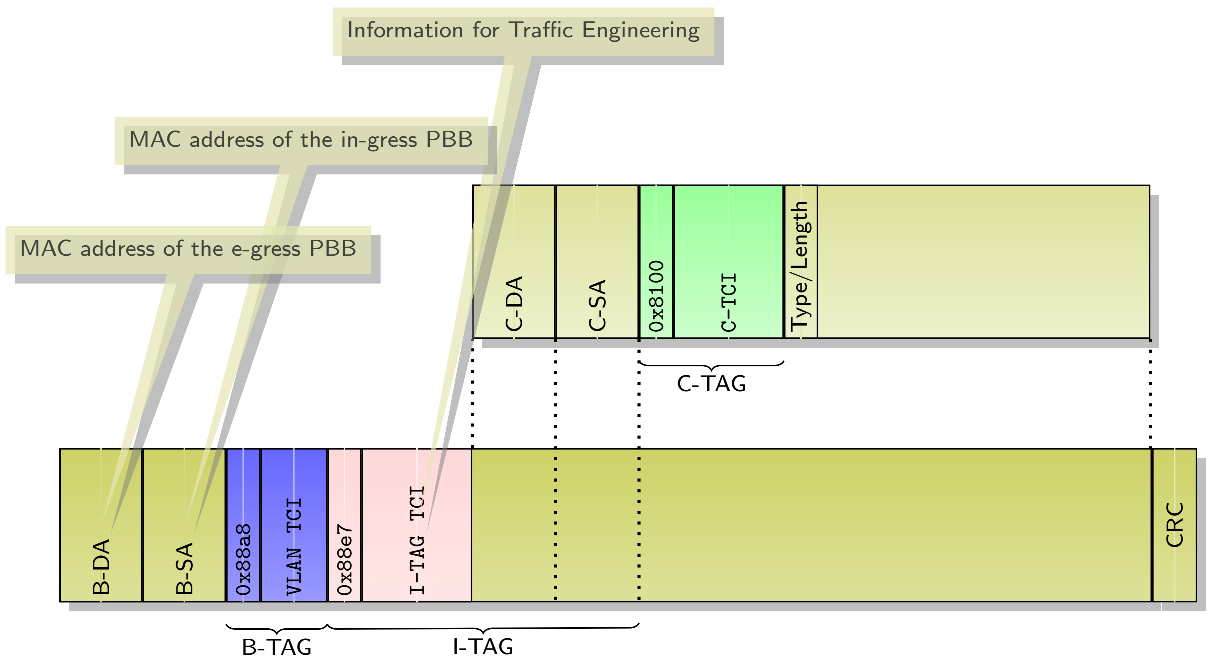

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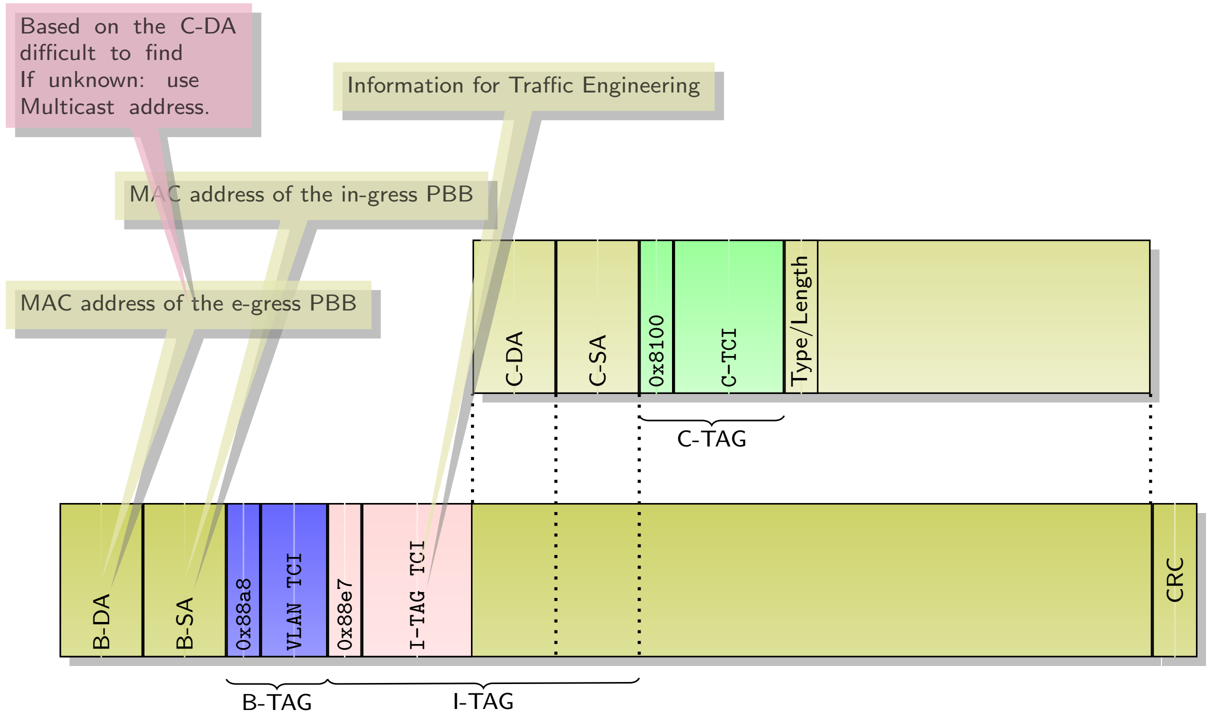

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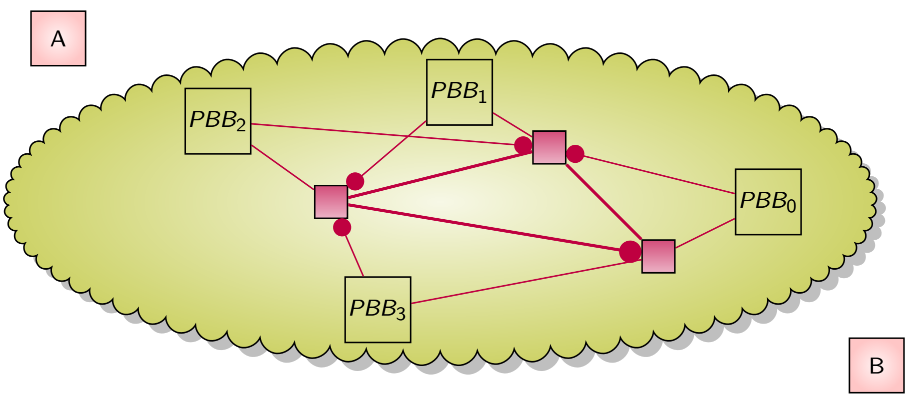
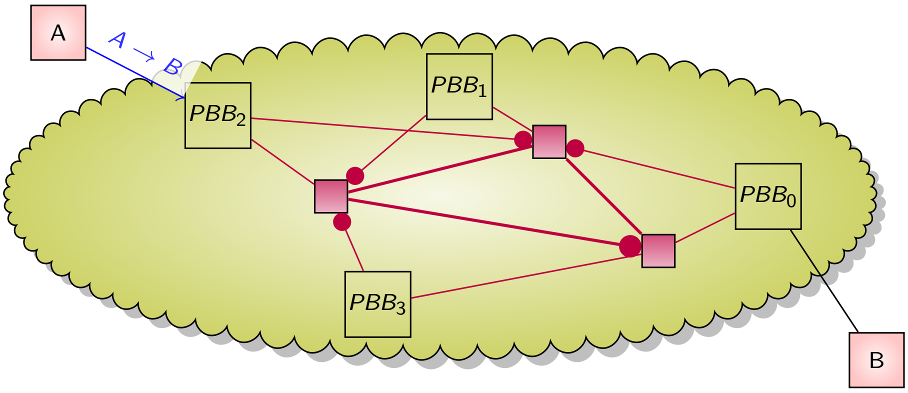
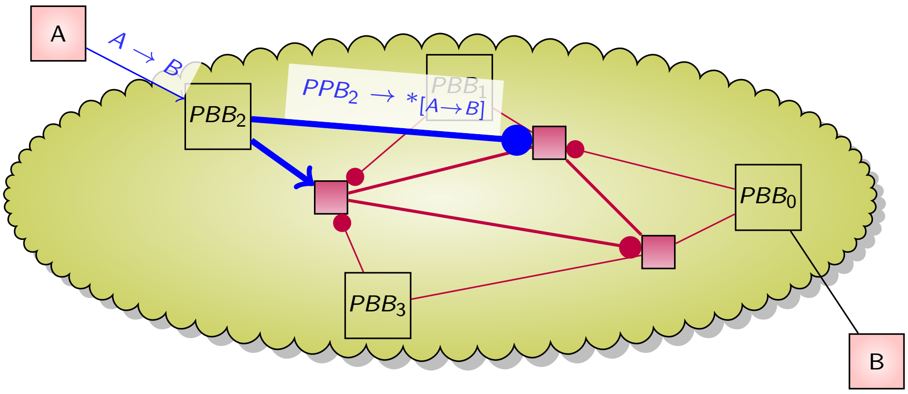




IEEE 802.1ah (MACinMAC)
Metropolitan Networks ▶ Mac In Mac



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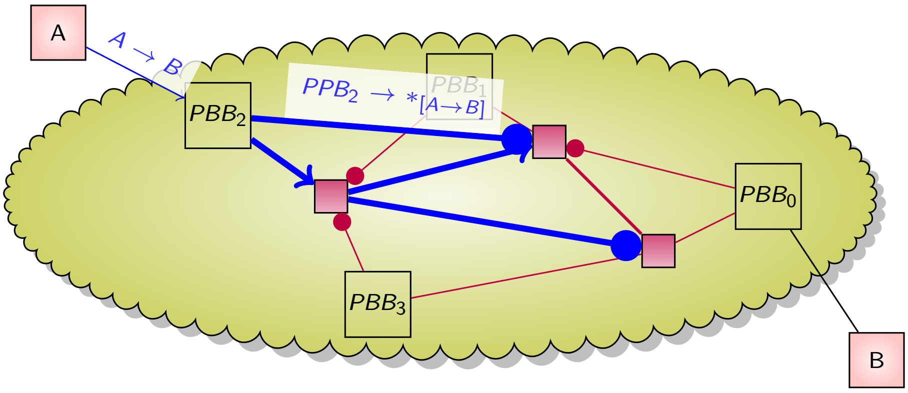
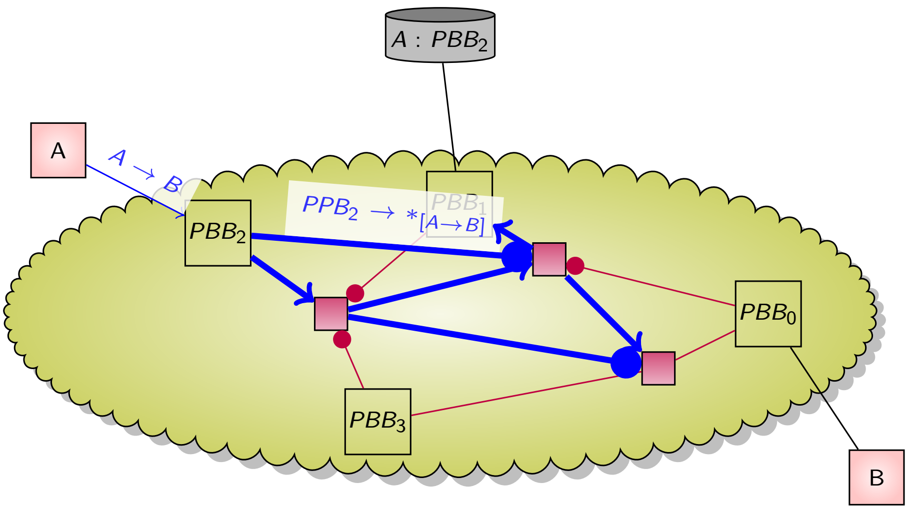


IEEE 802.1ah (MACinMAC)
Metropolitan Networks ▶ Mac In Mac



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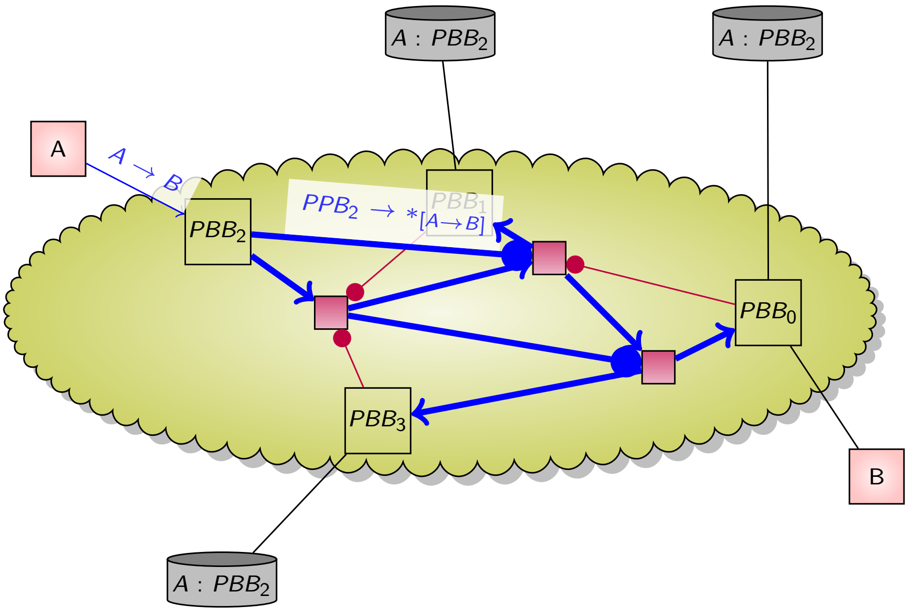
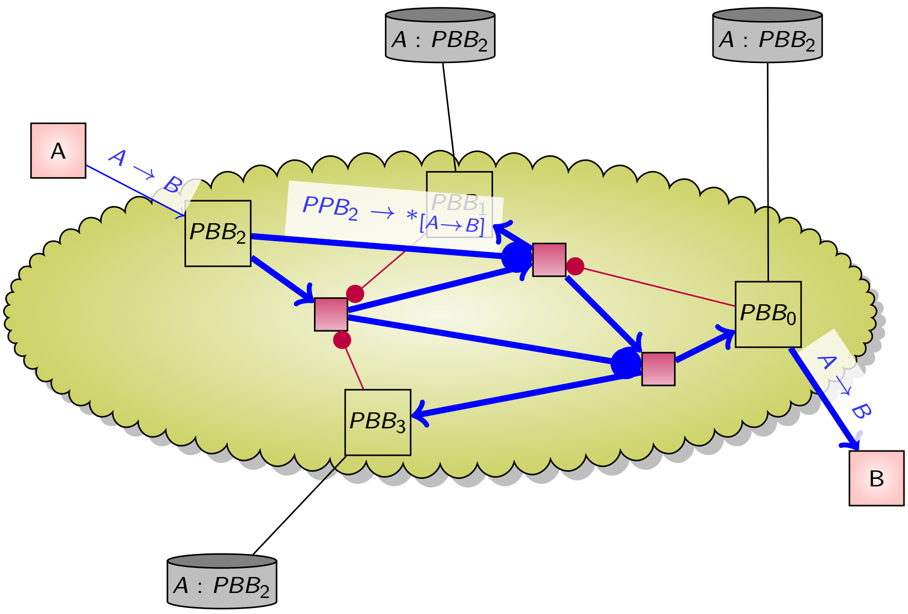


IEEE 802.1ah (MACinMAC)

Metropolitan Networks ▶ Mac In Mac



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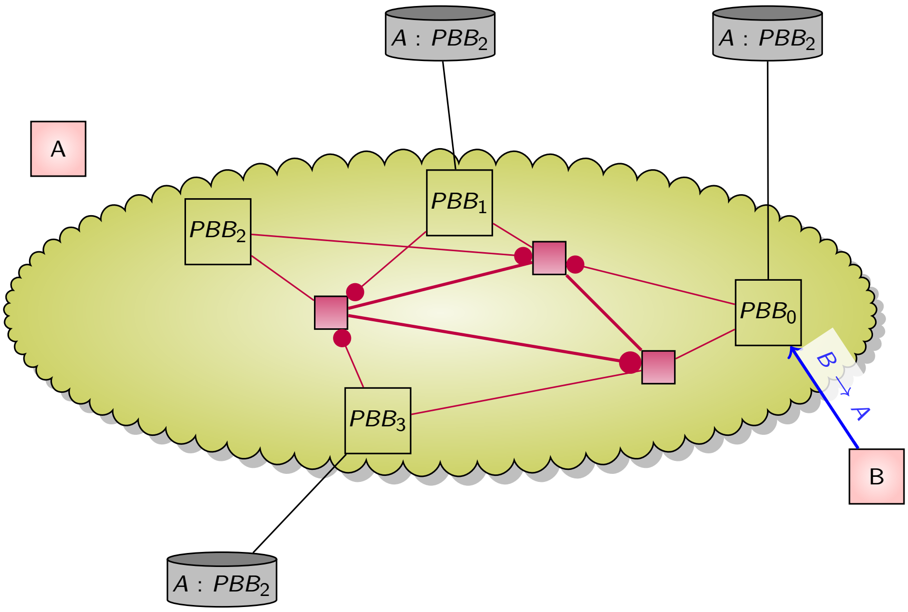

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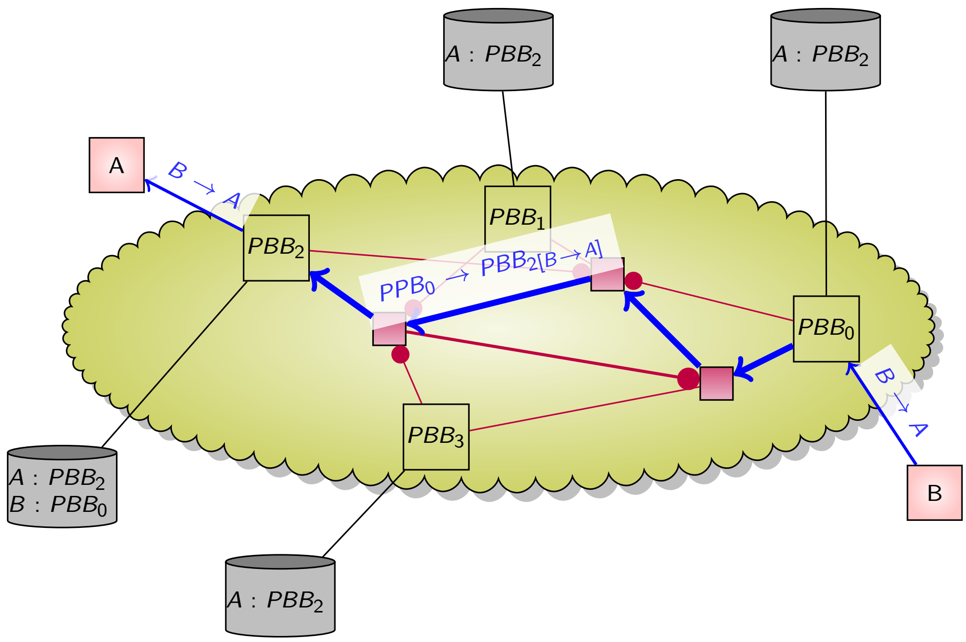

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