The Link Layer

COMP 30650: Networks and Internet Systems

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LINK LAYER

1. **Framing**
   - Delimiting start/end of frames
2. **Error detection/correction**
   - Handling errors

Done

LINK LAYER

3. **Retransmissions**
   - Handling loss
4. **Multiple Access**
   - Classic Ethernet, 802.11
5. **Switching**
   - Modern Ethernet

TODAY'S PLAN

Handling Loss

- Retransmission

The Bigger Picture

- Link Layer in the bigger picture.

Multiplexing – Sharing of Links

- TDM
- FDM

HANDLING ERRORS AND DATA LOSS

Two techniques to recover from errors:

1. Correct errors with an error correcting code
2. Detect errors and retransmit frame
   - Automatic Repeat reQuest (ARQ)

AUTOMATIC REPEAT REQUEST - ARQ

ARQ is often used when errors are common or must be corrected

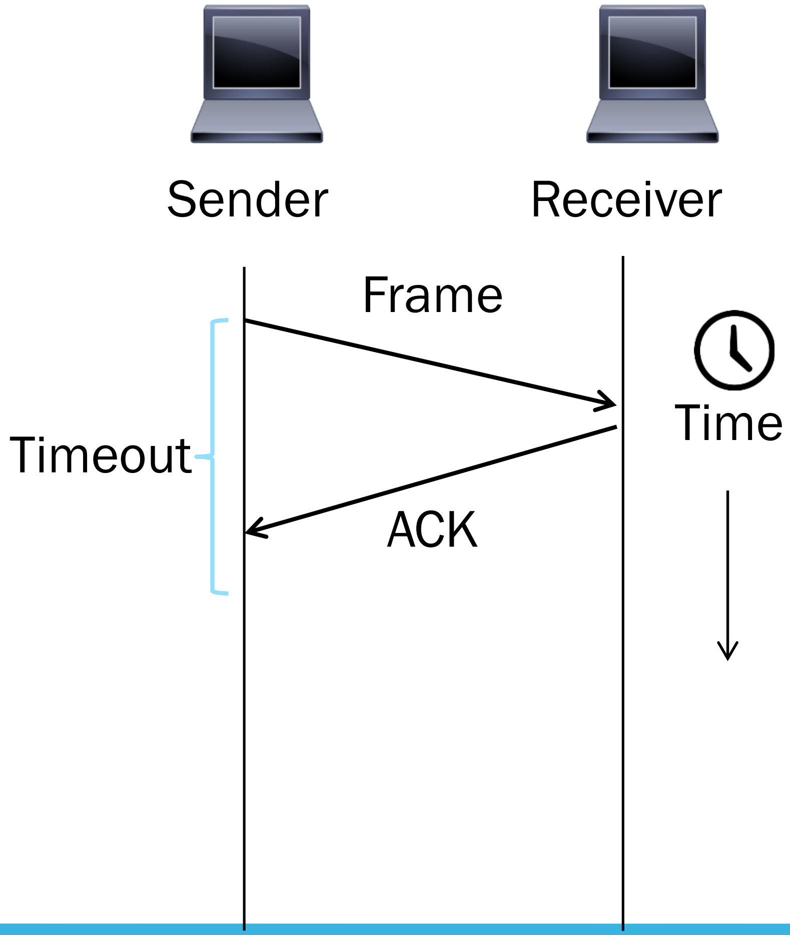
- E.g., WiFi, and TCP (later)

Rules at sender and receiver:

- Receiver automatically **acknowledges** correct frames with an ACK
- Sender automatically **resends** after a timeout, until an ACK is received

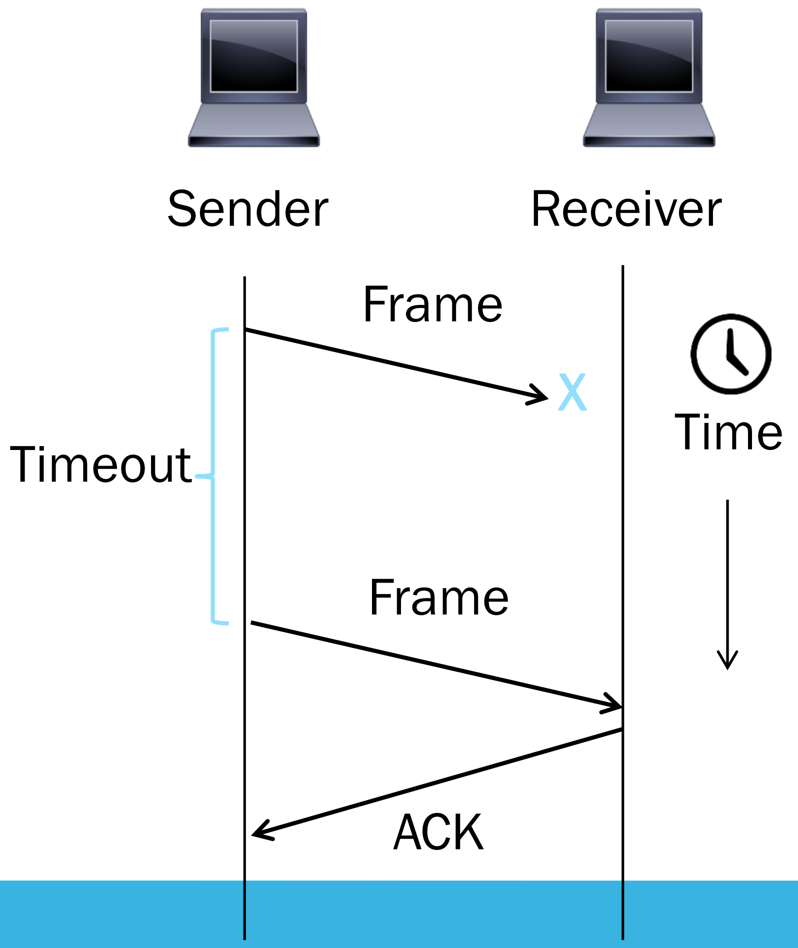
ARQ

Normal operation (no loss)



ARQ

- **Loss and retransmission**
  - Time out was reached and there was no ACK received so sender retransmits.



WHERE IS THE CATCH?

- How long to set the timeout?
- How to avoid accepting duplicate frames as new frames
- Performance
- Correctness always

TIMEOUTS

Timeout should be:

- Not too big (link goes idle)
- Not too small (spurious resend)

Fairly easy on a LAN

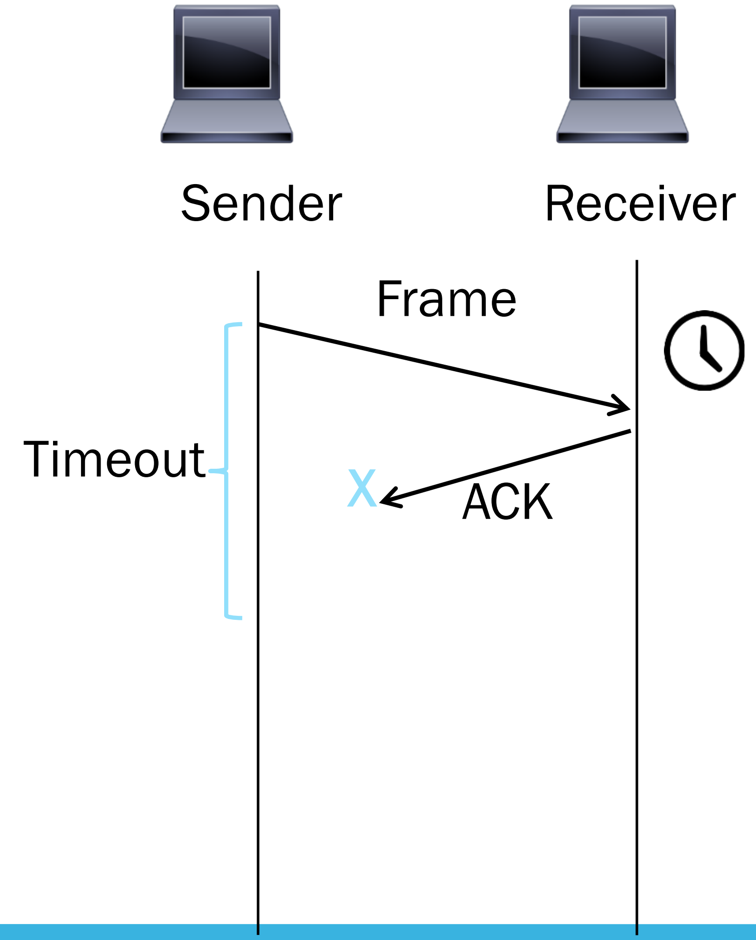
- Clear worst case, little variation

Fairly difficult over the Internet

- Much variation, no obvious bound
- We'll see all this with TCP (later)

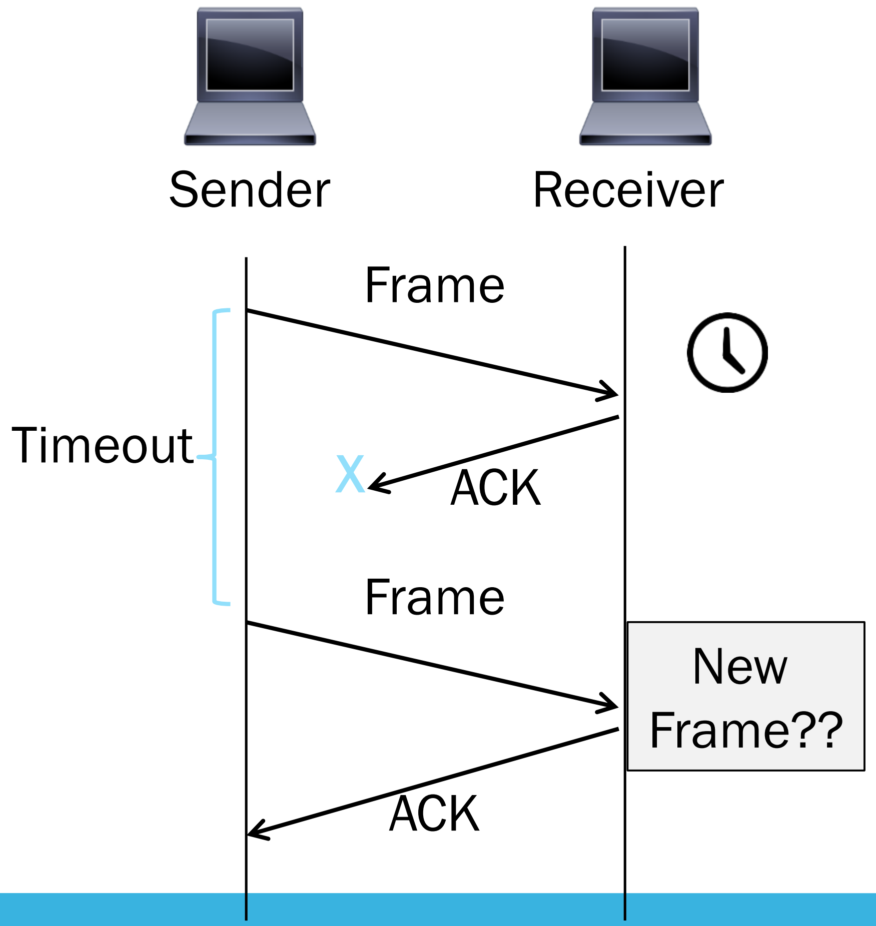
DUPLICATES

What happens if an ACK is lost?



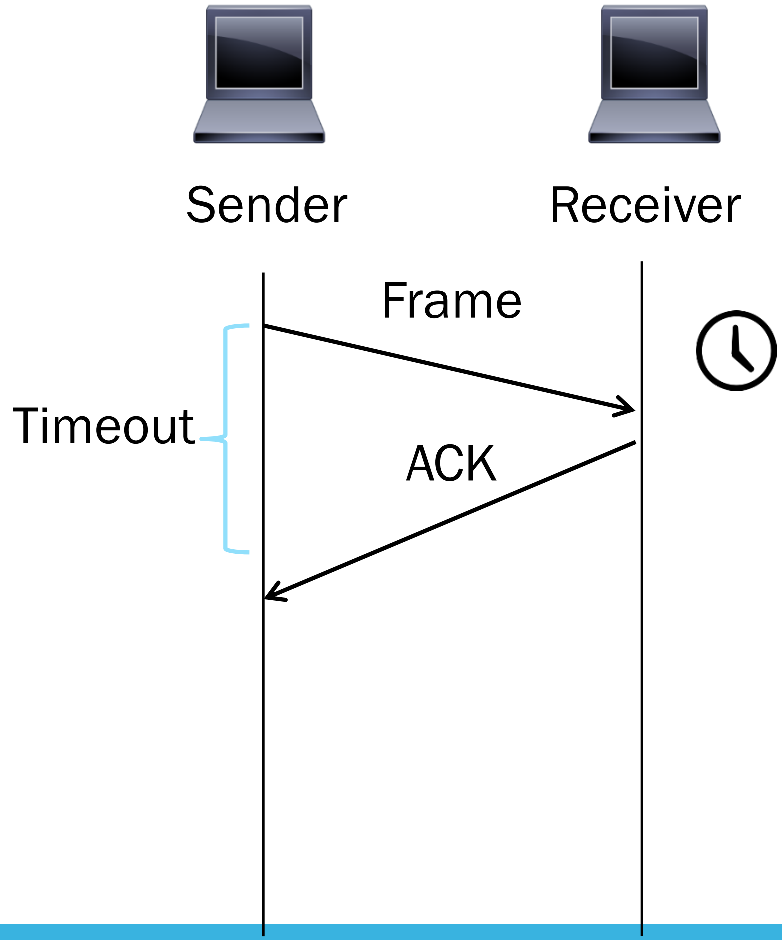
DUPLICATES

- **What happens if an ACK is lost?**
  - No ACK received so sender retransmits. The receiver may see this as a new frame/messages



DUPLICATES

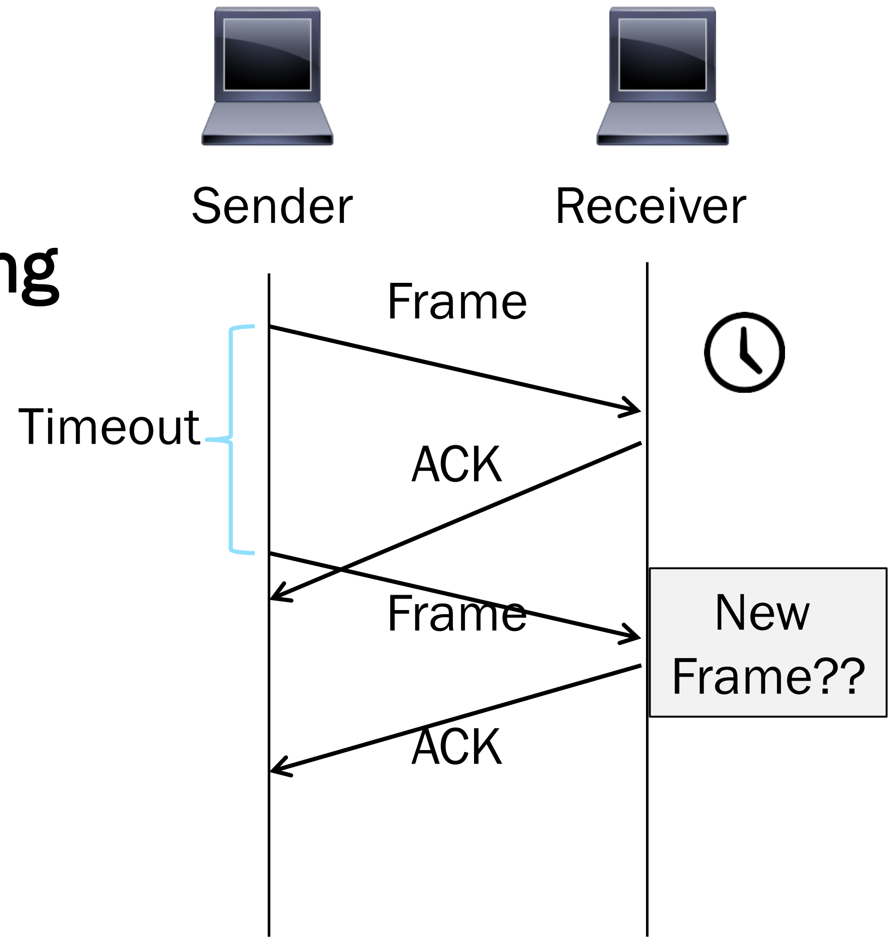
Or the timeout is early?



DUPLICATES

Or the timeout is early?

- ACK is acknowledging wrong frame



SEQUENCE NUMBERS

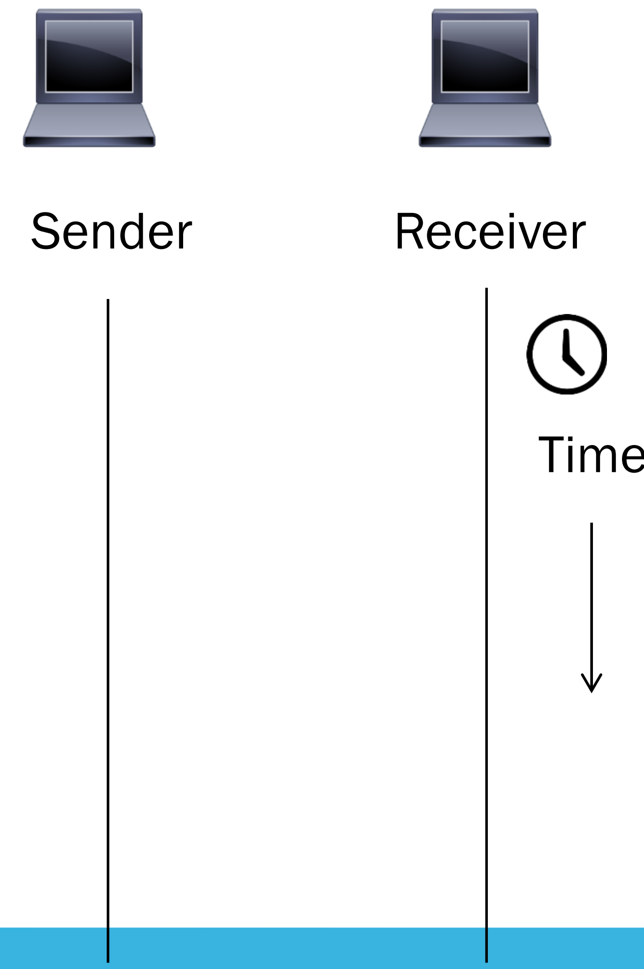
Frames and ACKs must both carry sequence numbers for correctness

To distinguish the current frame from the next one, a single bit (two numbers) is sufficient

- Called Stop-and-Wait

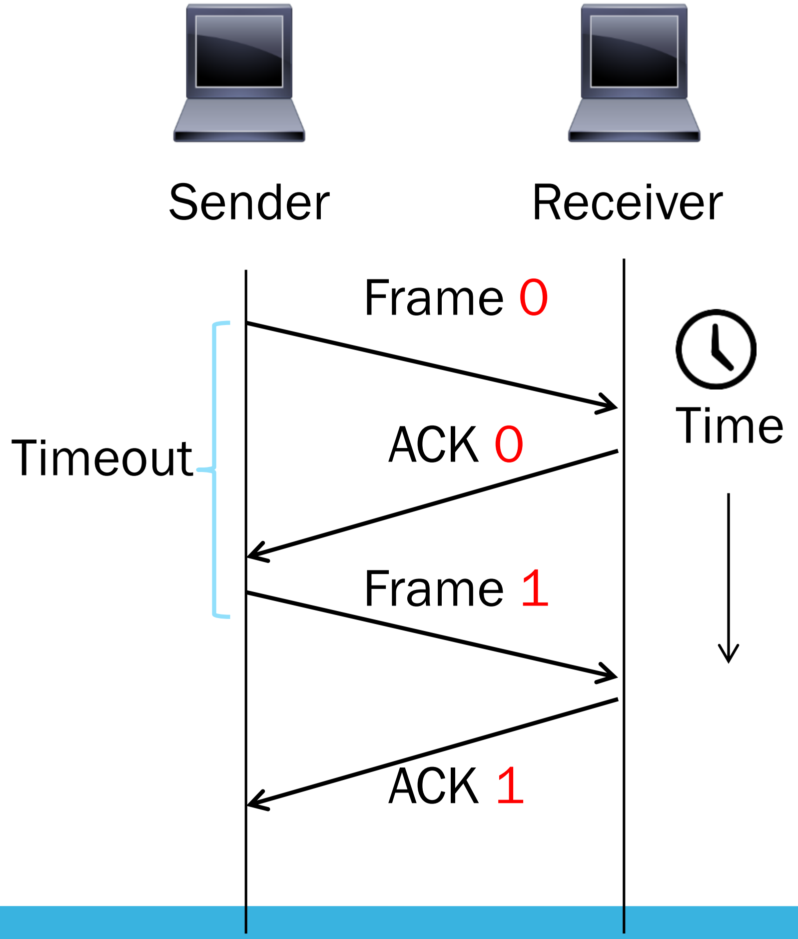
STOP-AND-WAIT

In the normal case:



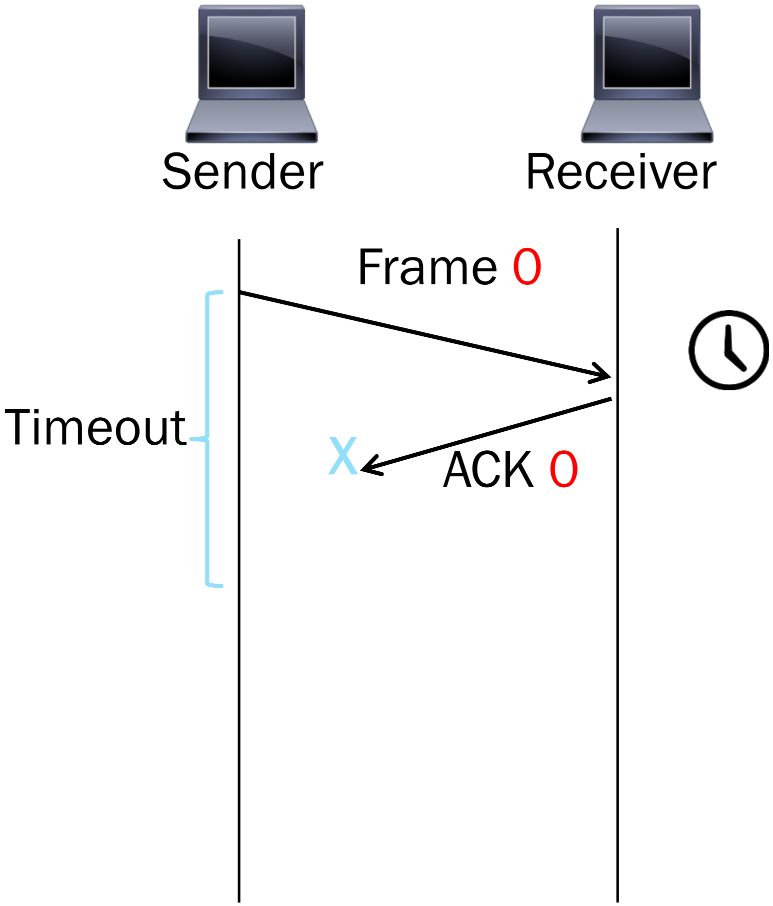
STOP-AND-WAIT

In the normal case:



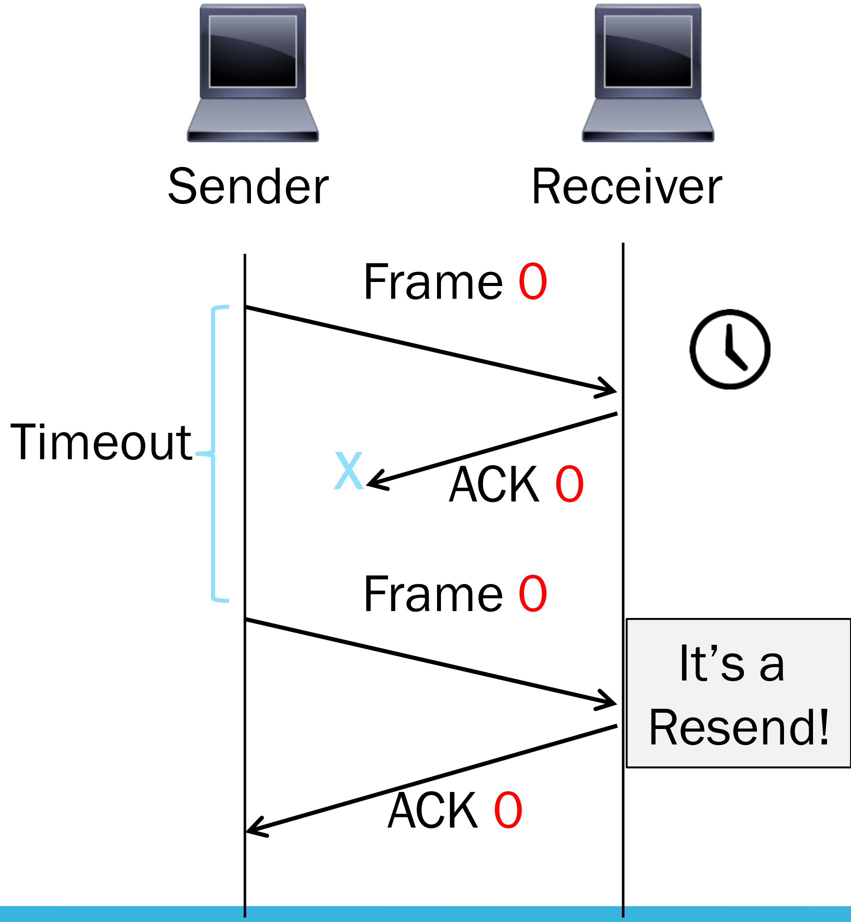
STOP-AND-WAIT

With ACK loss:



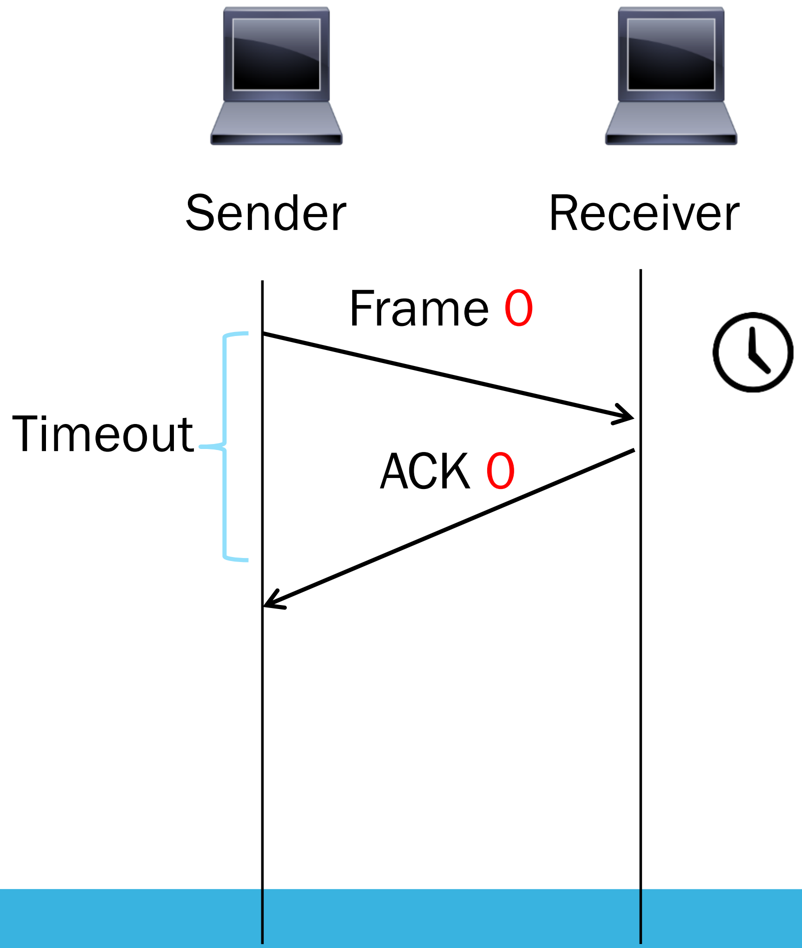
STOP-AND-WAIT

With ACK loss:



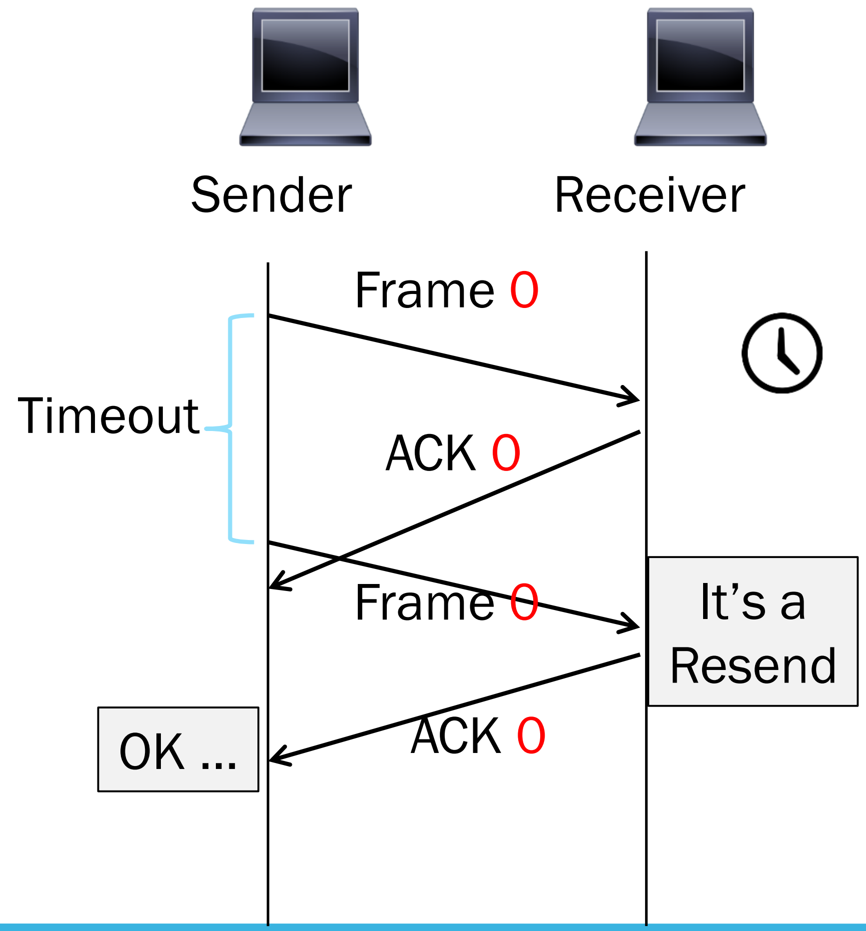
STOP-AND-WAIT

With early timeout:



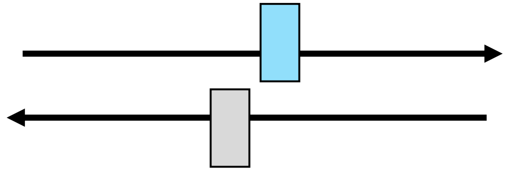
STOP-AND-WAIT

With early timeout:

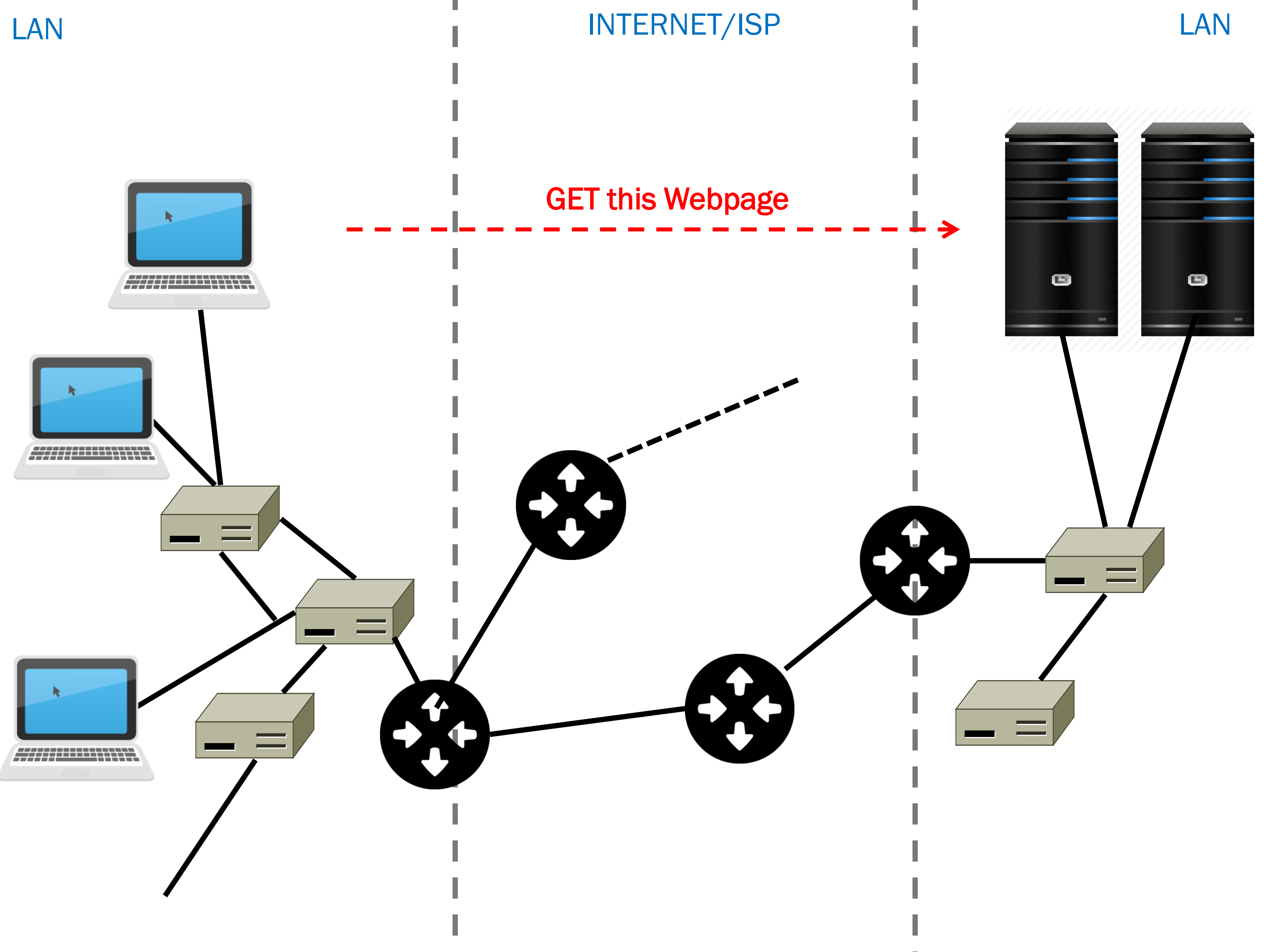


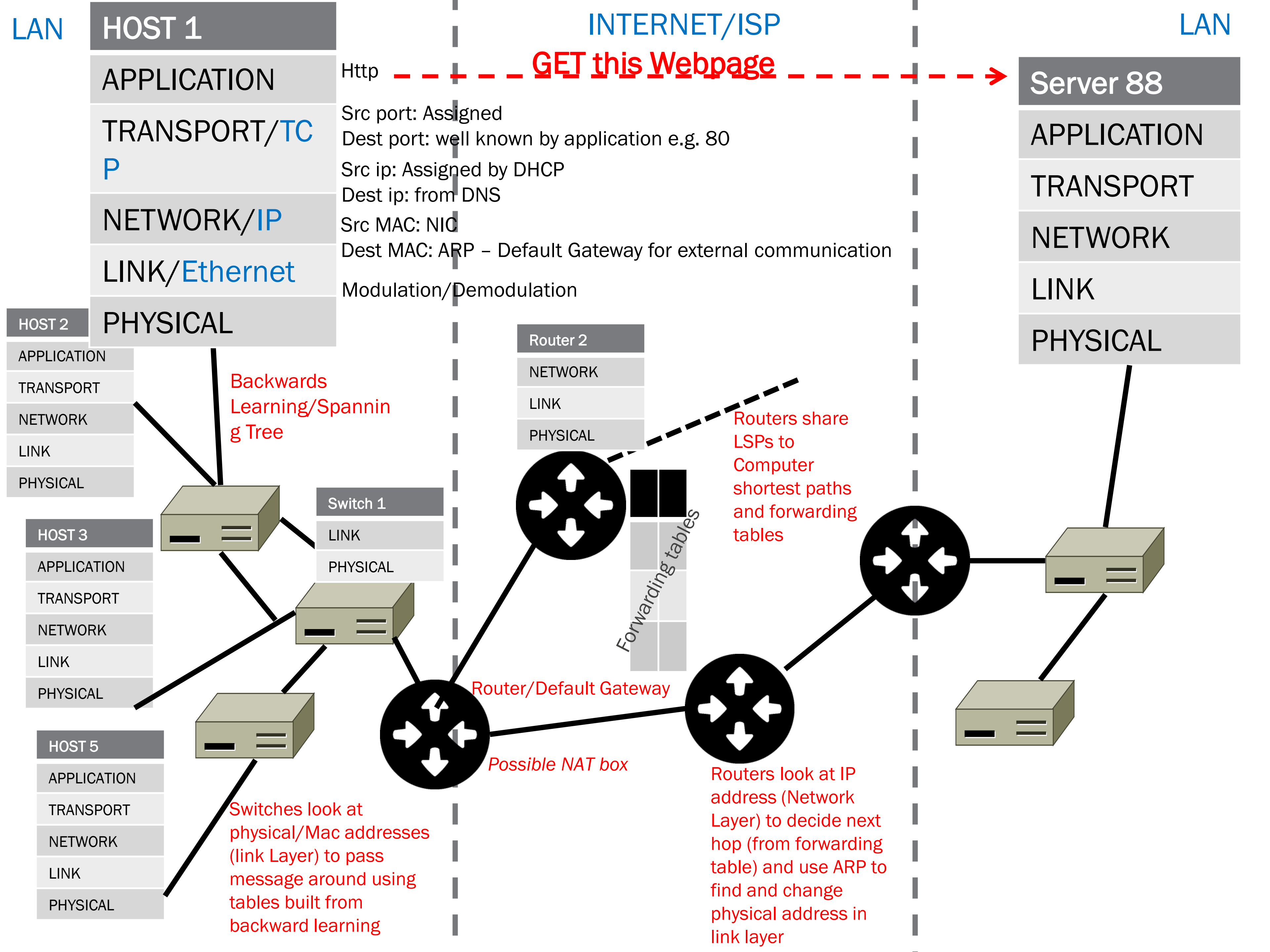
LIMITATION OF STOP-AND-WAIT

- **It only permits one frame to be outstanding from the sender at any time.**
  - Only one frame can be sent and then the sender must wait.
  - Good for LAN, not efficient for high BD



THE BIGGER PICTURE


LAN
INTERNET/ISP
LAN
GET this Webpage



LAN
HOST 1
APPLICATION
TRANSPORT/TCP
NETWORK/IP
LINK/Ethernet
PHYSICAL
INTERNET/ISP
GET this Webpage
LAN
Http
Src port: Assigned
Dest port: well known by application e.g. 80
Src ip: Assigned by DHCP
Dest ip: from DNS
Src MAC: NIC
Dest MAC: ARP – Default Gateway for external communication
Modulation/Demodulation
Server 88
APPLICATION
TRANSPORT
NETWORK
LINK
PHYSICAL
HOST 2
APPLICATION
TRANSPORT
NETWORK
LINK
PHYSICAL
Backwards Learning/Spanning Tree
Router 2
NETWORK
LINK
PHYSICAL
Routers share LSPs to Computer shortest paths and forwarding tables
Forwarding tables
HOST 3
APPLICATION
TRANSPORT
NETWORK
LINK
PHYSICAL
Switch 1
LINK
PHYSICAL
Router/Default Gateway
Possible NAT box
HOST 5
APPLICATION
TRANSPORT
NETWORK
LINK
PHYSICAL
Switches look at physical/Mac addresses (link Layer) to pass message around using tables built from backward learning
Routers look at IP address (Network Layer) to decide next hop (from forwarding table) and use ARP to find and change physical address in link layer

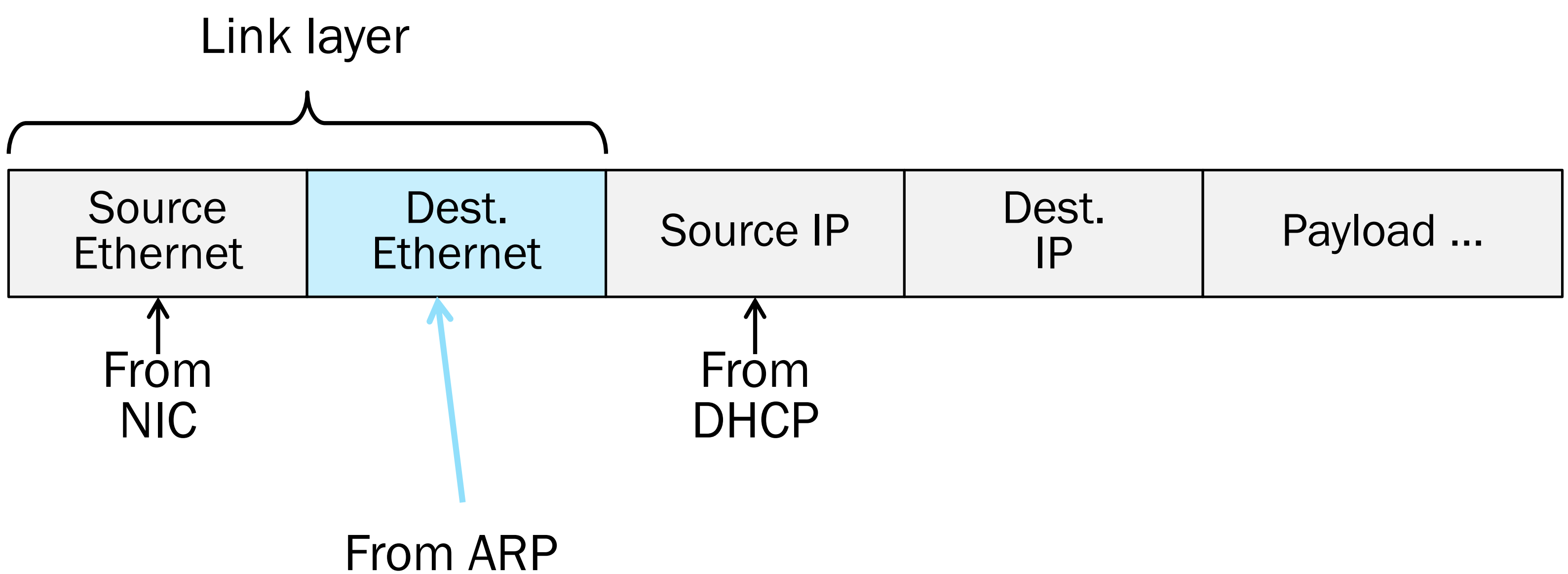
IP ADDRESS – MAC ADDRESS??

Applications communicate with each other using IP Addresses. For example in LAb 3, the ping application was used with an IP address to query the status of another node. For the communication to occur, the IP addresses need to be translated to a MAC Address which is globally unique. Although it appears as if the two nodes are communicating directly, message are actually being sent from node to node in networks and internetworks and unique addresses of these nodes are required – link layer addresses.

Address Resolution Protocol is used for resolving an IP Address to a MAC Address. Remember the Application Layer is not concerned with Physical Layer properties (such as MAC addresses) so lower layers (e.g. Physical and Link Layer) are managed by the OS which uses the ARP protocol to learn MAC Addresses and store this information in a local table in the OS - called the srp table. Each node is responsible for populating its own arp table to map IP Addresses to MAC Addresses.

ARP (ADDRESS RESOLUTION PROTOCOL)

A node uses it to map a Local IP address to its Link Layer addresses (MAC Address, Ethernet Address, Physical Address

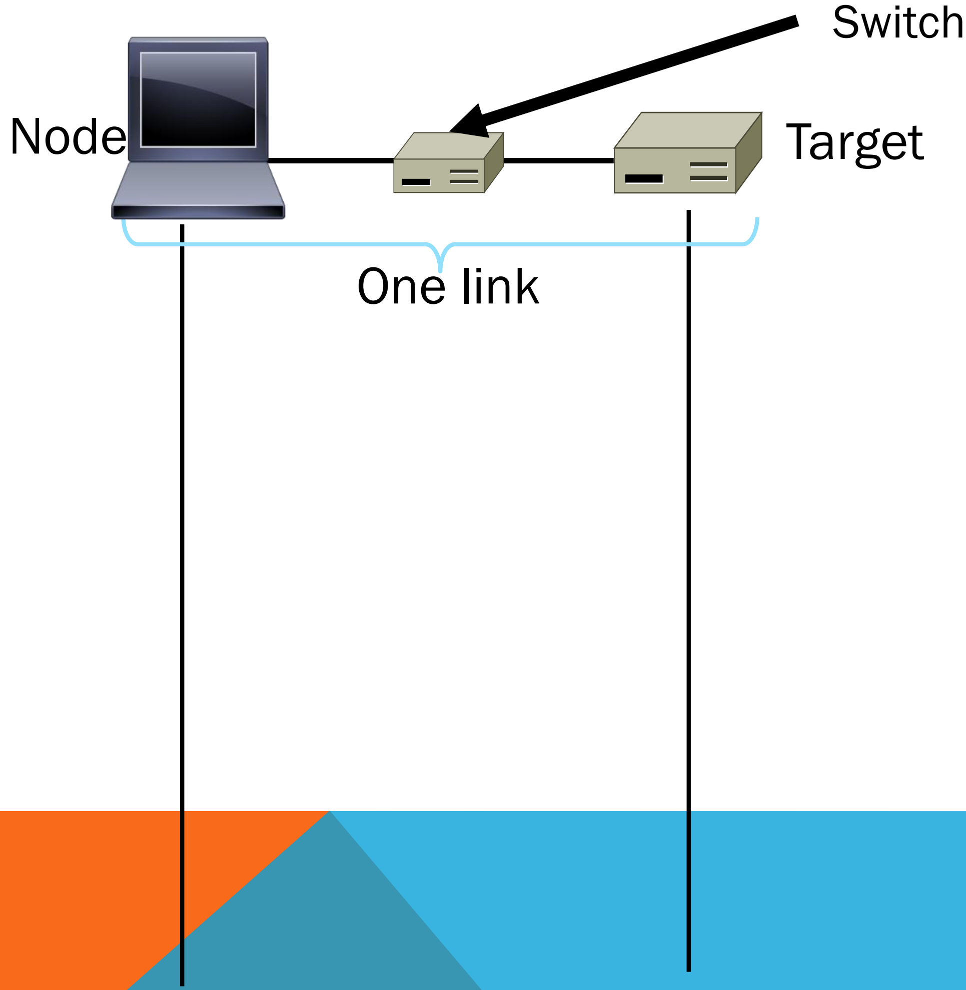


ARP PROTOCOL STACK

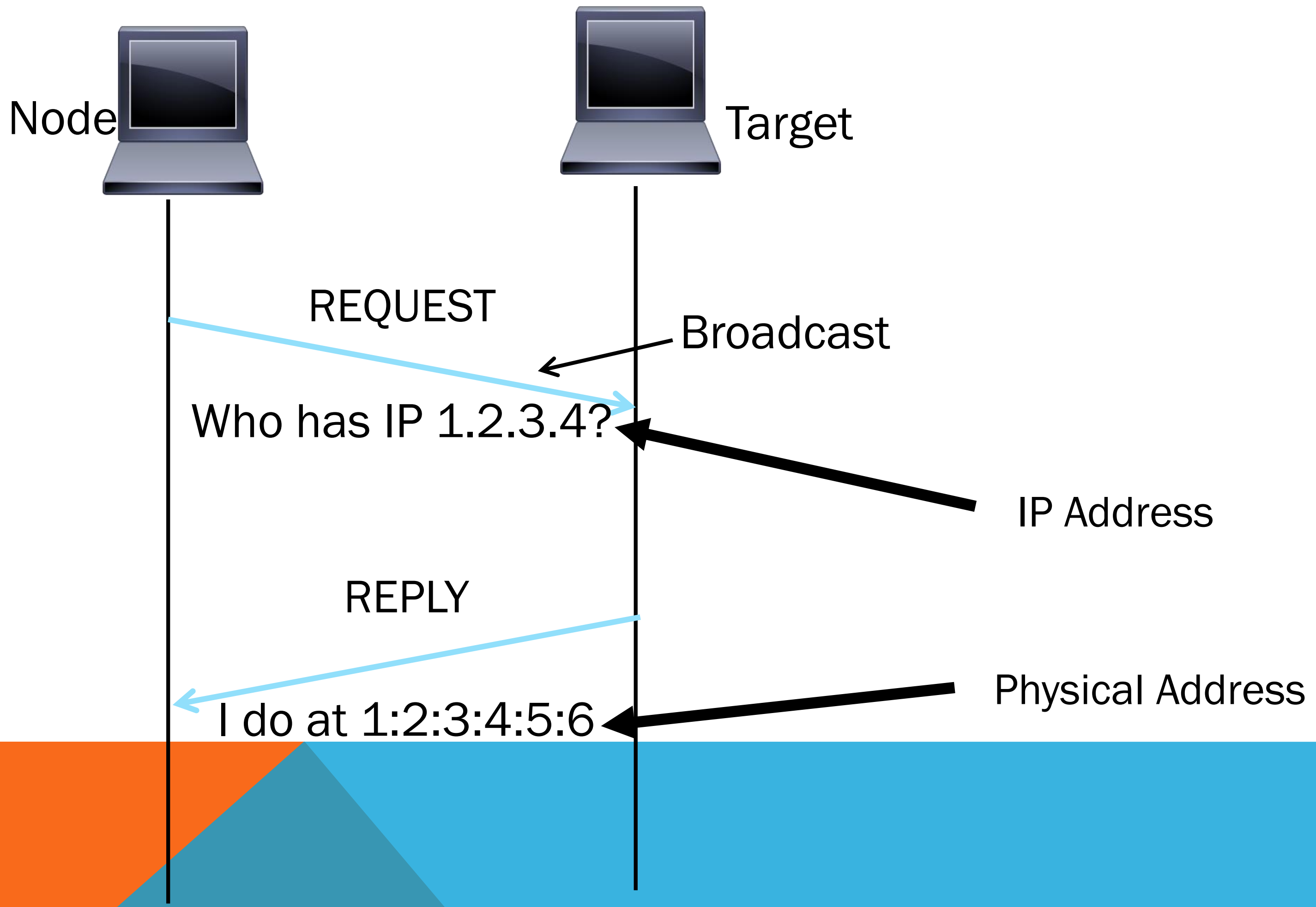
ARP sits right on top of Link Layer

- No servers, just asks node with target IP to identify itself
- Uses broadcast to reach all nodes
- Builds an arp table in OS with the mappings.

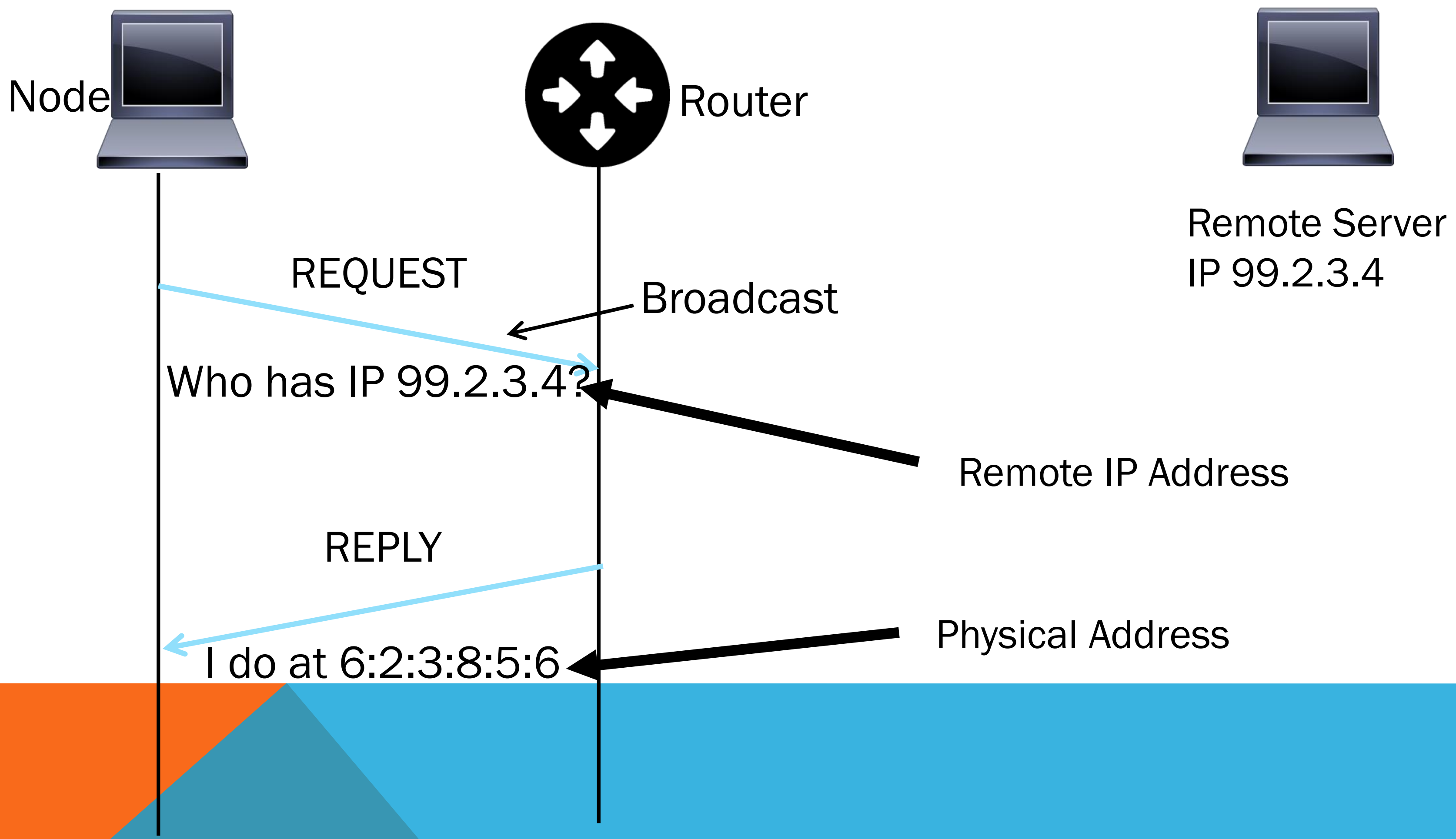
ARP MESSAGES – LOCAL NETWORK



ARP MESSAGES – LOCAL NETWORK



ARP MESSAGES – REMOTE HOST



MULTIPLEXING

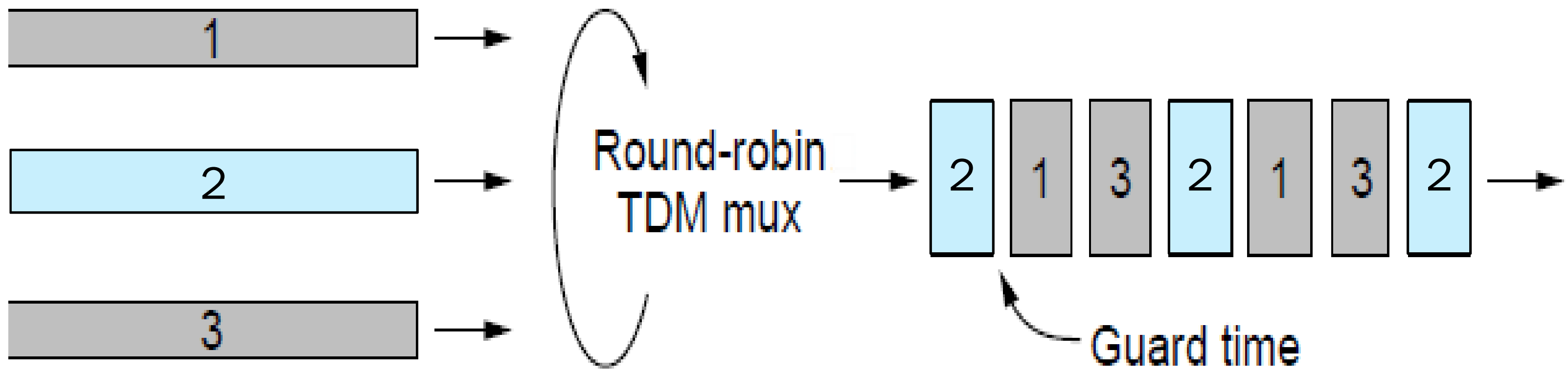
Multiplexing is the network word for the sharing of a resource

E.g. Sharing a link or channel among different users

- Time Division Multiplexing (TDM)
- Frequency Division Multiplexing (FDM)

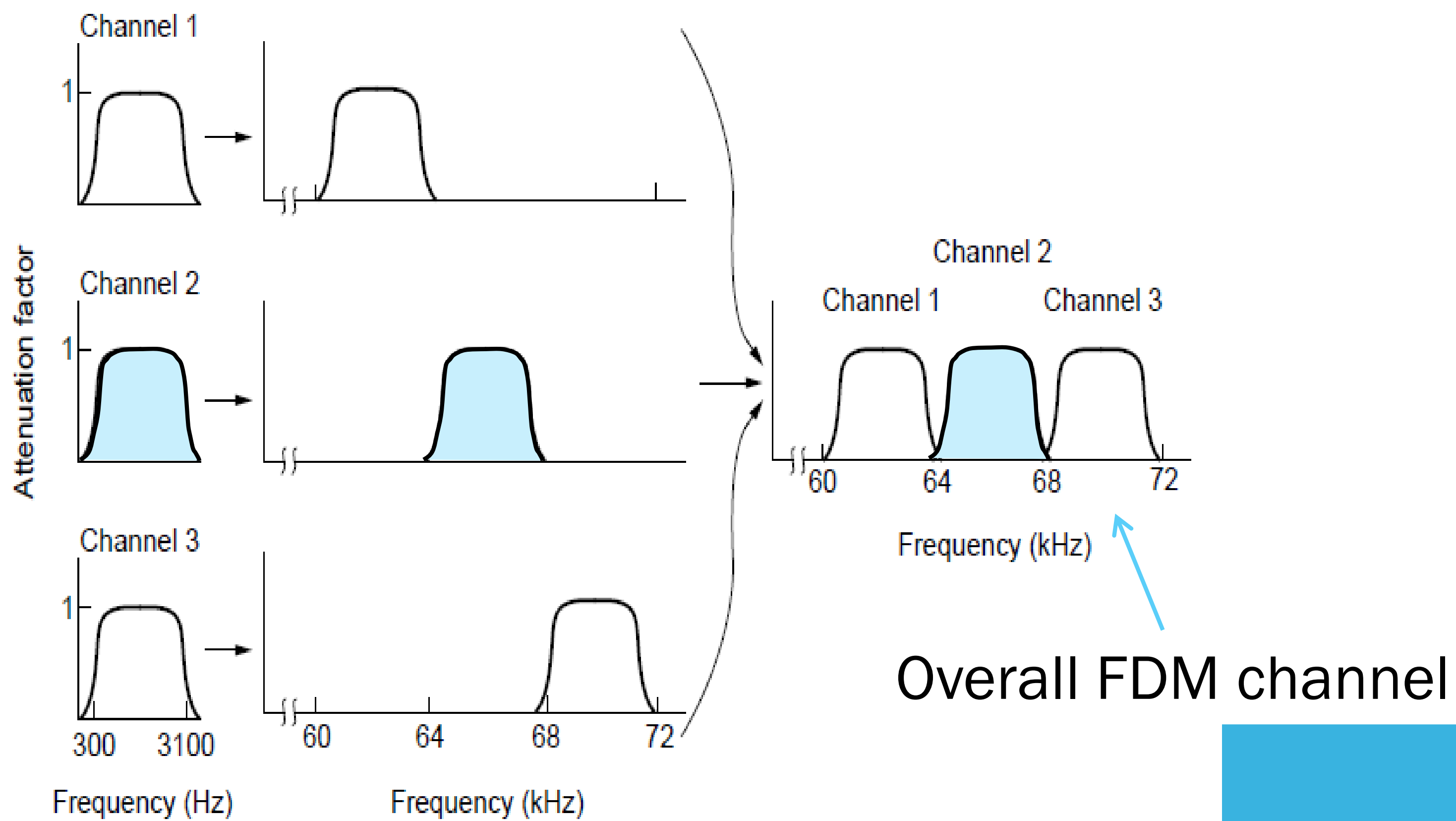
TIME DIVISION MULTIPLEXING (TDM)

Users take turns on a fixed schedule



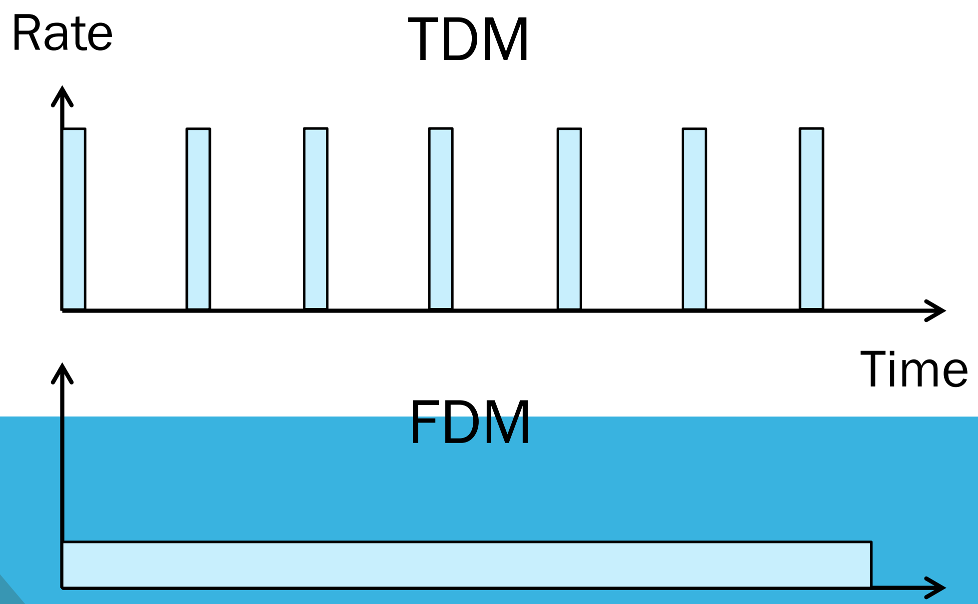
FREQUENCY DIVISION MULTIPLEXING (FDM)

Put different users on different frequency bands



TDM VERSUS FDM

- TDM: a user sends at a high rate a fraction of the time
- FDM: a user sends at a low rate all the time



TDM/FDM USAGE

Statically divide a resource

- Suited for continuous traffic, fixed number of users

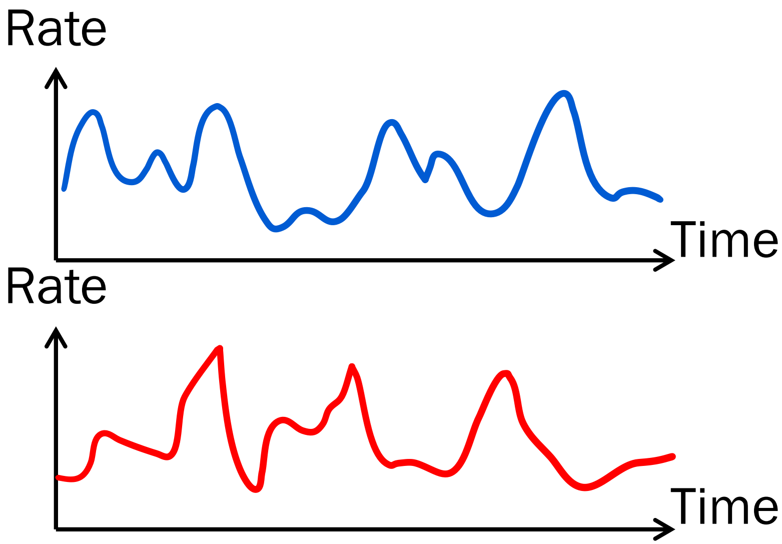
Widely used in telecommunications

- TV and radio stations (FDM)
- GSM (2G cellular) allocates calls using TDM within FDM

MULTIPLEXING NETWORK TRAFFIC

Network traffic is <u>bursty</u>

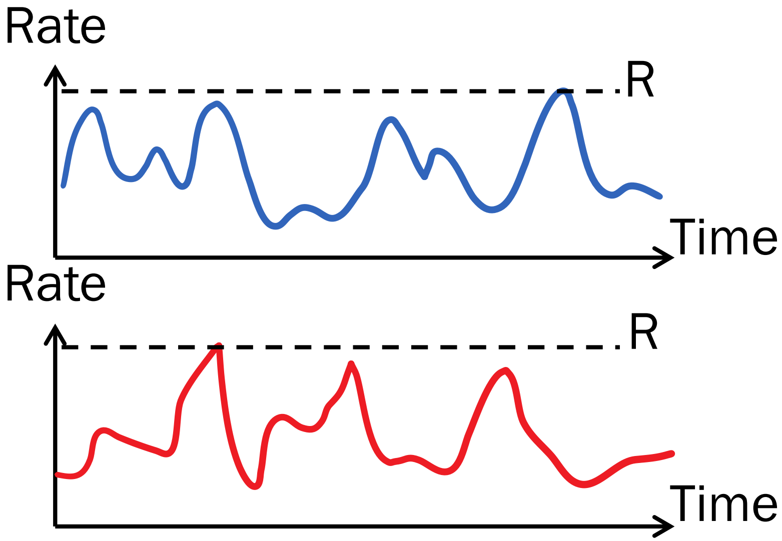
- ON/OFF sources
- Load varies greatly over time



MULTIPLEXING NETWORK TRAFFIC

Network traffic is bursty

- Inefficient to always allocate user their ON needs with TDM/FDM



MULTIPLEXING NETWORK TRAFFIC

<u>Multiple access</u> schemes multiplex users according to their demands – for gains of statistical multiplexing