# Mobile Communication



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# Reference Books

- J. Schiller, *"Mobile Communications"*, 2nd Edition, Addison-Wesley
- Andrew S. Tanenbaum, *"Computer Networks"*, 4th Edition, PHI
- W. Stallings, *"Wireless Communications and Networking"*, 2nd Edition, PHI
- V. K. Garg, *"Wireless Network Evolution: 2G to 3G"*, PHI
- M. Hassan, R. Jain, *"High Performance TCP/IP Networking"*, PHI

# Introduction

- Two aspects of mobility:
  - **user mobility:** ***users communicate (wireless) "anytime, anywhere, with anyone"***
  - **device portability:** ***devices can be connected anytime, anywhere to the network***

- Wireless vs. mobile Examples

| Wireless | Mobile | Examples |
|---|---|---|
| ✘ | ✘ | stationary computer |
| ✘ | ✓ | notebook in a hotel |
| ✓ | ✘ | wireless LANs in historic buildings |
| ✓ | ✓ | Mobile Phones |

# Introduction

- The demand for mobile communication creates the need for integration of wireless networks into existing fixed networks:
  - **local area networks:** ***standardization of IEEE 802.11***
  - **Internet:** ***Mobile IP extension of IP***
  - **wide area networks:** ***e.g., internetworking of GSM and ISDN***

# Applications

- Vehicles
  - *transmission of news, road condition, weather, music*
  - *vehicle data (e.g., from busses, high-speed trains) can be transmitted in advance for maintenance*
- Emergencies
  - *early transmission of patient data to the hospital, current status, first diagnosis*
  - *replacement of a fixed infrastructure in case of earthquakes*

# Applications

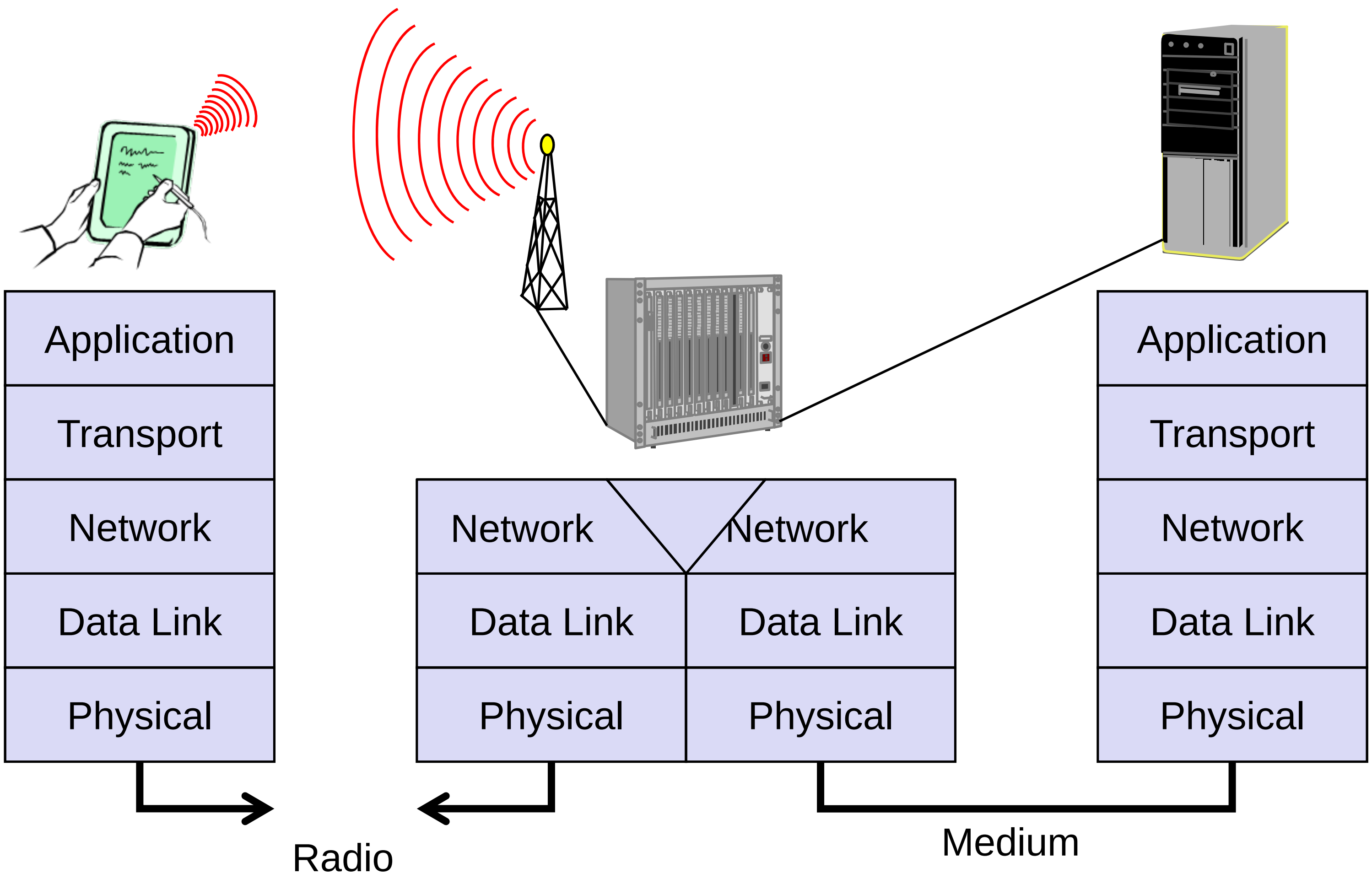
- Traveling salesmen
  - *direct access to customer files stored in a central location*
  - *consistent databases for all agents*

- Entertainment, education, ...
  - *outdoor Internet access*

# Wireless network in comparison to fixed network

- *Higher loss-rates due to interference*
- *Low transmission rates*
- *Higher delays, higher jitter*
- *Lower security, simpler active attacking*
- *Always shared medium*

# Simple Reference Model to be used





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# Types of wireless networks

- Categories of wireless networks:
  - ***System interconnection***
  - ***Wireless LANs***
  - ***Wireless WANs***



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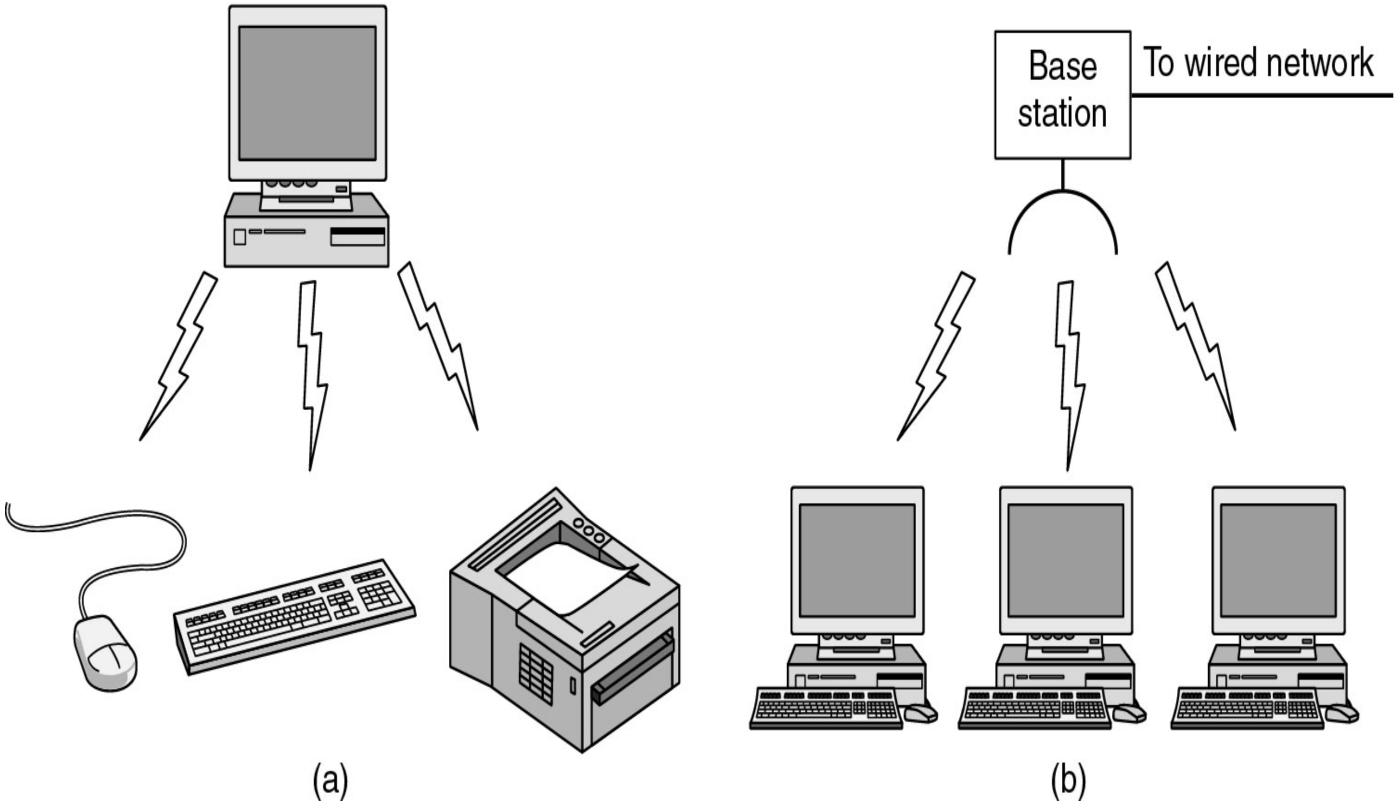
# Types of wireless networks




(a) Bluetooth configuration

(b) Wireless LAN



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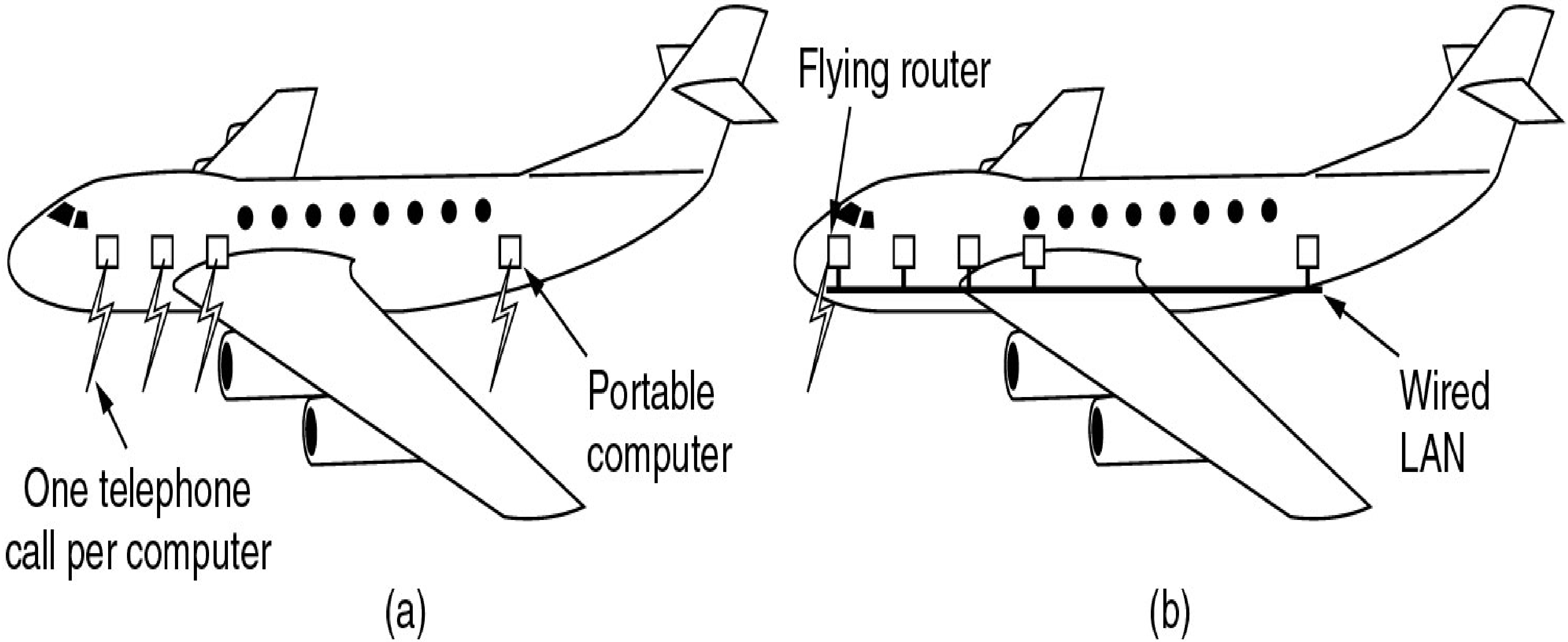
# Types of wireless networks




(a) Individual mobile computers (b) A flying LAN



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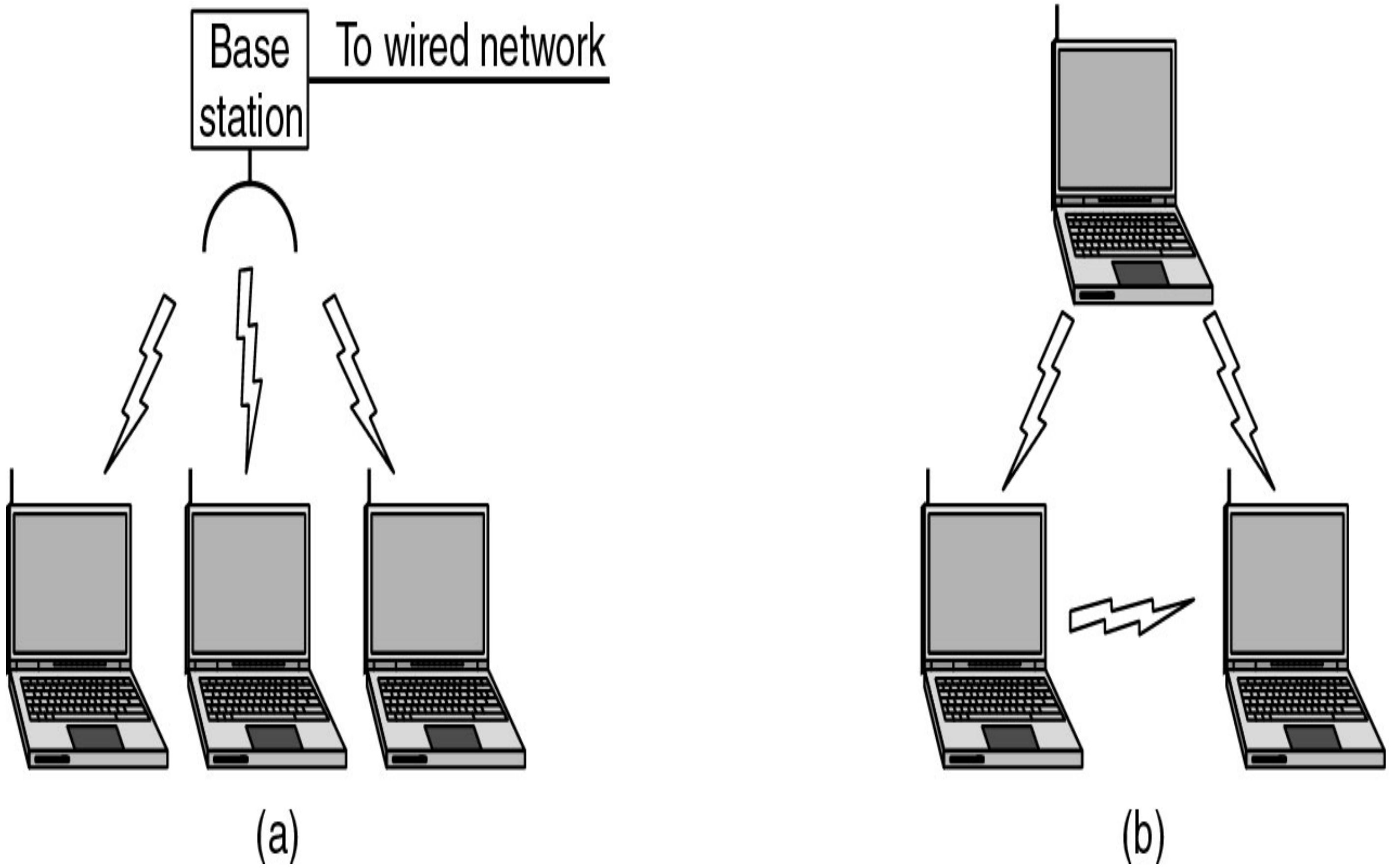
# Wireless LANs




(a) Wireless networking with a base station (b) Ad hoc networking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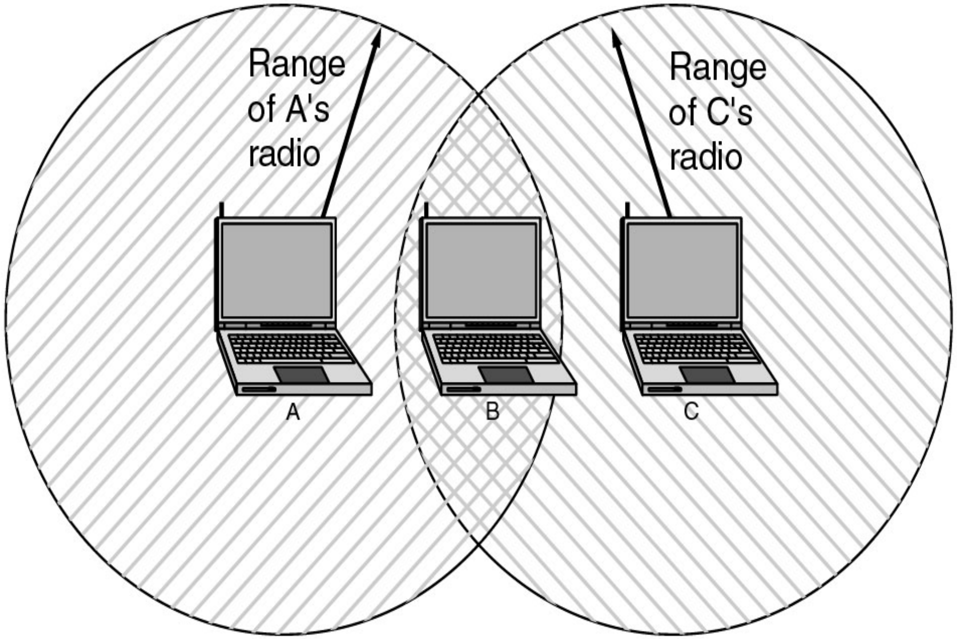
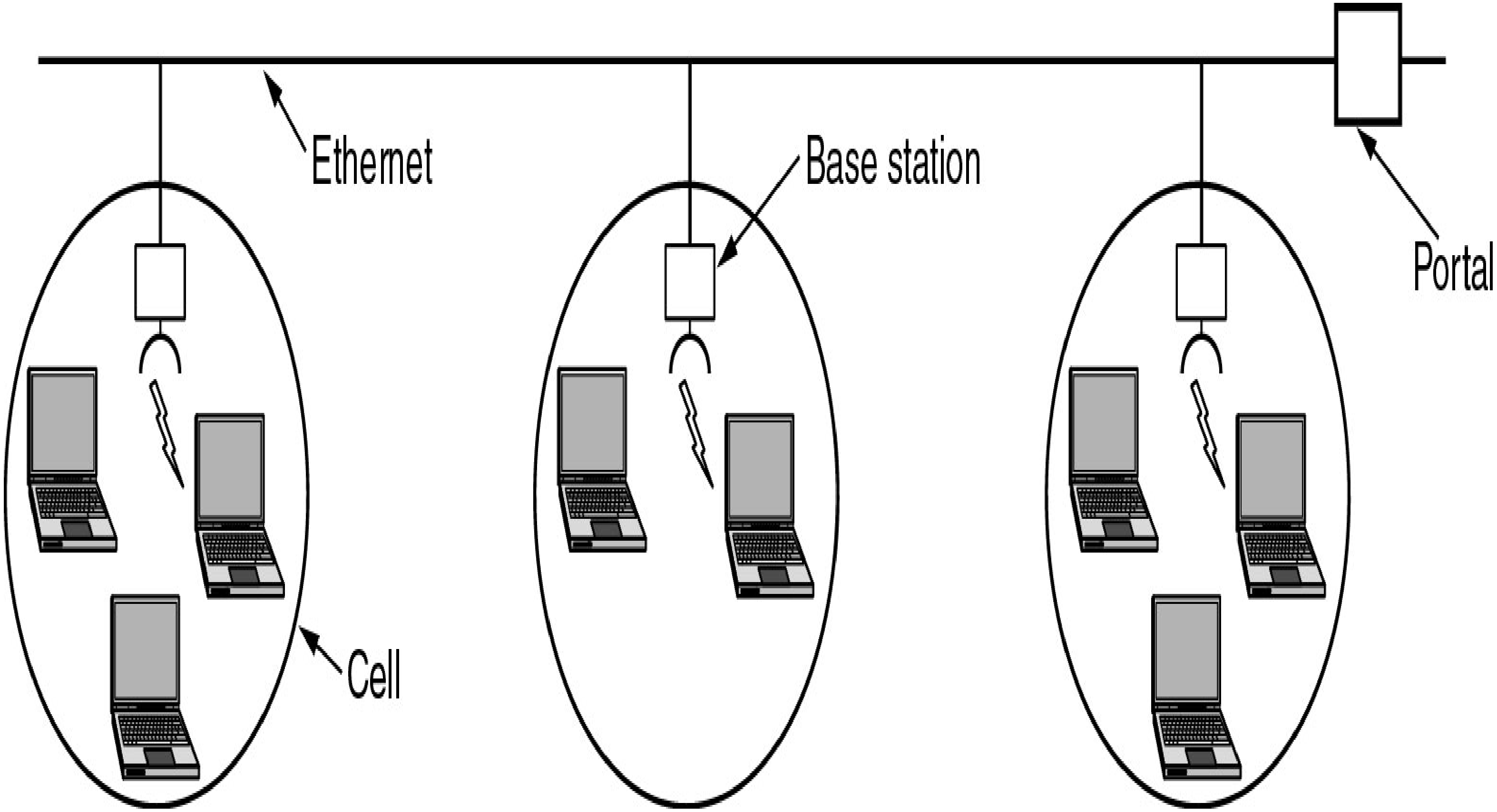
# Wireless LANs




**The range of a single radio may not cover the entire system**

# Wireless LANs




A multicell 802.11 network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# Media Access

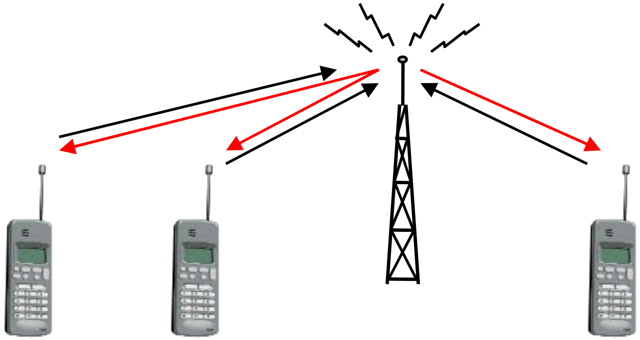
# Polling Mechanism

- If one terminal can be heard by all others, this "***central***" terminal (a.k.a. base station) can poll all other terminals according to a certain scheme

- Example: ***Randomly Addressed Polling***
  - ***base station signals readiness to all mobile terminals***
  - ***terminals ready to send can now transmit a random number without collision (the random number can be seen as dynamic address)***
  - ***the base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)***
  - ***the base station acknowledges correct packets and continues polling the next terminal***
  - ***this cycle starts again after polling all terminals of the list***

# ISMA (Inhibit Sense Multiple Access)

- Current state of the medium is signaled via a "***busy tone***"
  - ***the base station signals on the downlink (base station to terminals) if the medium is free or not***
  - ***terminals must not send if the medium is busy***
  - ***terminals can access the medium as soon as the busy tone stops***
  - ***the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)***





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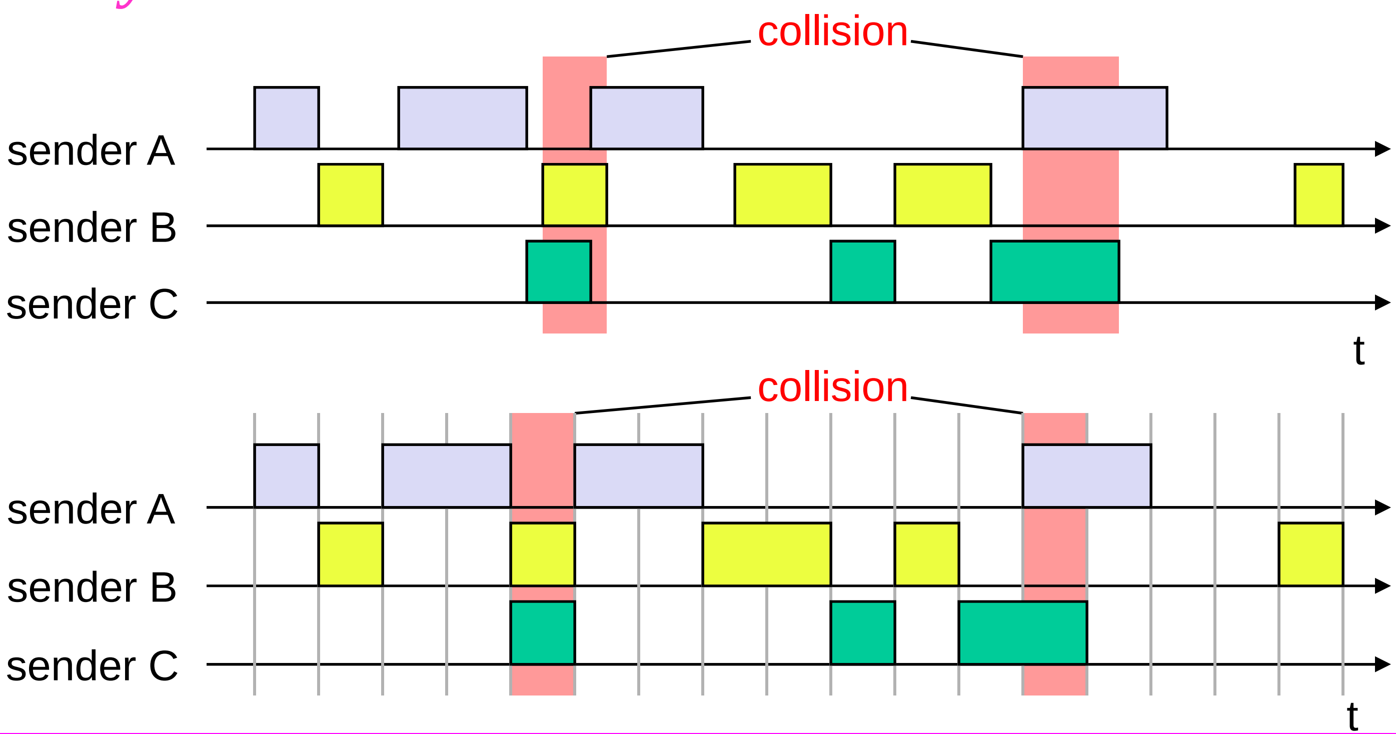
# Aloha/Slotted Aloha

- Mechanism
  - *random, distributed (no central arbiter), time-multiplex*
  - *Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries*





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# DAMA (Demand Assigned Multiple Access)

- Reservation can increase efficiency to 80%
  - ***a sender* reserves *a future time-slot***
  - ***sending within this reserved time-slot is possible without collision***
  - ***reservation also causes higher delays***
  - ***typical scheme for satellite links***

- Examples for reservation algorithms:
  - **Explicit Reservation according to Roberts (Reservation-ALOHA)**
  - **Implicit Reservation (PRMA)**
  - **Reservation-TDMA**



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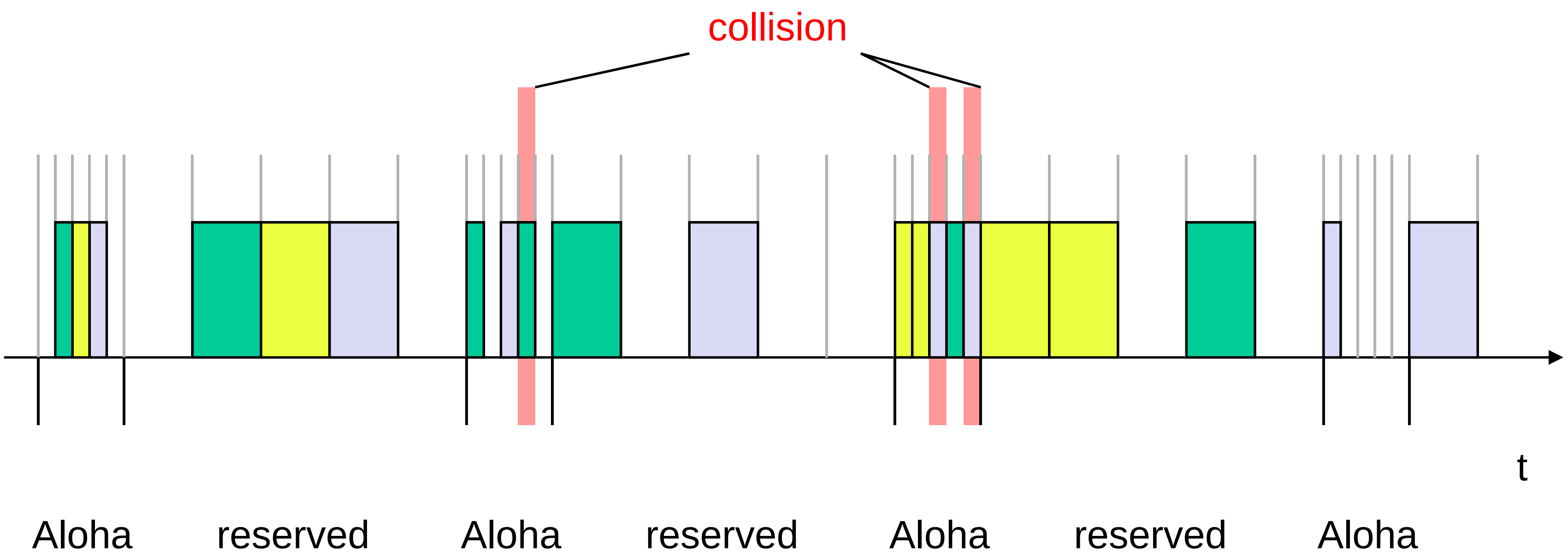
# DAMA: Explicit Reservation

- Explicit Reservation (Reservation Aloha):
  - *two modes:*
    - *ALOHA mode* for reservation: competition for small reservation slots, collisions possible
    - *reserved mode* for data transmission within successful reserved slots (no collisions possible)
  - *it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time*

# DAMA: Explicit Reservation



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# DAMA: PRMA

- Implicit reservation (PRMA - Packet Reservation MA):
  - *a certain number of slots form a frame, frames are repeated*
  - *stations compete for empty slots according to the slotted aloha principle*
  - *once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send*
  - *competition for this slots starts again as soon as the slot was empty in the last frame*


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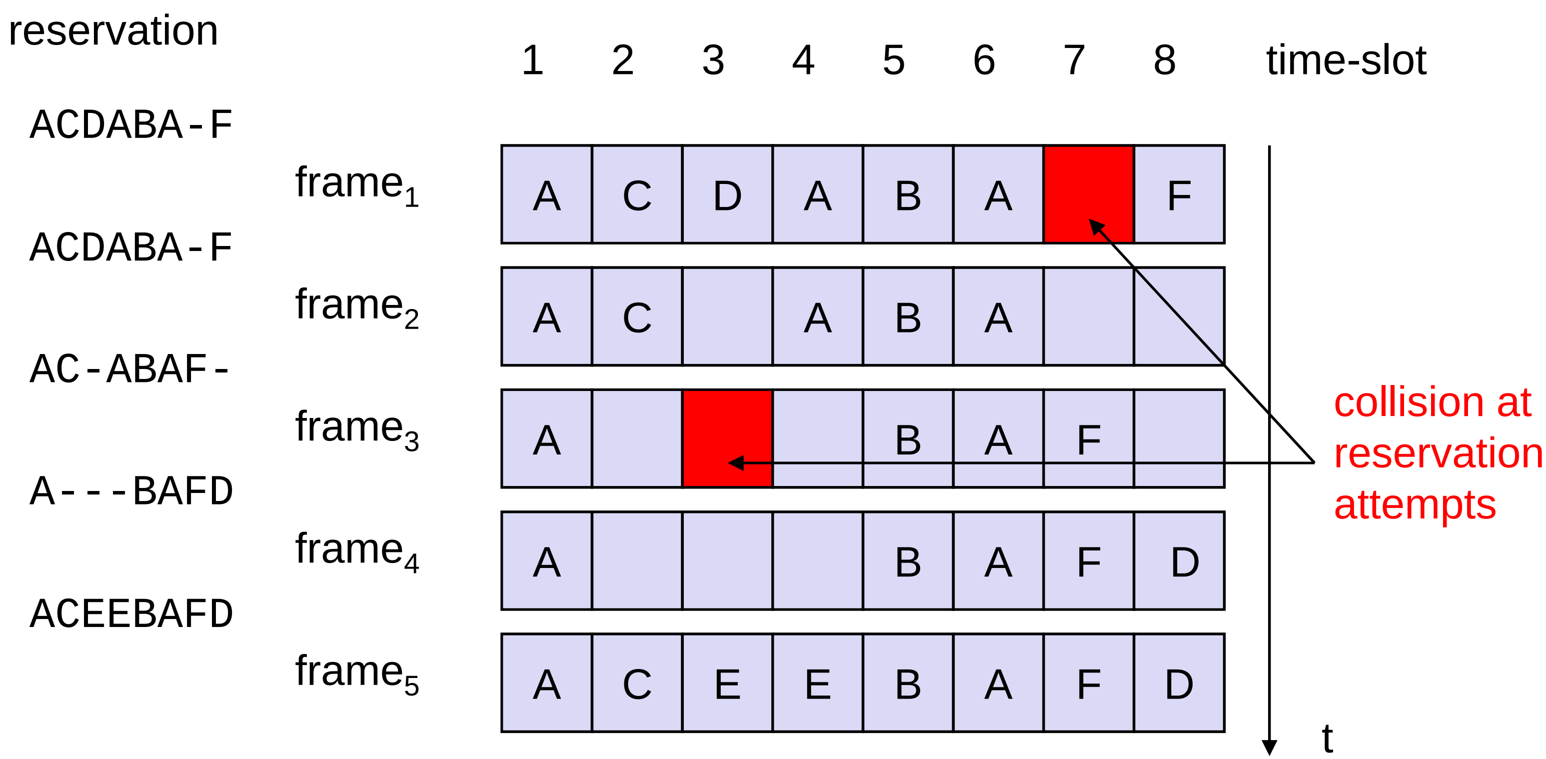
# DAMA: PRMA



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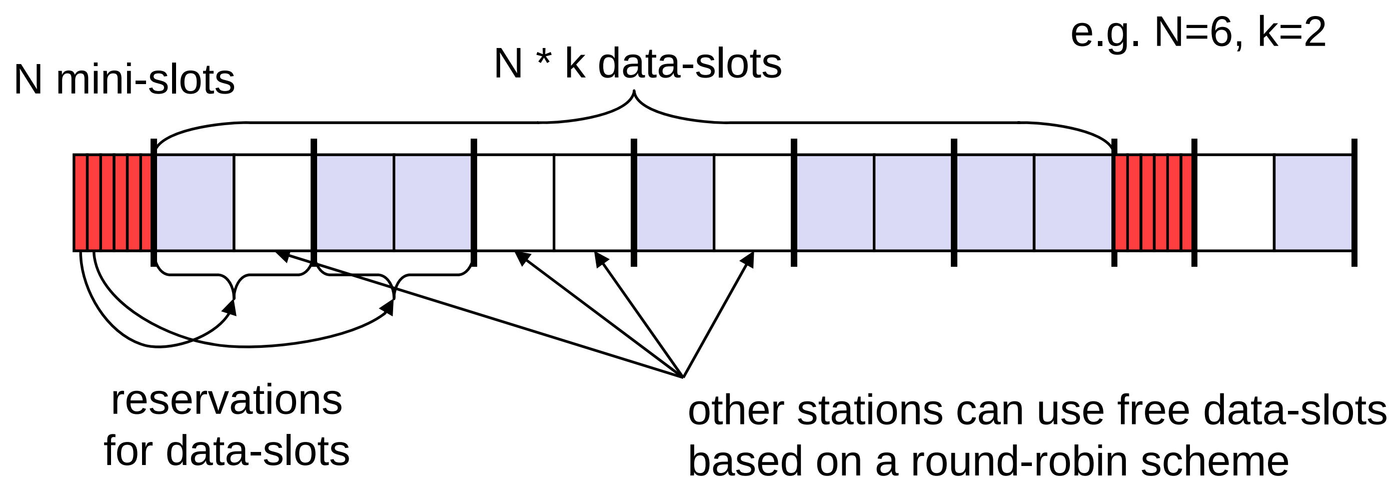
# DAMA: Reservation TDMA

- Reservation Time Division Multiple Access
  - *every frame consists of N mini-slots and x data-slots*
  - *every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).*
  - *other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)*



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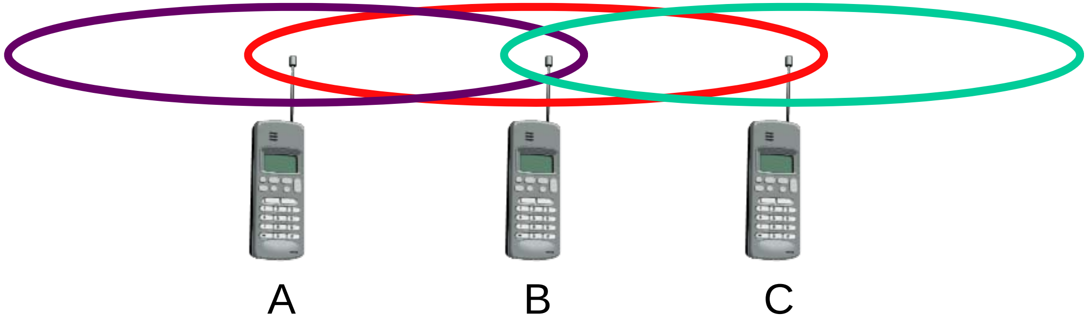
# Motivation for new Access Protocol

- Can we apply media access methods from fixed networks?

- Example: CSMA/CD
  - *Carrier Sense Multiple Access with Collision Detection*
  - ***send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)***
- Problems in wireless networks
  - ***signal strength decreases proportional to the square of the distance***
  - ***the sender would apply CS and CD, but the collisions happen at the receiver***
  - ***it might be the case that a sender cannot "hear" the collision, i.e., CD does not work***
  - ***furthermore, CS might not work if, e.g., a terminal is "hidden"***

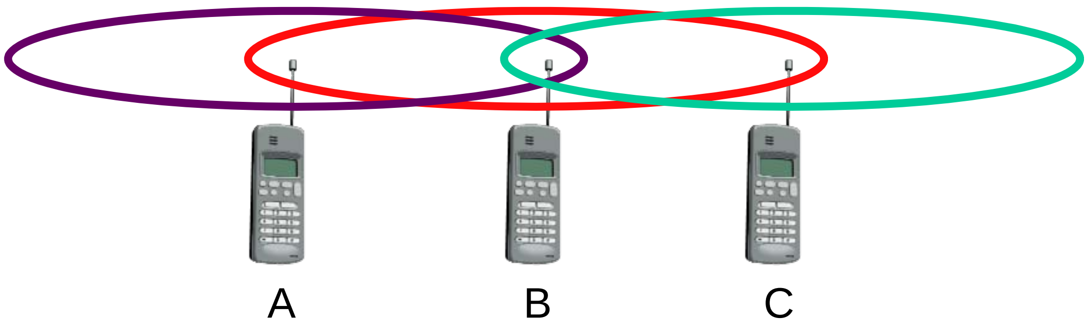
# Motivation: Hidden Terminal

- **Hidden terminals**
  - ***A sends to B, C cannot receive A***
  - ***C wants to send to B, C senses a "free" medium (CS fails)***
  - ***collision at B, A cannot receive the collision (CD fails)***
  - ***A is "hidden" for C***



# Motivation: Exposed Terminal

- **Exposed terminals**
  - ***B sends to A, C wants to send to another terminal (not A or B)***
  - ***C has to wait, CS signals a medium in use***
  - ***but A is outside the radio range of C, therefore waiting is not necessary***
  - ***C is "exposed" to B***



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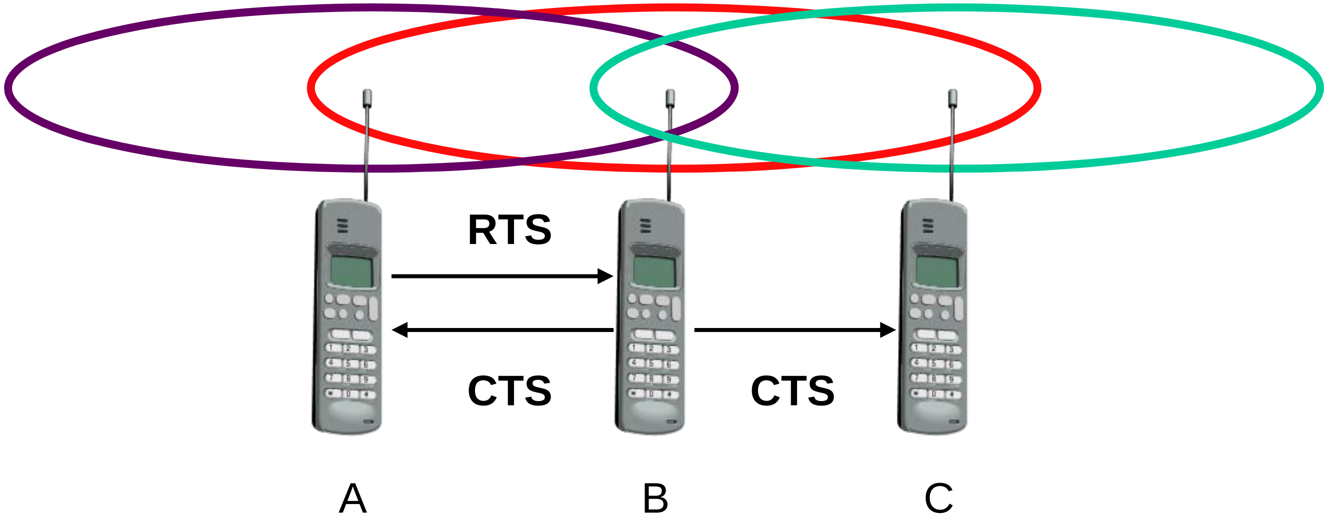
# MACA: Collision Avoidance

- MACA uses short signaling packets for collision avoidance
  - ***RTS (request to send):*** ***a sender request the right to send from a receiver with a short RTS packet before it sends a data packet***
  - ***CTS (clear to send):*** ***the receiver grants the right to send as soon as it is ready to receive***
- Signaling packets contain
  - ***sender address***
  - ***receiver address***
  - ***packet size***

- Variants of this method can be found in IEEE802.11 as DFWMAC (Distributed Foundation Wireless MAC)

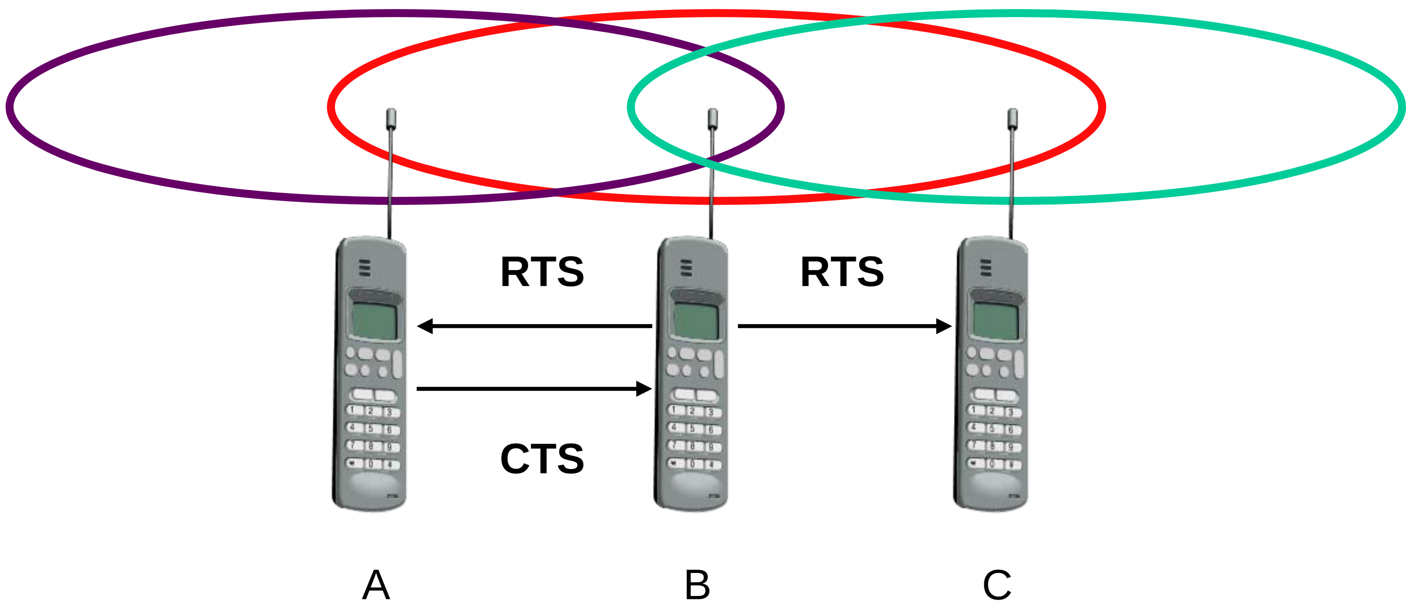
# MACA Examples

- MACA avoids the problem of hidden terminals
  - *A and C want to send to B*
  - *A sends RTS first*
  - *C waits after receiving CTS from B*



# MACA Examples

- MACA avoids the problem of exposed terminals
  - *B wants to send to A, C to another terminal*
  - *now C does not have to wait for it cannot receive CTS from A*



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# The Mobile Telephone Systems


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# Three Generations

- First-Generation Mobile Phones: Analog Voice
- Second-Generation Mobile Phones: Digital Voice
- Third-Generation Mobile Phones: Digital Voice and Data


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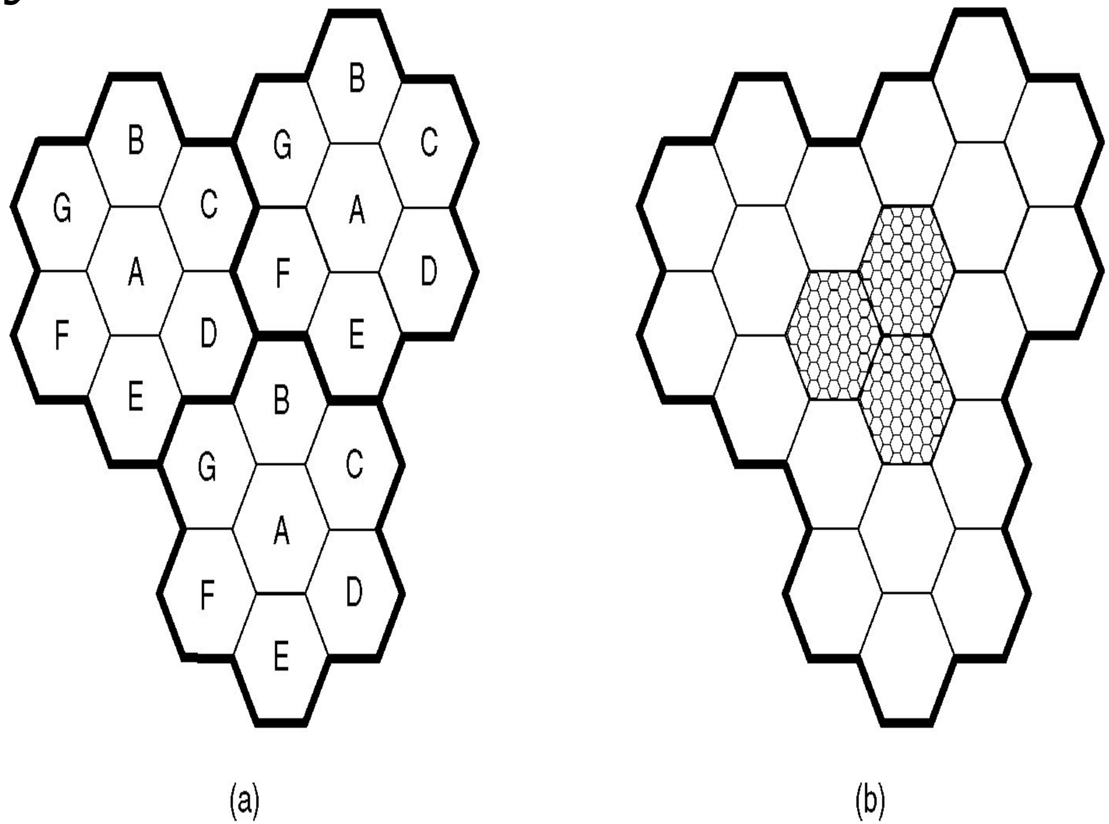
# Advanced Mobile Phone System (AMPS)

- Cellular concept introduced
  - ***Cells are 10-20 km across***
- Uses FDM
- Uses frequency reuse
- Small cells increases system capacity
- Handoff
  - ***Soft handoff***
  - ***Hard handoff***

# Advanced Mobile Phone System (AMPS)

- Frequency Reuse




(a) Frequencies are not reused in adjacent cells (b) To add more users, smaller cells can be used



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# Advanced Mobile Phone System (AMPS)

The 832 channels are divided into four categories:

- ***Control (base to mobile) to manage the system***
- ***Paging (base to mobile) to alert users to calls for them***
- ***Access (bidirectional) for call setup and channel assignment***
- ***Data (bidirectional) for voice, fax, or data***

# D-AMPS

- Fully Digital
- Uses same 30 kHz channels in same frequency as in AMPS
- Compression is done using vocoder
  - ***Compression is done in the telephone***
- Uses FDM and TDM



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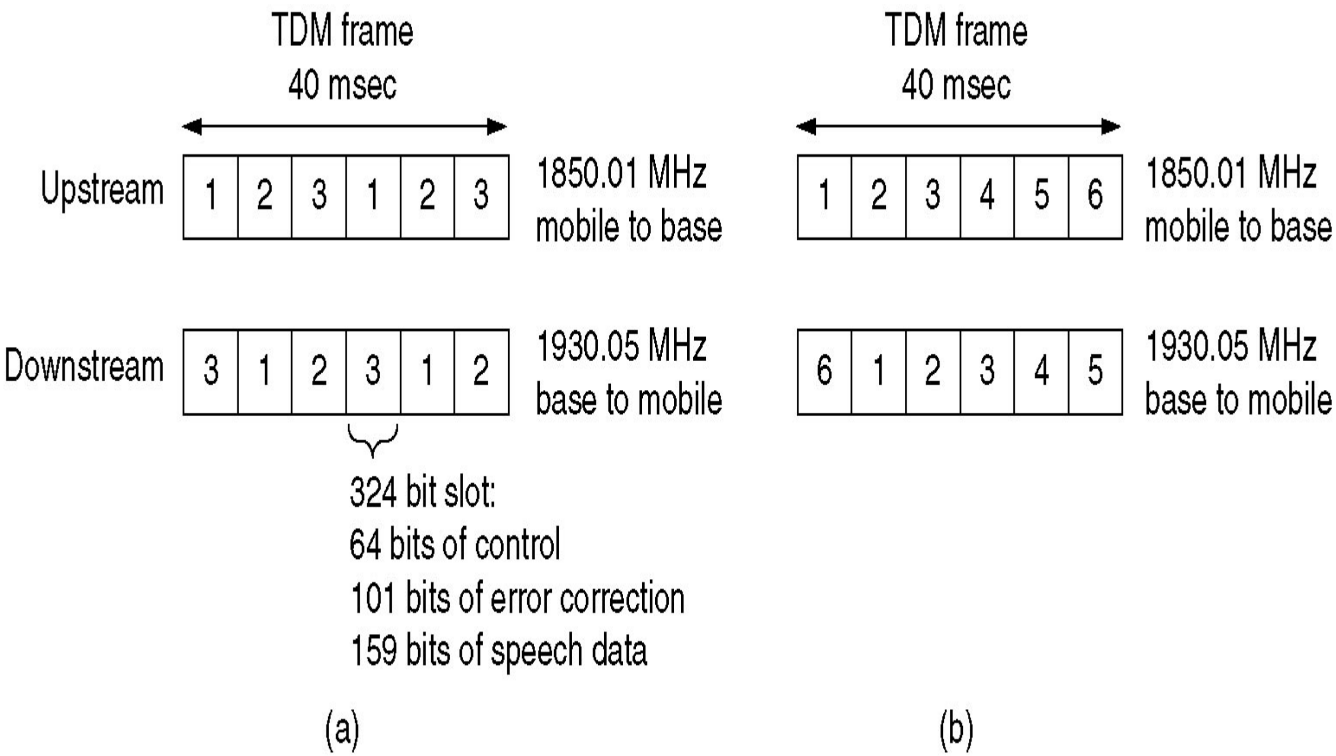
# D-AMPS




(a) A D-AMPS channel with three users (b) A D-AMPS channel with six users



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# Global System for Mobile Communication (GSM)

# Overview

- formerly: Groupe Spéciale Mobile (founded 1982)
- now: Global System for Mobile Communication
- seamless roaming within Europe possible
- today many providers all over the world use GSM (more than 200 countries in Asia, Africa, Europe, Australia, America)
- more than 1.2 billion subscribers
- more than 75% of all digital mobile phones use GSM

# Services

- GSM offers
  - several types of connections
    - *voice connections, data connections, SMS*
  - multi-service options (combination of basic services)
- Three service domains
  - Bearer Services
    - *Transfer data between access points*
  - Telematic Services
    - *Enable voice communication via mobile phones*
    - *voice mailbox, electronic mail*
    - *Short Message Service (SMS)*
  - Supplementary Services
    - *identification: forwarding of caller number*
    - *automatic call-back*
    - *locking of the mobile terminal*

# Architecture

- **several providers setup mobile networks following the GSM standard within each country**

- **components**
  - *MS (mobile station)*
  - *BS (base station)*
  - *MSC (mobile switching center)*
  - *LR (location register)*

- **subsystems**
  - *RSS (radio subsystem): covers all radio aspects*
  - *NSS (network and switching subsystem): call forwarding, handover, switching*
  - *OSS (operation subsystem): management of the network*



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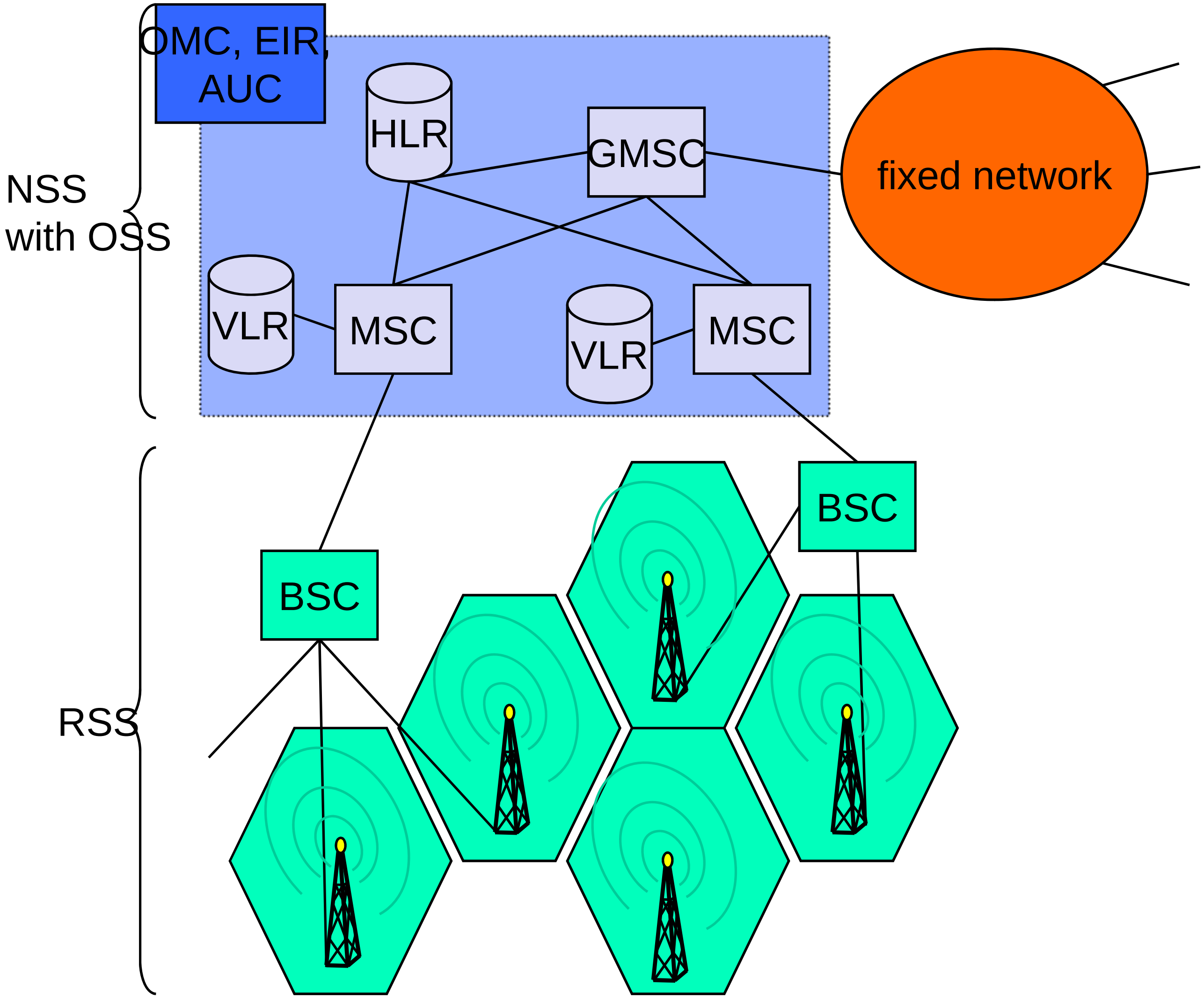
# Architecture



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# Radio Subsystem

- The Radio Subsystem (RSS) comprises the cellular mobile network up to the switching centers
- Components
  - **Base Station Subsystem (BSS):**
    - ***Base Transceiver Station (BTS): radio components including sender, receiver, antenna***
    - ***Base Station Controller (BSC): switching between BTSs, controlling BTSs***
    - ***BSS = BSC + sum(BTS) + interconnection***
  - **Mobile Stations (MS)**

# Mobile Station

- A mobile station (MS) comprises several functional groups
  - MT (Mobile Terminal):
    - *end-point of the radio interface*
  - TA (Terminal Adapter):
    - *terminal adaptation, hides radio specific characteristics*
  - TE (Terminal Equipment):
    - *peripheral device of the MS, offers services to a user*
    - *does not contain GSM specific functions*
  - SIM (Subscriber Identity Module):
    - *personalization of the mobile terminal, stores user parameters*

# Network and Switching Subsystem

- NSS is the main component of the public mobile network GSM
  - *switching, mobility management, interconnection to other networks, system control*

- Components
  - **Mobile Services Switching Center (MSC)**
    - *controls all connections via a separated network to/from a mobile terminal within the domain of the MSC*
  - **Databases (high capacity, low delay)**
    - **Home Location Register (HLR)**
      - *central database containing user data*
    - **Visitor Location Register (VLR)**
      - ***data about all user currently in the domain of the VLR***

# Mobile Switching Center (MSC)

- The MSC plays a central role in GSM
  - *switching functions*
  - *mobility support*
  - *management of network resources*
  - *interworking functions via Gateway MSC (GMSC)*
- Functions of a MSC
  - *specific functions for paging and call forwarding*
  - *mobility specific signaling*
  - *location registration and forwarding of location information*
  - *support of short message service (SMS)*
  - *generation and forwarding of accounting and billing information*

# Mobile Terminated Call

1: calling a GSM subscriber

2: forwarding call to GMSC

3: signal call setup to HLR

4, 5: request MSRN from VLR

6: forward responsible MSC to GMSC

7: forward call to current MSC

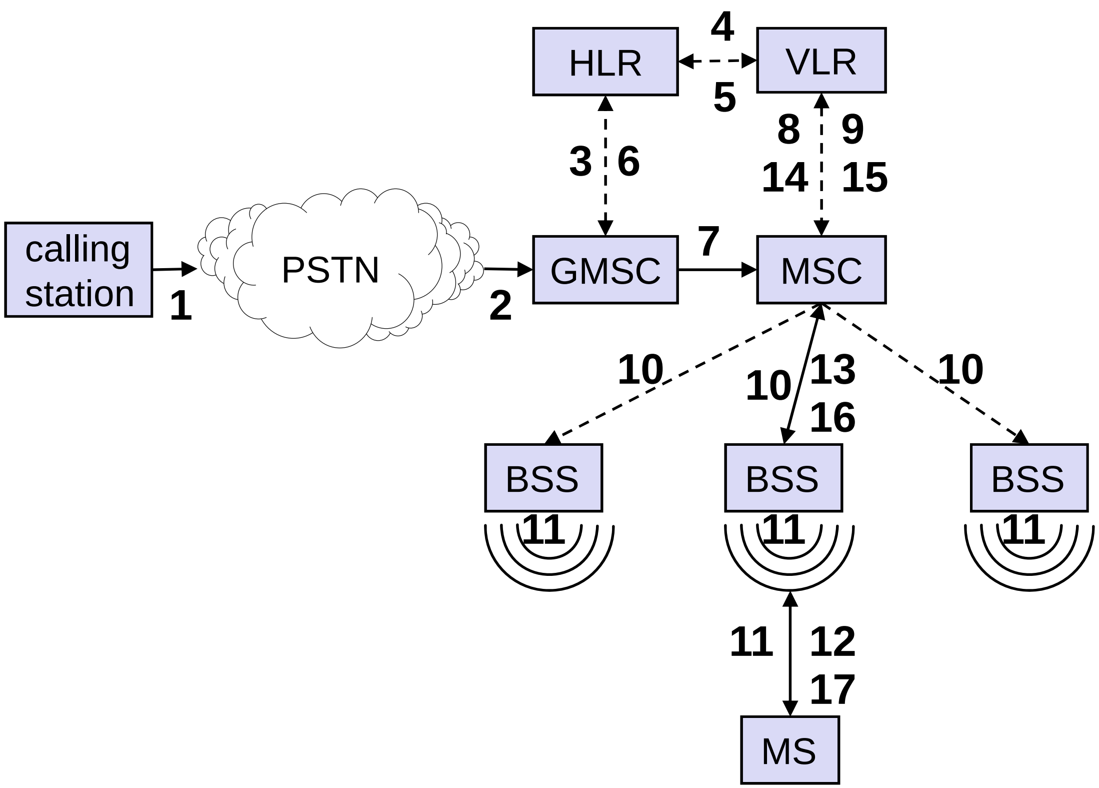
8, 9: get current status of MS

10, 11: paging of MS

12, 13: MS answers

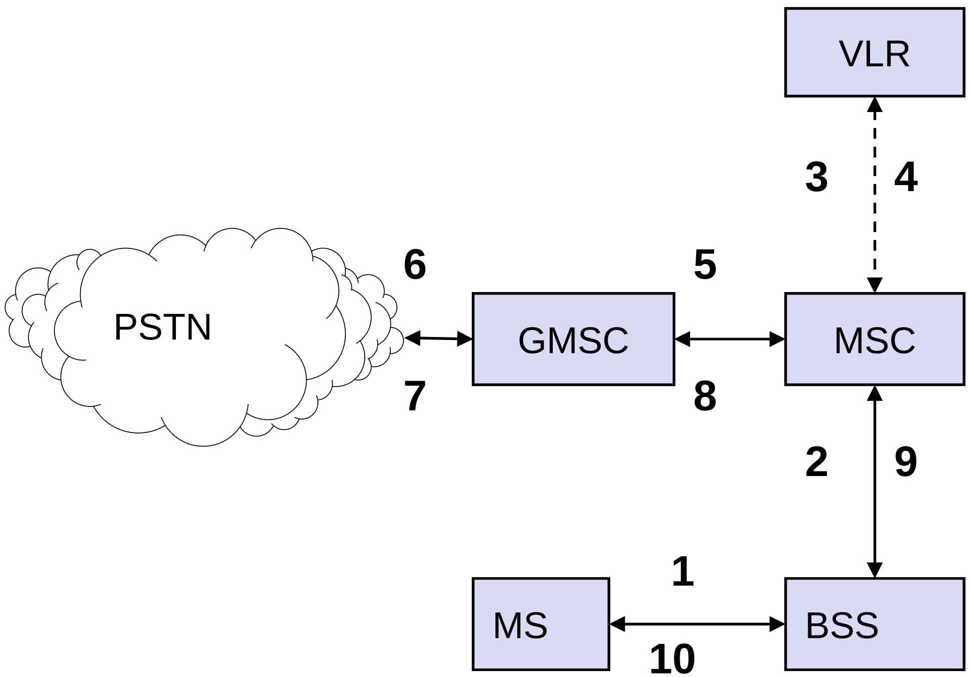
14, 15: security checks

16, 17: set up connection

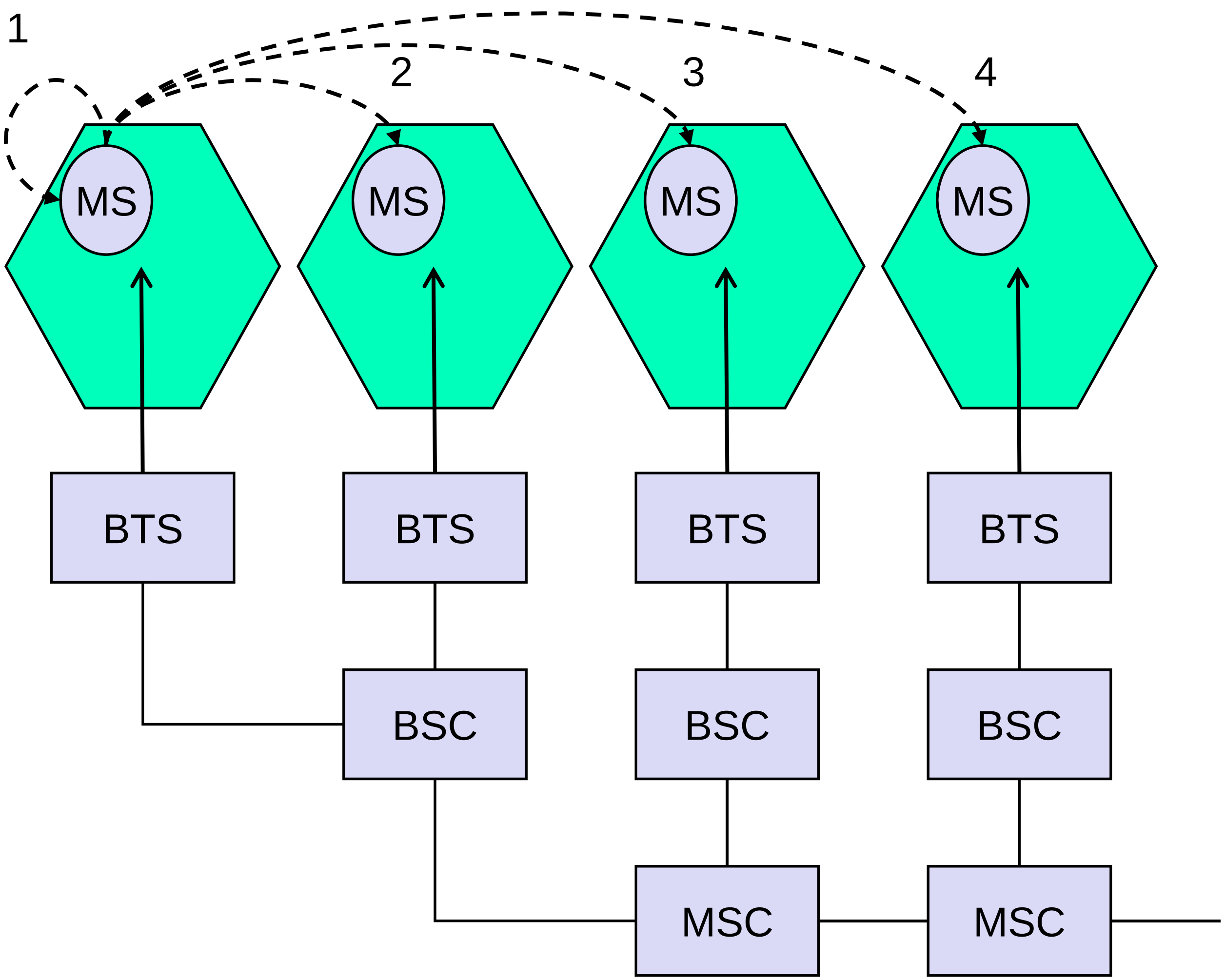


# Mobile Originated Call

- 1, 2: connection request
- 3, 4: security check
- 5-8: check resources (free circuit)
- 9-10: set up call



# Four Types of Handover





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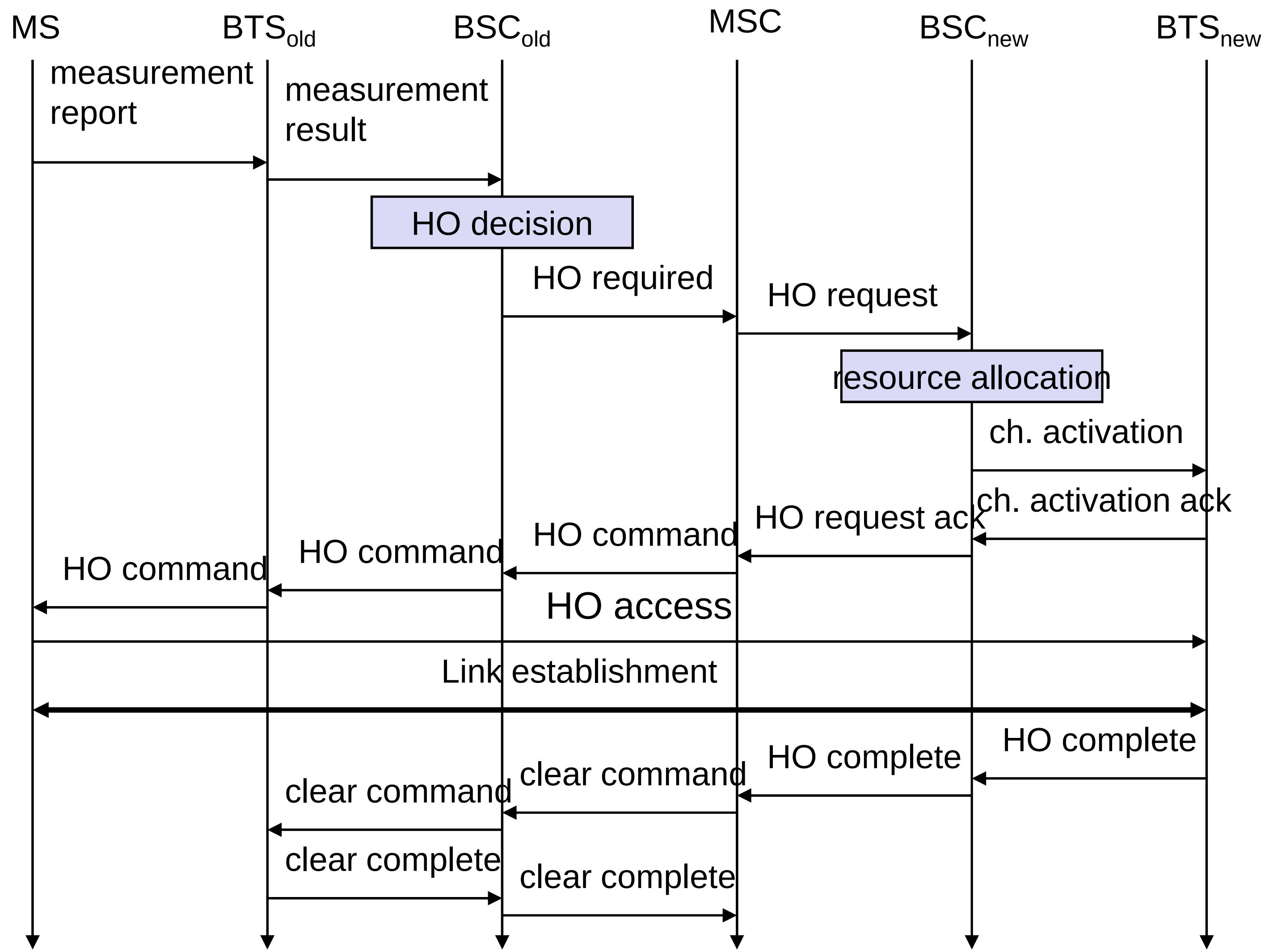
# Handover Procedure



# *Code Division Multiple Access (CDMA)*



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# Basic Principles

- Each user uses entire spectrum

- Collision occurs

  - ***Multiple signals add linearly***

  - ***Signals are separated using coding theory***



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# How it works

- Each bit time is subdivided into m short intervals called chips
- Each station is assigned a unique m-bit code called a chip sequence
- To send a 1 bit
  - *Send the chip sequence*
- To send a 0 bit
  - *Send negative of chip sequence*
- All chip sequences are pair wise Orthogonal
  - *Normalized inner product of S and T is 0*

# How to Recover Signal

- To recover information one has to know the senders chip sequence
- Compute the inner product of received signal and senders chip sequence
- Example
  - ***Three senders A, B, C. To recover C's signal compute S•C = (A+B+C)•C = C•C = 1***

# Example

A: 0 0 0 1 1 0 1 1
B: 0 0 1 0 1 1 1 0
C: 0 1 0 1 1 1 0 0
D: 0 1 0 0 0 0 1 0

(a)

A: (−1 −1 −1 +1 +1 −1 +1 +1)
B: (−1 −1 +1 −1 +1 +1 +1 −1)
C: (−1 +1 −1 +1 +1 +1 −1 −1)
D: (−1 +1 −1 −1 −1 −1 +1 −1)

(b)

Six examples:

| | | |
|---|---|---|
| − − 1 − | $\mathbf{C}$ | $S_1 = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$ |
| − 1 1 − | $\mathbf{B} + \mathbf{C}$ | $S_2 = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2)$ |
| 1 0 − − | $\mathbf{A} + \overline{\mathbf{B}}$ | $S_3 = (\ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2)$ |
| 1 0 1 − | $\mathbf{A} + \overline{\mathbf{B}} + \mathbf{C}$ | $S_4 = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$ |
| 1 1 1 1 | $\mathbf{A} + \mathbf{B} + \mathbf{C} + \mathbf{D}$ | $S_5 = (-4\ \ 0\ -2\ \ 0\ +2\ \ 0\ +2\ -2)$ |
| 1 1 0 1 | $\mathbf{A} + \mathbf{B} + \overline{\mathbf{C}} + \mathbf{D}$ | $S_6 = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)$ |

(c)

$S_1 \bullet C = (1\ +1\ +1\ +1\ +1\ +1\ +1\ +1)/8 = 1$
$S_2 \bullet C = (2\ +0\ +0\ +0\ +2\ +2\ +0\ +2)/8 = 1$
$S_3 \bullet C = (0\ +0\ +2\ +2\ +0\ -2\ +0\ -2)/8 = 0$
$S_4 \bullet C = (1\ +1\ +3\ +3\ +1\ -1\ +1\ -1)/8 = 1$
$S_5 \bullet C = (4\ +0\ +2\ +0\ +2\ +0\ -2\ +2)/8 = 1$
$S_6 \bullet C = (2\ -2\ +0\ -2\ +0\ -2\ -4\ +0)/8 = -1$

(d)

(a) Binary chip sequences for four stations
(b) Bipolar chip sequences
(c) Six examples of transmissions
(d) Recovery of station C’s signal


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# *Wireless LAN: IEEE 802.11*


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# Characteristics of WLAN

- Very flexible within the reception area
- Ad-hoc networks without previous planning possible
- (almost) no wiring difficulties
- more robust against disasters like, e.g., earthquakes
- typically very low bandwidth compared to wired networks (1-10 Mbit/s) due to shared medium


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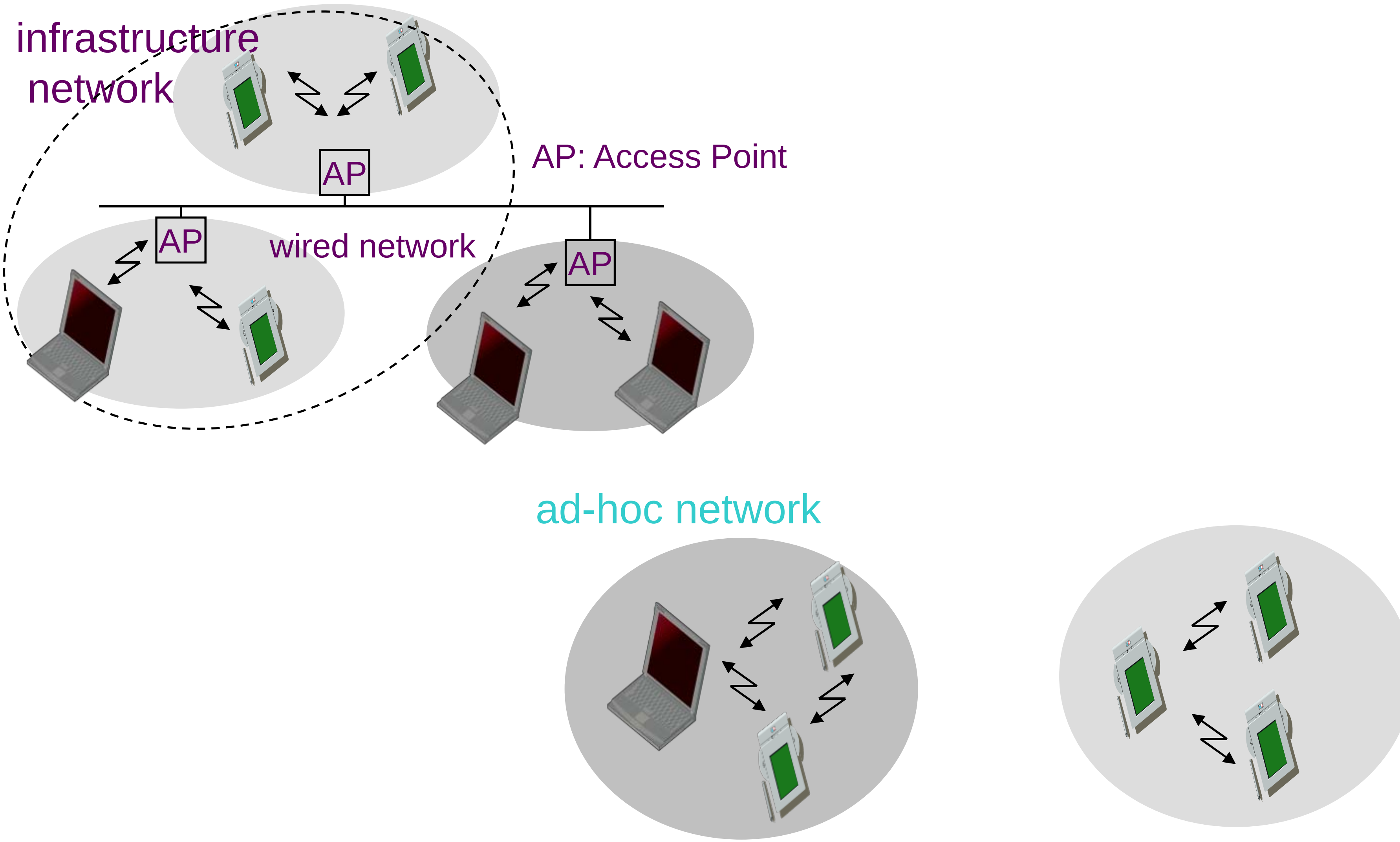
# Comparison: Infrastructure Vs Ad-hoc



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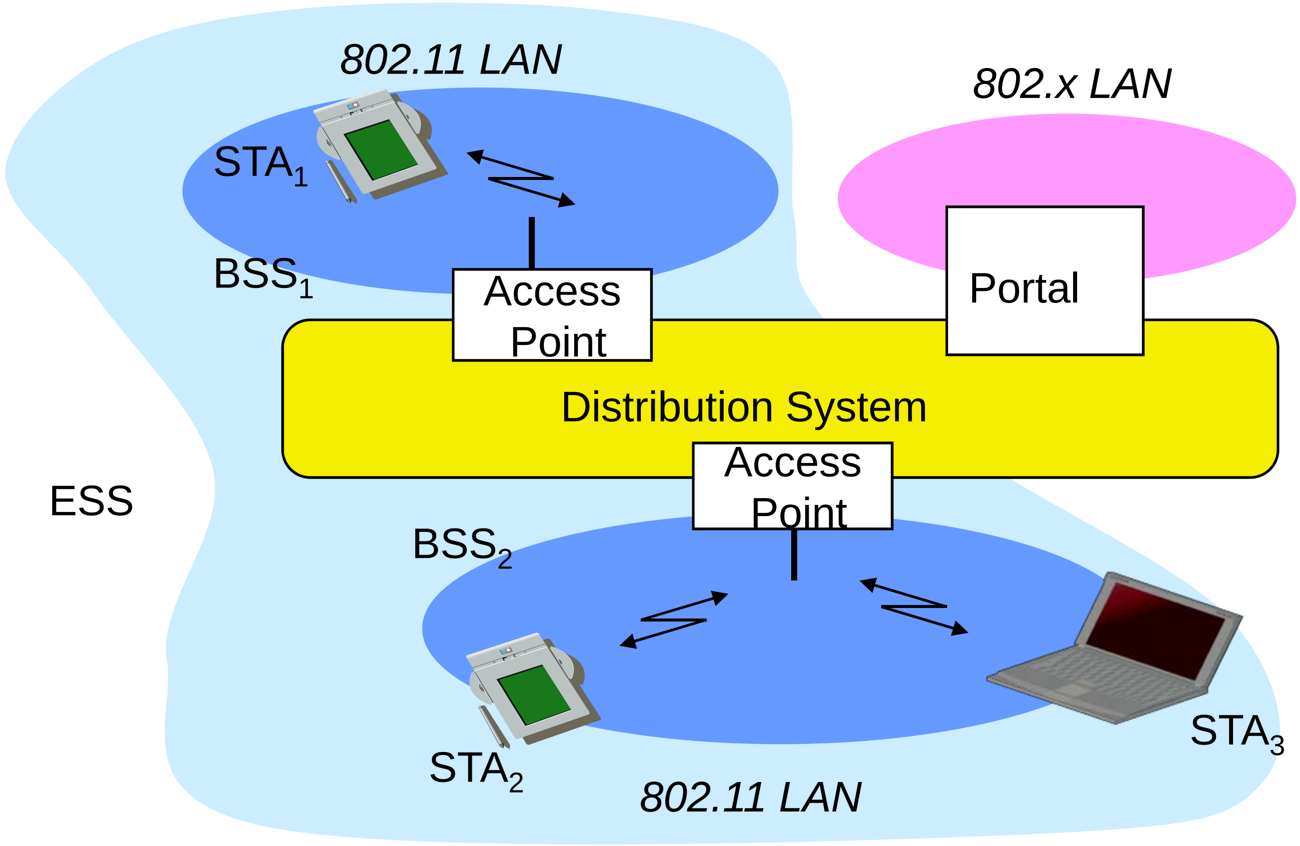
# Architecture of an Infrastructure Network




*STA: Station, BSS: Basic Service Set, ESS: Extended Service Set*



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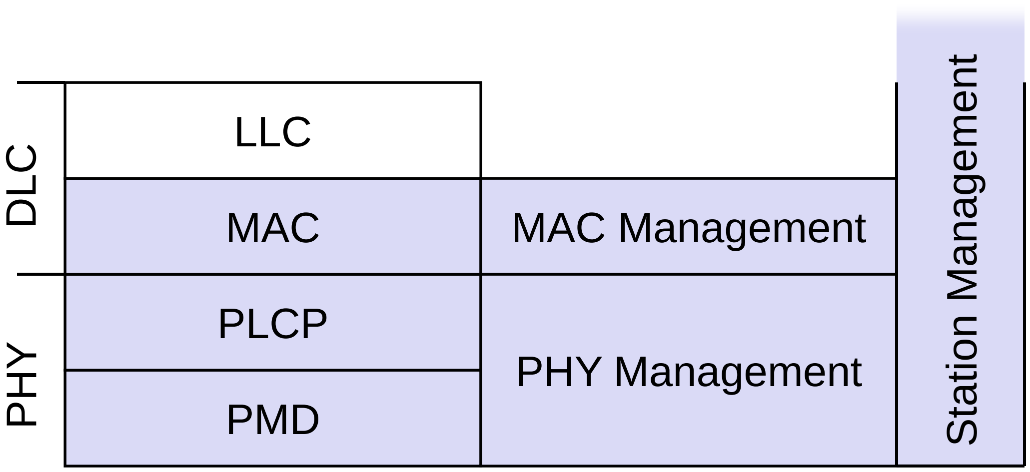
# Layers and Functions

- MAC
  - *access mechanisms, fragmentation*
- MAC Management
  - synchronization, roaming, power management




- PLCP - Physical Layer Convergence Protocol
  - *clear channel assessment signal*
- PMD - Physical Medium Dependent
  - *modulation, coding*
- PHY Management
  - *channel selection*
- Station Management
  - *coordination of all management functions*



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# MAC Layer I-DFWMAC

- **Traffic services**
  - *Asynchronous Data Service (mandatory)*
    - exchange of data packets based on "best-effort"
  - *Time-Bounded Service (optional)*
    - implemented using PCF (Point Coordination Function)
- ***Access methods***
  - *DFWMAC-DCF CSMA/CA (mandatory)*
    - collision avoidance via randomized "back-off" mechanism
    - ACK packet for acknowledgements (not for broadcasts)
  - *DFWMAC-DCF w/ RTS/CTS (optional)*
    - Distributed Foundation Wireless MAC
    - avoids hidden terminal problem
  - *DFWMAC- PCF (optional)*
    - access point polls terminals according to a list


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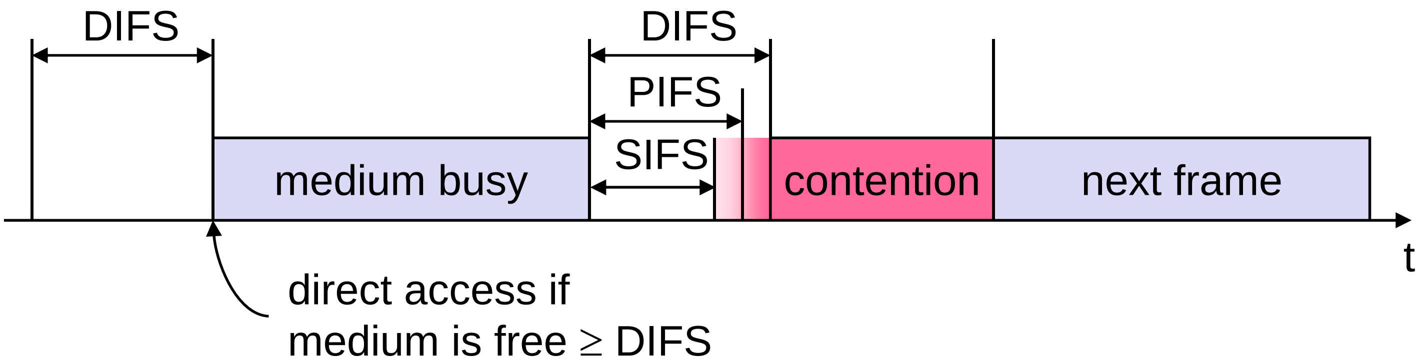
# MAC Layer II

- Priorities
  - *defined through different inter frame spaces*
  - ***SIFS (Short Inter Frame Spacing)***
    - highest priority, for ACK, CTS, polling response
  - ***PIFS (PCF IFS)***
    - medium priority, for time-bounded service using PCF
  - ***DIFS (DCF, Distributed Coordination Function IFS)***
    - lowest priority, for asynchronous data service



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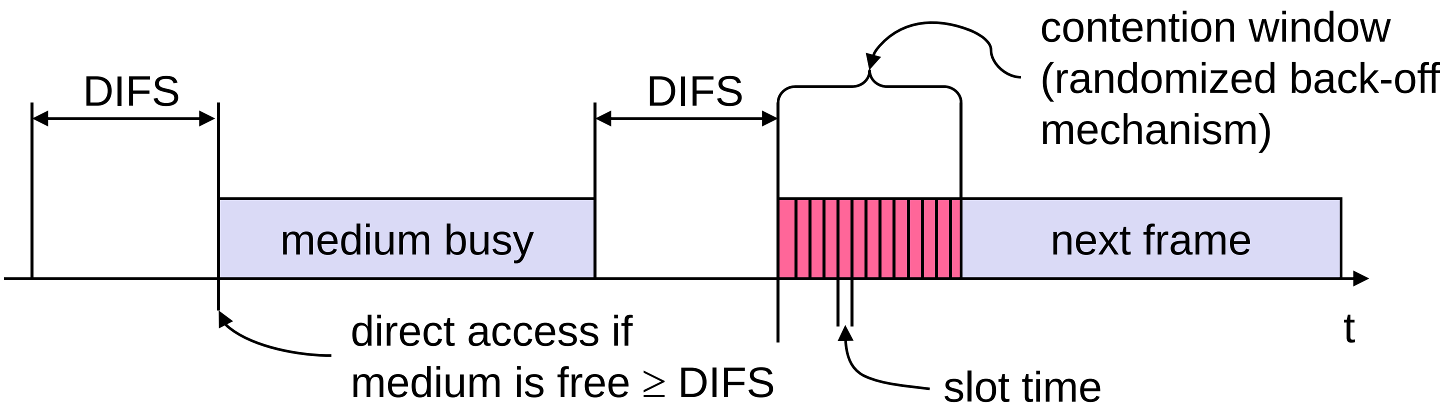
# CSMA/CA Access Method I




- station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- if the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending
- if the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- if another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)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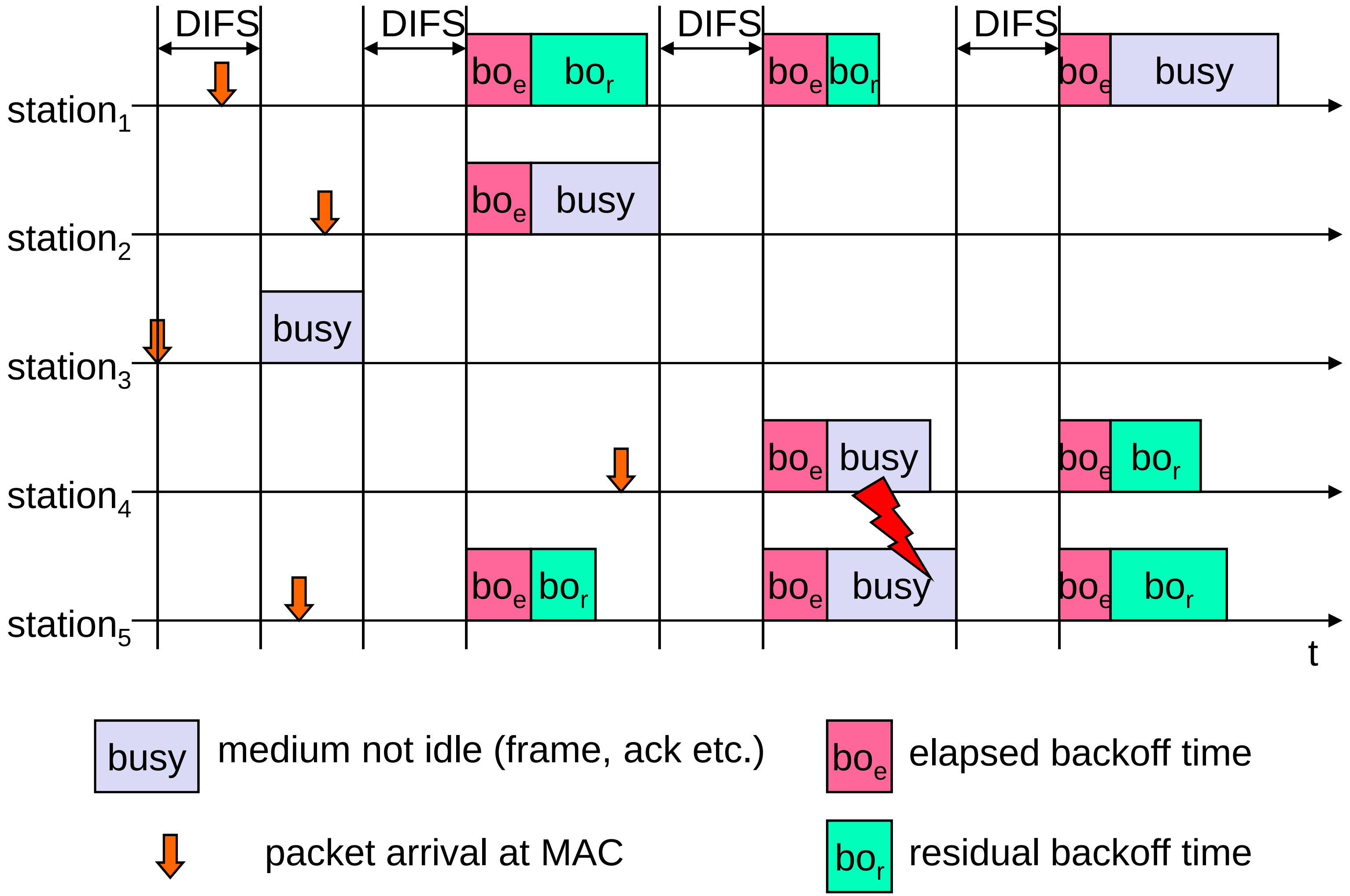
# Competing Stations-Simple Version



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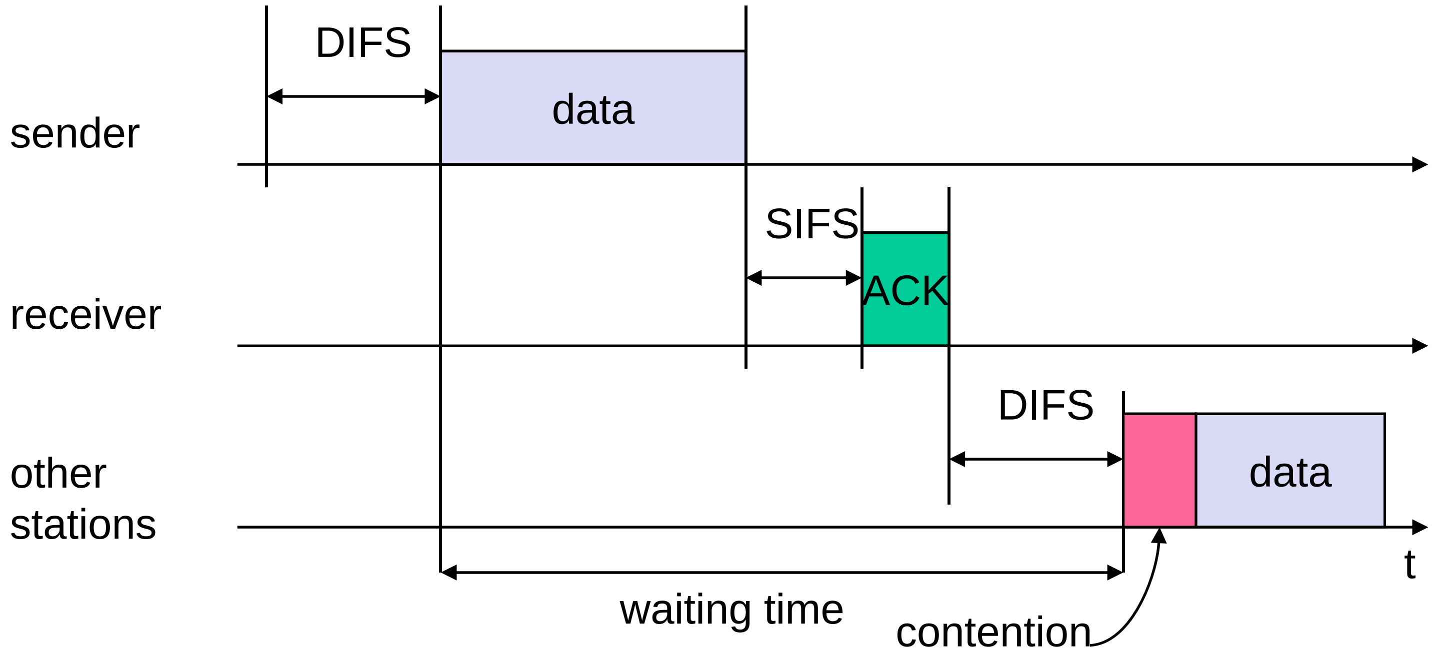
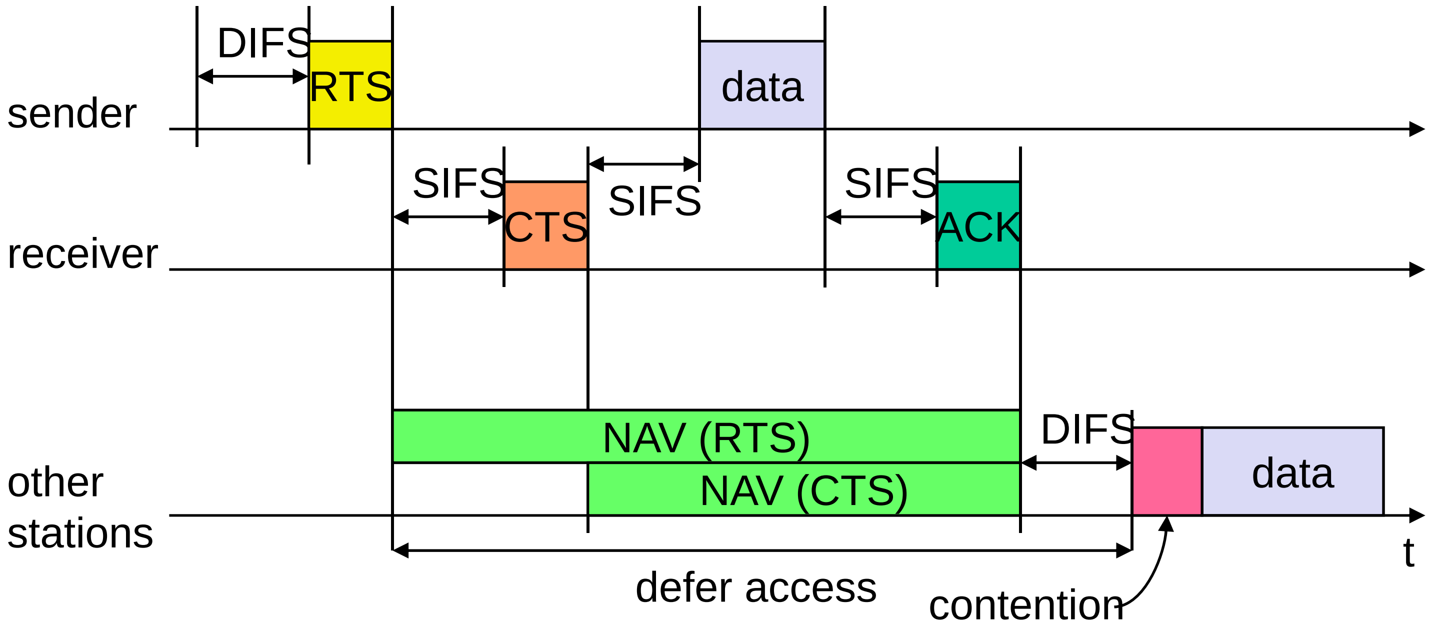
# CSMA/CA Access Method II

- Sending unicast packets
  - *station has to wait for DIFS before sending data*
  - *receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)*
  - *automatic retransmission of data packets in case of transmission errors*



# DFWMAC

- Sending unicast packets
  - *station can send RTS with reservation parameter after waiting for DIFS*
  - *acknowledgement via CTS after SIFS by receiver (if ready to receive)*
  - *sender can now send data at once, acknowledgement via ACK*
  - *other stations store medium reservations distributed via RTS and CTS*





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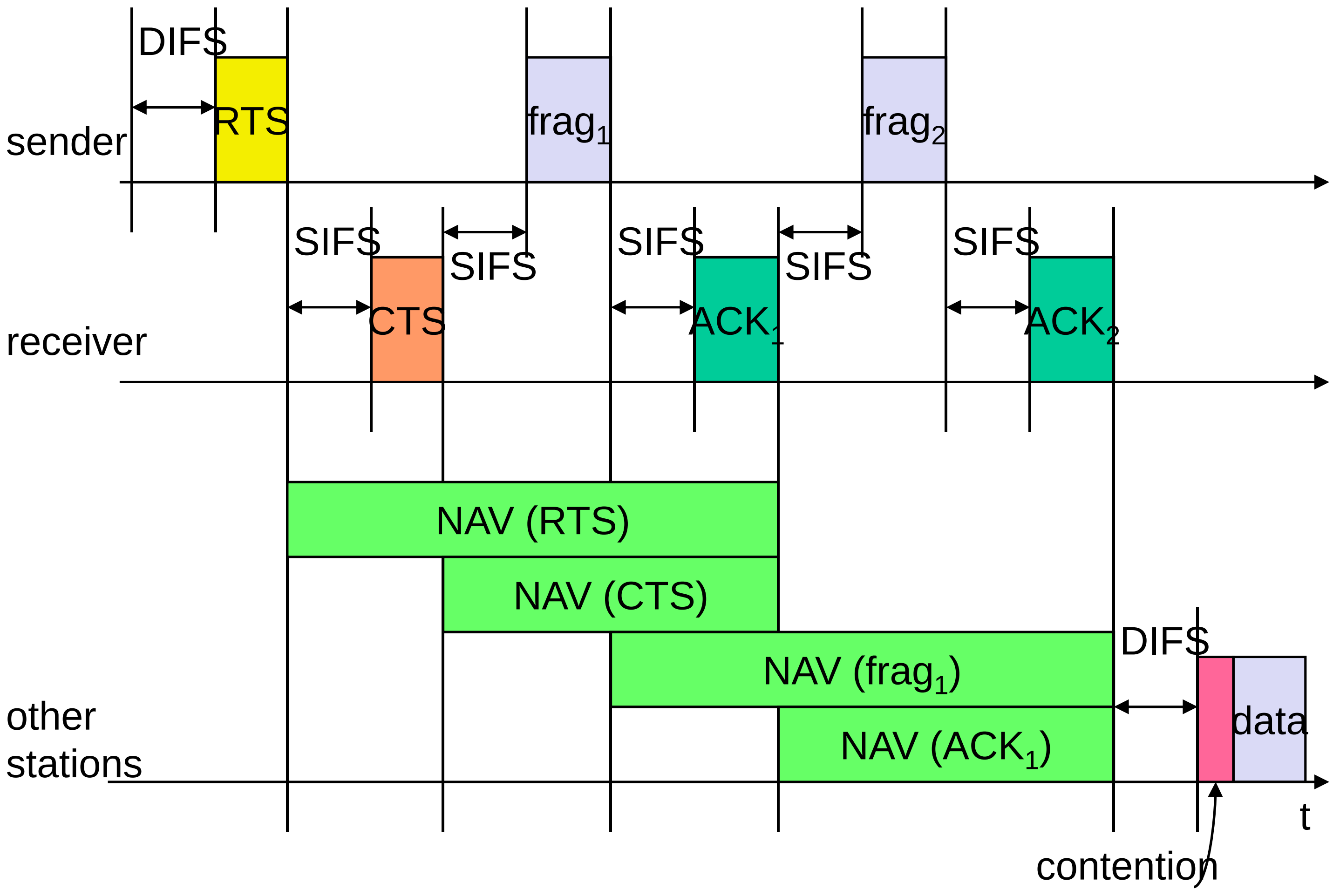
# Fragmentation



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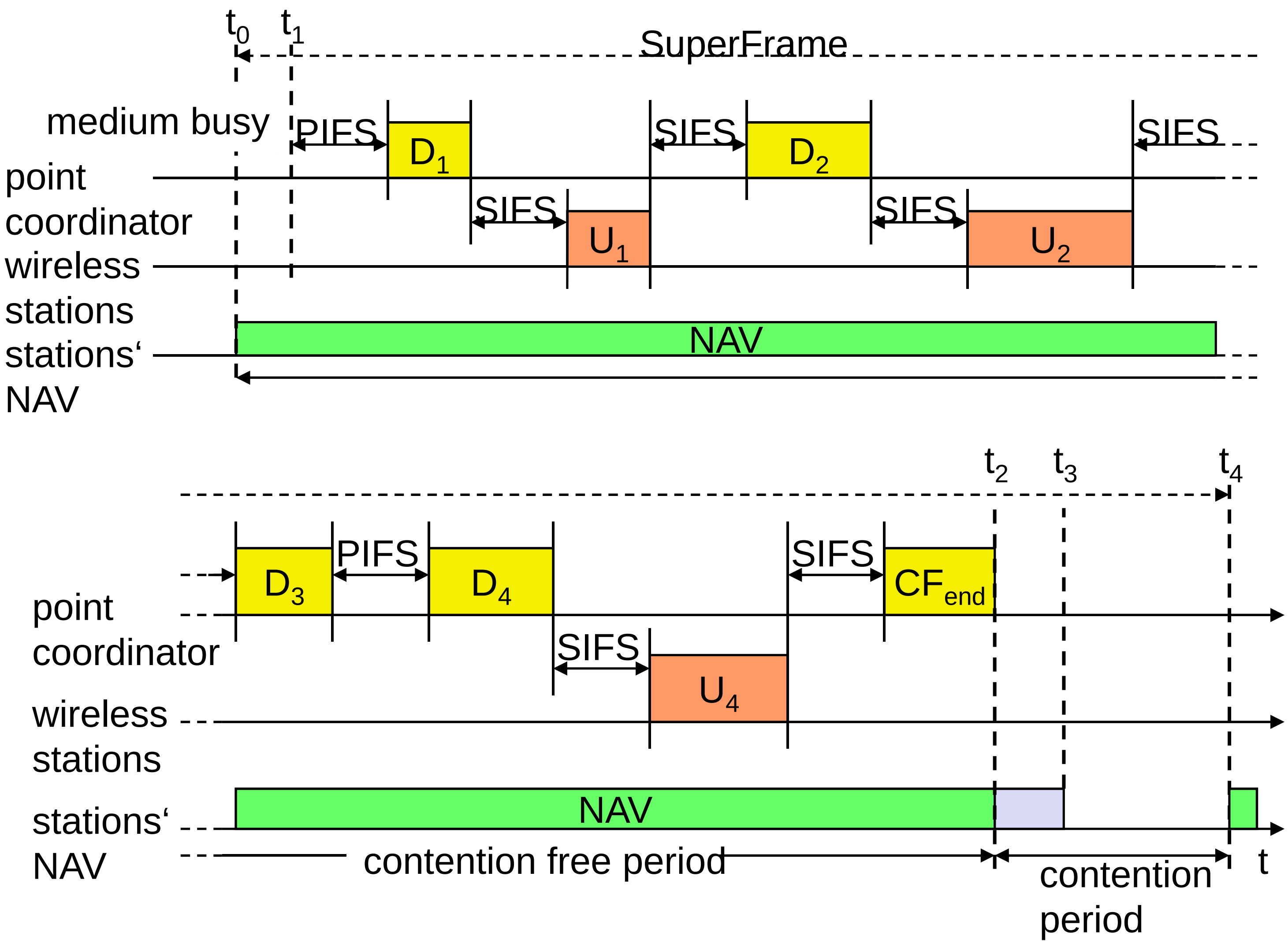
# DFWMAC-PCF



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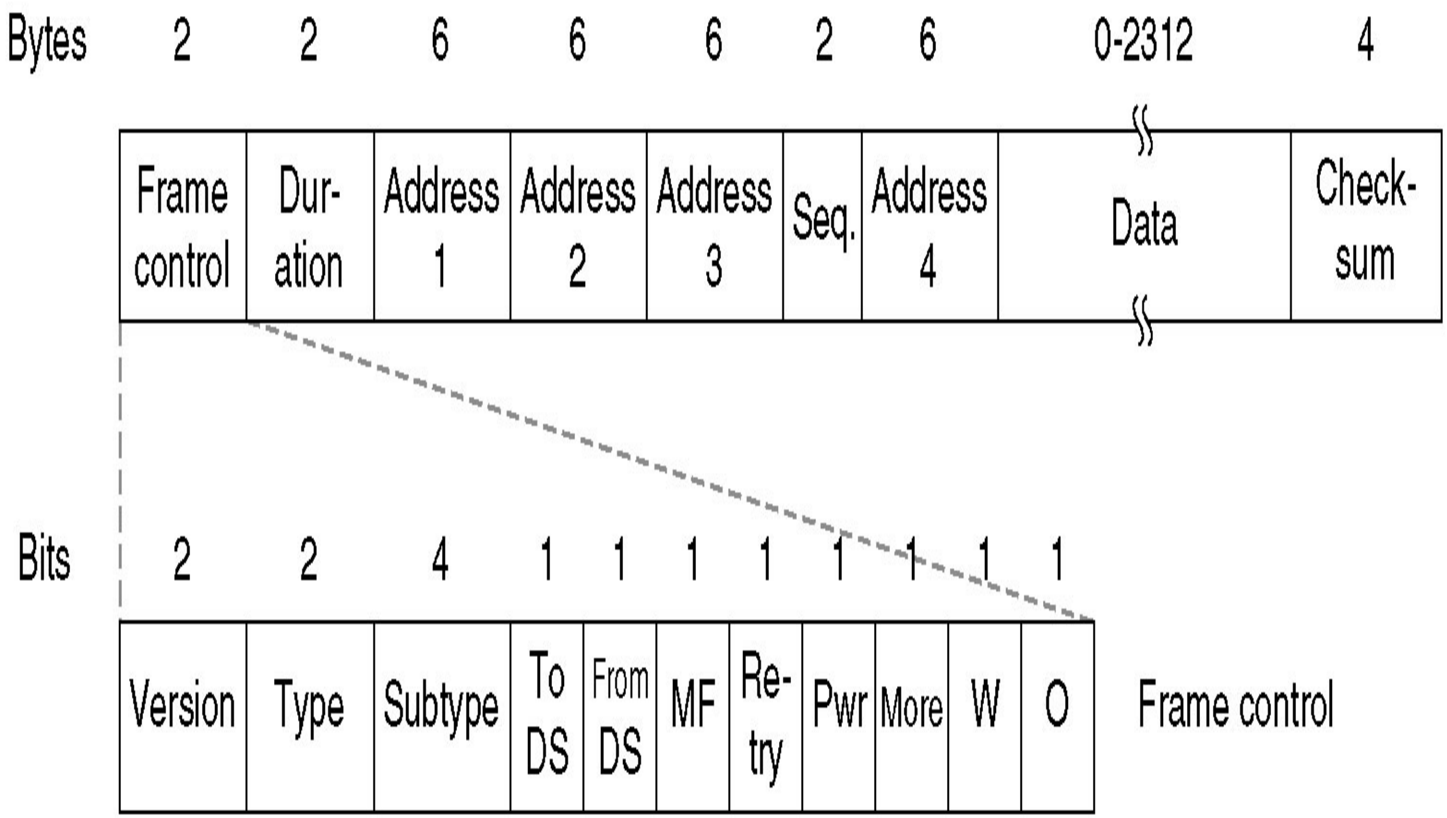
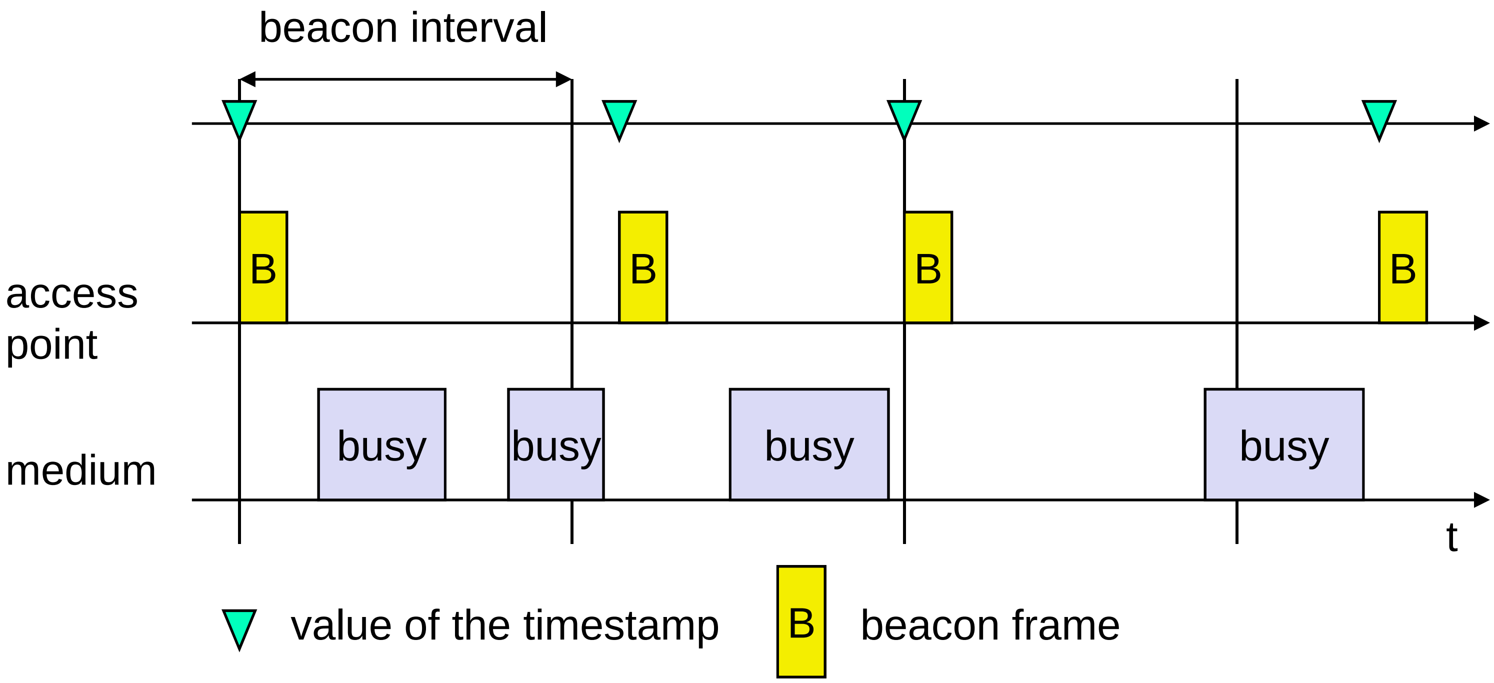
# Frame Format



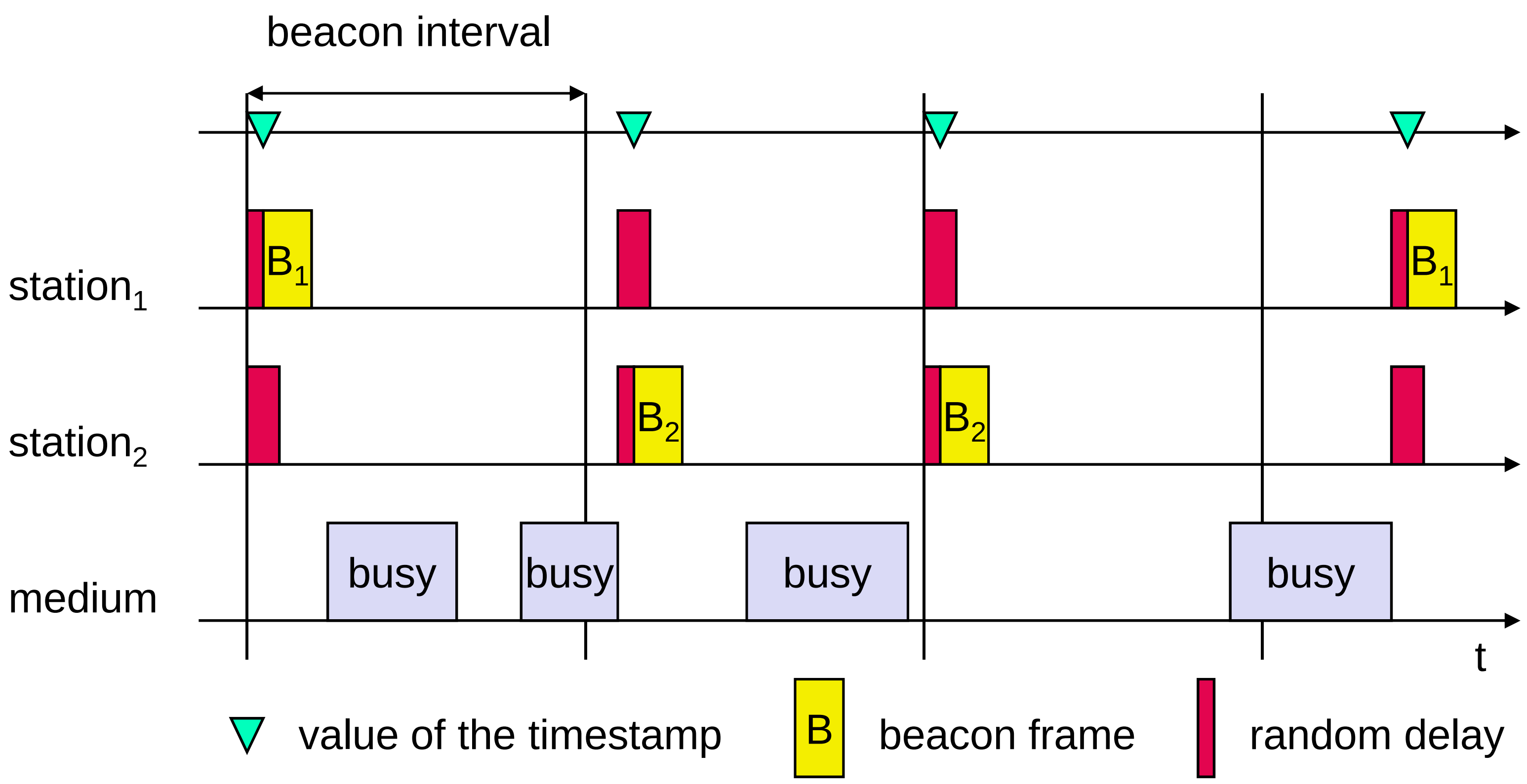
# Synchronization using Beacon

## *Infrastructure*



# Synchronization using Beacon

## *Ad-hoc*



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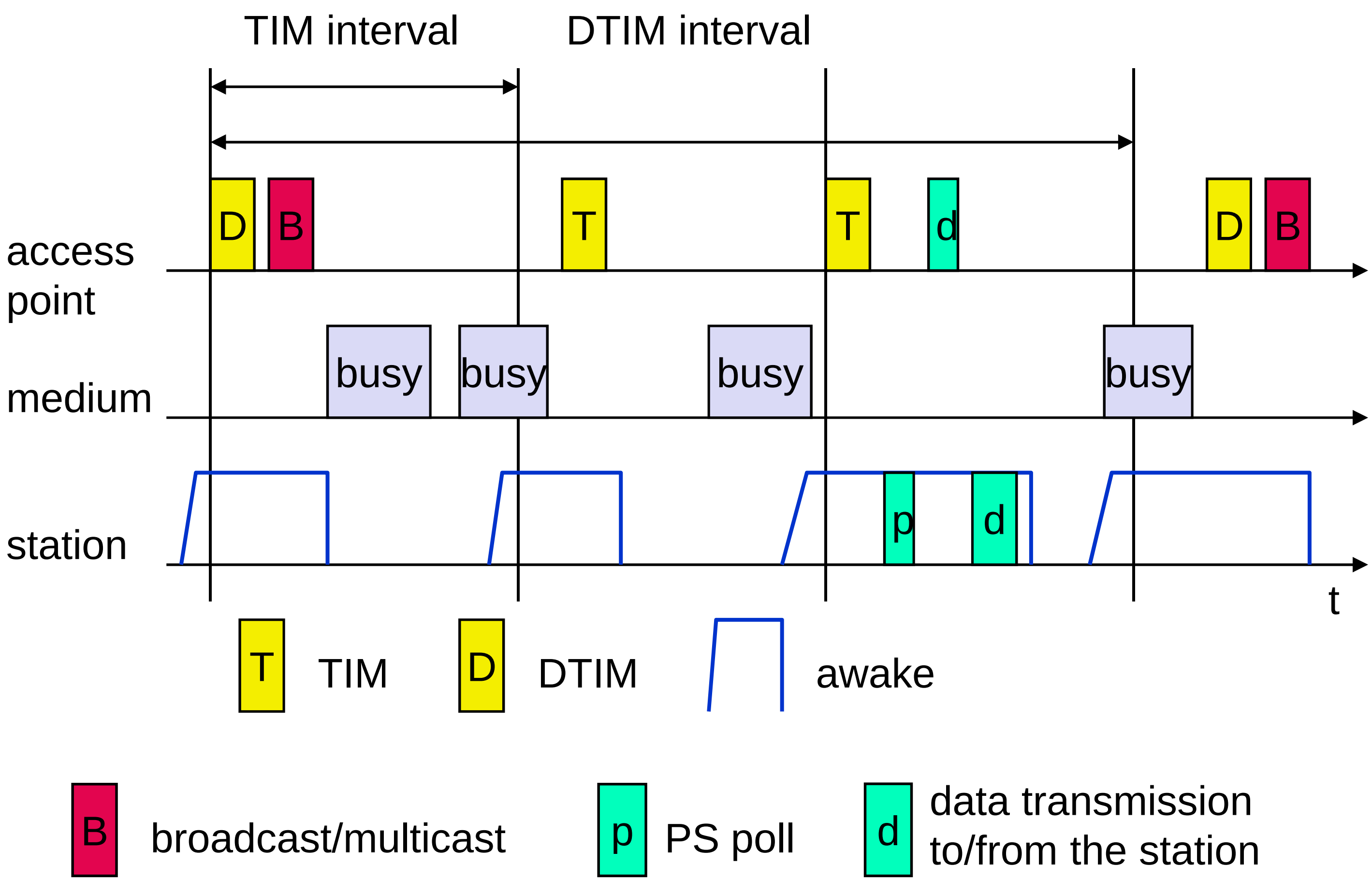
# Power Management

- ***Idea: switch the transceiver off if not needed***
- States of a station: sleep and awake
- *Timing Synchronization Function (TSF)*
  - ***stations wake up at the same time***
- *Infrastructure*
  - ***Traffic Indication Map (TIM)***
    - **list of unicast receivers transmitted by AP**
  - ***Delivery Traffic Indication Map (DTIM)***
    - **list of broadcast/multicast receivers transmitted by AP**
- *Ad-hoc*
  - ***Ad-hoc Traffic Indication Map (ATIM)***
    - **announcement of receivers by stations buffering frames**
    - **more complicated - no central AP**
    - **collision of ATIMs possible (scalability?)**

# Power Saving with Wake up Pattern

## *Infrastructure*



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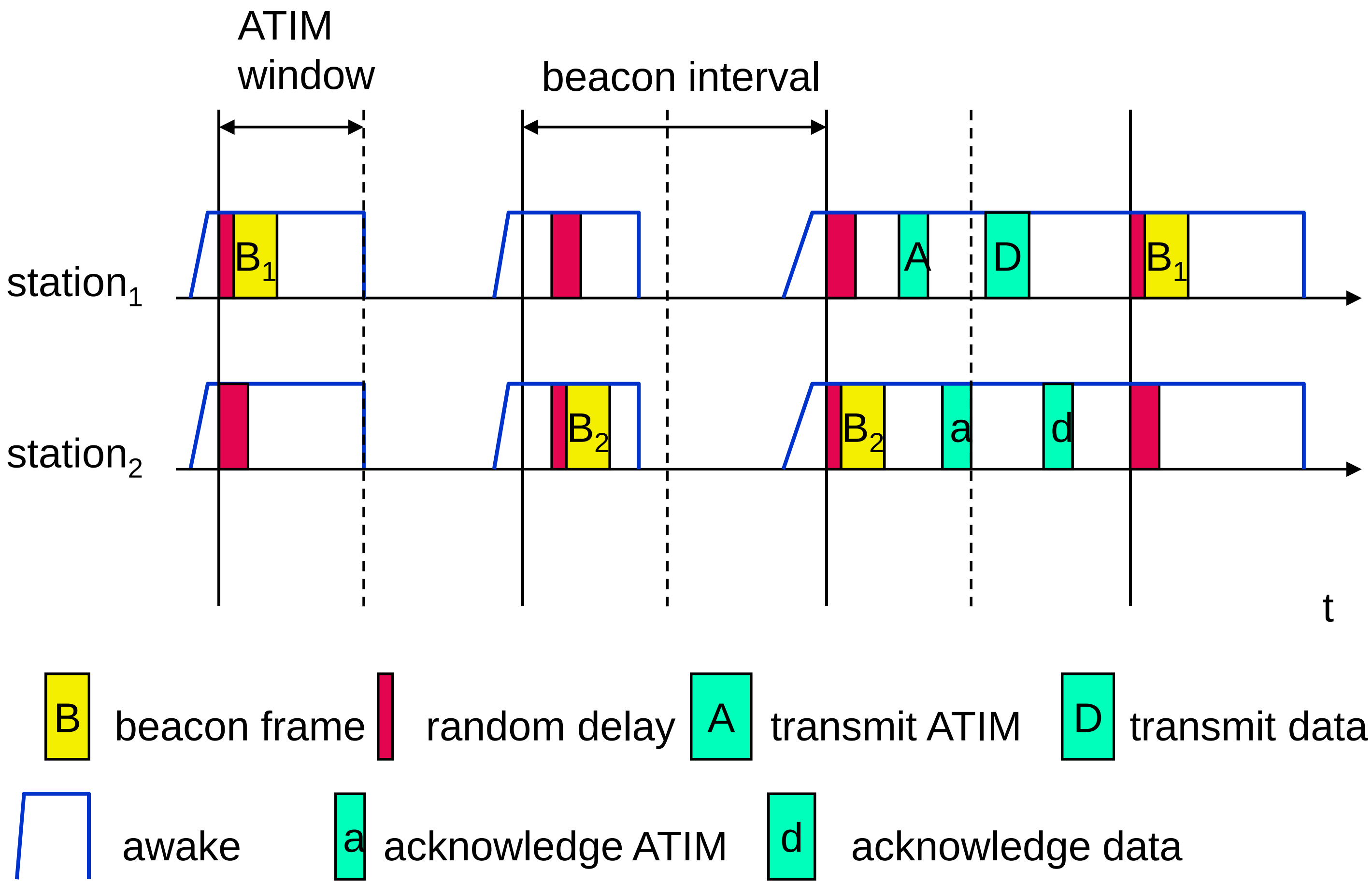
# Power Saving with Wake up Pattern

## *Ad-hoc*



# Roaming

- ***No or bad connection? Then perform:***
- *Scanning*
  - ***scan the environment***
- *Re-association Request*
  - ***station sends a request to one or several AP(s)***
- *Re-association Response*
  - ***success: AP has answered, station can now participate***
  - ***failure: continue scanning***
- *AP accepts Re-association Request*
  - ***signal the new station to the distribution system***
  - ***the distribution system updates its data base (i.e., location information)***
  - ***typically, the distribution system now informs the old AP so it can release resources***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# *Mobility Support in IP*

# Problems with IP Addressing

- An IP address serves two different functions…
  - ***The* name *for an interface (host) <u>and</u>***
  - ***The* location *(subnet) of the interface (host) in the network***

- The network identifier in the IP address is used by routers to deliver to the destination subnet
  - ***The IP address is associated with the location or subnet of the destination host***



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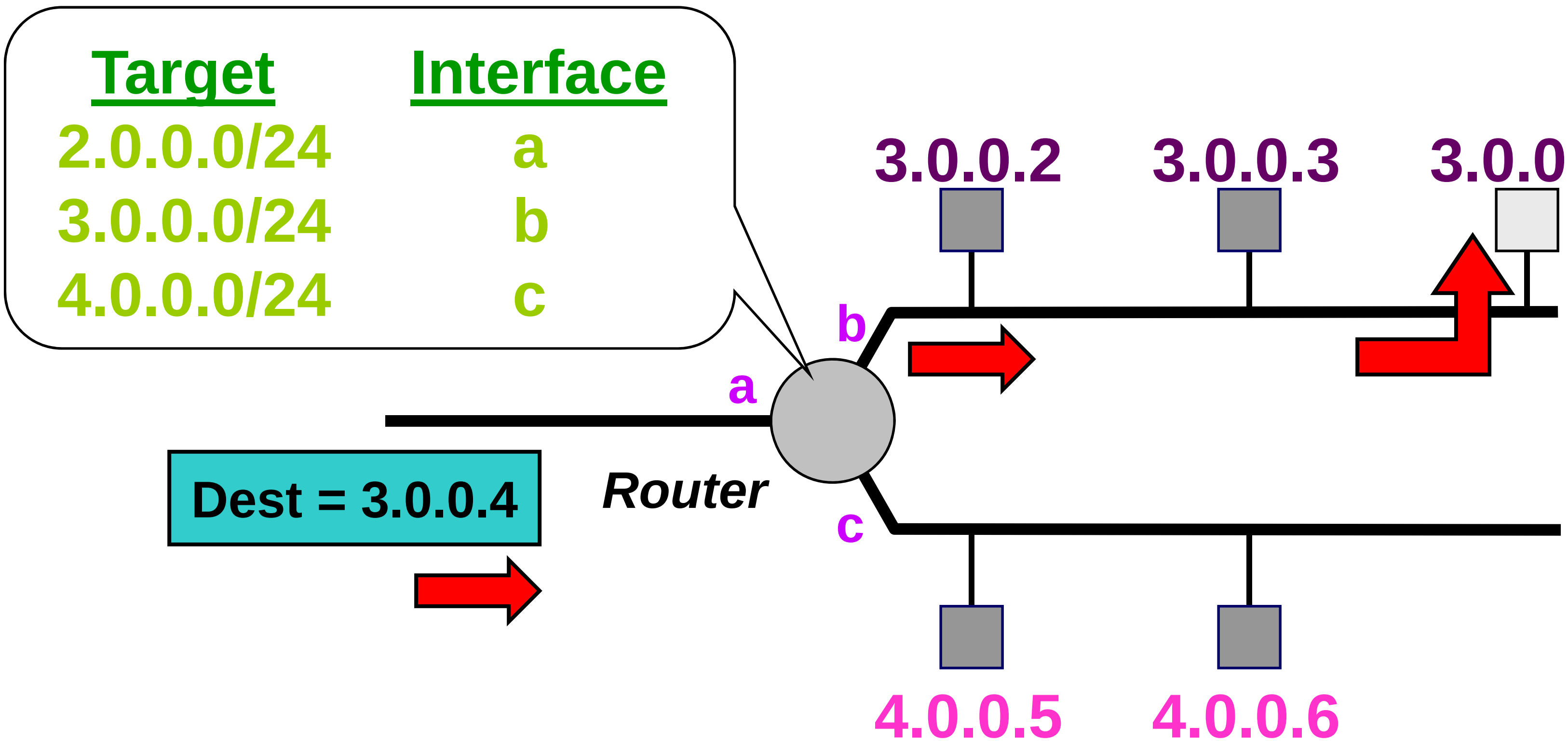
# Problems with IP Addressing

- Router uses routing table to direct packets to the appropriate interface



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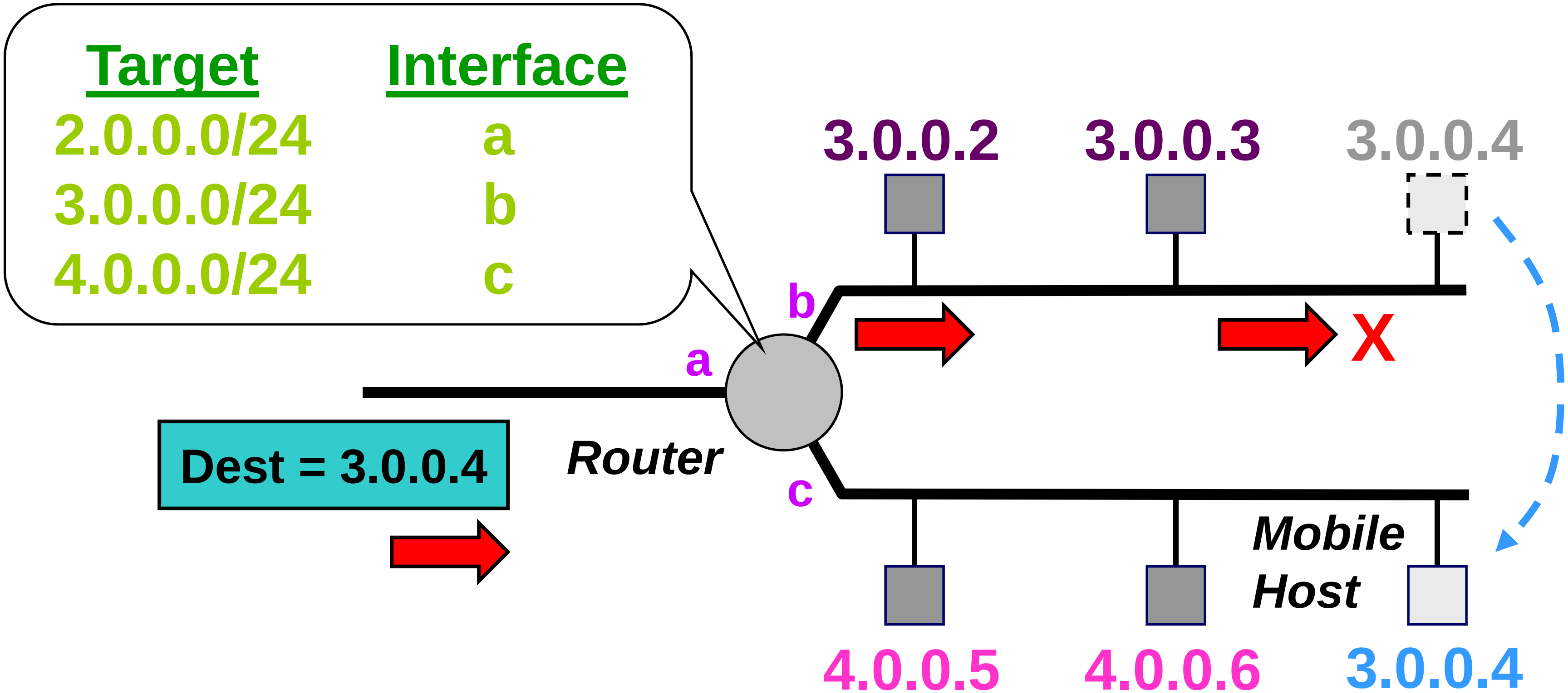
# Problems with IP Addressing

- Host moving to another network is unreachable





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# Solution to the problem

- Change IP address
  - *Mobile host can change its address to the foreign link's network prefix*
  - *Need to register new IP address with DNS (if it is to maintain identity), resulting in added load on the DNS server and network*
  - *Communications, e.g., TCP connections, would be disrupted*
    - **Both ends of a TCP connection need to keep the same IP address for the life of the session**
      - **TCP connection: (IPsrc, IPdst, Portsrc, Portdst)**


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# Solution to the problem

- Modify TCP and applications to adapt to mobile hosts
  » *Not practical/scalable*
- Solve the problem at the IP layer in a way that is transparent to existing applications
  – ***Mobile IP***
    - Allow the hosts to retain original IP address and obtain a second IP address when visiting other networks
    - Two-tier IP addressing
      – applications use a static IP address, the ***home address***
      – routing is performed using a topologically significant address, the ***care-of-address*** (CoA)
      – a protocol and sub-layer convert the CoA into the Home address and the home address into the CoA



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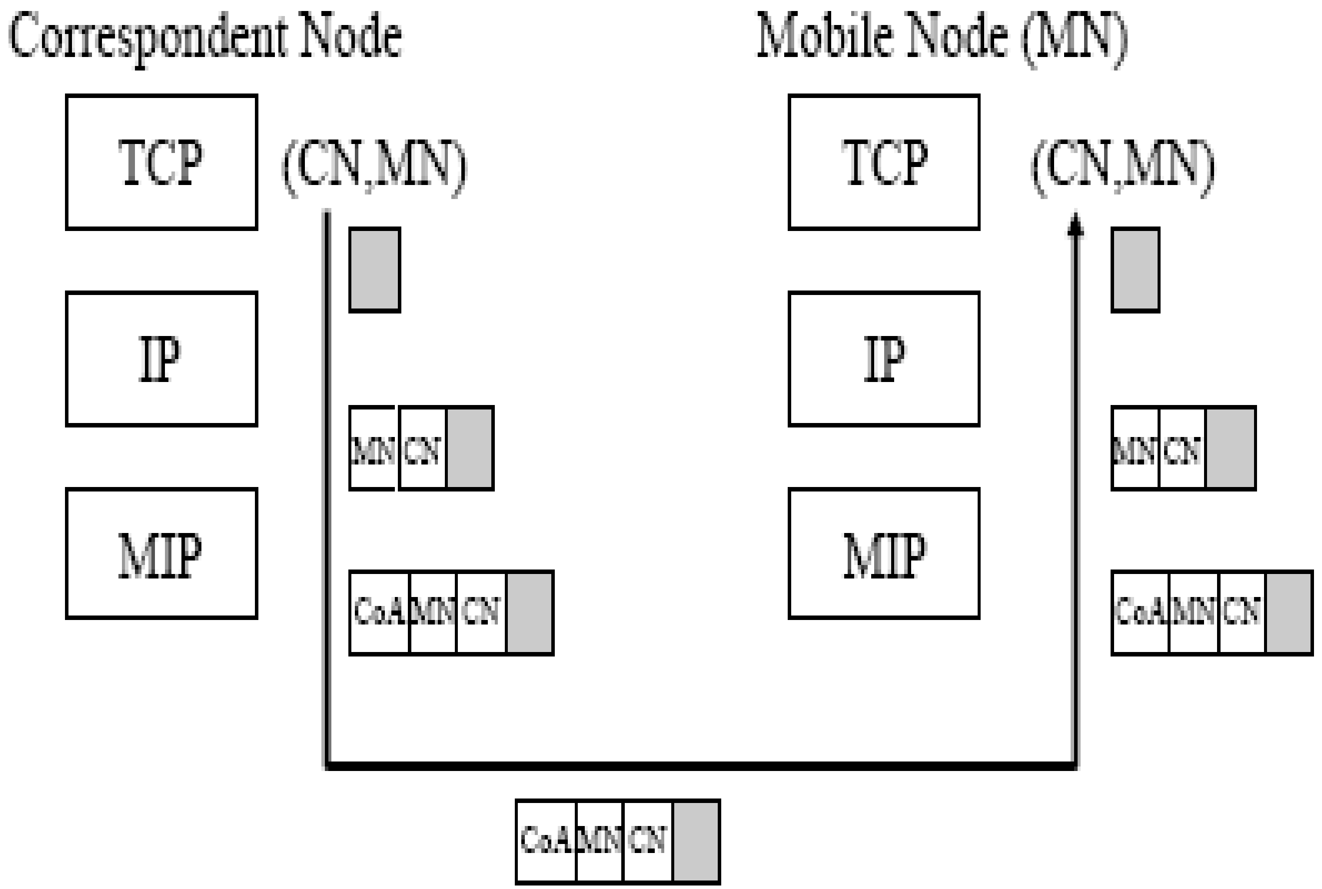
# Mobile IP




Mobility (i.e. Change of CoA) is ***transparent*** to applications and IP layer that are always using the MN’s permanent address



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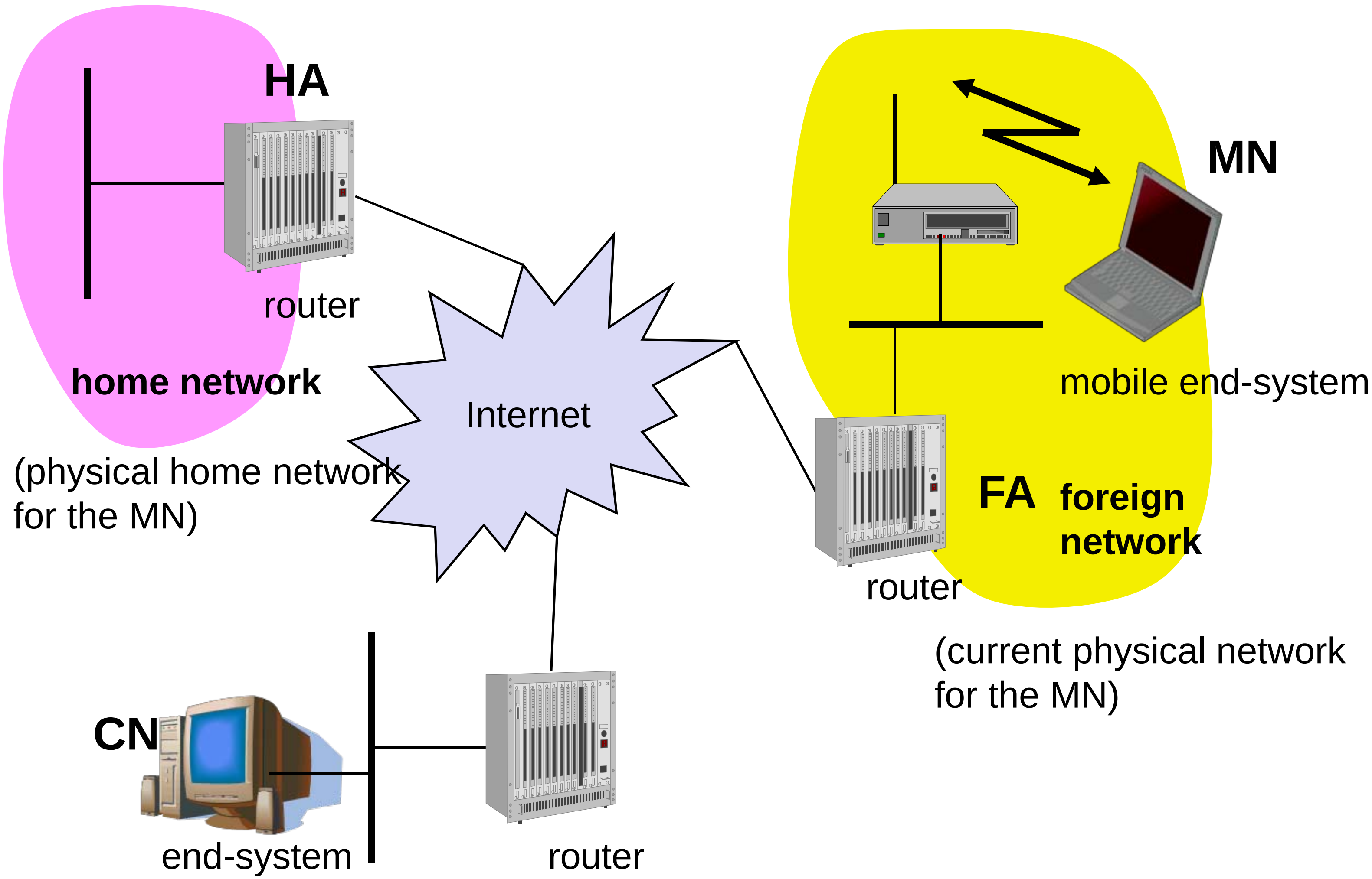
# Mobile IP Components



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# Mobile IP: Registration

- **Foreign network runs system known as *foreign agent***
  - ***Visiting host registers with foreign agent***
  - ***Foreign agent assigns host a temporary address***
    - **Foreign agent care-of address**
  - ***Foreign agent registers host with* home agent**

- Foreign network does not run a *foreign agent*
  - ***Host uses DHCP to obtain temporary address***
    - **Colocated care-of address**
  - ***Host registers directly with home agent***



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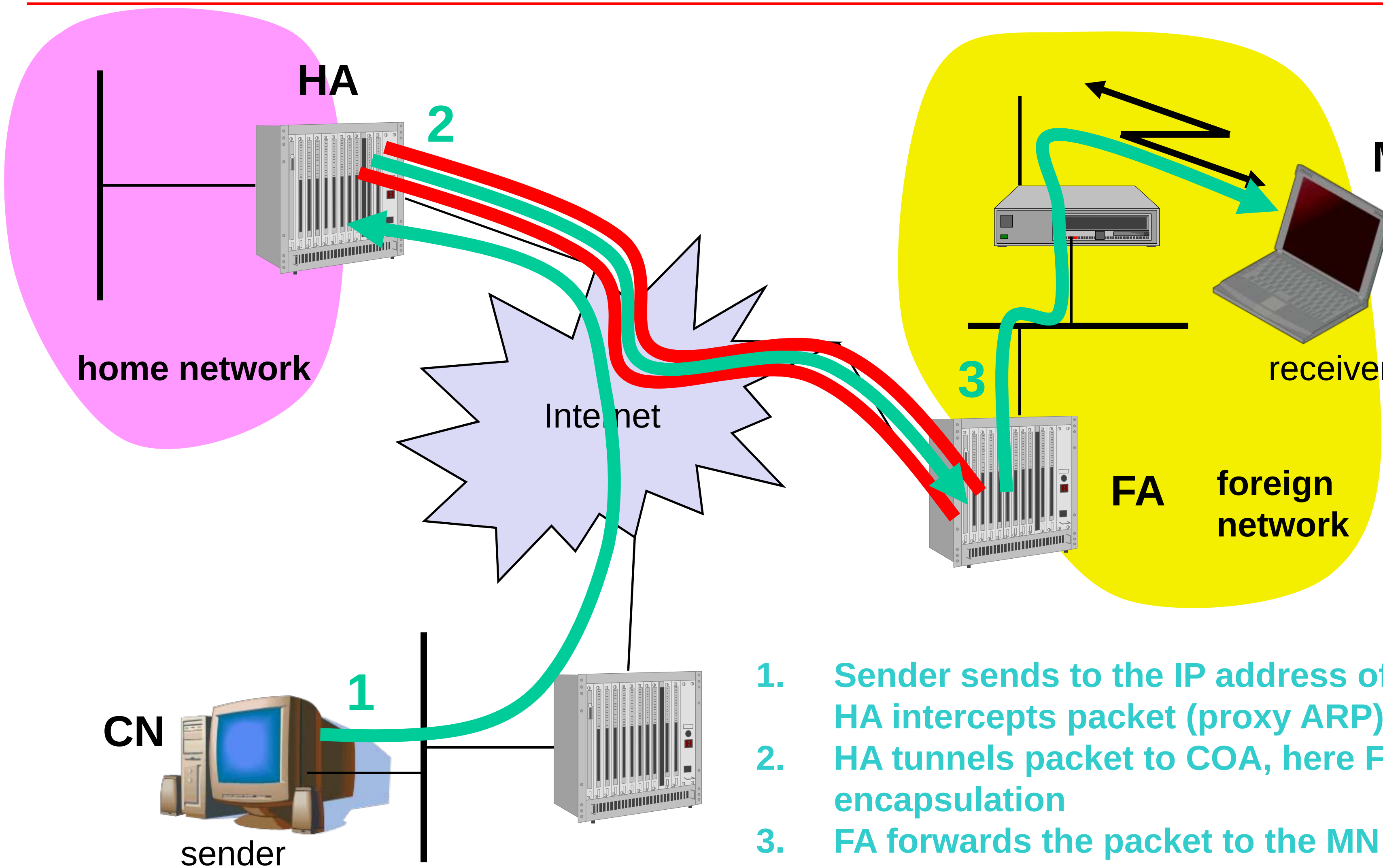
# Data Flow: CN to MH




1. Sender sends to the IP address of MN, HA intercepts packet (proxy ARP)
2. HA tunnels packet to COA, here FA, by encapsulation
3. FA forwards the packet to the MN



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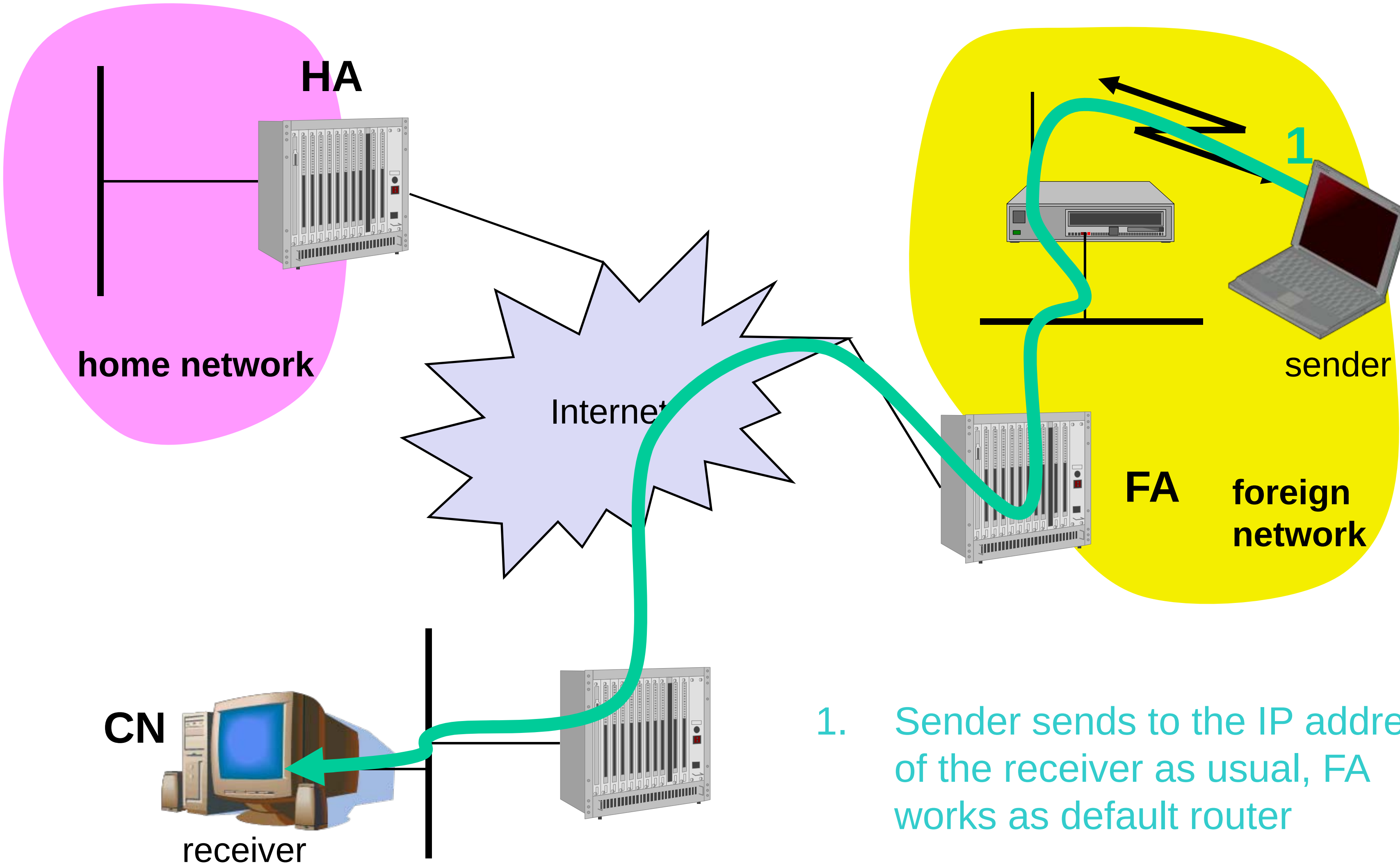
# Data Flow: MH to CN




1. Sender sends to the IP address of the receiver as usual, FA works as default router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# Route Optimization

- "Triangle routing" in basic Mobile IP is inefficient
  - ***the CN sends all packets via HA to MN***
  - ***higher latency and network load***

- Solutions: Route Optimization
  - ***the CN learns the current location (CoA) of MN***
    - **IPv4: HA sends a BU to the CN specifying MN's current CoA**
    - **IPv6: upon reception of the first tunneled packets from the HA, the MN can send a BU to the CN**



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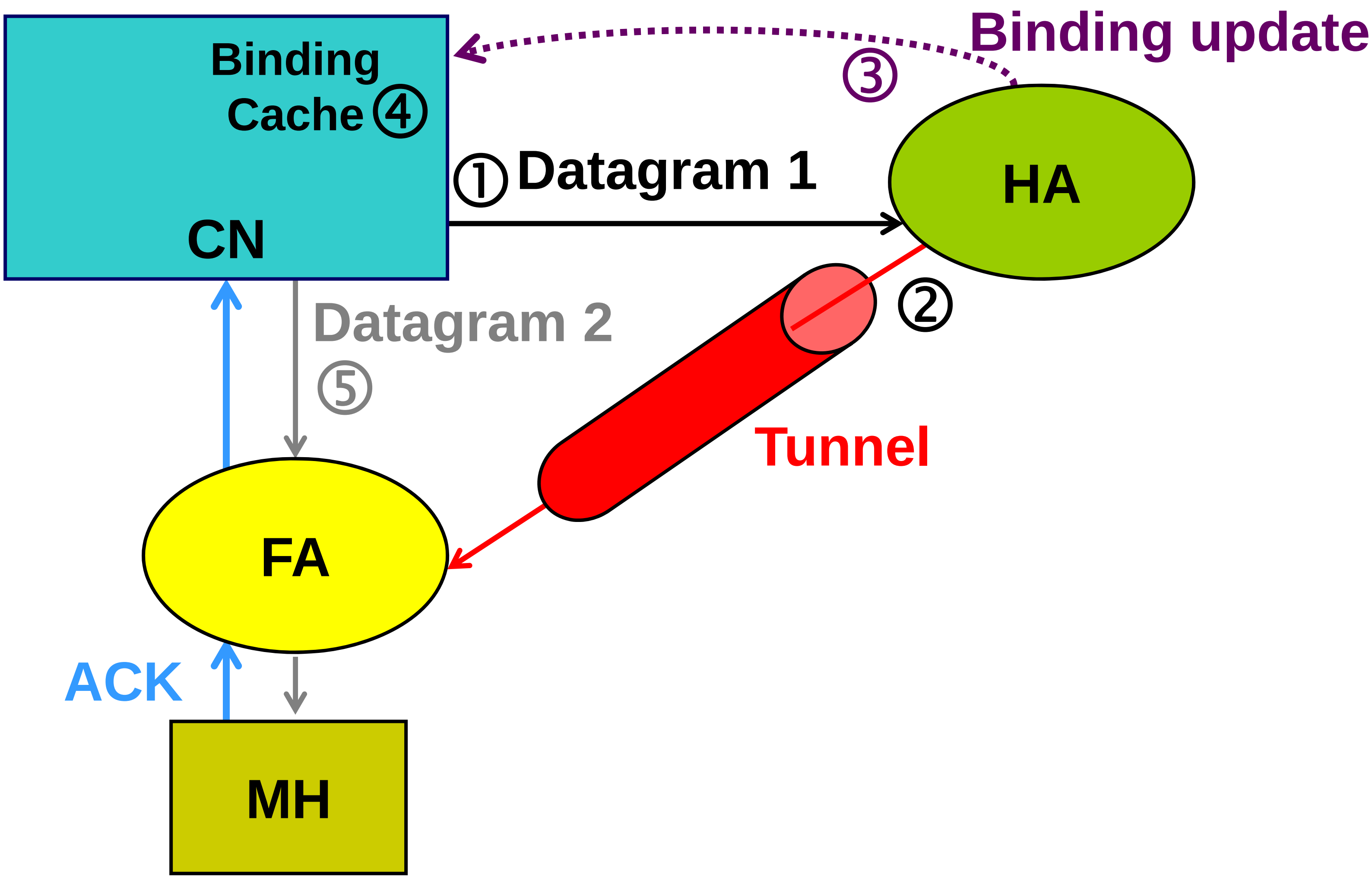
# Route Optimization (MIPv4)



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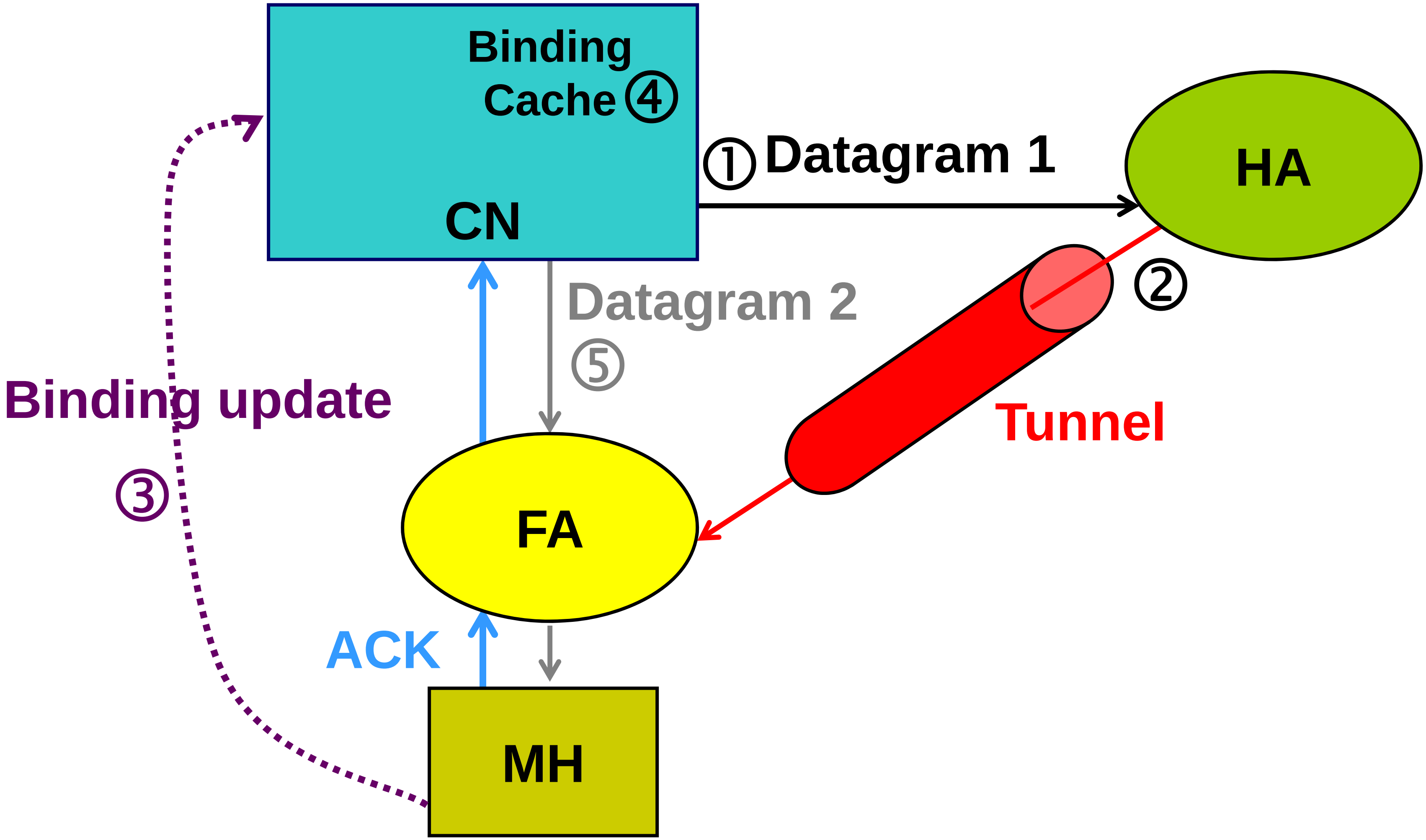
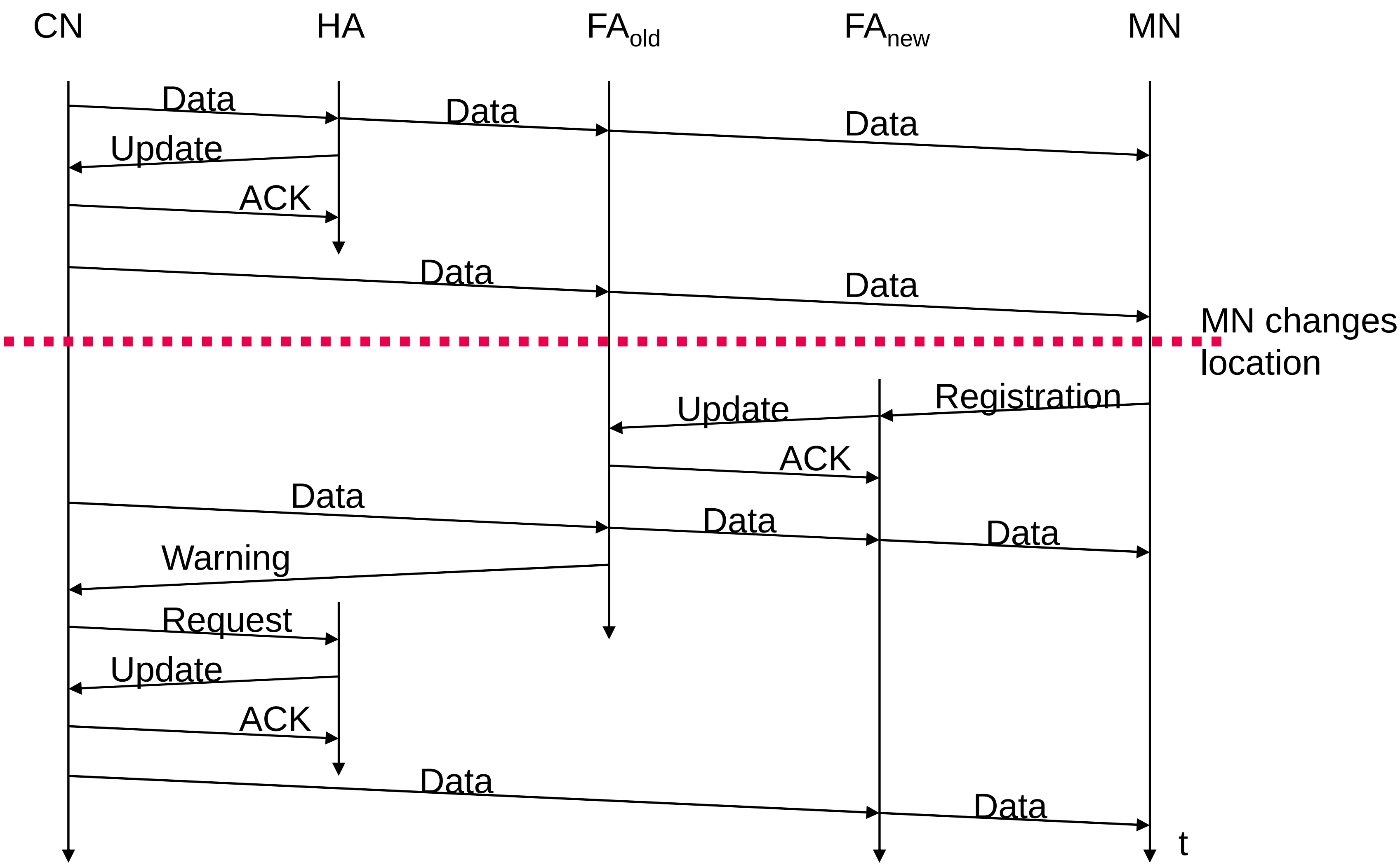
# Route Optimization (MIPv6)



# Changing FA



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# HA Destination option Vs Routing Option

***MN → CN***

- when leaving MN MIP

| | | |
|---|---|---|
| CN, CoA | HA dst opt | data |

- at CN, after option processing

| | |
|---|---|
| CN, HA | data |

- the final *source* addr is that of the MN

***CN → MN***

- when leaving CN MIP

| | | |
|---|---|---|
| CoA, CN | HA routing opt | data |

- at MN, after option processing

| | |
|---|---|
| HA, CN | data |

- the final *destination* addr is that of the MN !



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# MIPv6 Vs MIPv4

- FAs are no longer necessary in IPv6
- In MIPv6 the "'Route optimization'' is always available, whereas it is optional in IPv4
- In MIPv6, a packet sent by a MH has its source address set to its CoA and an Home Address option indicating its Home Address. This solves the ingress filtering problem...
- Encapsulation is avoided between CN-MN with the IPv6 Routing Header
- MIPv4 can not be used with firewalls
- Soft Handoff is supported

# *Micro Mobility Support in IP*



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# Introduction

- Micro-mobility support:
  - *Efficient local handover inside a foreign domain without involving a home agent*
  - *Reduces control traffic on backbone*
  - *Especially needed in case of route optimization*
- Example approaches:
  - *Cellular IP*
  - *HAWAII*
  - *Hierarchical Mobile IP (HMIP)*



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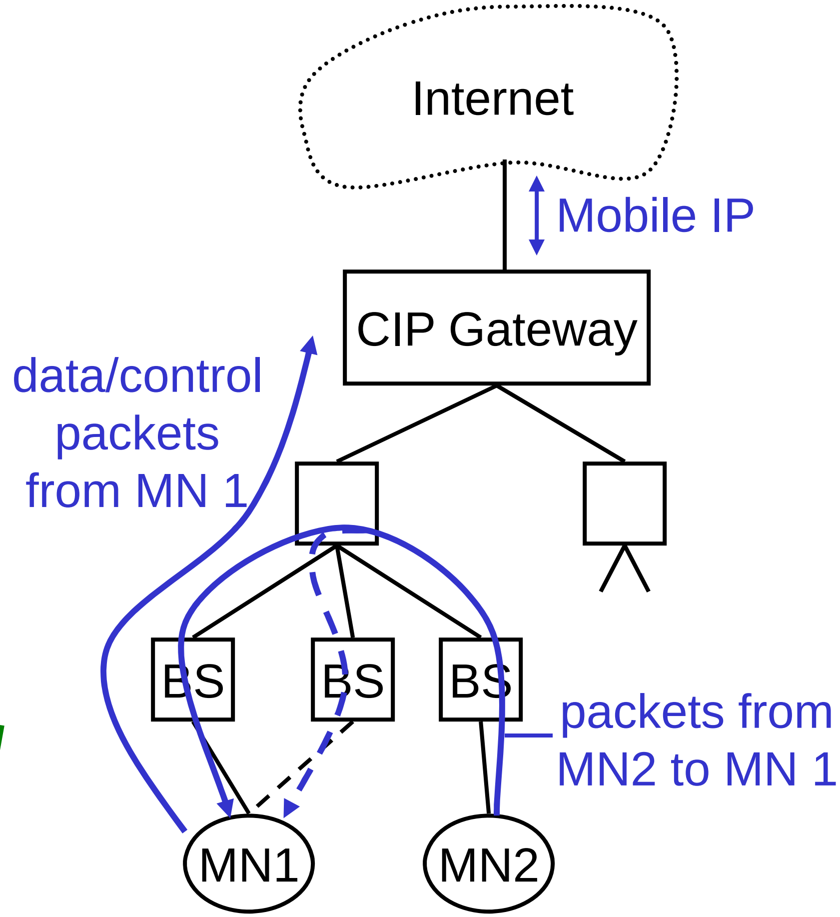
# Cellular IP

- Operation:
  - *“CIP Nodes” maintain routing entries (soft state) for MNs*
  - *Routing entries updated based on packets sent by MN*
- CIP Gateway:
  - *Mobile IP tunnel endpoint*
  - *Initial registration processing*





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# Cellular IP

- Advantages:
  - *Simple and elegant architecture*
  - *Initial registration involves authentication of MNs and is processed centrally by CIP Gateway*
- Potential problems:
  - *MNs can directly influence routing entries*
  - *Multiple-path forwarding may cause inefficient use of available bandwidth*


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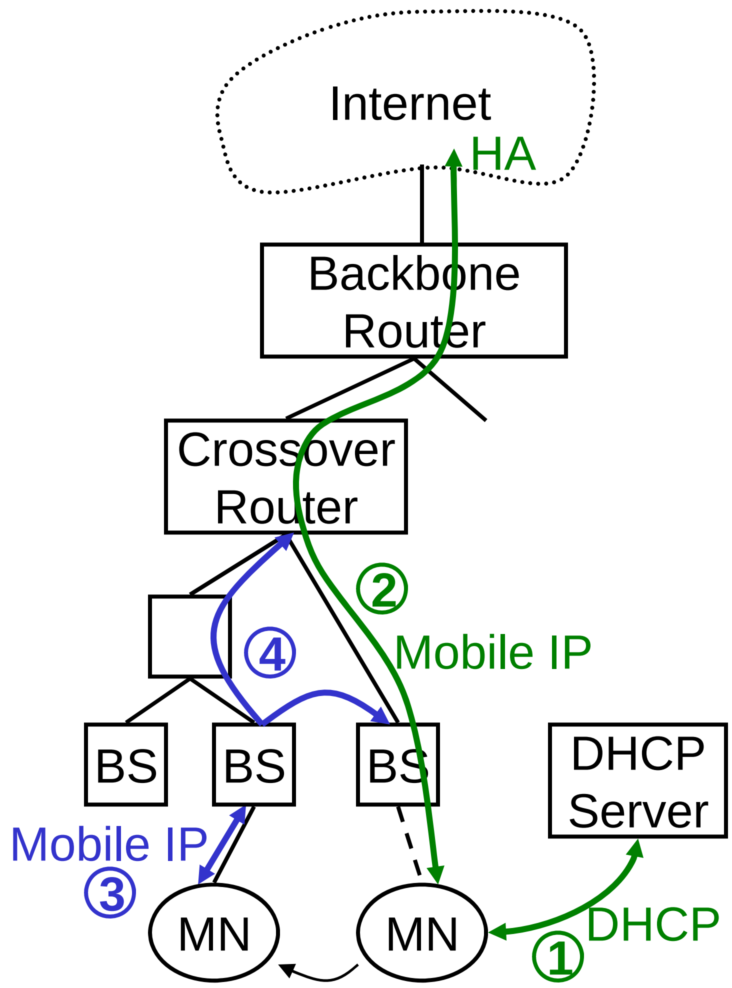
# HAWAII

- Operation:
  - *MN obtains co-located COA ① and registers with HA②*
  - *Handover: MN keeps COA, new BS answers Reg. Request ③ and updates routers ④*
  - *MN views BS as foreign agent*





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# HAWAII

- Advantages:
  - ***Mostly transparent to MNs (MN sends/receives standard Mobile IP messages)***
  - ***Only infrastructure components can influence routing entries***
- Potential problems:
  - ***Mixture of co-located COA and FA concepts may not be supported by some MN implementations***



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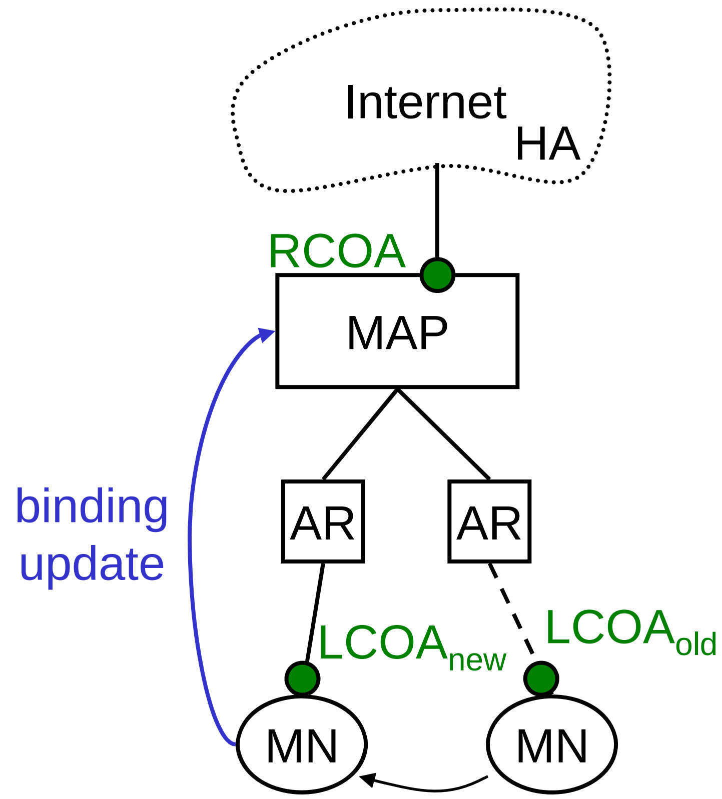
# Hierarchical MIPv6 (HMIPv6)

- Operation:
  - *Network contains mobility anchor point (MAP)*
    - **mapping of regional COA (RCOA) to link COA (LCOA)**
  - *Upon handover, MN informs MAP only*
    - **gets new LCOA, keeps RCOA**
  - *HA is only contacted if MAP changes*



# HMIPv6

- Advantages:
  - *Local COAs can be hidden, which provides some location privacy*
  - *Handover requires minimum number of overall changes to routing tables*
  - *Integration with firewalls / private address support possible*
- Potential problems:
  - *Not transparent to MNs*
  - *MNs can directly influence routing entries via binding updates (authentication necessary)*

# *Routing in Ad-hoc Networks*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# Algorithms for Wired Networks

- Distance Vector Routing
    - **Routing table exchange periodically**
    - **Slow convergence**
        - Count-to-infinity problem
- Link State Routing
    - **Collect neighbor information**
    - **Flood neighbor information to all nodes**
- Both work well in wired networks due to predictable network properties
- Fails in highly dynamic environments



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# Problems in Ad-hoc Networks

- No specific devices to do routing
  - ✓**All nodes must participate**
- Dynamic nature of the network
  - ➢**Nodes change their position frequently!!!!!**
- Asymmetric links
  - **A receives B but not vice-versa**
- Limitations of Ad Hoc Networks like
  - ***high power consumption***
  - ***low bandwidth***
  - ***high error rates***



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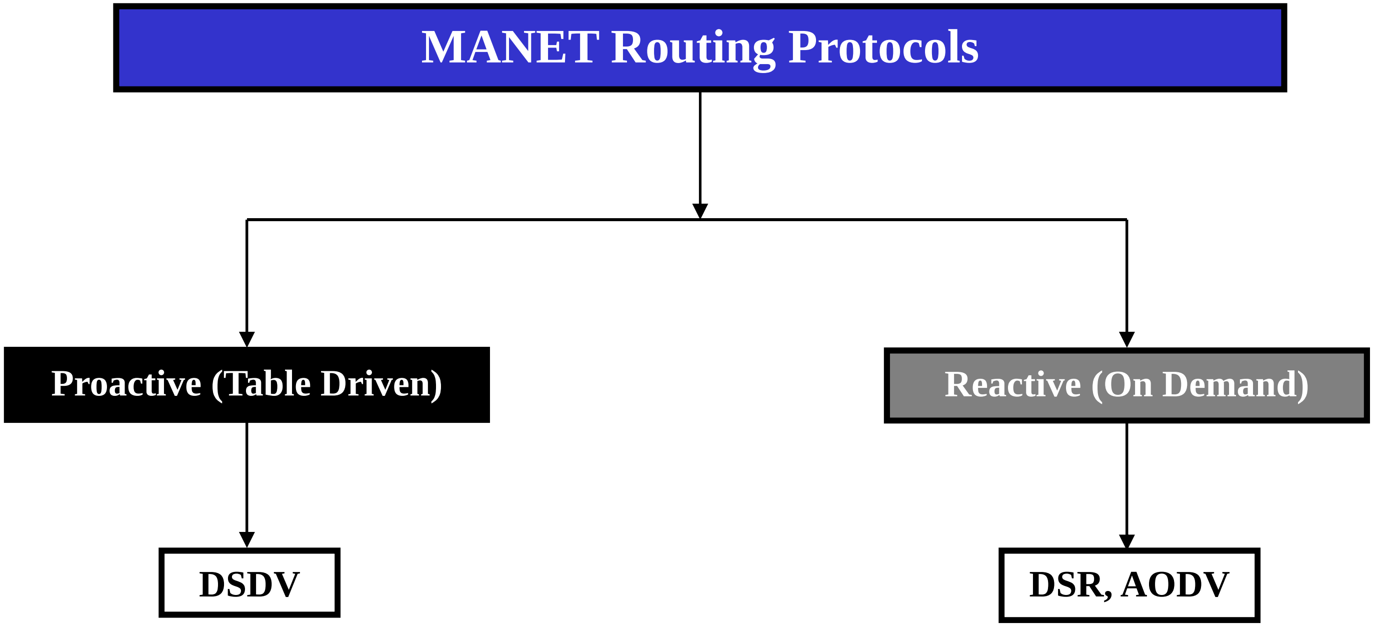
# Classification of Routing Algorithms



# Destination Sequence Distance Vector (DSDV)

- DSDV is Proactive (Table Driven)
  - ***Keep the simplicity of Distance Vector***
  - ***Each node maintains routing information for all known destinations***
  - ***Routing information must be updated periodically***
  - ***Traffic overhead even if there is no change in network topology***
  - ***Maintains routes which are never used***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# Destination Sequence Distance Vector (DSDV)

- Guarantee Loop Freeness
  - ***New Table Entry for Destination Sequence Number***

- Allow fast reaction to topology changes
  - ***Make immediate route advertisement on significant changes in routing table***
    - **but wait with advertising of unstable routes (damping fluctuations)**


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# Destination Sequence Distance Vector (DSDV)

## Routing table

| Destination | Next | Metric | Seq. Nr | Install Time | Stable Data |
|---|---|---|---|---|---|
| A | A | 0 | A-550 | 001000 | Ptr_A |
| B | B | 1 | B-102 | 001200 | Ptr_B |
| C | B | 3 | C-588 | 001200 | Ptr_C |
| D | B | 4 | D-312 | 001200 | Ptr_D |

# Destination Sequence Distance Vector (DSDV)

- Advertise to each neighbor own routing information
  - ✓ ***Destination Address***
  - ✓ ***Metric***
  - ✓ ***Destination Sequence Number***
- Rules to set sequence number information
  - ***On each advertisement increase own destination sequence number (use only even numbers)***
  - ***If a node is no more reachable (timeout) increase sequence number of this node by 1 (odd sequence number) and set metric = $\infty$.***


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# Destination Sequence Distance Vector (DSDV)

- Update information is compared to own routing table
  - ***Select route with higher destination sequence number to ensure using newest information from destination***
  - ***Select the route with better metric when sequence numbers are equal.***



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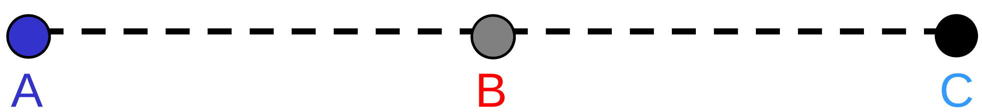
# Destination Sequence Distance Vector (DSDV)




| Dest. | Next | Metric | Seq |
|---|---|---|---|
| A | A | 0 | A-550 |
| B | B | 1 | B-100 |
| C | B | 2 | C-588 |

| Dest. | Next | Metric | Seq |
|---|---|---|---|
| A | A | 1 | A-550 |
| B | B | 0 | B-100 |
| C | C | 1 | C-588 |

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | B | 2 | A-550 |
| B | B | 1 | B-100 |
| C | C | 0 | C-588 |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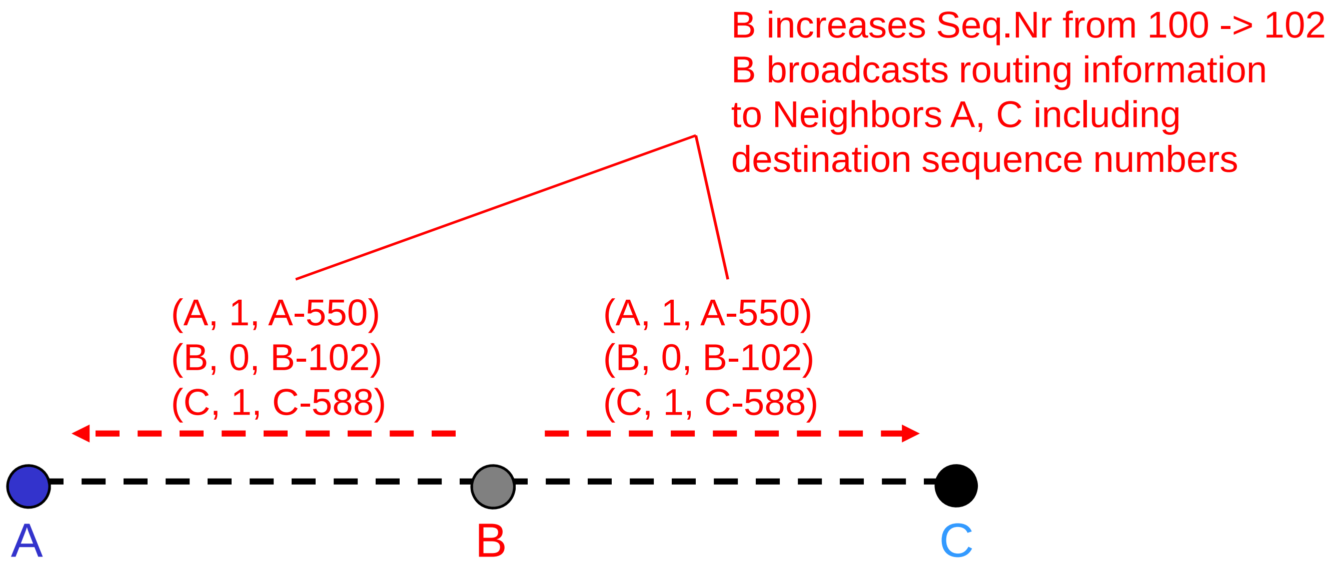
# Destination Sequence Distance Vector (DSDV)




| Dest. | Next | Metric | Seq |
|---|---|---|---|
| A | A | 0 | A-550 |
| B | B | 1 | B-102 |
| C | B | 2 | C-588 |

| Dest. | Next | Metric | Seq |
|---|---|---|---|
| A | A | 1 | A-550 |
| B | B | 0 | B-102 |
| C | C | 1 | C-588 |

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | B | 2 | A-550 |
| B | B | 1 | B-102 |
| C | C | 0 | C-588 |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# Destination Sequence Distance Vector (DSDV)

- Respond to topology changes
  - ***Immediate advertisements***
    - **Information on new Routes, broken Links, metric change is immediately propagated to neighbors.**
  - ***Full/Incremental Update:***
    - **Full Update: Send all routing information from own table.**
    - **Incremental Update: Send only entries that has changed. (Make it fit into one single packet)**



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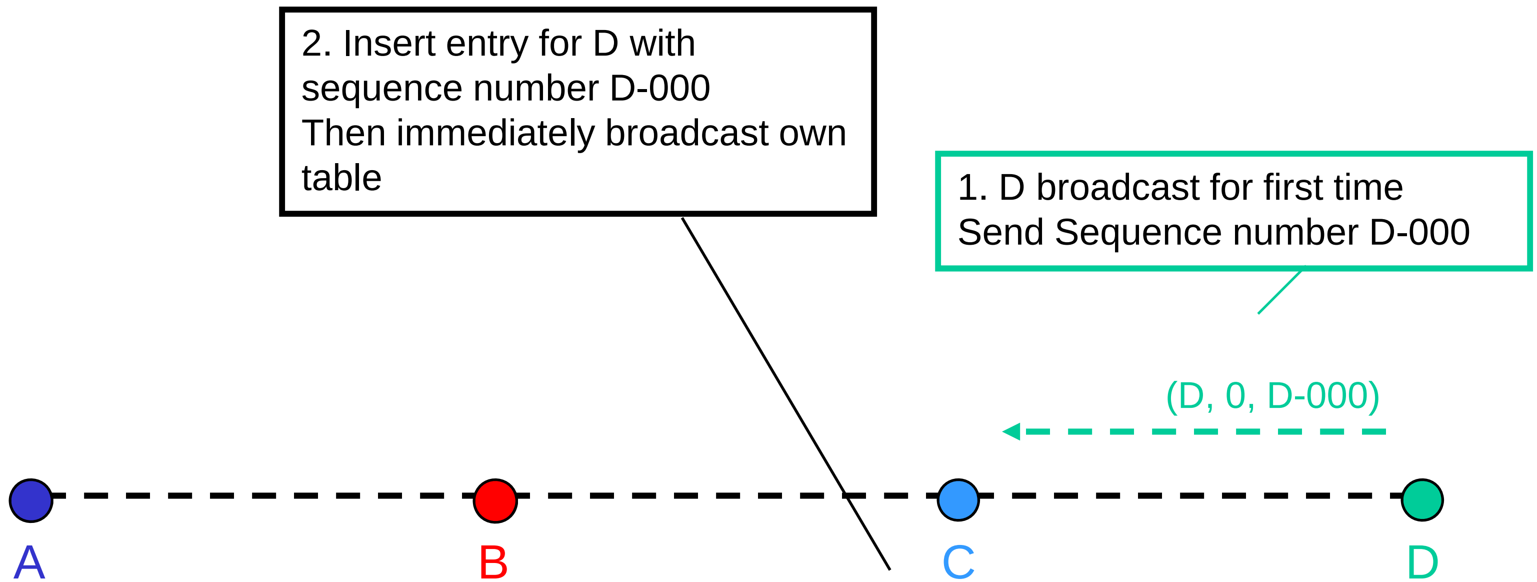
# Destination Sequence Distance Vector (DSDV)

## New node




| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | A | 0 | A-550 |
| B | B | 1 | B-104 |
| C | B | 2 | C-590 |
| | | | |

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | A | 1 | A-550 |
| B | B | 0 | B-104 |
| C | C | 1 | C-590 |
| | | | |

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | B | 2 | A-550 |
| B | B | 1 | B-104 |
| C | C | 0 | C-590 |
| D | D | 1 | D-000 |



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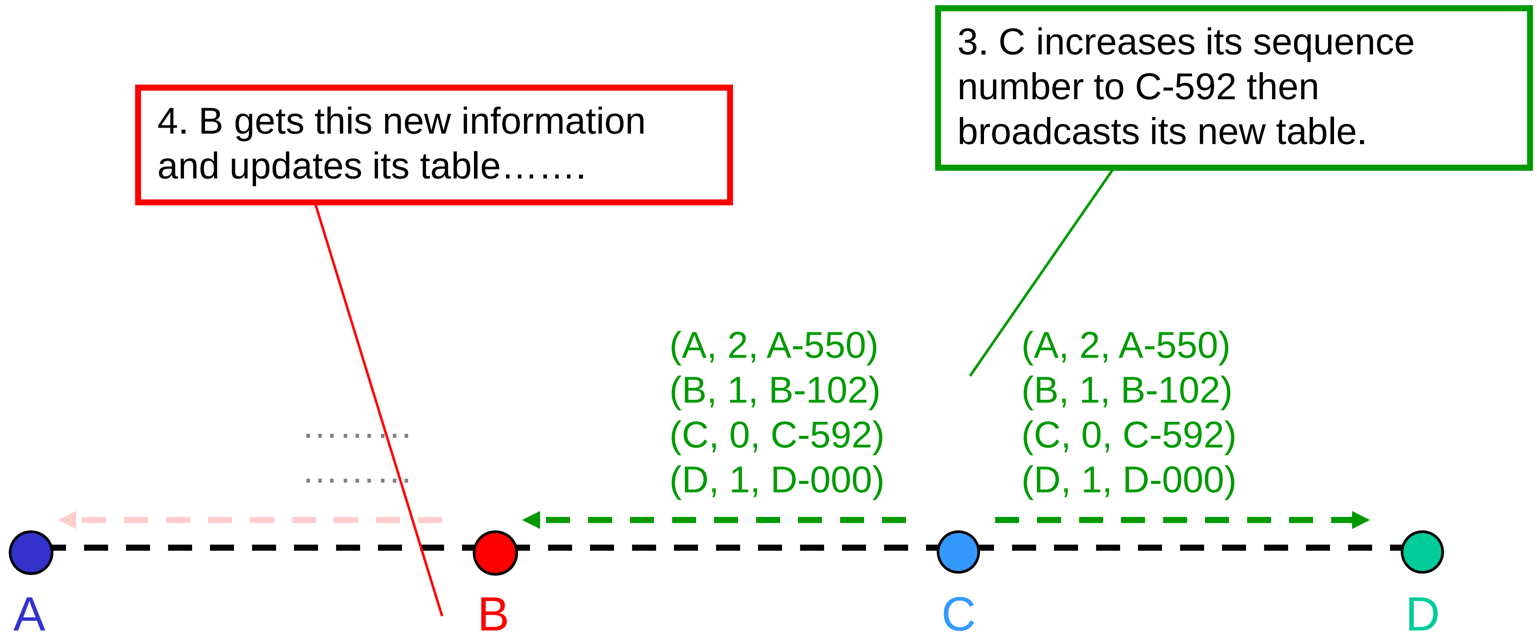
# Destination Sequence Distance Vector (DSDV)

## New node




| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | A | 0 | A-550 |
| B | B | 1 | B-104 |
| C | B | 2 | C-590 |
| | | | |

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | A | 1 | A-550 |
| B | B | 0 | B-104 |
| C | C | 1 | C-592 |
| D | C | 2 | D-000 |

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| A | B | 2 | A-550 |
| B | B | 1 | B-104 |
| C | C | 0 | C-592 |
| D | D | 1 | D-000 |



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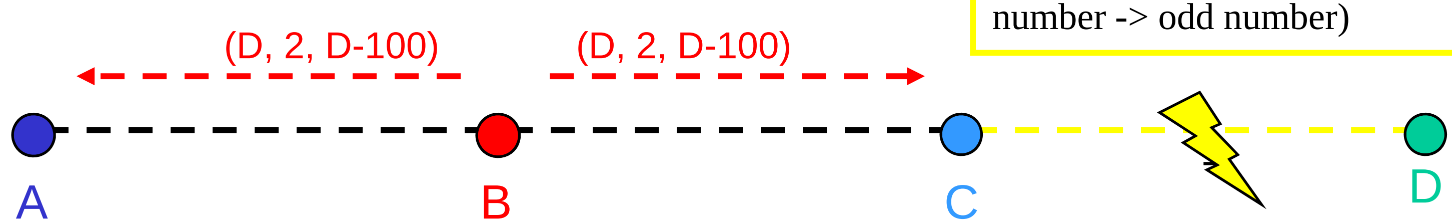
# Destination Sequence Distance Vector (DSDV)

## No loops and count-to-infinity problem

2. B does its broadcast
-> no affect on C (C knows that B has stale information because C has higher seq. number for destination D)
-> no loop -> no count to infinity

1. Node C detects broken Link:
-> Increase Seq. No. by 1
(only case where not the destination sets the sequence number -> odd number)




A

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| … | … | … | |
| D | B | 3 | D-100 |

B

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| … | … | … | |
| D | C | 2 | D-100 |

C

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| … | … | … | |
| D | D | ∞ | D-101 |



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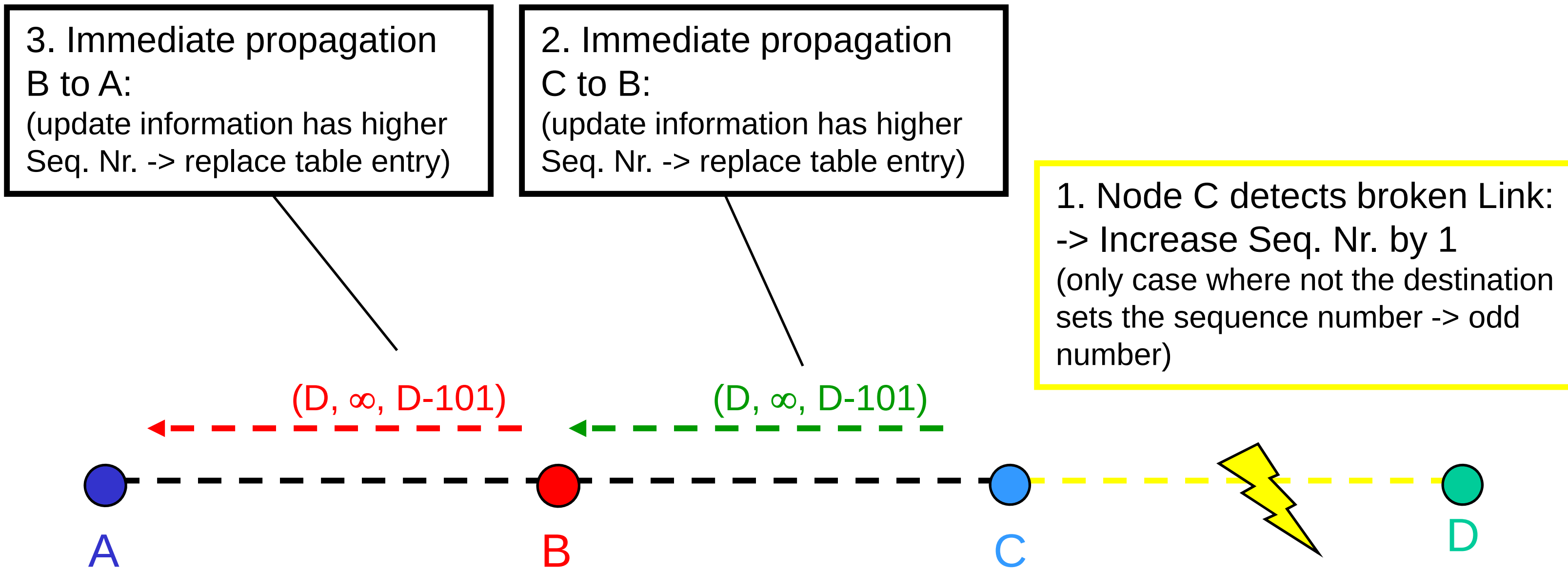
# Destination Sequence Distance Vector (DSDV)

## Immediate advertisement




| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| … | … | … | ... |
| ~~D~~ | ~~B~~ | ~~3~~ | ~~D-100~~ |
| D | B | ∞ | D-101 |

| Dest | Next | Metric | Seq. |
|---|---|---|---|
| … | … | … | ... |
| ~~D~~ | ~~C~~ | ~~2~~ | ~~D-100~~ |
| D | C | ∞ | D-101 |

| Dest. | Next | Metric | Seq. |
|---|---|---|---|
| … | … | … | |
| ~~D~~ | ~~D~~ | ~~1~~ | ~~D-100~~ |
| D | D | ∞ | D-101 |



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# Destination Sequence Distance Vector (DSDV)

- Advantages
  - ***Simple (almost like Distance Vector)***
  - ***Loop free through destination sequence numbers***

- Disadvantages
  - ***Bi-directional links required***
  - ***Overhead: most routing information never used***
  - ***Scalability is a major problem***



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# Dynamic Source routing (DSR)

- A reactive routing protocol
  - *No periodic updates*
  - *bandwidth, battery power*
- Adapt quickly to dynamic topology
- Links need not be bi-directional
- No loops
- Assumptions
  - *All hosts willing to forward packets for others*
  - *Network diameter (# hops) small*
  - *Hosts may move at any time*
  - *Promiscuous receive*



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# Dynamic Source routing (DSR)

- Sending to other hosts
  - ***Sender puts* source route *in header***
    - **Large overhead in data packtes**
  - ***If a recipient is not destination, keep forwarding***

- *Route Cache*
  - ***Store of source routes***
  - ***Expiration period for each entry***



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# Dynamic Source routing (DSR)

- Route discovery
  - ***The sender***
    - Broadcast a route request (RREQ) packet (S, id, D)
  - ***The receiver***
    - <initiator address, request id>
      - » If same, discard
    - This host's address is already listed in the route record - loop
      - » Discard
    - This host is the target
      - » **Send a route reply (RREP) packet**
    - Else
      - » Append this host's address to the route record, and re-broadcast



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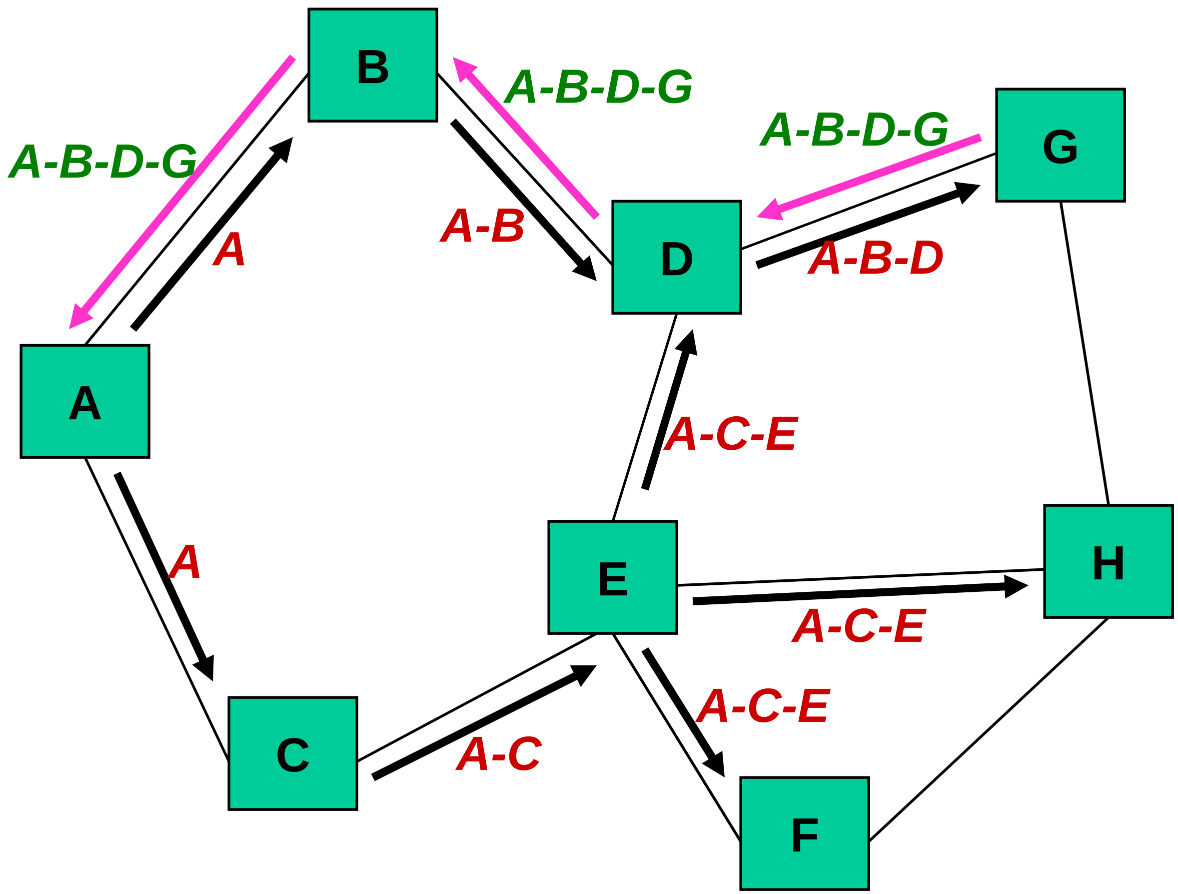
# Dynamic Source routing (DSR)

- Piggybacking
  - ***When sending*** **route reply,** ***cannot just reverse*** **route record**
    - **Unless there is an entry in cache**
  - ***Must piggyback*** **route reply** ***on a*** **route request** ***targeted at initiator***

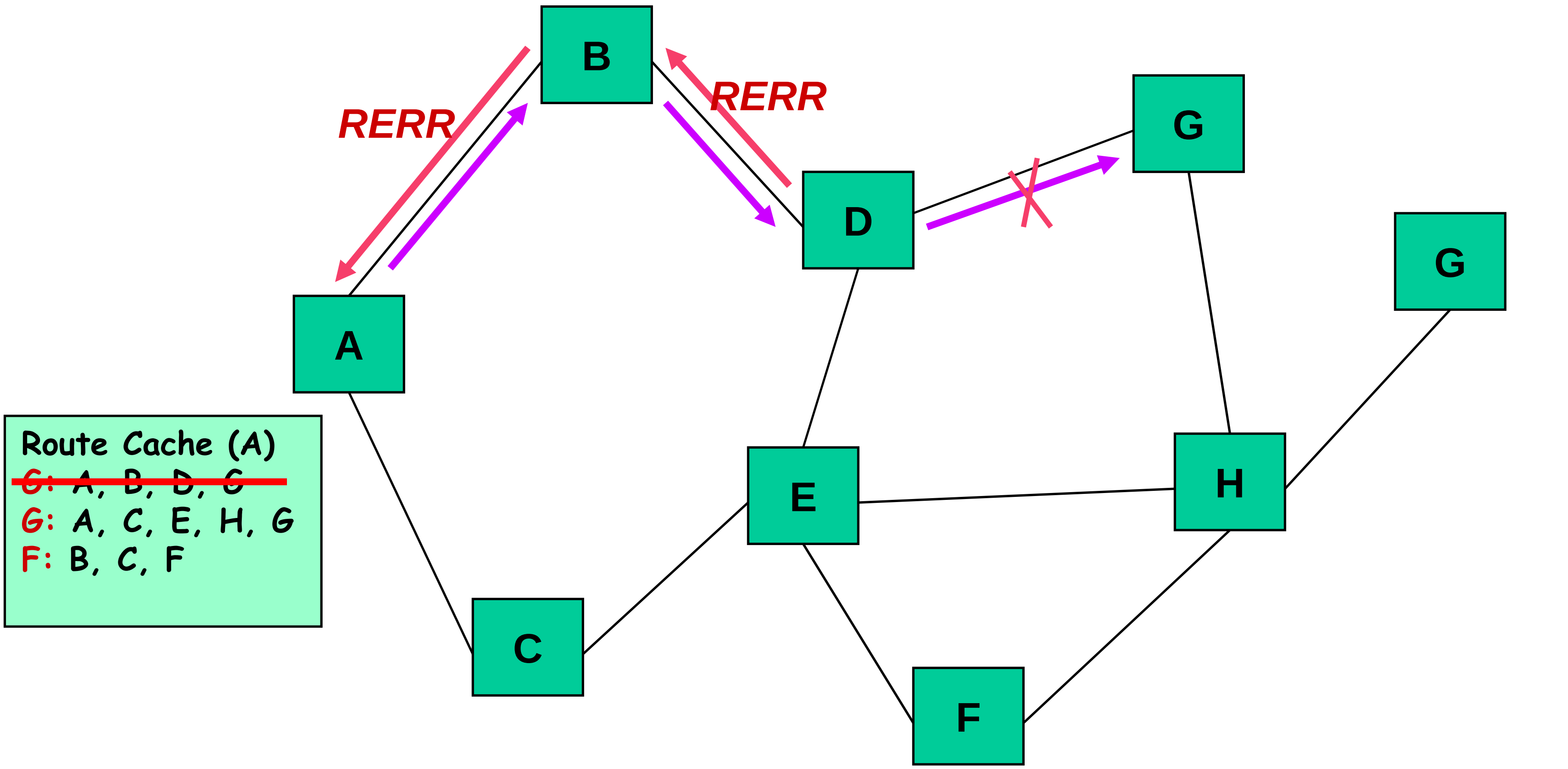
# Dynamic Source routing (DSR)



# Dynamic Source routing (DSR)

- *Route Maintenance*
  - ***No periodic messages***
    - **Monitors the operation of the route and informs the sender of any routing errors**
  - ***If data link layer reports problems, send a* route error *packet (REP) to sender***
    - Contains the addresses of the hosts at both ends of the hop in error
    - Removed from the route cache
    - Send to the sender
      - » Route cache, reverse the route from the packet in error, route discovery
  - ***Else, use* passive acknowledgement**

# Dynamic Source routing (DSR)



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# Dynamic Source routing (DSR)

- Optimizations
  - ***Full use of route cache***
    - **A hop can add entries to its route cache any time it learns a new route**
    - **If the host has a route cache entry for the target, return a route reply without re-broadcasting**
    - **Specify the maximum number of hops over which the packet may be propagated**
      - Procedure
        - » To perform a route discovery, send the route request with a hop limit of one
        - » If no route reply is received, send a new route request with a hop limit of the maximum value
      - Purpose
        - » Check if the target is currently within the transmitter range

# Ad-hoc On-demand Distance Vector (AODV)

- On-demand version of DSDV
  - ***Demand driven***
  - ***Table driven***
    - **One entry per destination**
- Uses sequence number for fresh and loop free routes
- Effective use of available bandwidth
  - ***Minimizes broadcast***
- Highly scalable



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# Ad-hoc On-demand Distance Vector (AODV)

- Route discovery
  - *Initiated when a communication need arises*
  - *Source node initiates path discovery by broadcasting a route request (RREQ) packet to its neighbors*
  - *Every node maintains two separate counters*
    - **Sequence number**
    - **Broadcast-id**
  - *A neighbor either broadcasts the RREQ to its neighbors or satisfies the RREQ by sending a RREP back to the source*
  - *Later copies of the same RREQ request are discarded*



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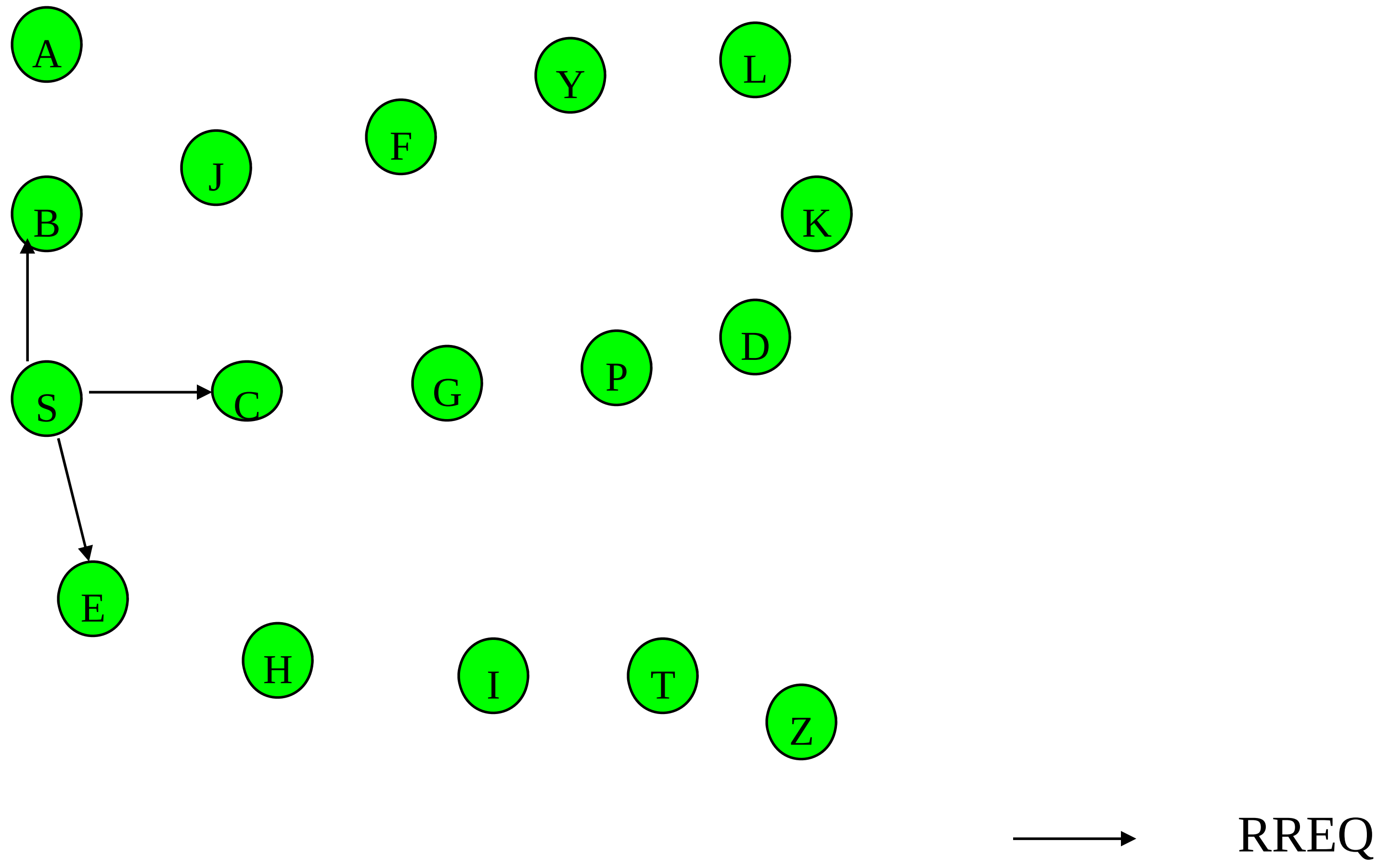
# Ad-hoc On-demand Distance Vector (AODV)

- **Route discovery**
  - ***The sender***
    - **Broadcast a route request (RREQ) packet (S, id, Seq. no, D)**
    - **Every node maintains two separate counters**
      - Sequence number
      - Broadcast-id
  - ***The receiver***
    - **<initiator address, request id> is looked up in history table**
      - If found, discard
    - **The receiver looks up the destination in routing table**
      - If stored route is fresh, send RREP to the initiator
    - **Re-broadcast RREQ packet**
      - **Reverse path set-up**
        - » **Copy data from RREQ packet and store in reverse route table**

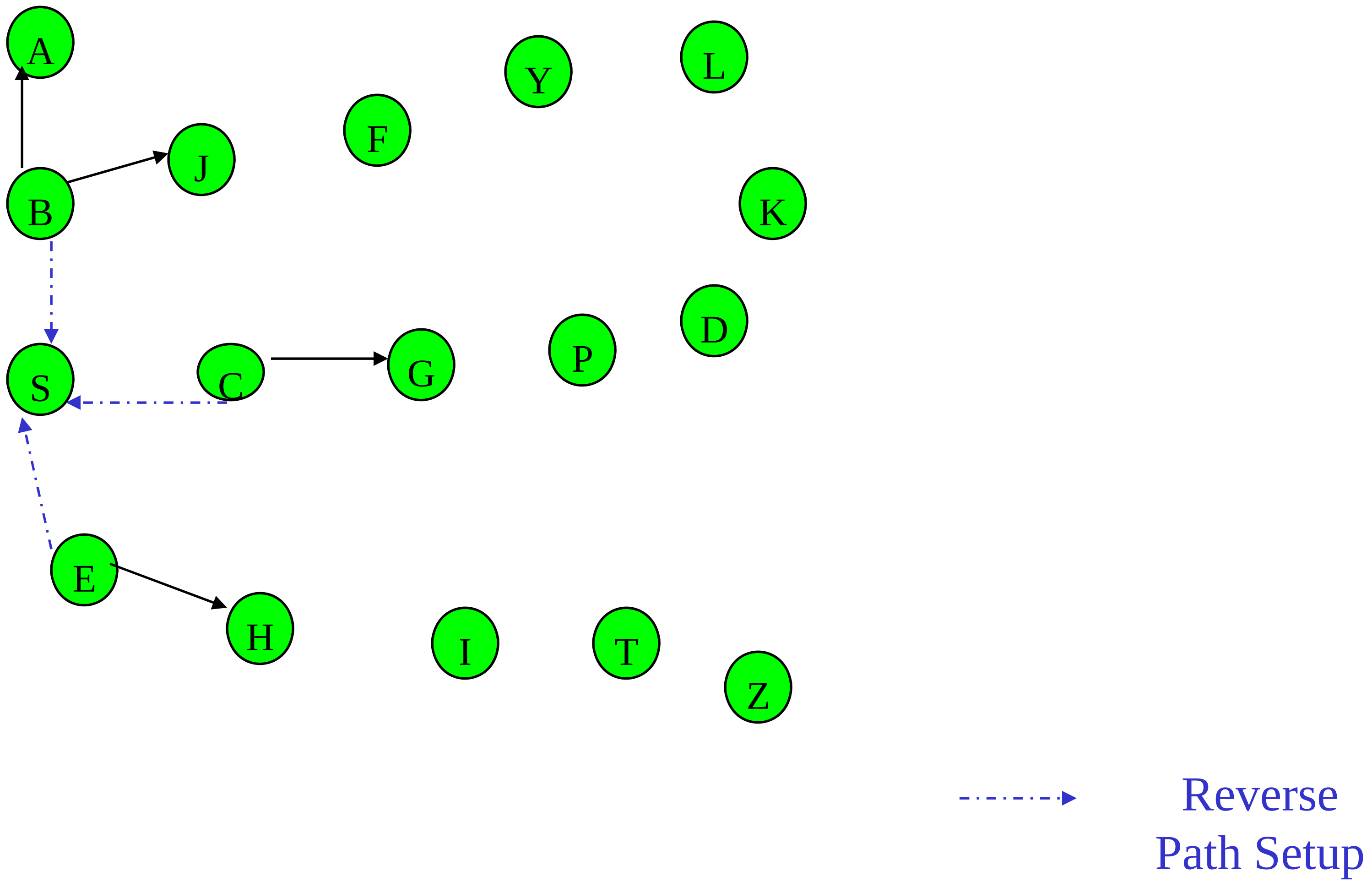
# Ad-hoc On-demand Distance Vector (AODV)

- Forward path set-up
  - *Eventually, RREQ arrives at a node that possesses the current route for the destination (Comparison of sequence numbers)*
  - *Node unicasts a RREP back to the neighbor from which it received the RREQ.*
    - **The RREP travels along the path established in the reverse path set-up**
  - *Each node along the RREP journey sets up a forward pointer, records the destination sequence number of requested destination.*

# Ad-hoc On-demand Distance Vector (AODV)



# Ad-hoc On-demand Distance Vector (AODV)



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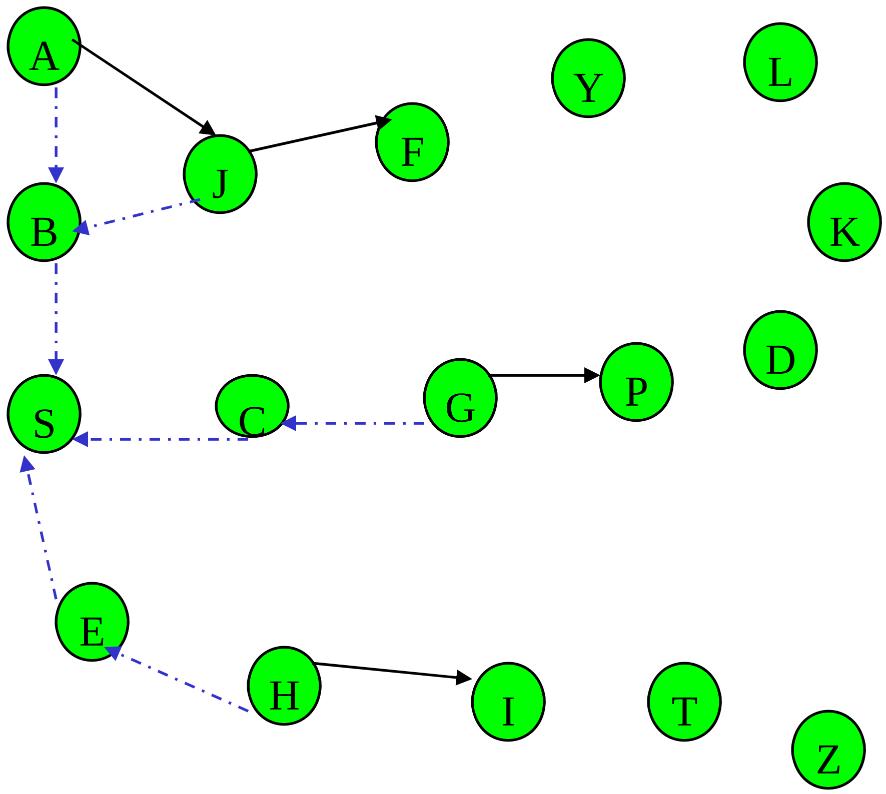
# Ad-hoc On-demand Distance Vector (AODV)



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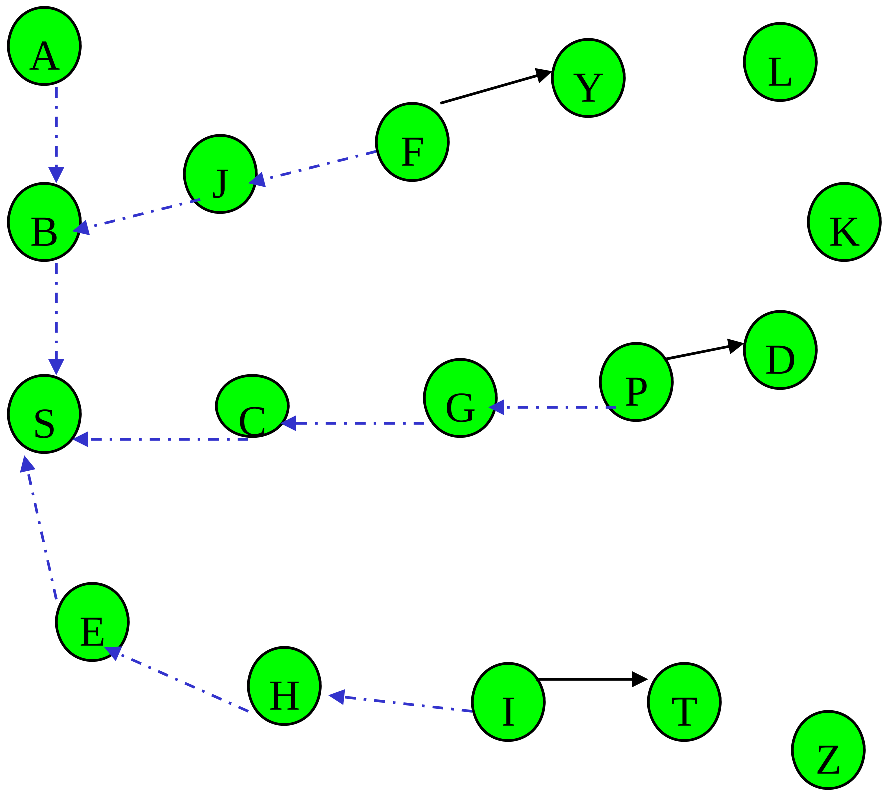

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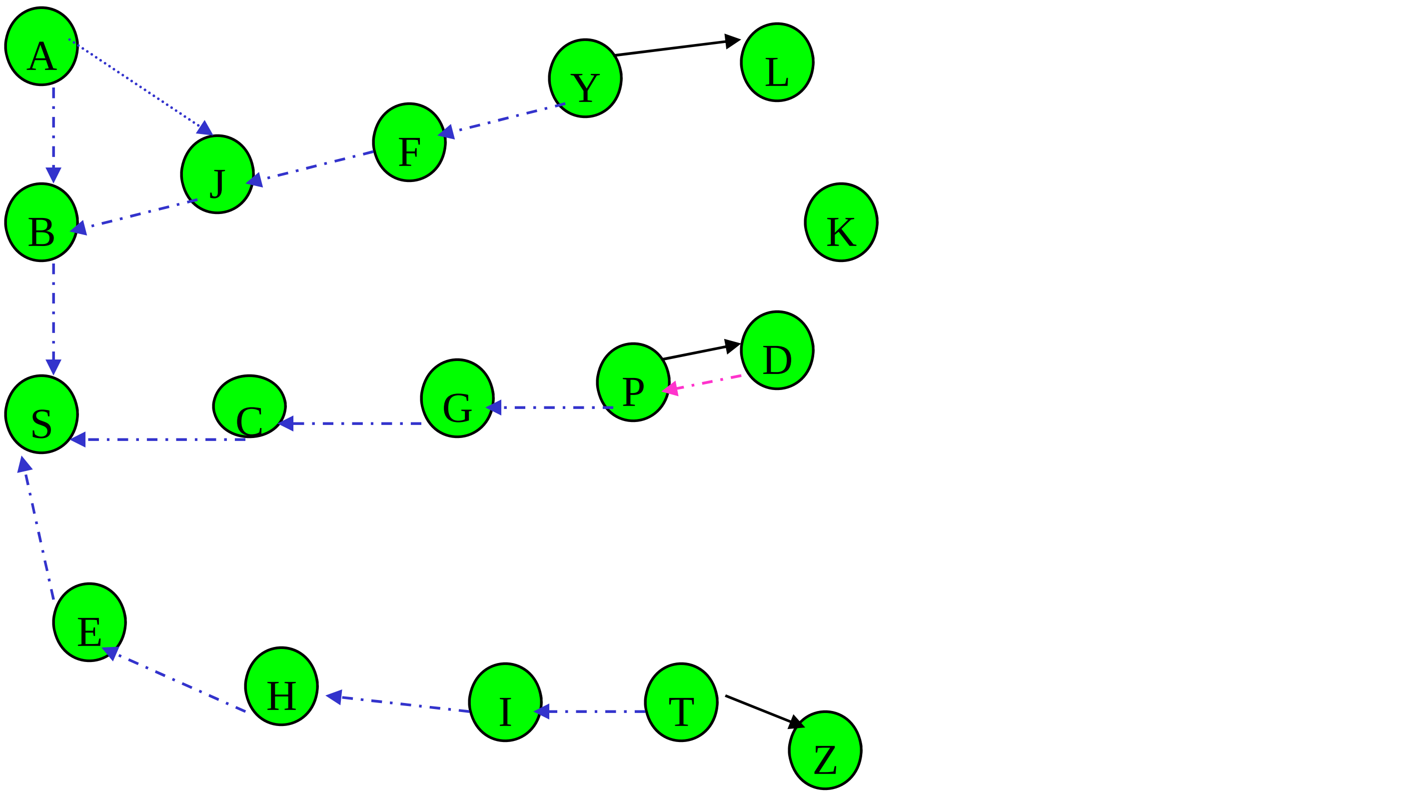




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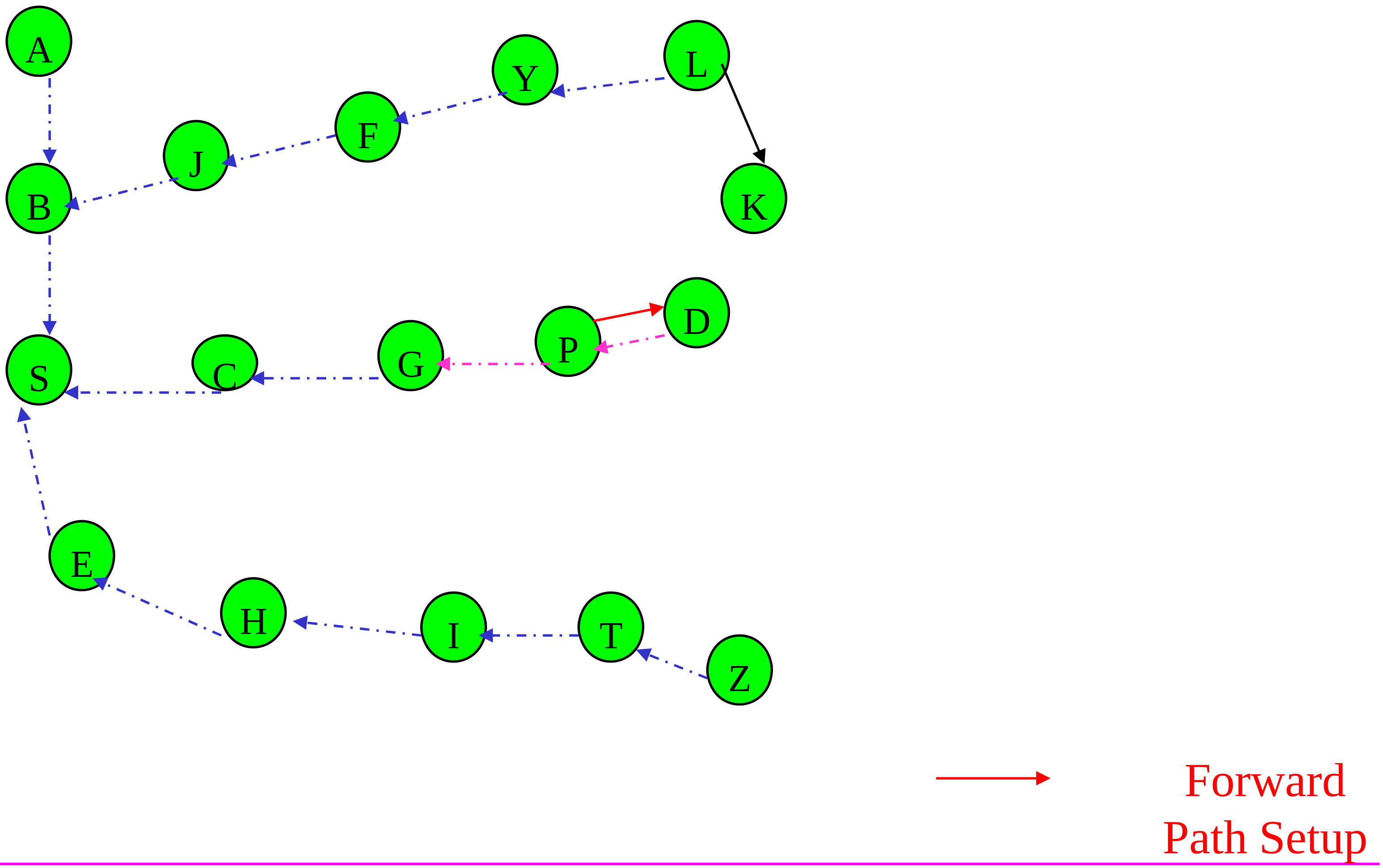




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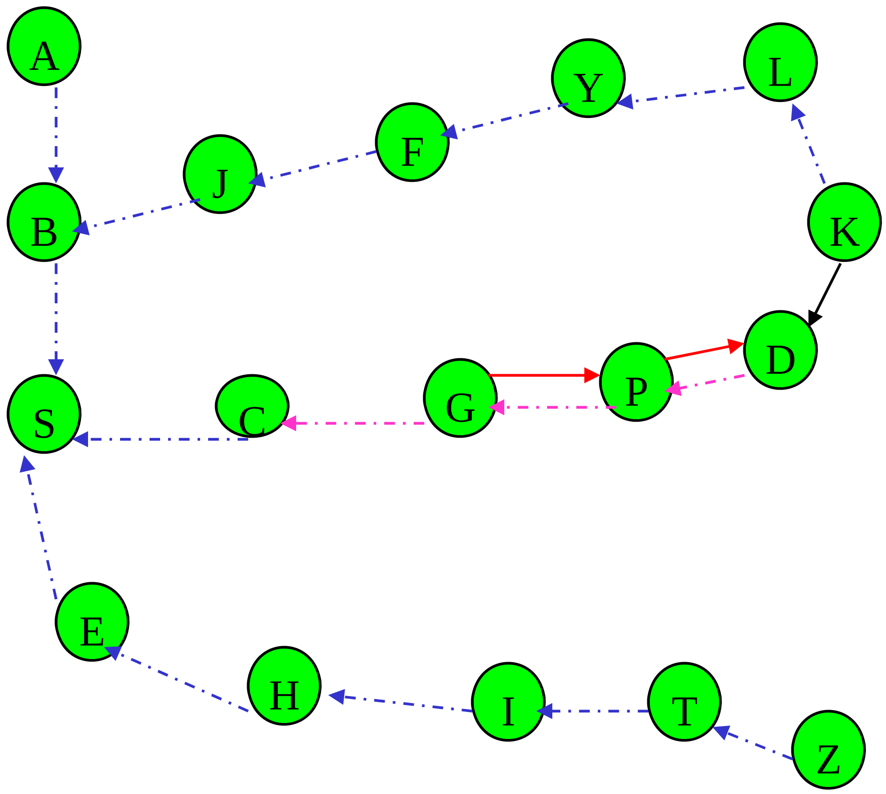
# Ad-hoc On-demand Distance Vector (AODV)



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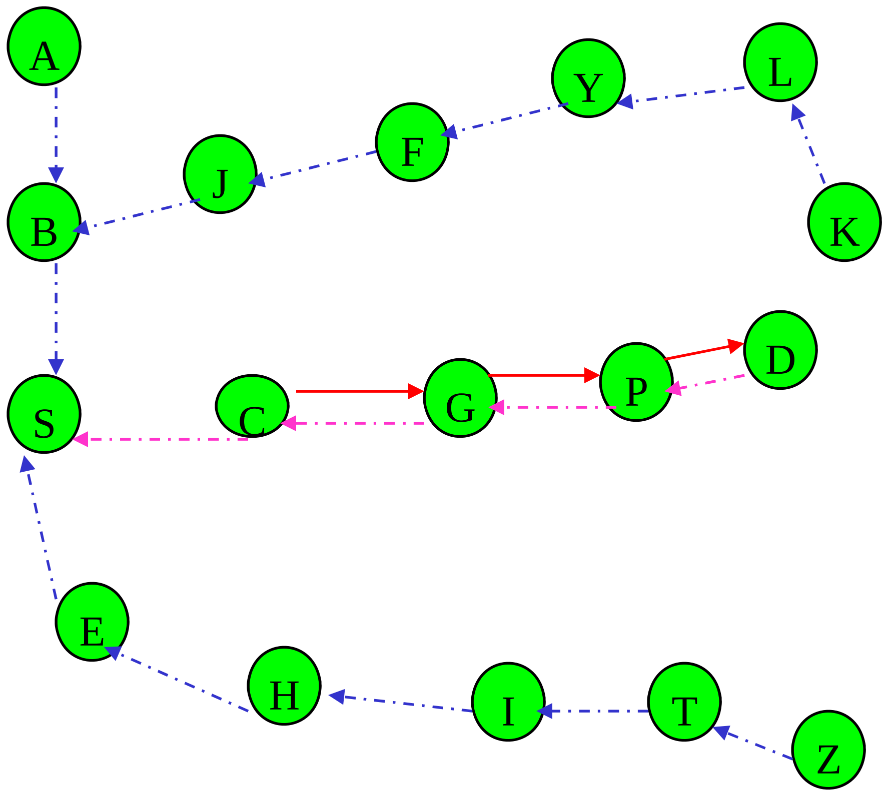




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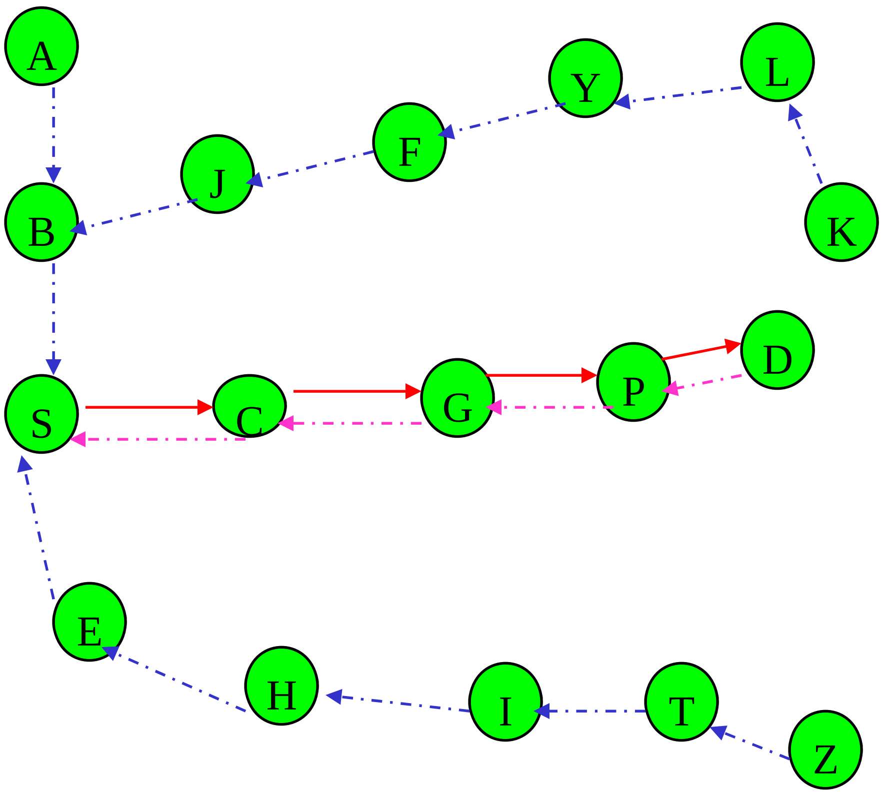




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# Ad-hoc On-demand Distance Vector (AODV)

- Path maintenance
  - ***Nodes can be switched off, move away***
    - **Topology changes**
- Each node periodically sends HELLO packet to the neighbors
  - ***If reply received***
    - **O.K.**
  - ***Otherwise***
    - **Route is no longer valid**
      - Send special RREP packet to the sender
      - Sender initiates route discovery


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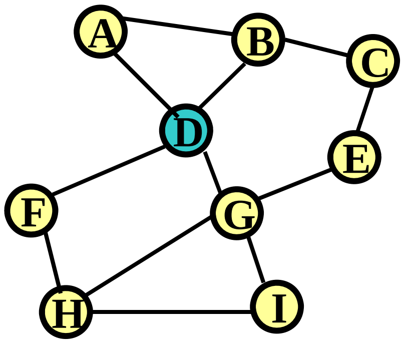
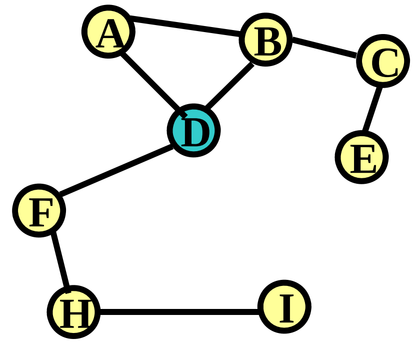
# Ad-hoc On-demand Distance Vector (AODV)

- Path maintenance




| Destination | Next Hop | Distance | Active Neighbor | Other fields |
|---|---|---|---|---|
| A | A | 1 | **F, G** | |
| B | B | 1 | **F, G** | |
| C | B | 2 | **F** | |
| E | G | 2 | | |
| F | F | 1 | **A, B** | |
| G | G | 1 | **A, B** | |
| H | F | 2 | **A, B** | |
| I | G | 2 | **A, B** | |

# Problems of Running TCP in Wireless Networks

# Wireless Issues

- The following characteristics have major impact on the performance of TCP:
  - » High Bit Error Rate (BER)
  - » Handoff
  - » Frequent Disconnection
  - » Large and Varying delays
  - » Limited Spectrum
  - » Limited Energy
  - » Path Asymmetry



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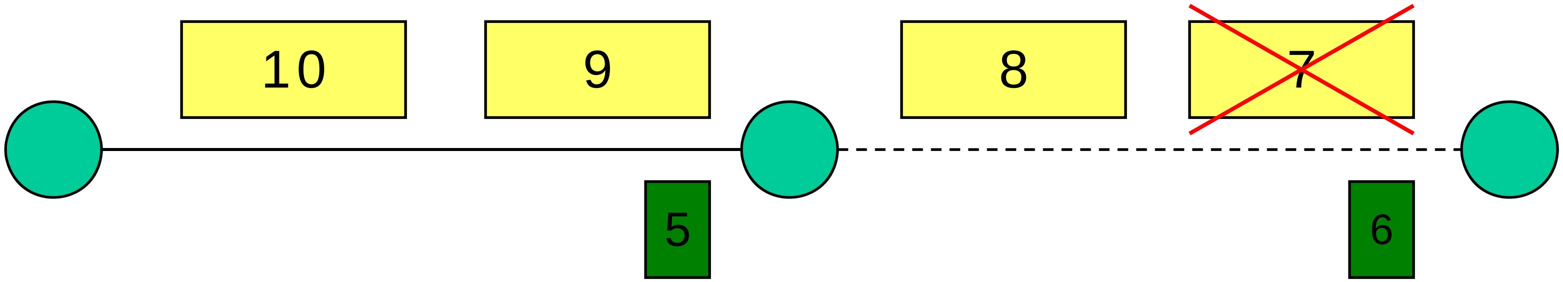
# Problem of Pseudo-congestion

- **TCP interprets any packet loss as a sign of network congestion.**
  - TCP sender reduces congestion window.
- **On wireless links, packet loss can *also* occur due to reasons other than Congestion.**
  - ***TCP will cut down its rate* (is this right?)**
  - **Fundamental question: How to distinguish loss due to congestion from non-congestion loss?**
  - **Hard to do: TCP is fundamentally end-to-end.**
    - **We just know that packet is lost, not why it is lost.**

# High BER

## Following example assumes Random Error



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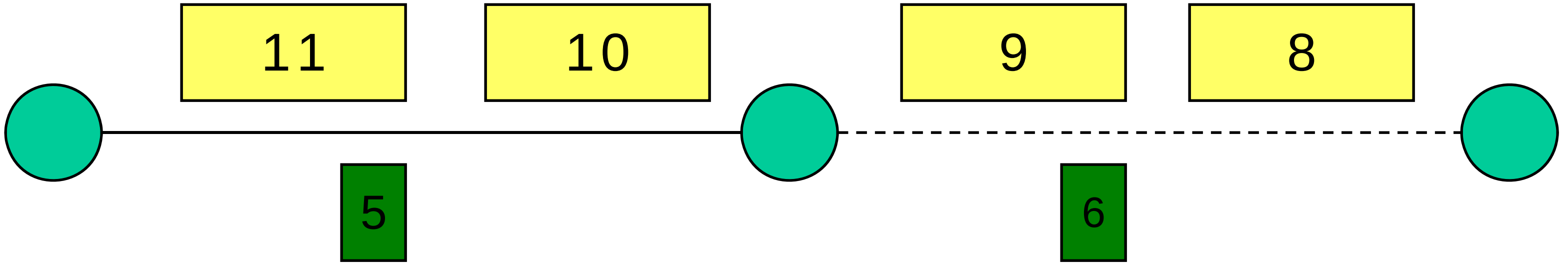
# High BER



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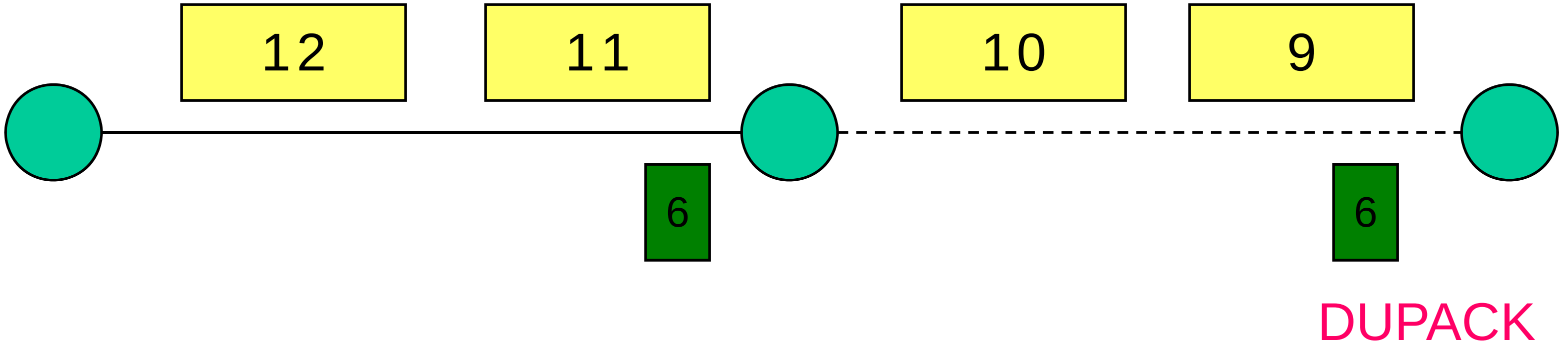
# High BER



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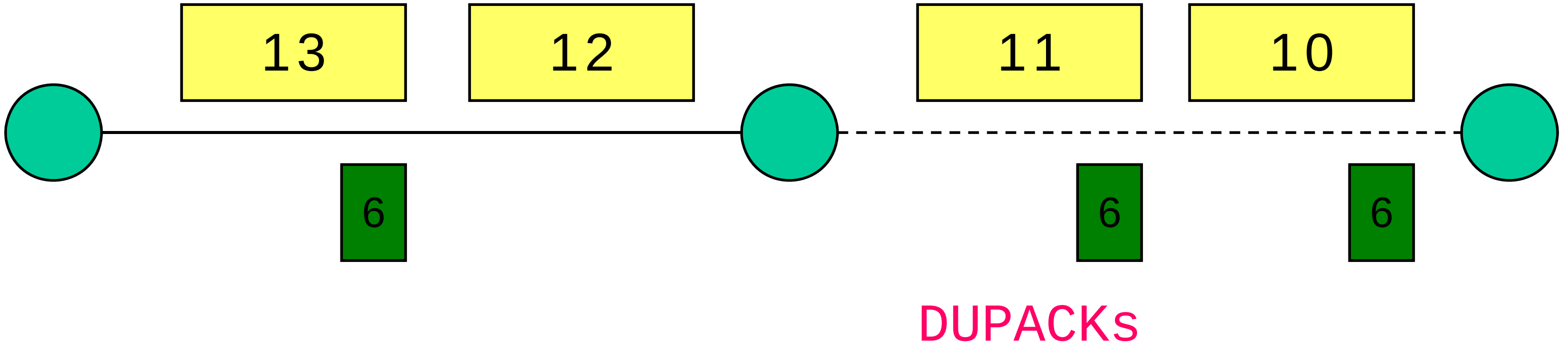
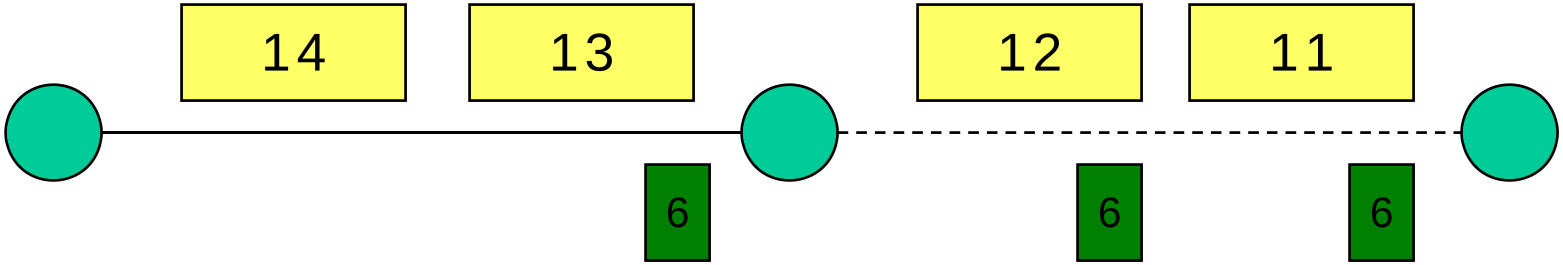
# High BER



# High BER




3 DUPACKs trigger
fast retransmit at sender

# Handoff and Frequent Disconnection

- TCP interprets handoff and disconnection related losses as congestion based losses
  - *reduces congestion window every time handoff and disconnection related losses occur*
  - *Black-outs will further result in TCP experiencing multiple timeouts of increasing granularity*



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# Large and Varying Delay

- TCP uses $RTT_{avg} + 4 * RTT_{mdev}$ as the retransmission timeout (Karn's Algorithm)
  - ***If there is large variance in delay, mean deviation is high resulting in inflated timeout values***
  - ***Hence, if there are burst losses resulting in a timeout, the sender would take longer time to detect losses and recover***



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# Limited Spectrum

- TCP uses window based congestion control.
- If there is free space in the congestion window, TCP will transmit.
  - ***TCP's output can be bursty***
  - ***This coupled with the low bandwidths can result in queue build-ups in the network adversely affecting RTT calculations and causing packet drops***

- Sharing wireless bandwidth between different classes of traffic is a major task.

# Limited Energy

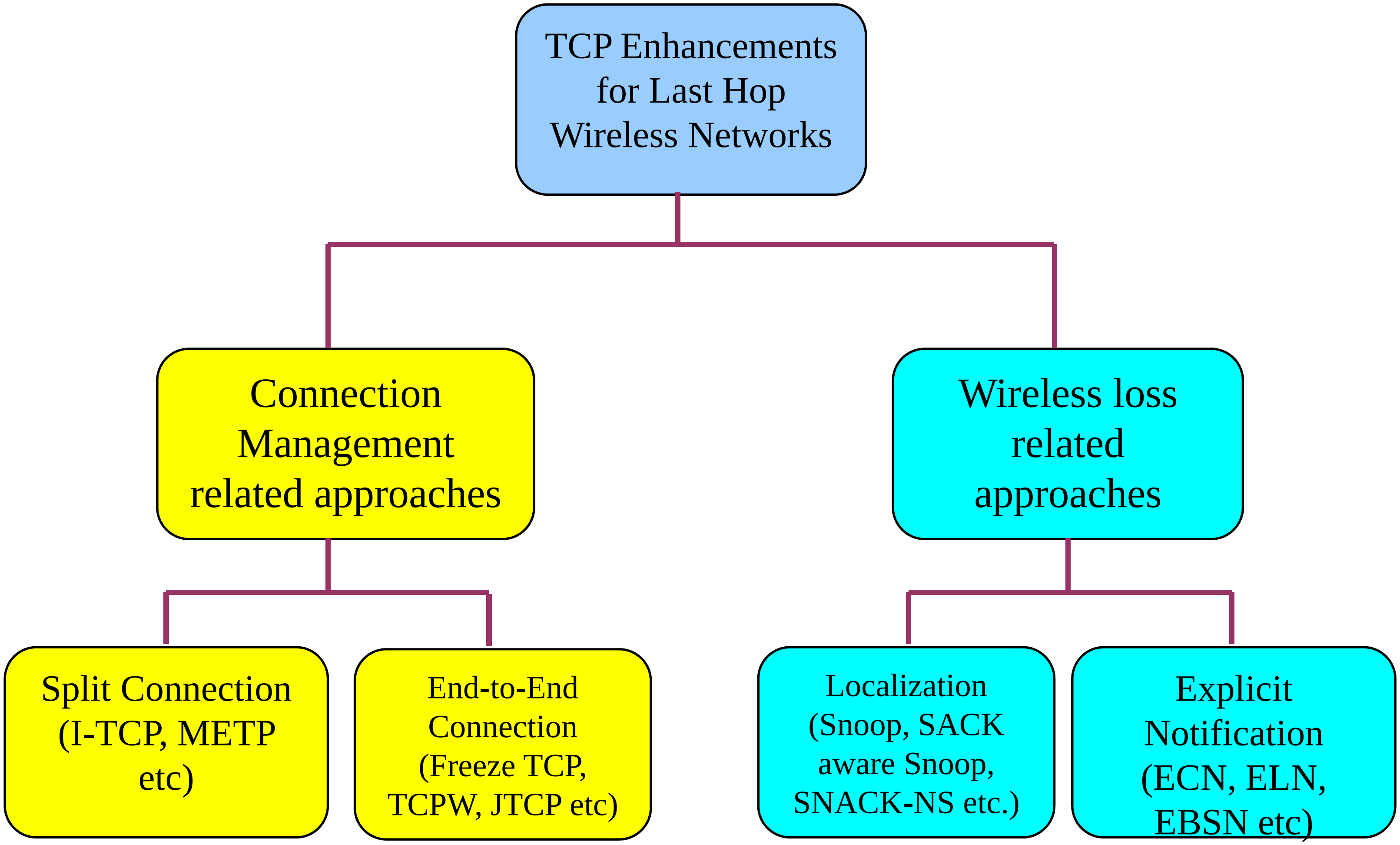
- Mobile devices are battery powered
  - ***Each transmission consumes certain amount of battery power***
  - ***Can not afford too many retransmissions***
  - ***TCP is not designed as energy efficient protocol***

# Path Asymmetry

- TCP relies on ACK arrivals for congestion window progression
- If path asymmetry exists, a TCP connection's performance will be influenced by the reverse path characteristics too
  - ***Indirect effects of path asymmetry (ACK bunching)***

# Classification of TCP performance schemes in wireless networks

# Classification of Solutions





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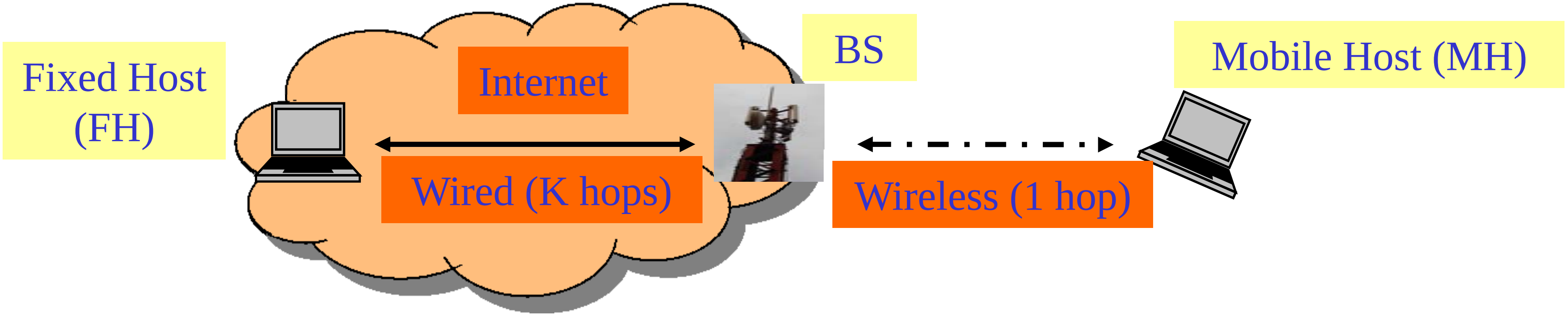
# Split Connection

- Segments TCP connection into two at the Base Station (BS)
  - » FH-MH=FH-BS + BS-MH
  - » If more than one wireless link exists, then more than two TCP connection is needed





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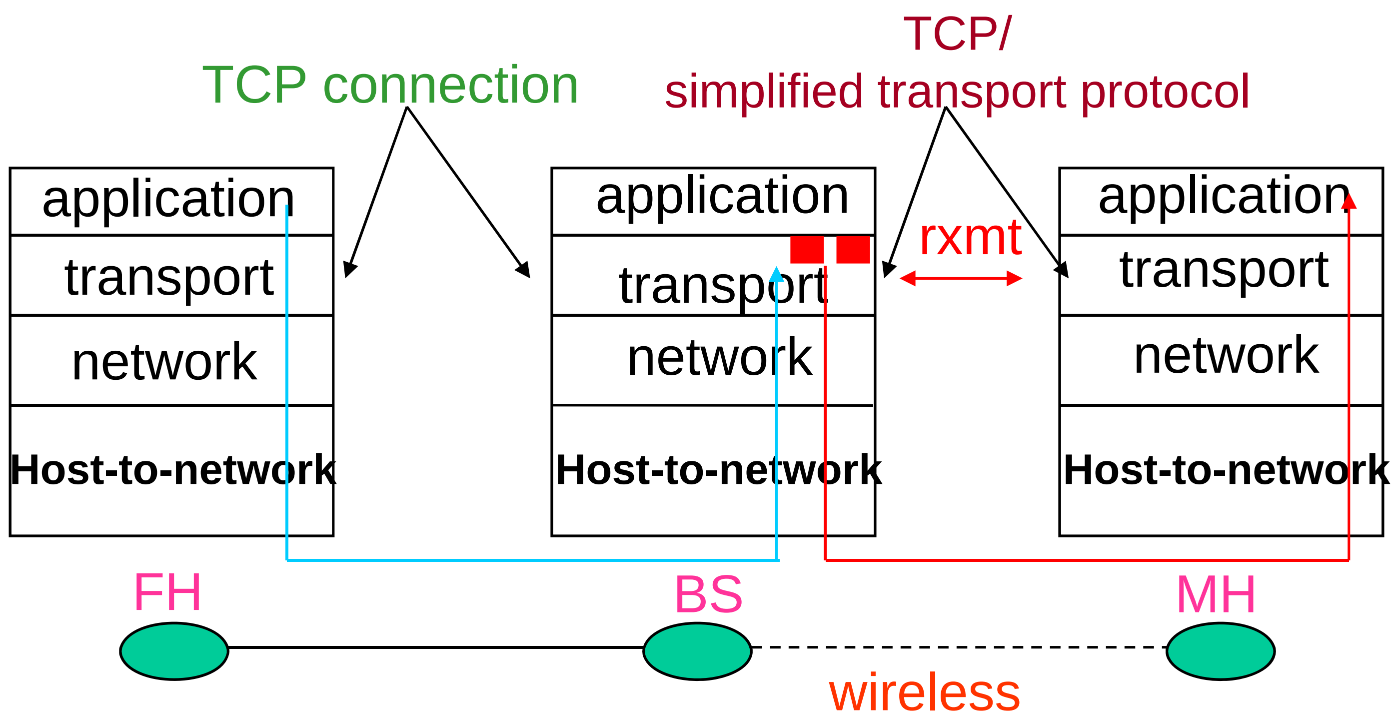
# Split Connection

- It takes care of the fact that MH has limited resources (e.g. power supply, memory)
  - Moves much of the networking task to the BS
  - Allows MH to use simple transport protocol over the wireless link



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# Split Connection

- Packets are received, Buffered, and ACKed by BS
- Results in independent congestion/flow/error control for the two parts
  - » BS guarantees delivery to MH
- Protocol syntax, semantics may be different for each part
- To ensure mobility support
  - » Connection state and buffered packets are to transferred to new BS

# Split Connection

- Advantages:
  - *BS-MH protocol can be optimized keeping wireless characteristic in mind*
  - *Local recover of wireless losses*
    - » *Faster than normal TCP due to shorter RTT in wireless link*
  - *Allows MH to move to a new cell with little disruption*



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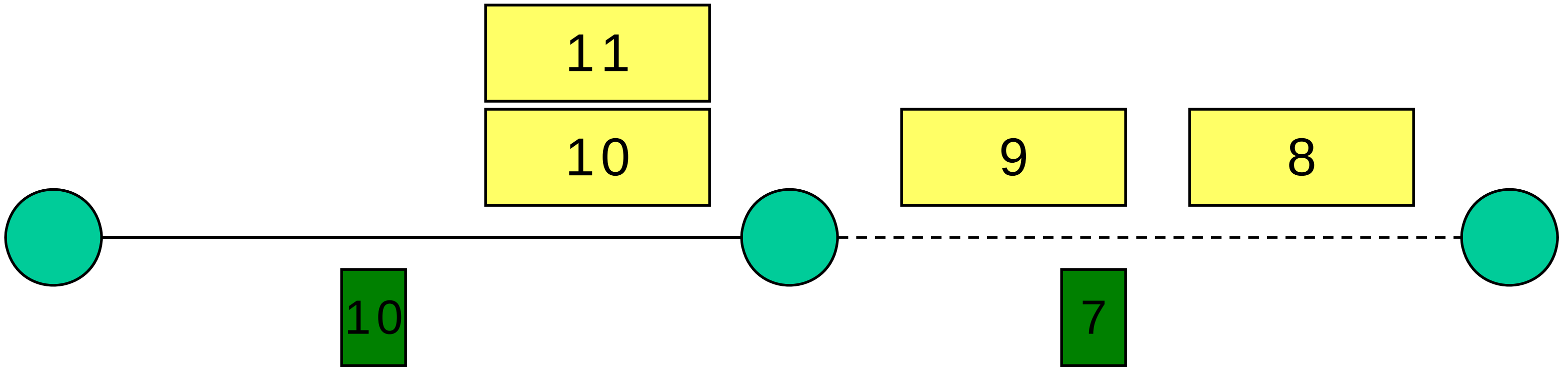
# Split Connection

- Cons:
  - *End-to-end Autonomy is violated*
  - *Permanent data loss if BS crashes*



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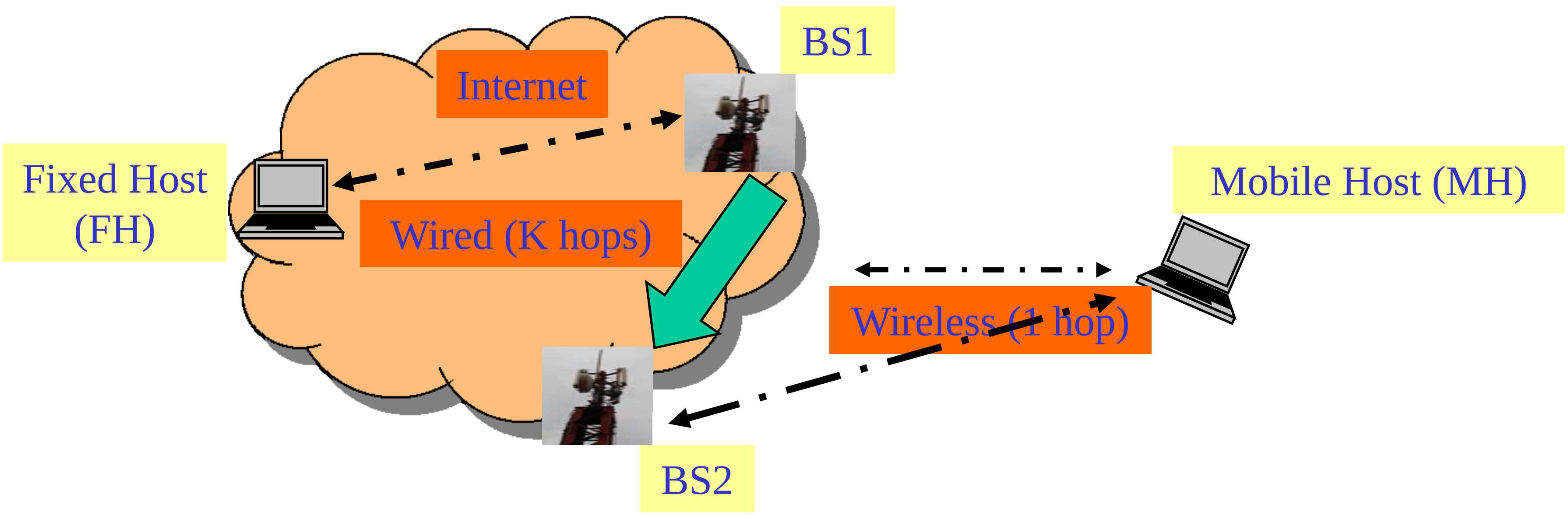
# Split Connection

- Cons:
  - *Handoff latency is high due to state transfer*



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# Split Connection

- Cons:
  - *Is the approach Scalable?*
    - » Buffer needed for each TCP connection
    - » BS may be overwhelmed
    - » Smart buffering technique is required
  - *Extra copying of data at BS*
  - *Increases end-to-end latency*
  - *Can not be used with IPSec*

# End-to-End Connection

- Do not depend on the intermediate nodes
- Modify the actual protocol, keeping wireless characteristics in mind
- Sender and Receiver attempt to determine cause of packet loss


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# End-to-End Connection

- Sender: statistics based on RTT, window size, loss pattern

- Receiver: Heuristic
    - If determined by the receiver, it sends notification to the sender
    - Upon receipt of the notification or by self evaluation, the sender takes appropriate action
        - » Reduce congestion window only if congestion is detected
        - » Retransmit lost packet if loss is due to error

# End-to-End Connection

- Advantages:
  - ***Highly Scalable***
  - ***End-to-End semantic is preserved***
  - ***Can deal with congestion and wireless losses effectively***
  - ***Can be implemented without any help from the network***
  - ***Can work with IPSec***



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# End-to-End Connection

- Disadvantages:
  - ***Deployment is difficult***
  - ***Does not work well as yet***
    - » Traffic pattern changes frequently



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# Localization

- Employs link layer retransmission technique
- Hides wireless link from the sender
- Local recovery of wireless loss
    - ***Propagation delay is shorter, so recovery is quick***
- Uses BS to minimize the effect of wireless error
- Restricts TCP response mostly to congestion



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# Localization

- Retransmission may cause congestion at BS
  - ***Retransmissions effectively consumes bandwidth***
  - ***Queue build up at the BS***
  - ***Is it desirable?***



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# Localization

- BS stores unacknowledged packets
- If ACK is received, the packet is removed
- If packet loss is detected (via DUPACK)
  - ***If packet found:***
    - » Retransmit, Discard DUPACKs
  - ***If not found:***
    - » forward DUPACK, Congestion case



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# Localization

- May interfere with TCP retransmission
  - ***Set timer properly***
  - ***Limit number of retransmission at link layer***


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# Localization

- When Localization is useful
  - ***If it provides in-order delivery***
  - ***If TCP retransmission timer is high***



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# Localization

- Advantages:
  - *End-to-End Autonomy is preserved*
  - *Deployment is easy*
  - *Deals congestion and wireless losses effectively*


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# Localization

- Disadvantages:
  - ***What about scalability?***
    - » BS may be overwhelmed
  - ***What about encrypted traffic?***
    - » IPSec is an integral part of IPv6
  - ***About mobility?***

# Explicit Notification

- Intermediate nodes knows better the cause of packet loss
- Ideal TCP behavior
  - ***Reduce congestion window in response to congestion***
  - ***Simply retransmit lost packet when loss is due to error***
- Receiver sends notification to the sender
- Receiver depends on routers to get this information
- Sender takes appropriate action depending on the nature of loss reported in the notification

# Explicit Notification

- Many design options:
    - » Who sends notification?
    - » How?
    - » How notification is interpreted?

# Explicit Notification

- Advantages:
  - *Very effective in dealing with packet losses*
  - *Can work with encrypted packets*
  - *Highly Scalable*



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# Explicit Notification

- Disadvantages
  - *May fail if path changes frequently*
  - *Deployment is very difficult*


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# Comparison

| Categories/ Wireless Issues | Split Connection | End-to-End Connection | Localization of Wireless Loss | Explicit Notification |
|---|---|---|---|---|
| *Mobility* | Supported but at the cost of high handoff latency | Not supported | Not supported | Not supported |
| *Distinction Between Congestion and Link Error* | Supported | Supported | Supported | Supported |
| *Encrypted Traffic* | Not Handled | Handled | Not Handled | Handled |
| *Scalability* | BS may be overwhelmed if it has to serve large number of MH | Supported | BS may be overwhelmed if it has to serve large number of MH | Supported |
| *Deployment* | Easy | Difficult | Easy | Difficult |
| *End-to-End Autonomy* | Not Maintained | Maintained | Maintained | Not Maintained |



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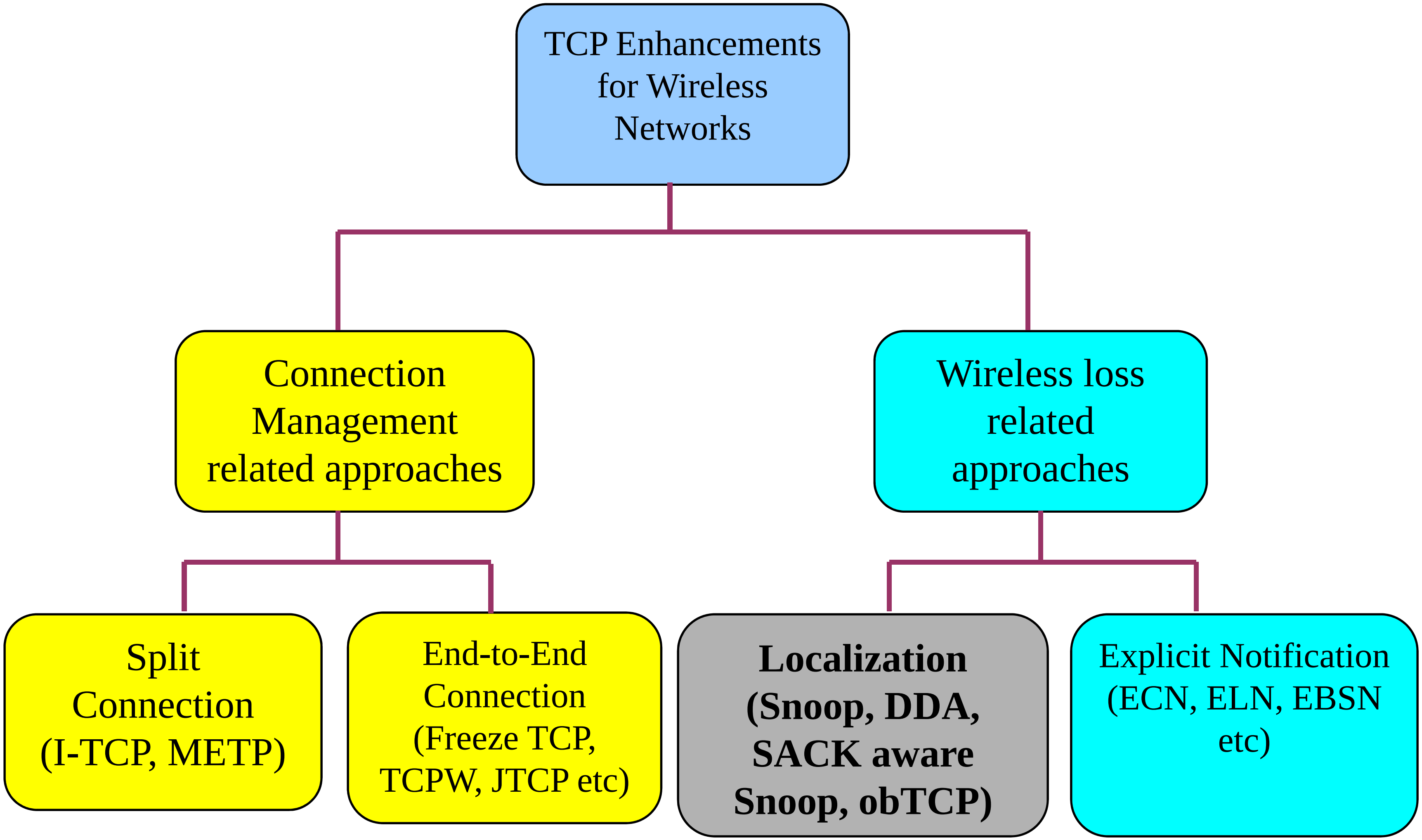
# TCP Enhancements

# Classification of Solutions



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# TCP Snoop

# TCP Snoop

- Employs Snoop agent at BS
- Snoop agent:
  - *Buffers TCP packets at BS*
  - *Monitors every ACK*
  - *If packet loss, retransmits lost packet (if available in cache)*
  - *Drop DUPACKs to avoid fast retransmission at FH*



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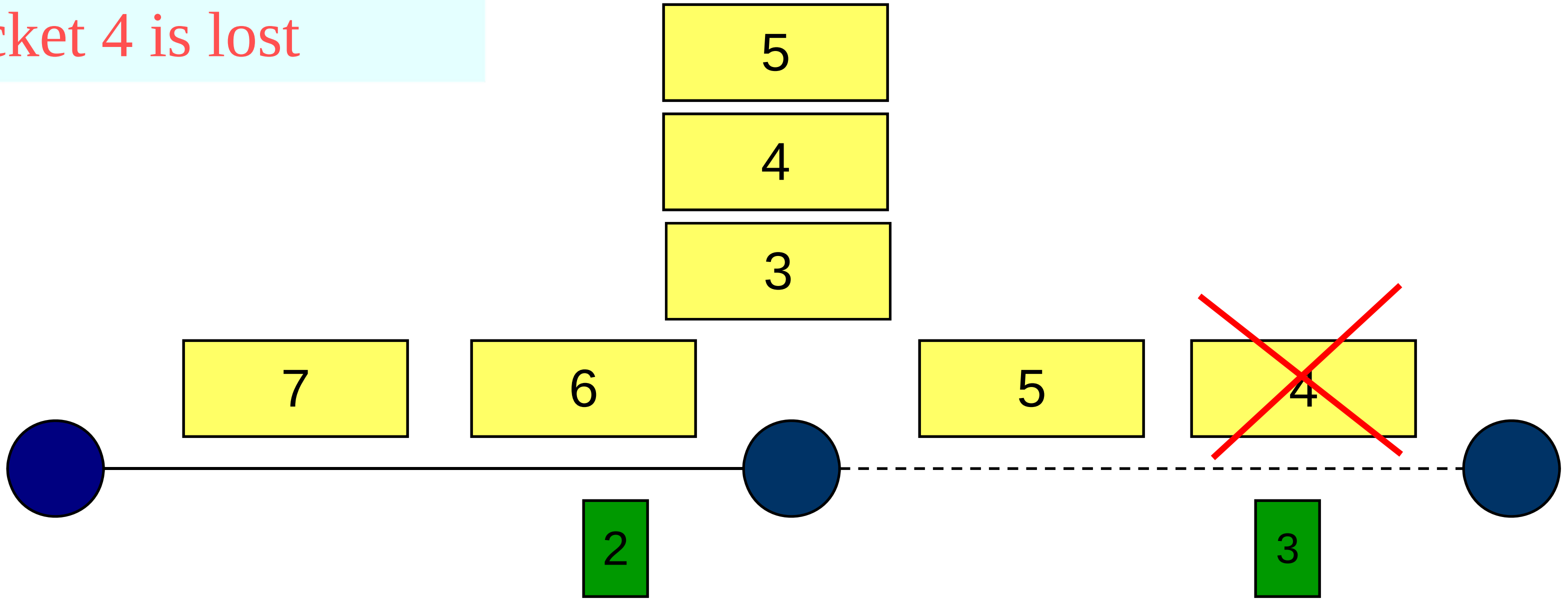
# TCP Snoop

Case of wireless loss

Packet 4 is lost



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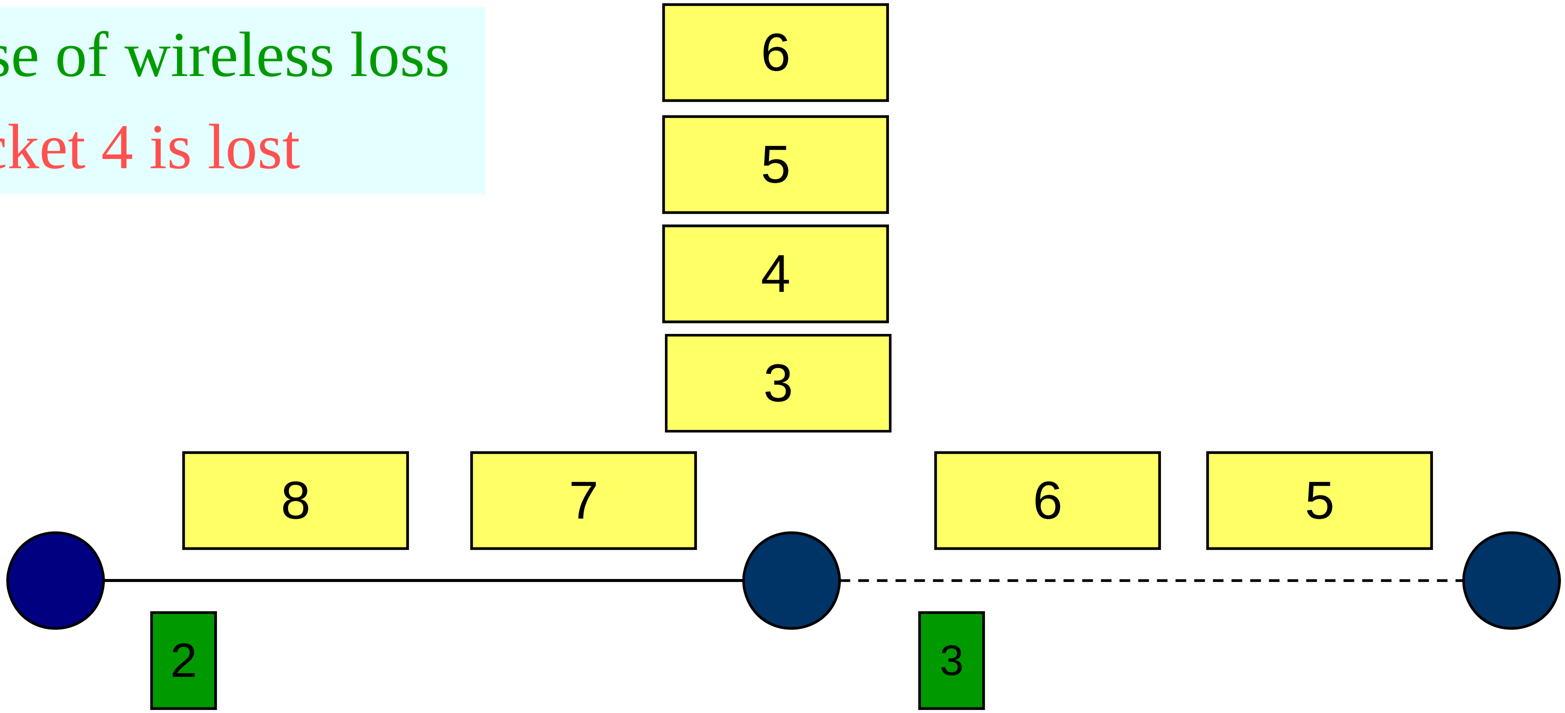




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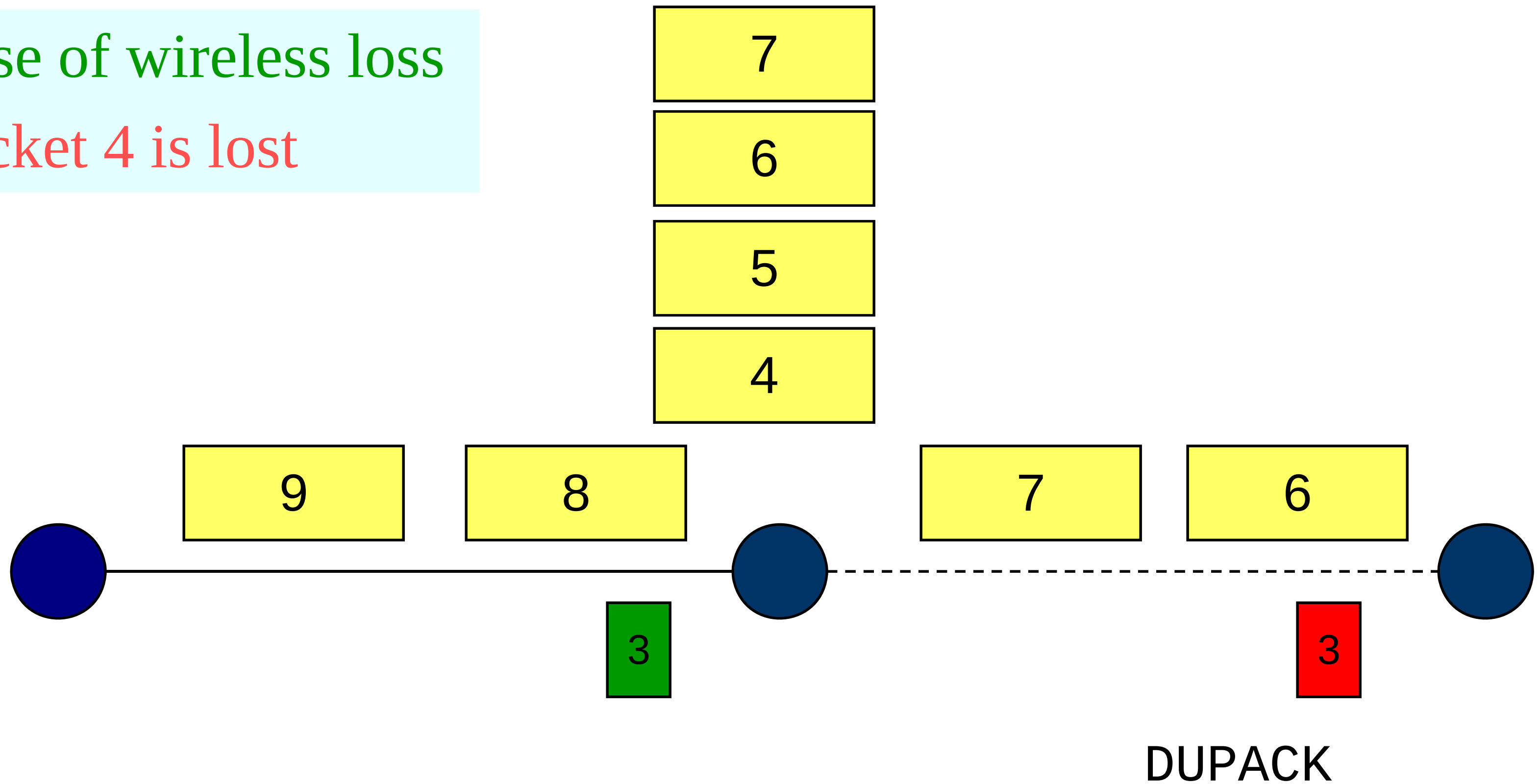




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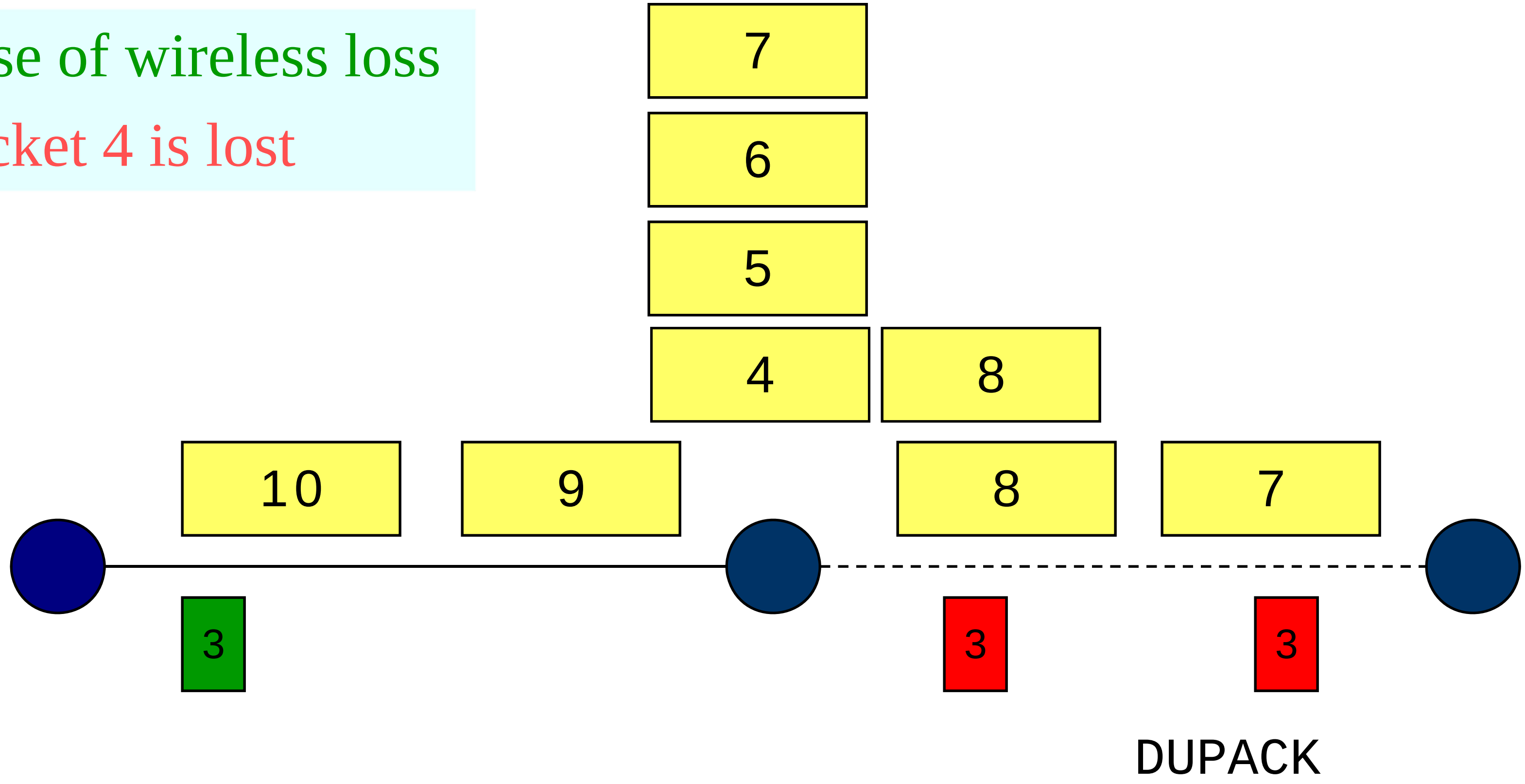




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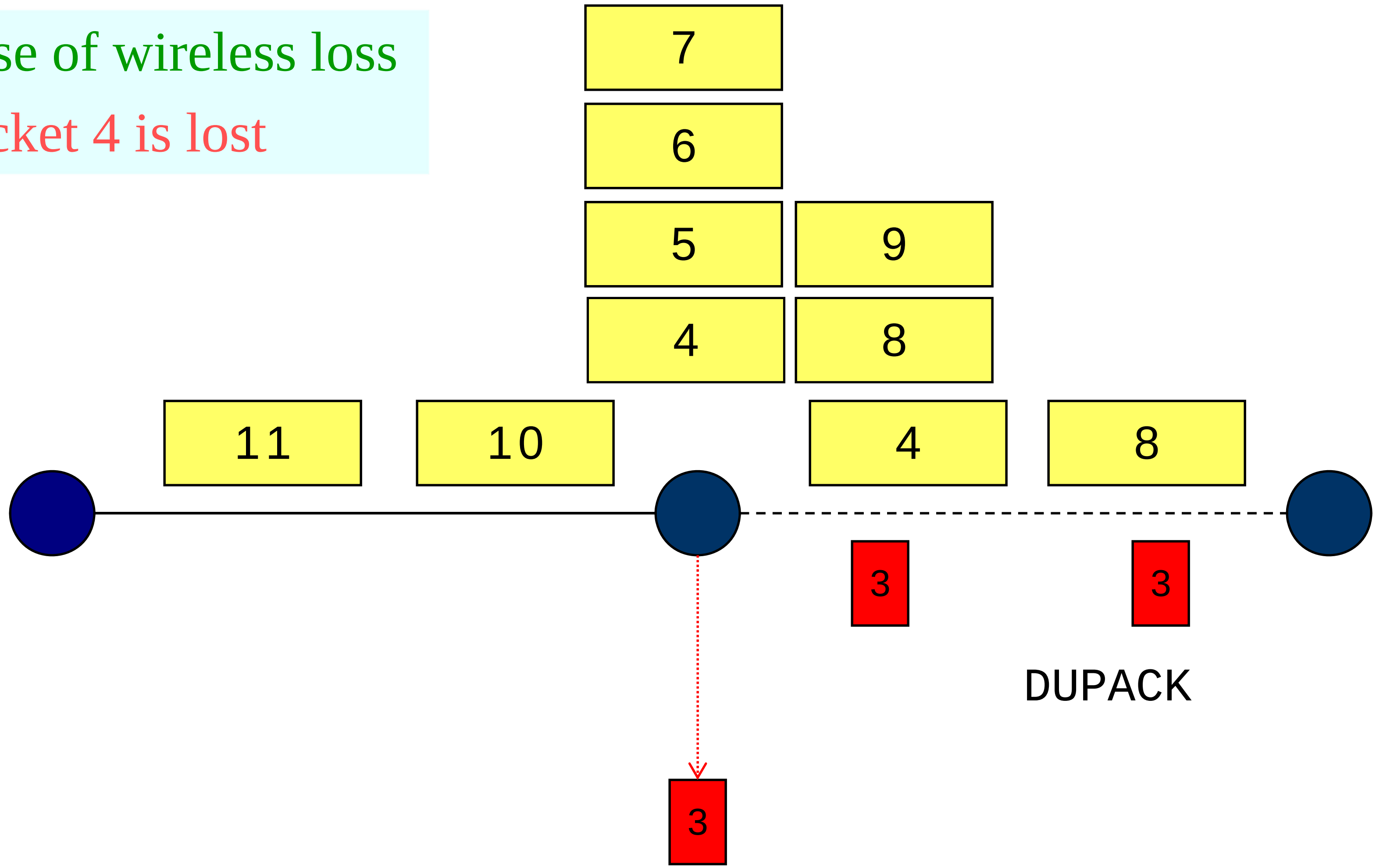




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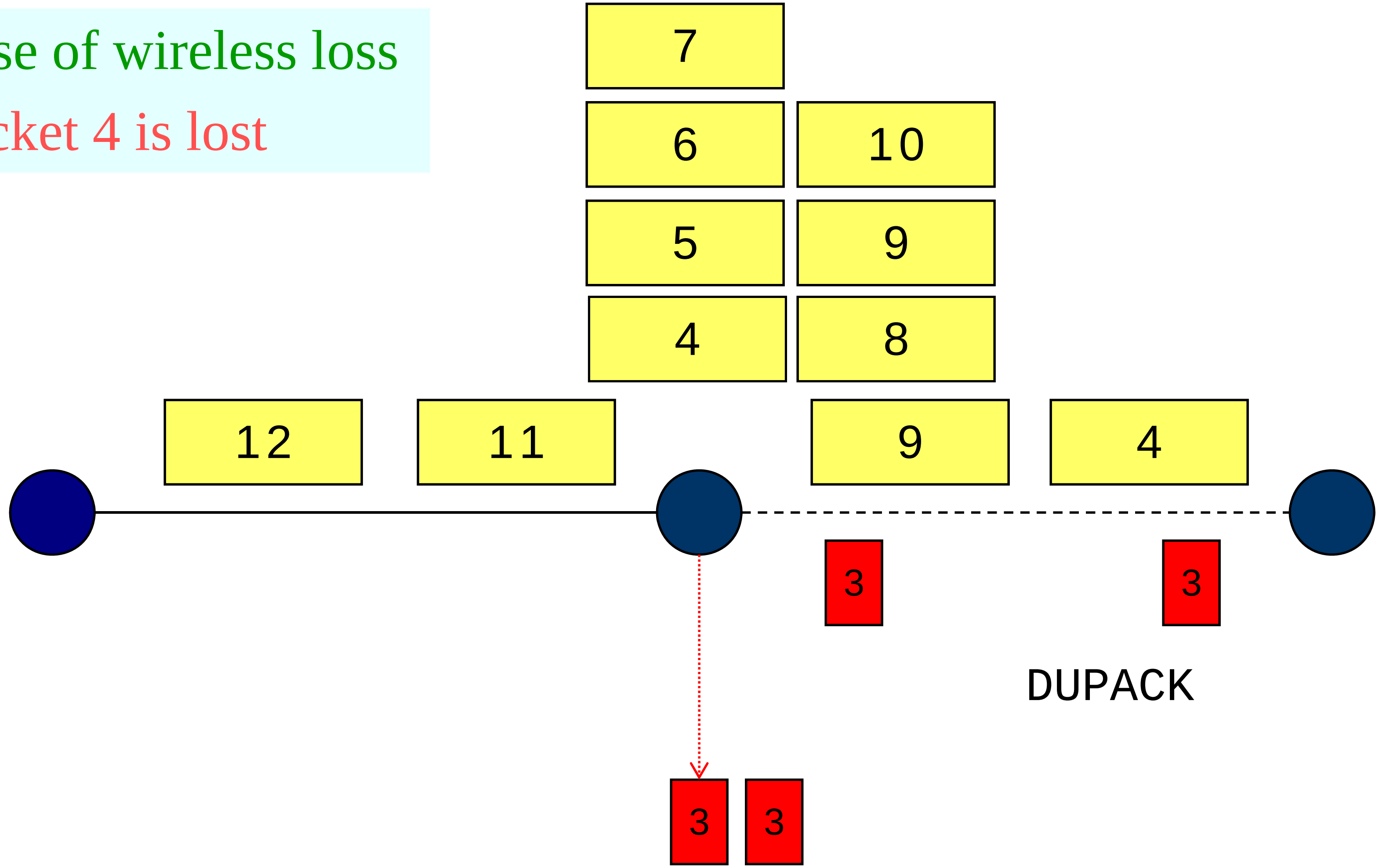




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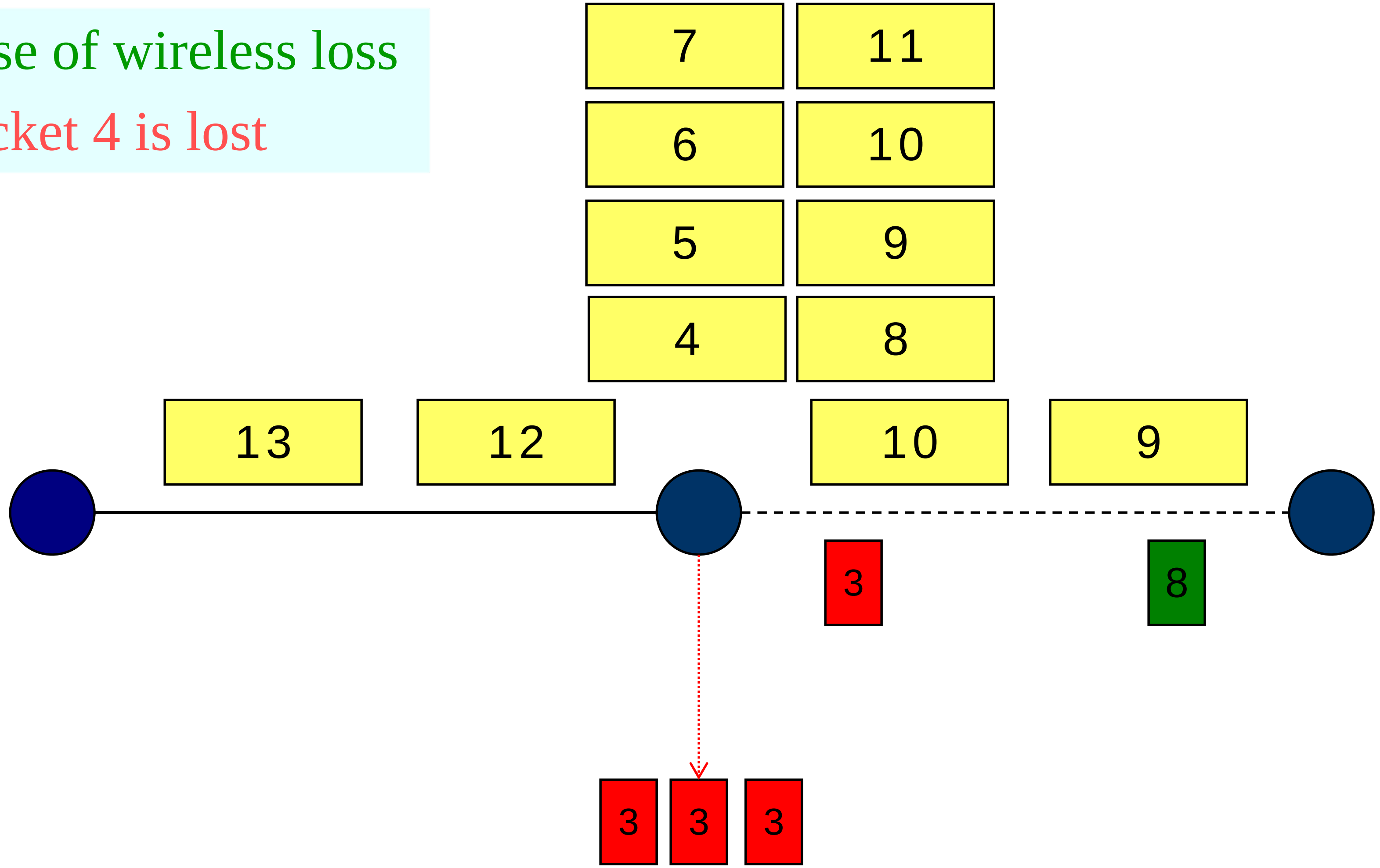

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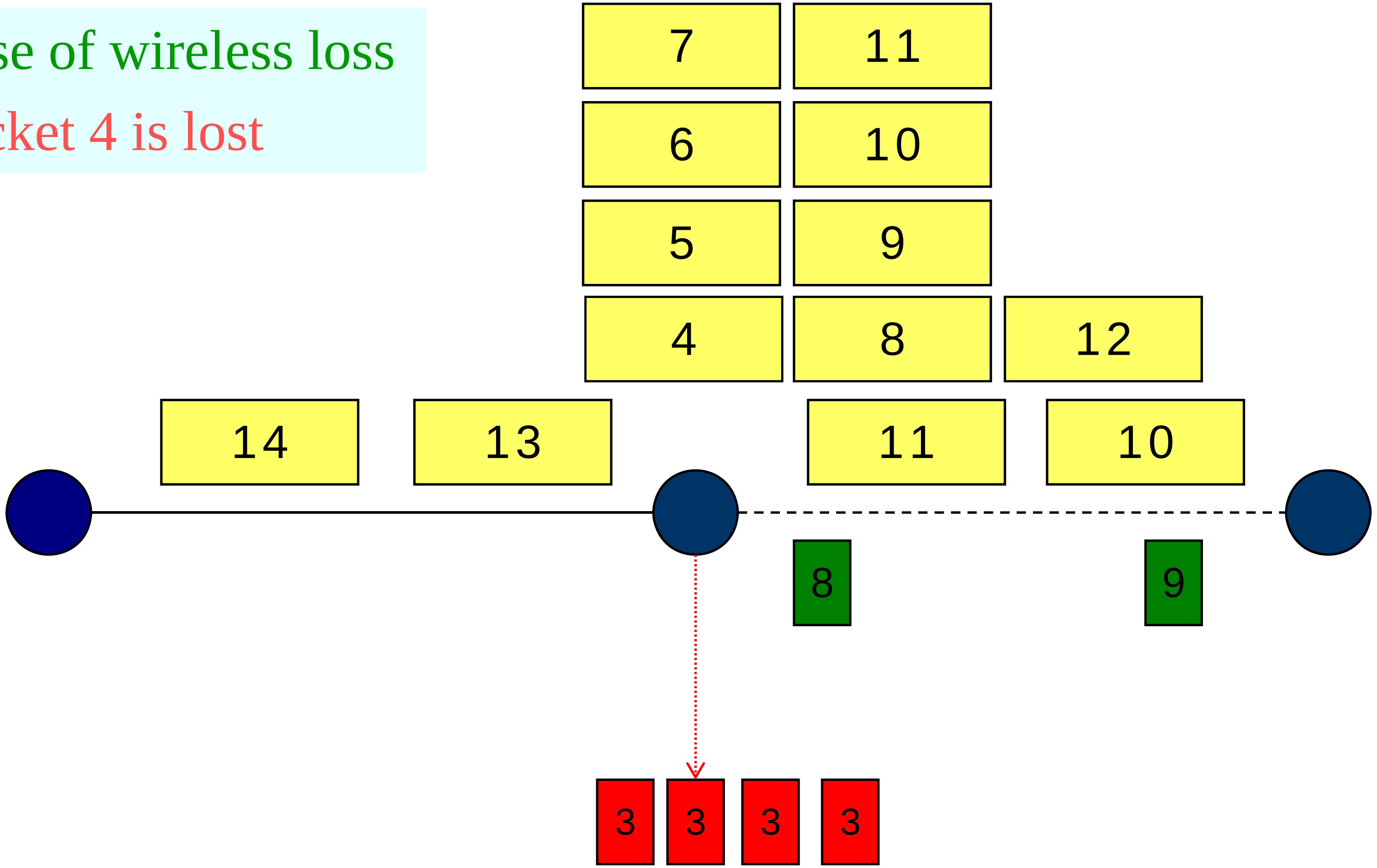




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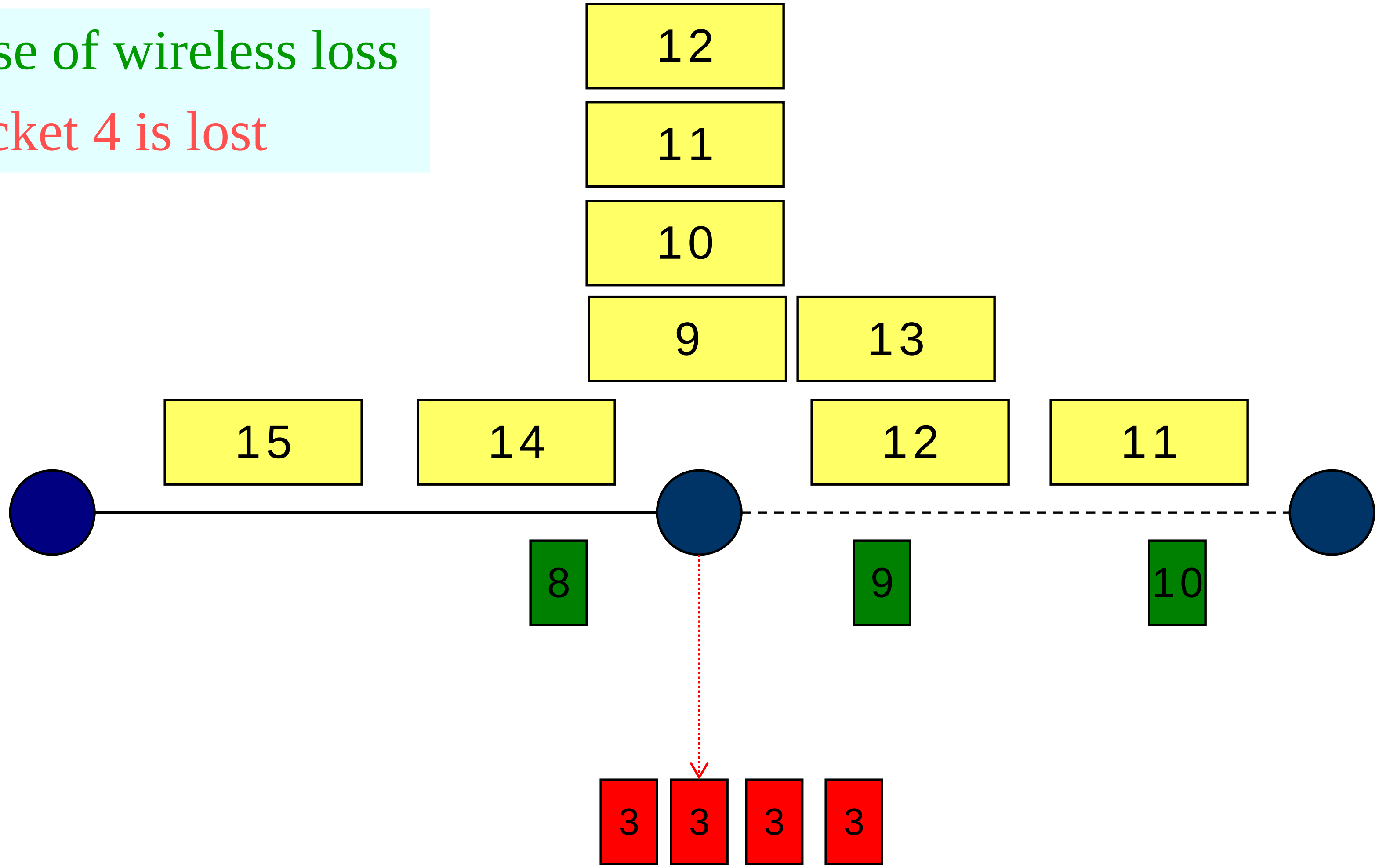




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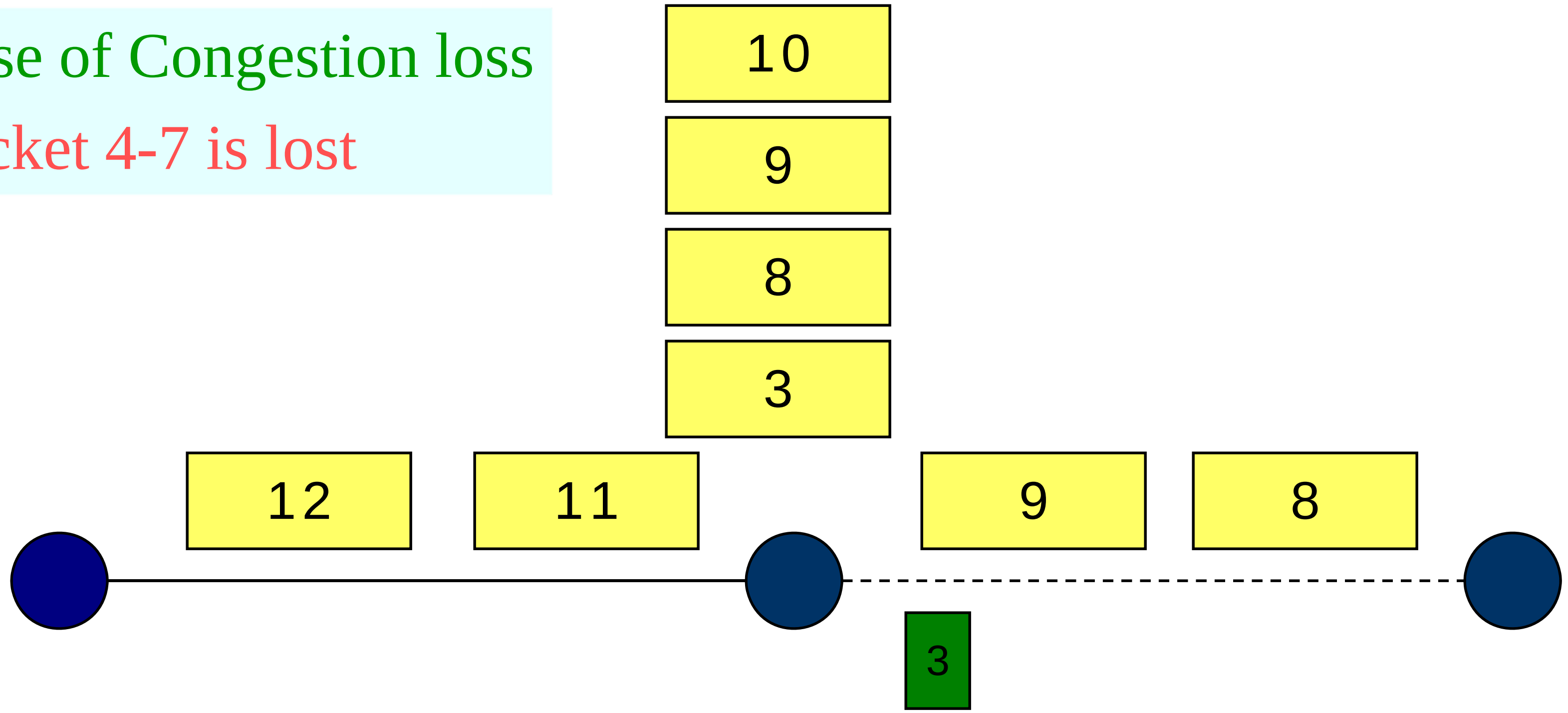
# TCP Snoop

Case of Congestion loss

Packet 4-7 is lost



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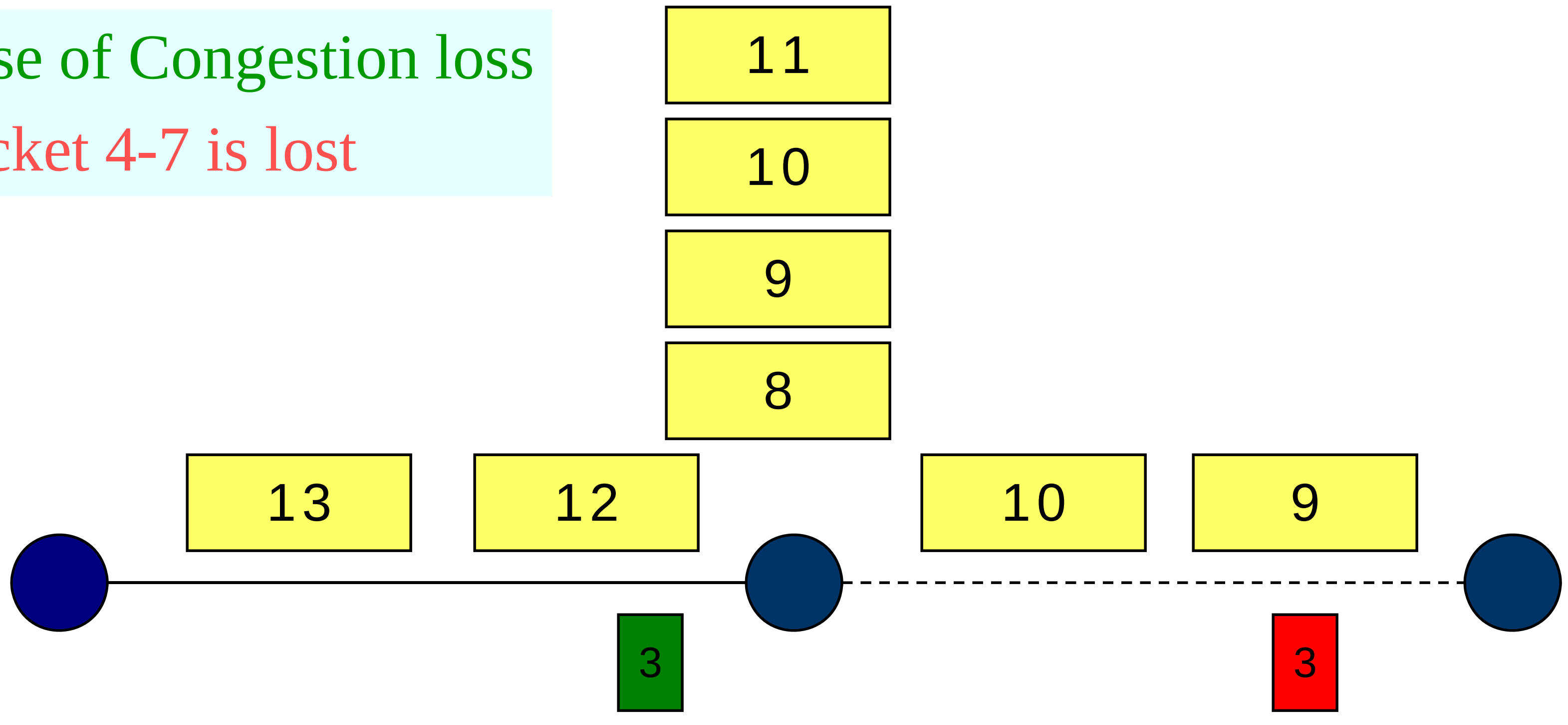
# TCP Snoop

Case of Congestion loss

Packet 4-7 is lost



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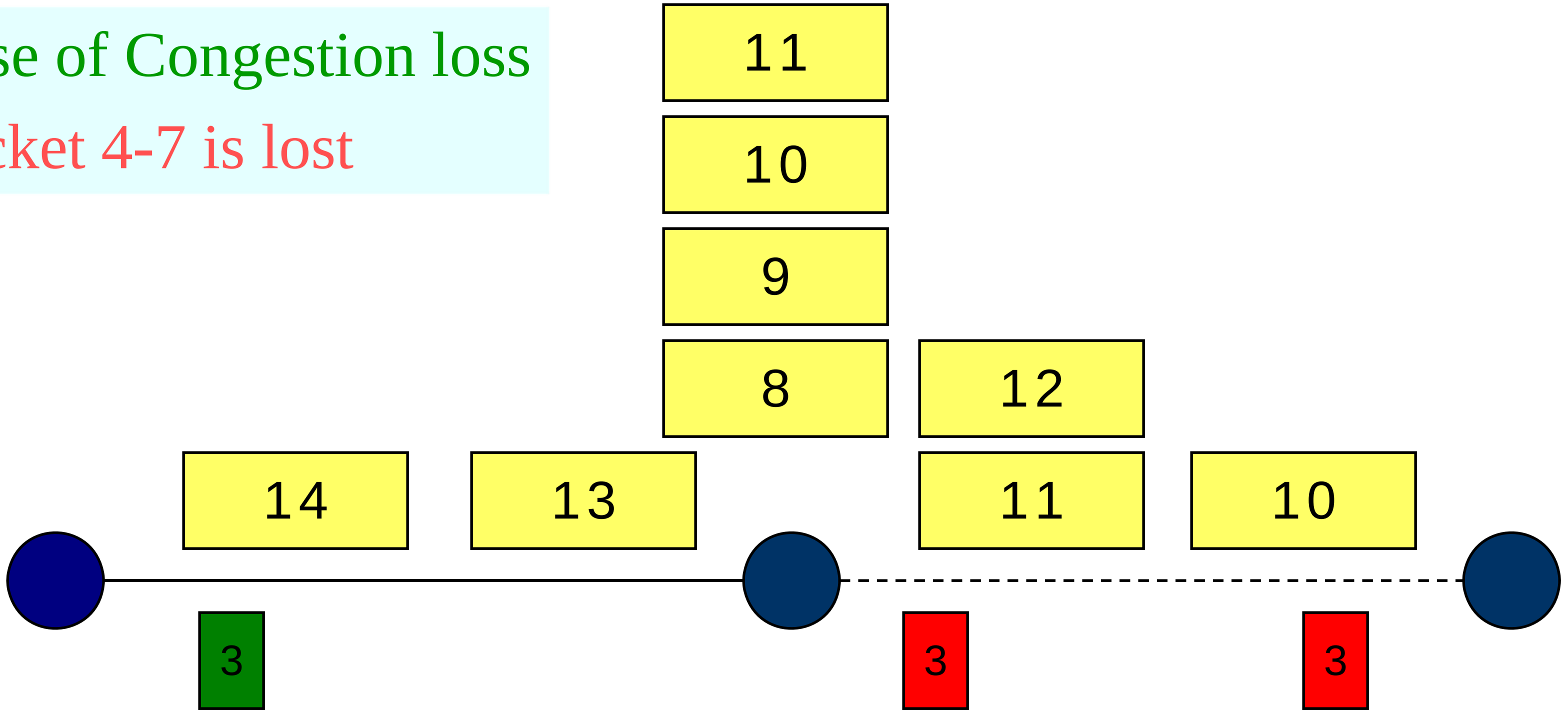




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# TCP Snoop

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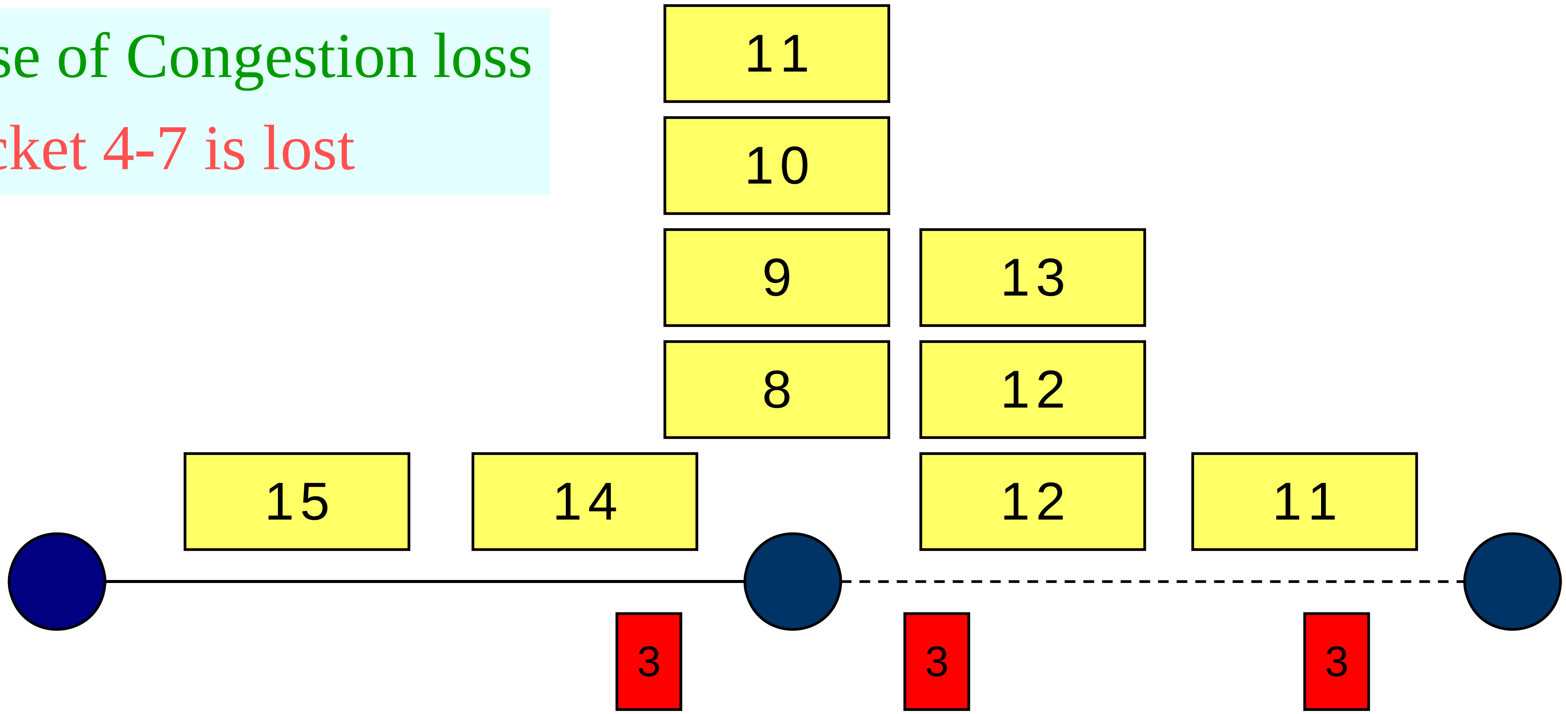


DUPACKS are not dropped
to activate Fast Retransmit



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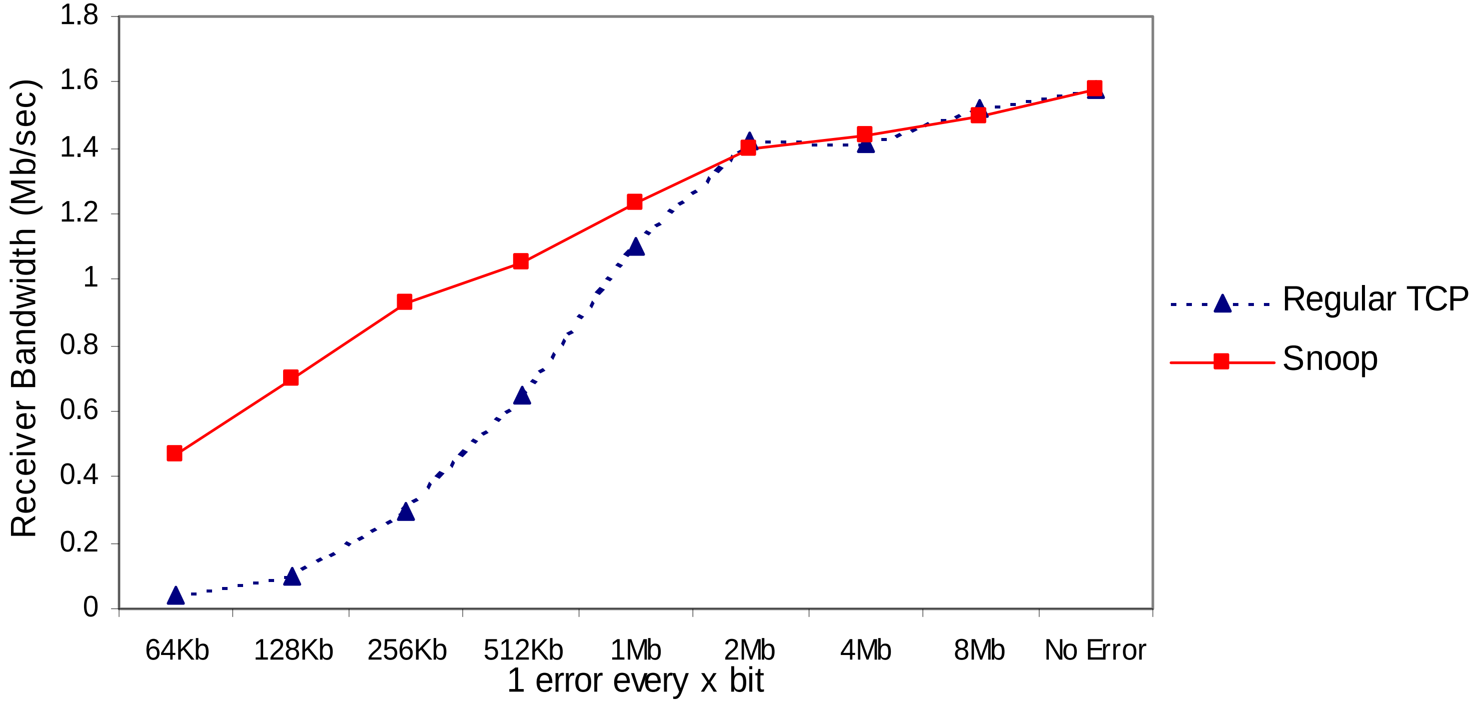
# TCP Snoop

## 10 MB file transfer over 2 Mbps wireless link



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# TCP Snoop

- Advantages:
  - ***Local retransmission***
    - » Faster recovery
  - ***End-to-end semantic maintained***
  - ***No Fast retransmission in the face of wireless loss***

# TCP Snoop

- Disadvantages:
  - *Can not be used if wireless RTT is high*
  - *Can not be used if IPSec is used*
  - *Can not be used in asymmetric links*
  - *BS requires larger buffer space*
  - *Link layer need to be TCP aware*



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# *DDA*



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# Delayed Duplicate ACK (DDA)

- Attempts to mimic TCP Snoop
- BS is not TCP aware
- Implements local retransmission at BS
  - » Uses link level ACK to trigger retransmission
- MH delays third and subsequent DUPACK to reduce interference with TCP sender
  - » Gives chance to BS to recover from losses


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# Delayed Duplicate ACK (DDA)

- DUPACK is delayed for some interval d
- Main design problem→value of d
  - ***If d is large enough, wireless loss is recovered***
  - ***If d is small enough, interference with TCP sender***
- If loss is not recovered within interval d, DUPACK is released



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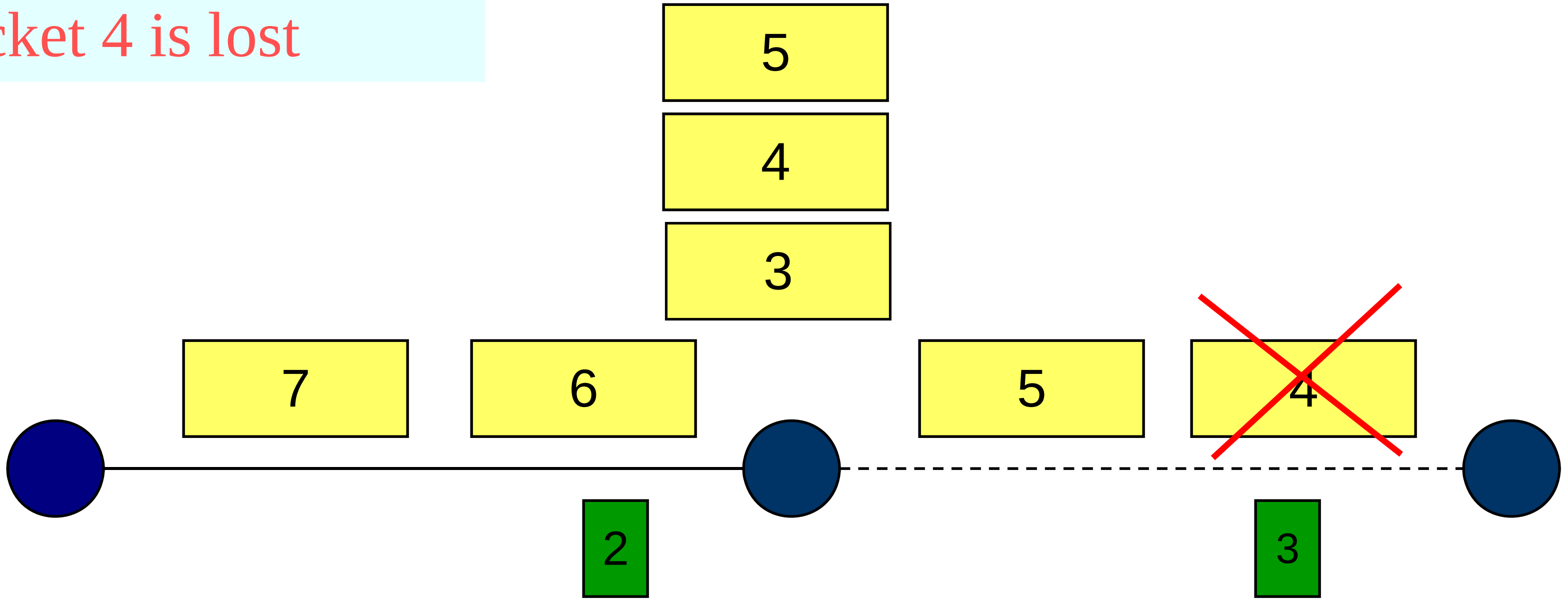
# Delayed Duplicate ACK (DDA)

Case of wireless loss

Packet 4 is lost



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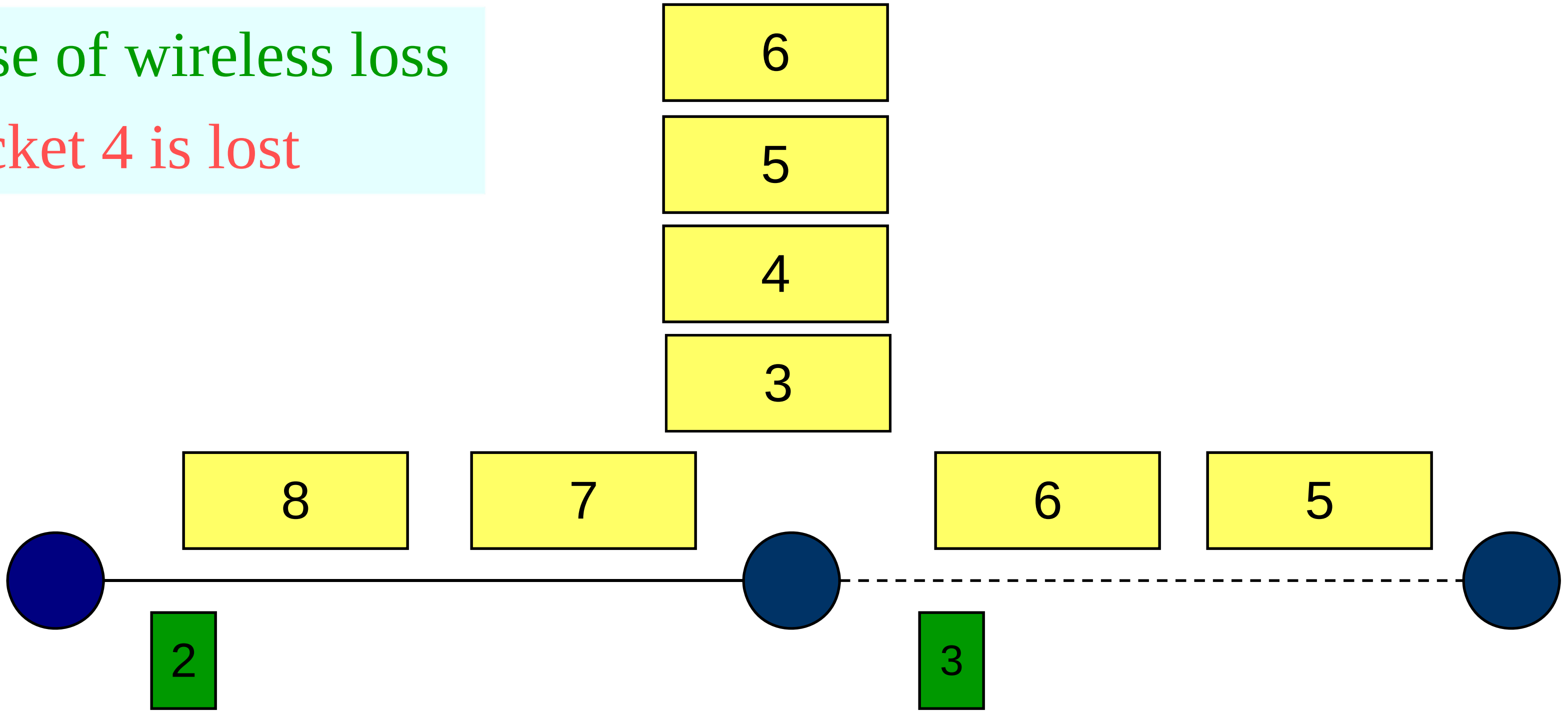
Case of wireless loss

Packet 4 is lost



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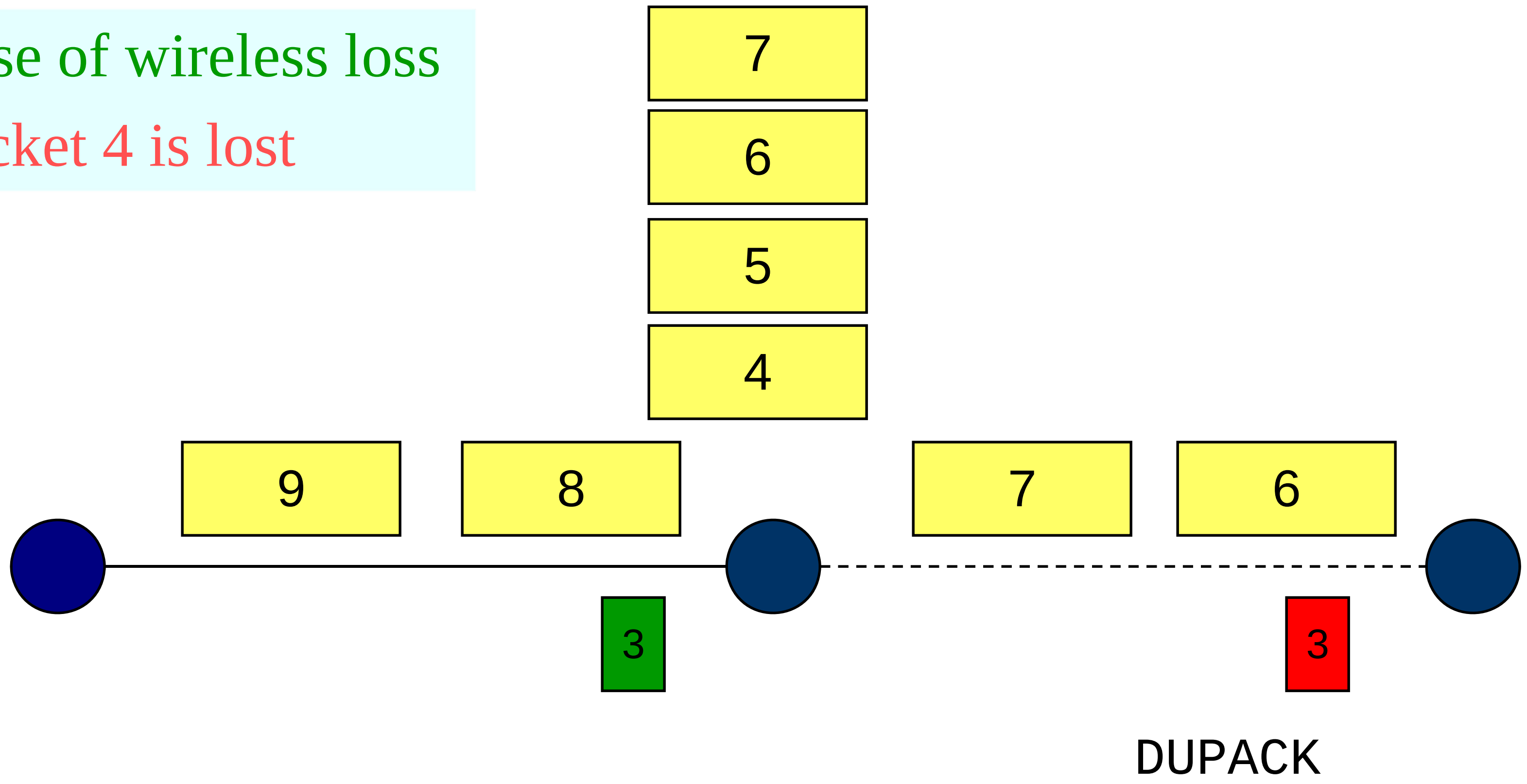


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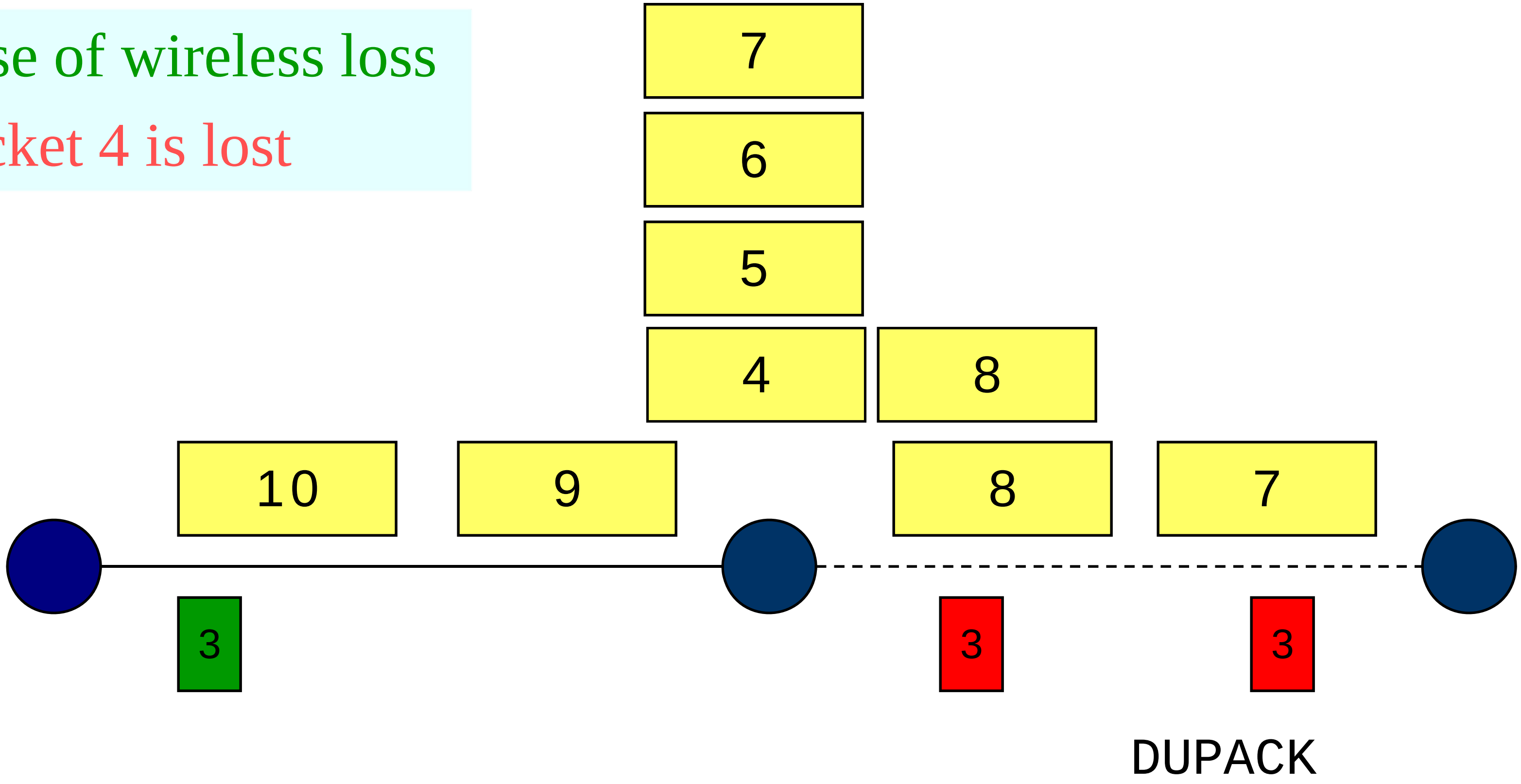
Case of wireless loss

Packet 4 is lost



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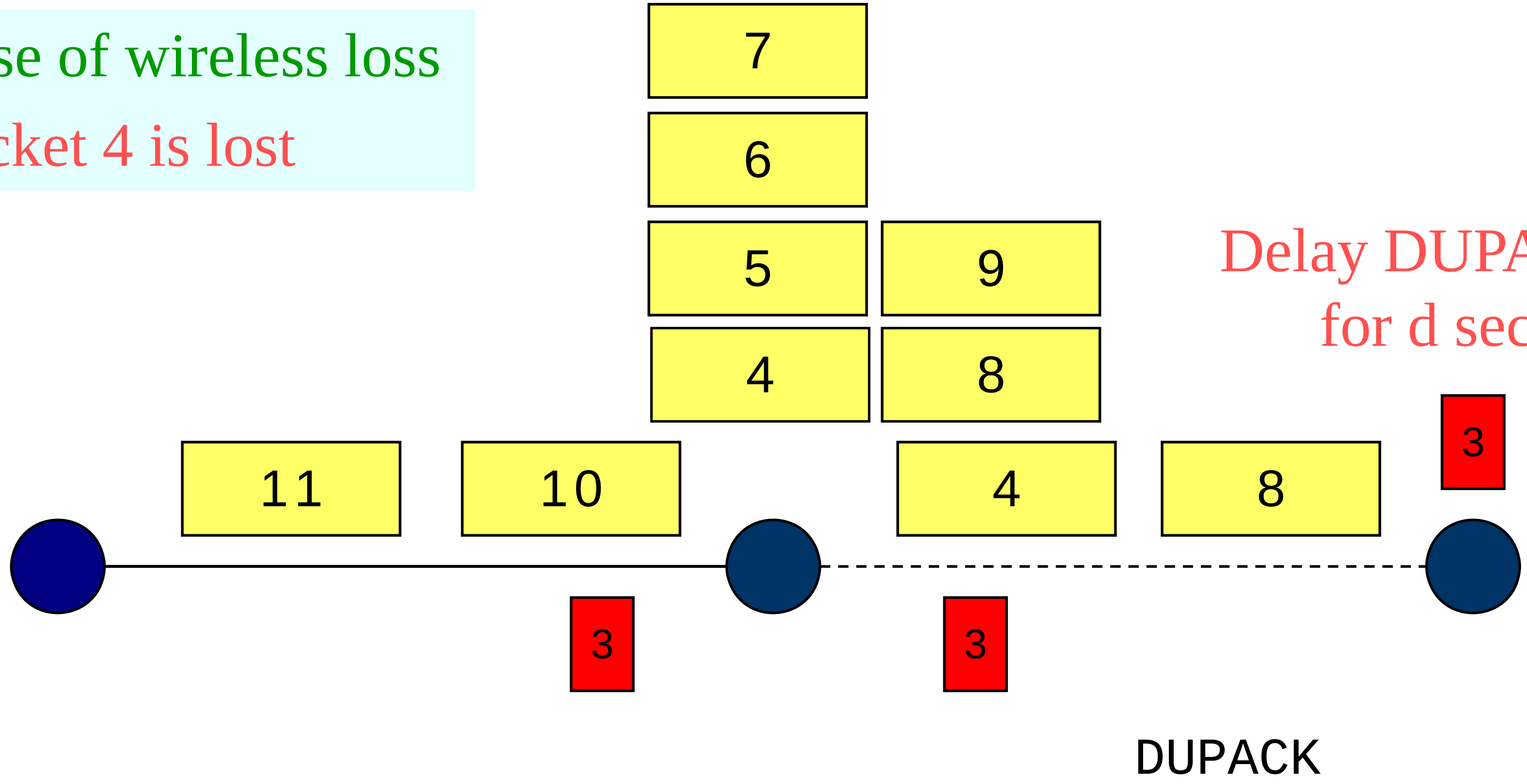
# Delayed Duplicate ACK (DDA)

Case of wireless loss

Packet 4 is lost

Delay DUPACK for d sec



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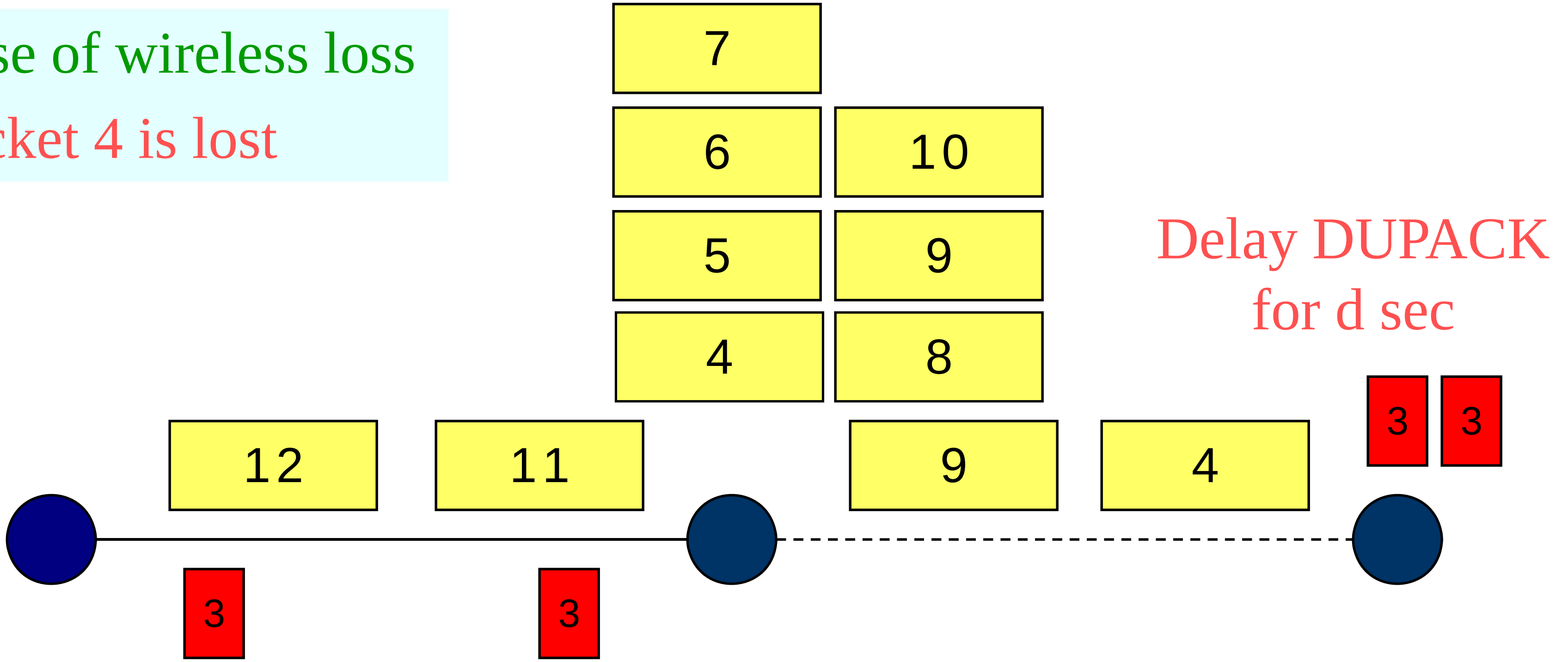




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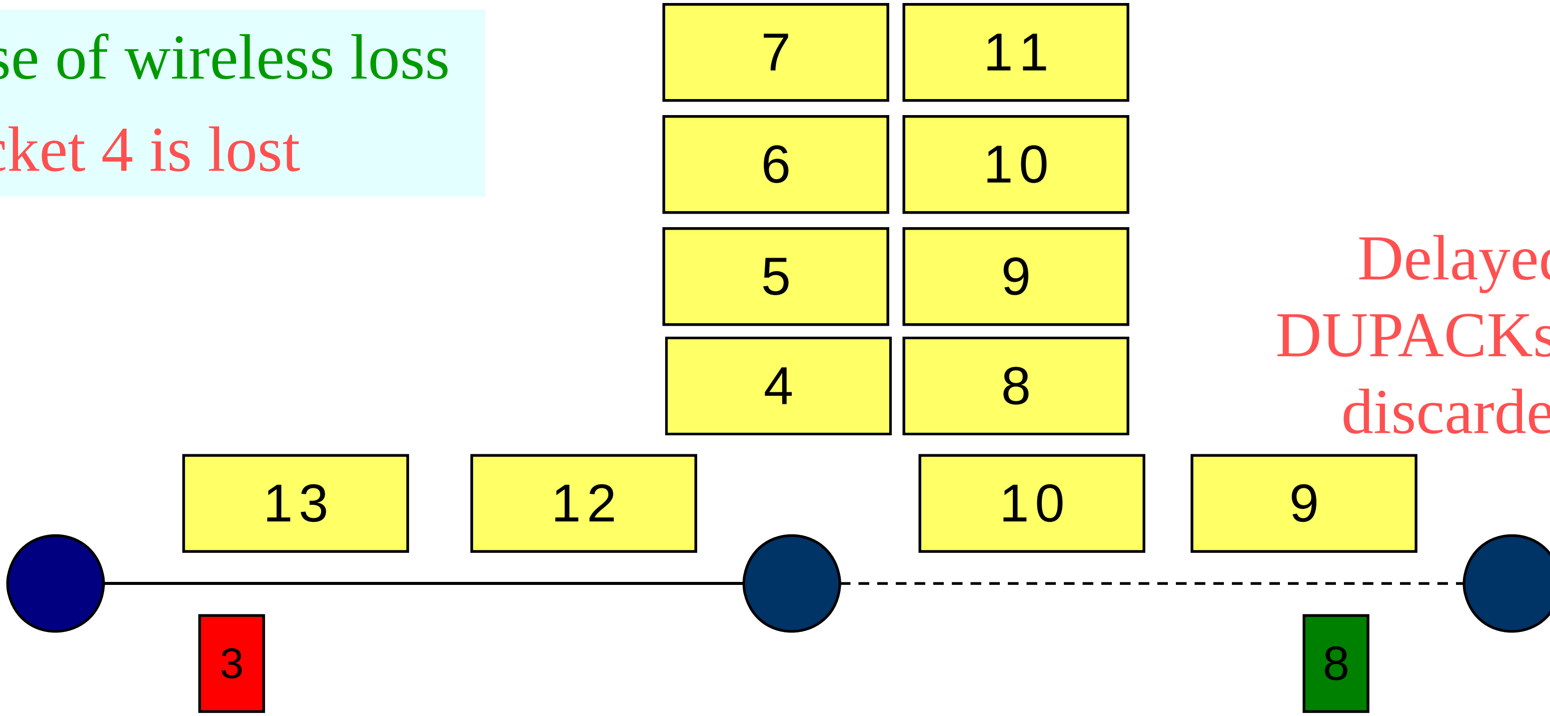


Delayed DUPACKs are discarded



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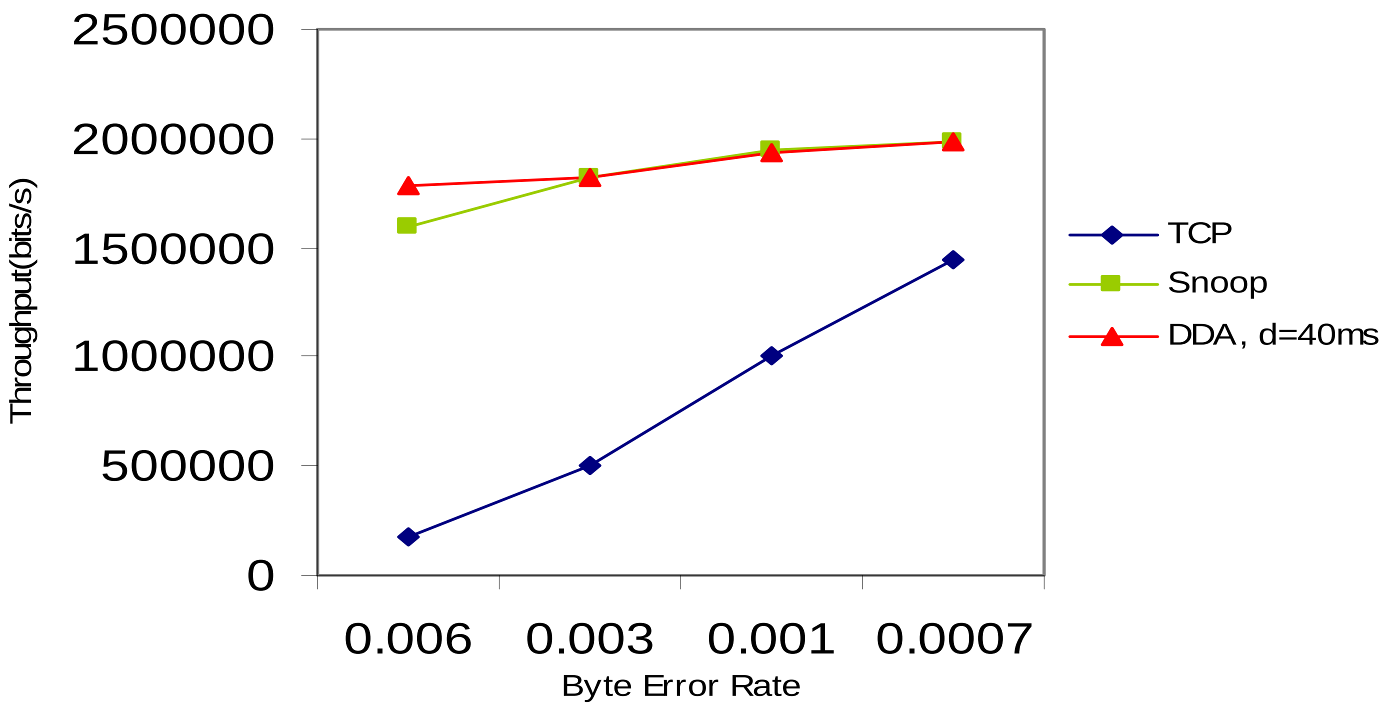
# Delayed Duplicate ACK (DDA)

Wireless link bandwidth 2Mbps, wireless delay 1 ms with no congestion loss



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# Delayed Duplicate ACK (DDA)

- Advantages:
  - ***BS need not be TCP aware***
  - ***Recovery from wireless loss is possible without response from FH***
  - ***Can be used with IPSec***

# Delayed Duplicate ACK (DDA)

- Disadvantages:
  - *Choosing right value of d is difficult*
  - *Performs poorly in the face of real congestion, as it delays third effectively delaying Fast Retransmission*



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# SACK-Aware Snoop

# TCP SACK-Aware Snoop

- Improvement over TCP Snoop

- Snoop can recover only one packet per RTT
  - **Fails when burst loss occur**

- Uses TCP SACK option

# TCP SACK-Aware Snoop

- If ordinary ACK
  - ***Retransmit the lost packet as indicated by the DUPACK***
- If SACK block
  - ***Retransmit all lost packet indicated in the SACK block***
- Advantage:
  - » Multiple losses are recovered within one RTT


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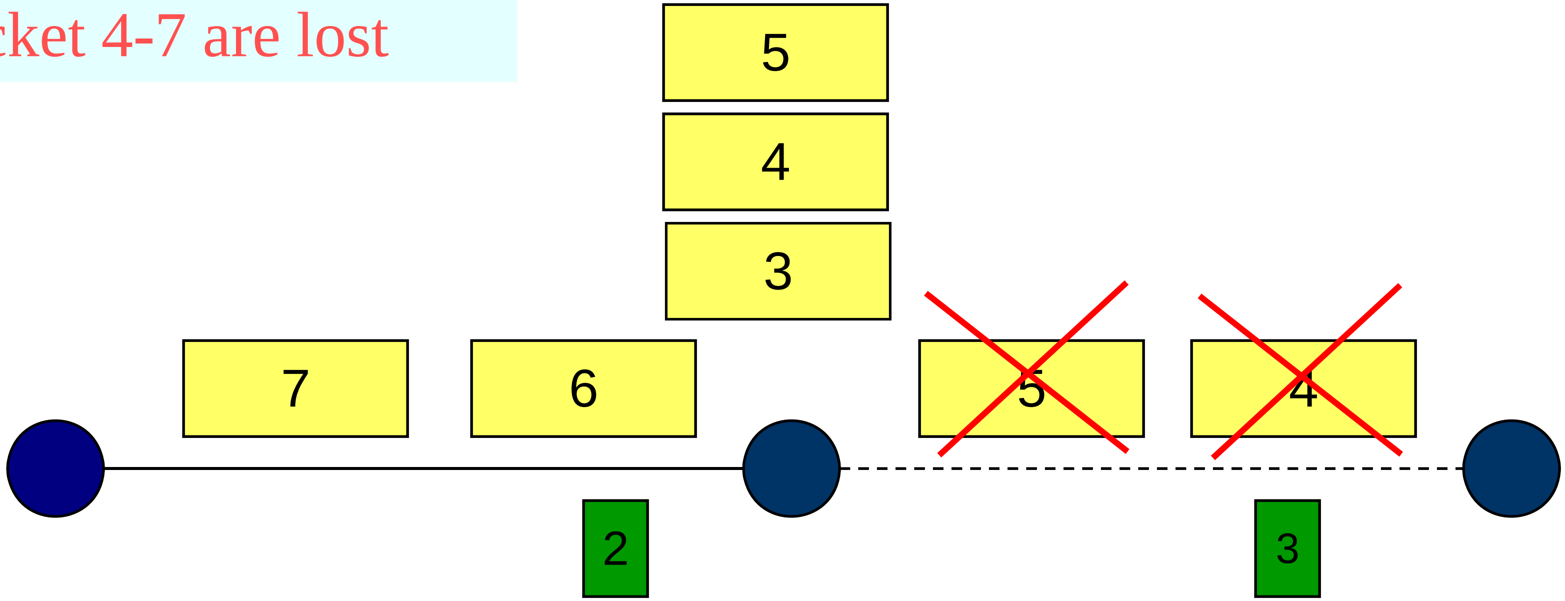
# TCP SACK-Aware Snoop

Multiple wireless loss

Packet 4-7 are lost



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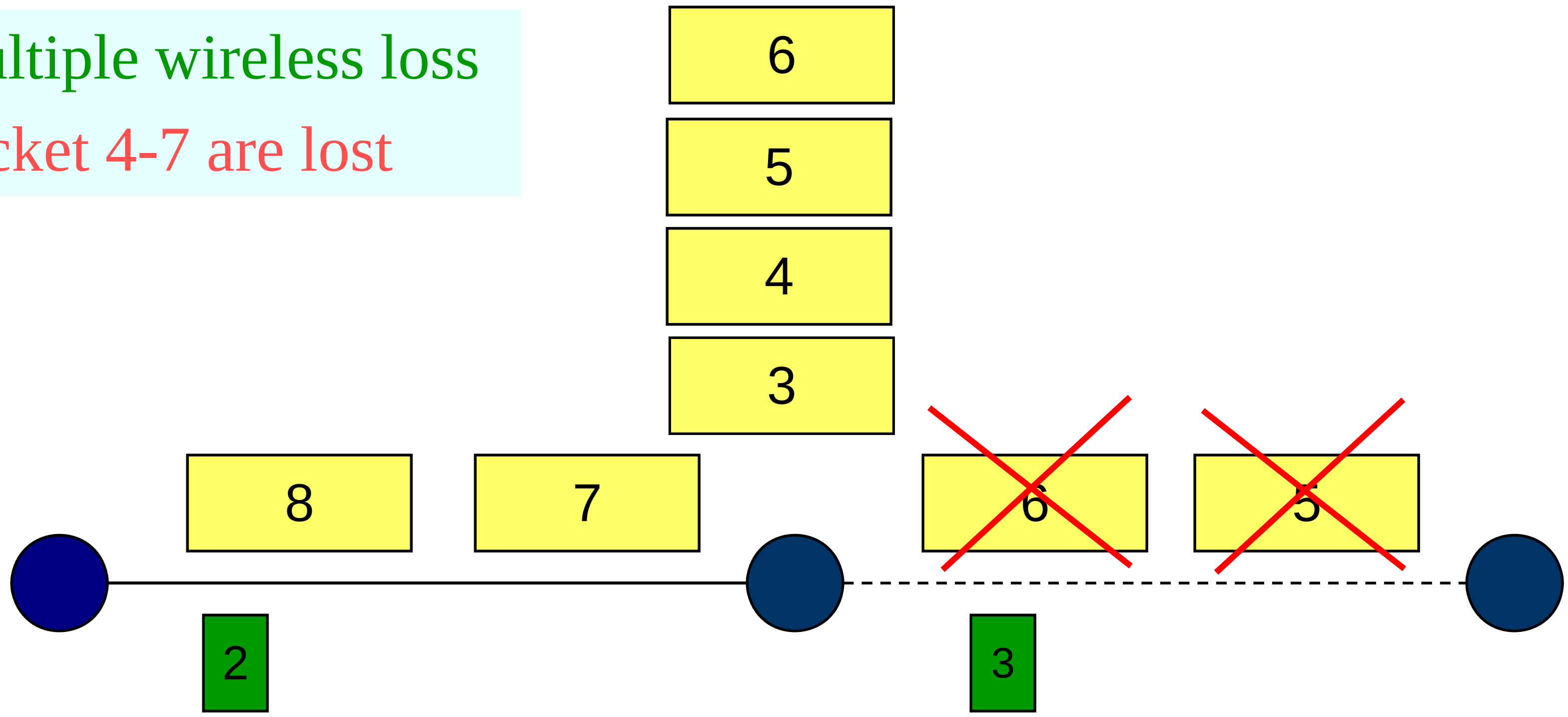




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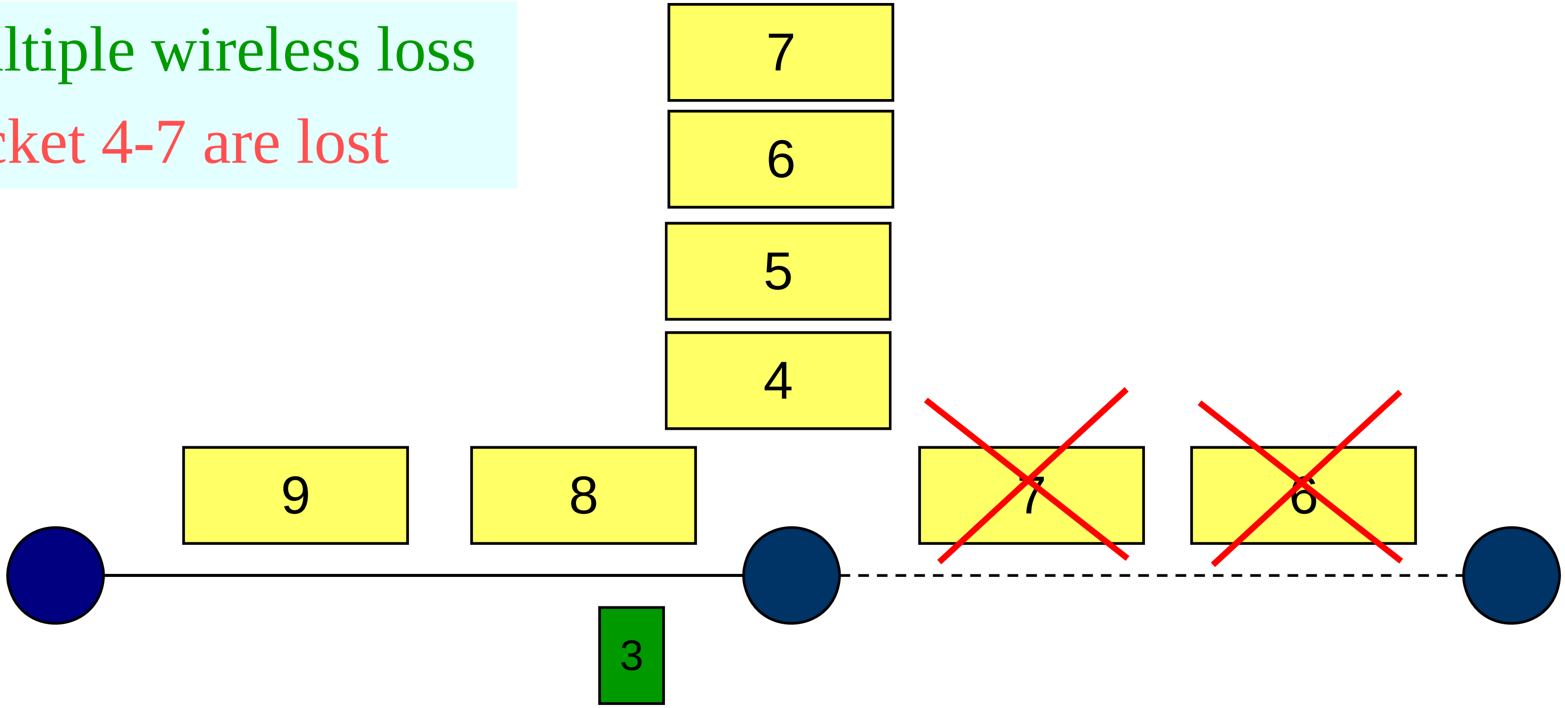




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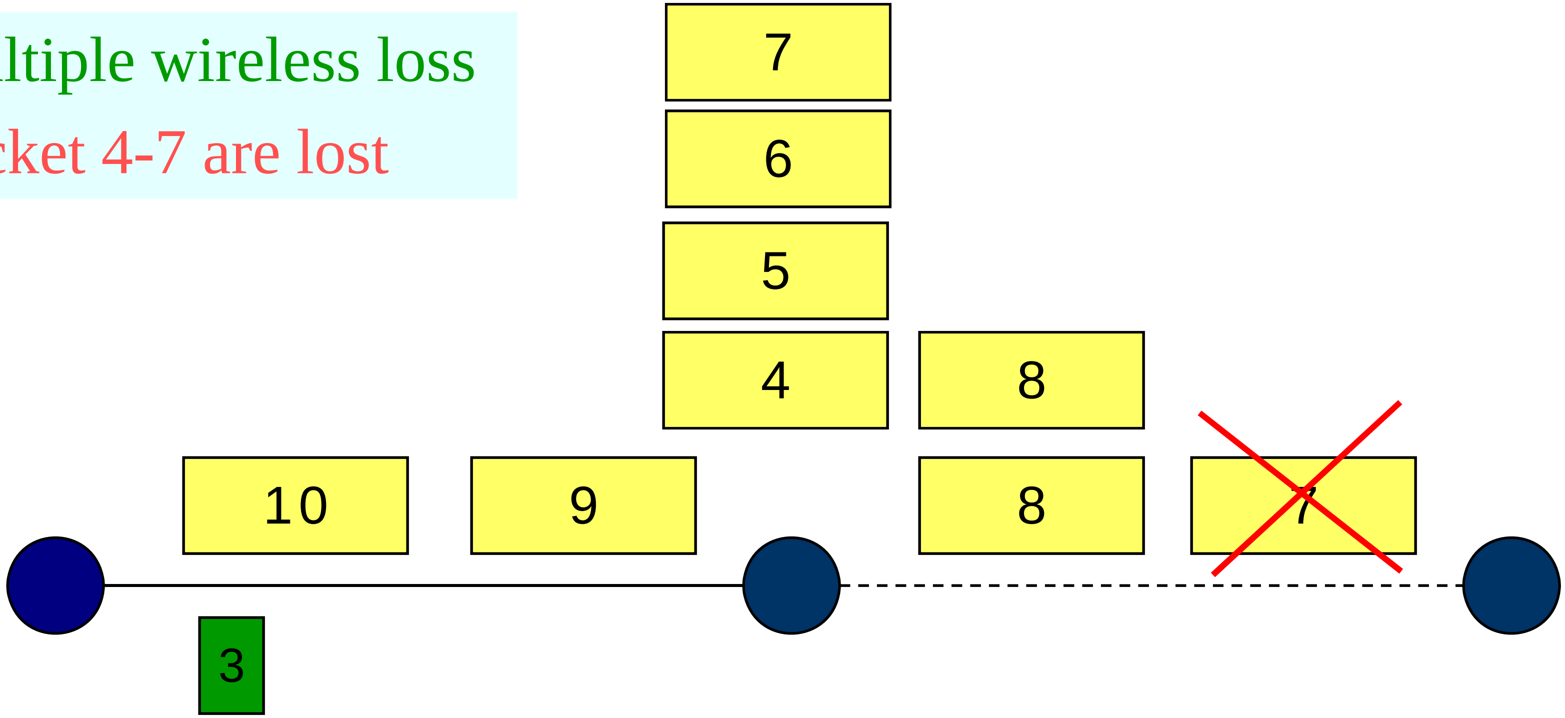




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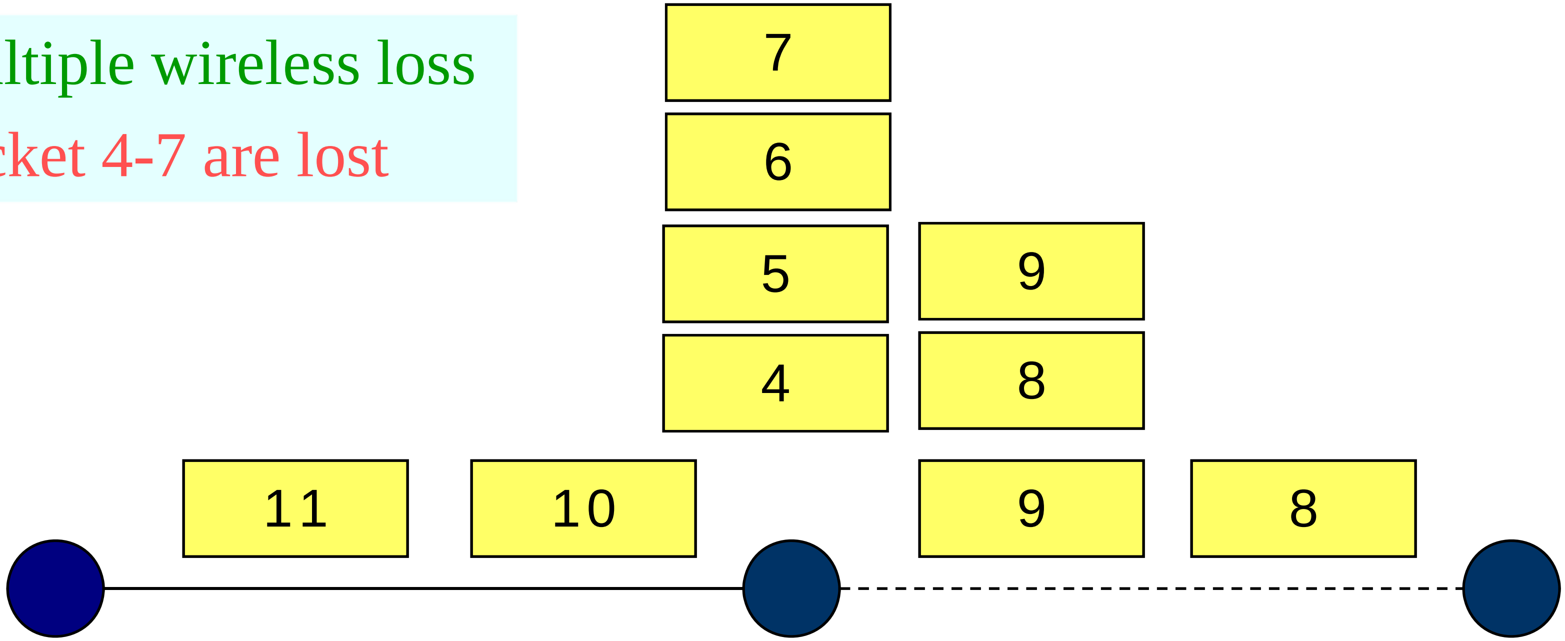




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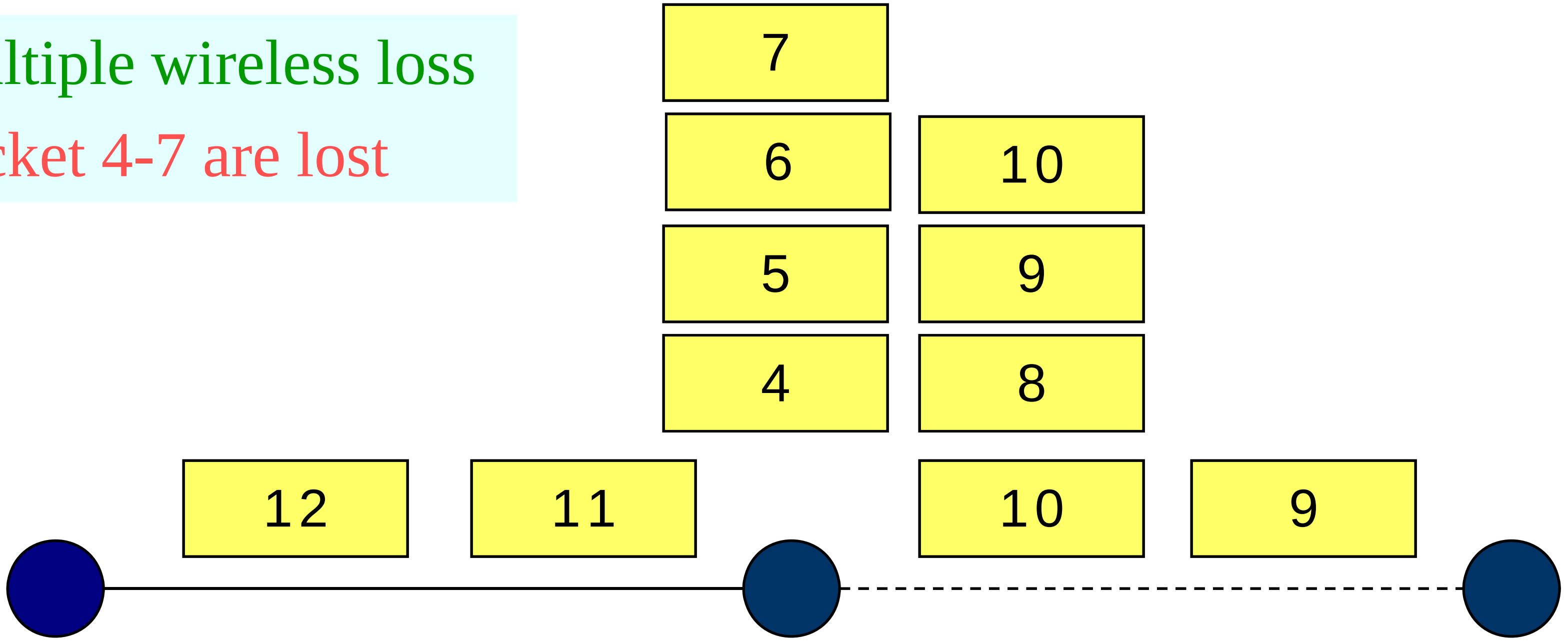




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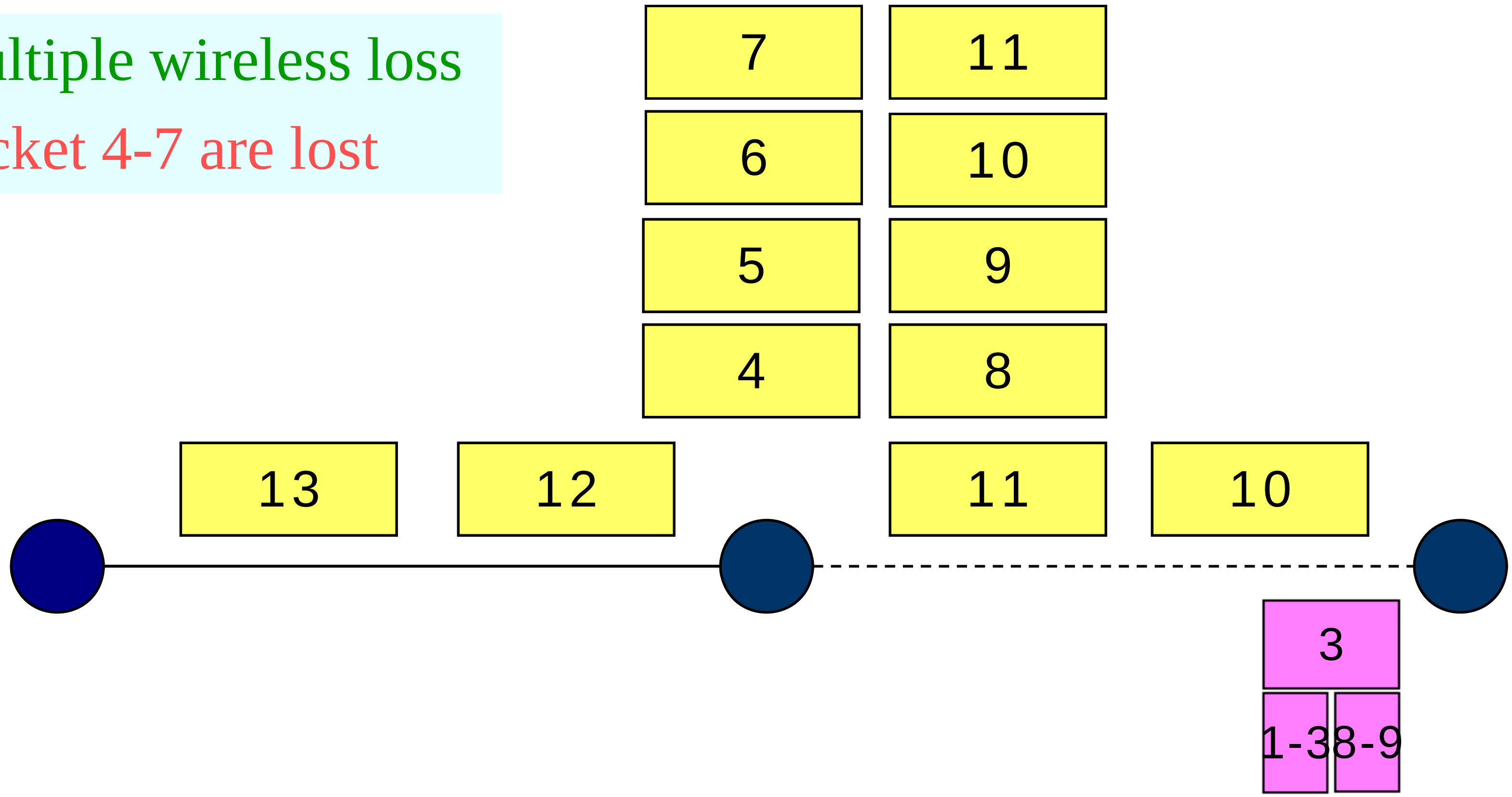




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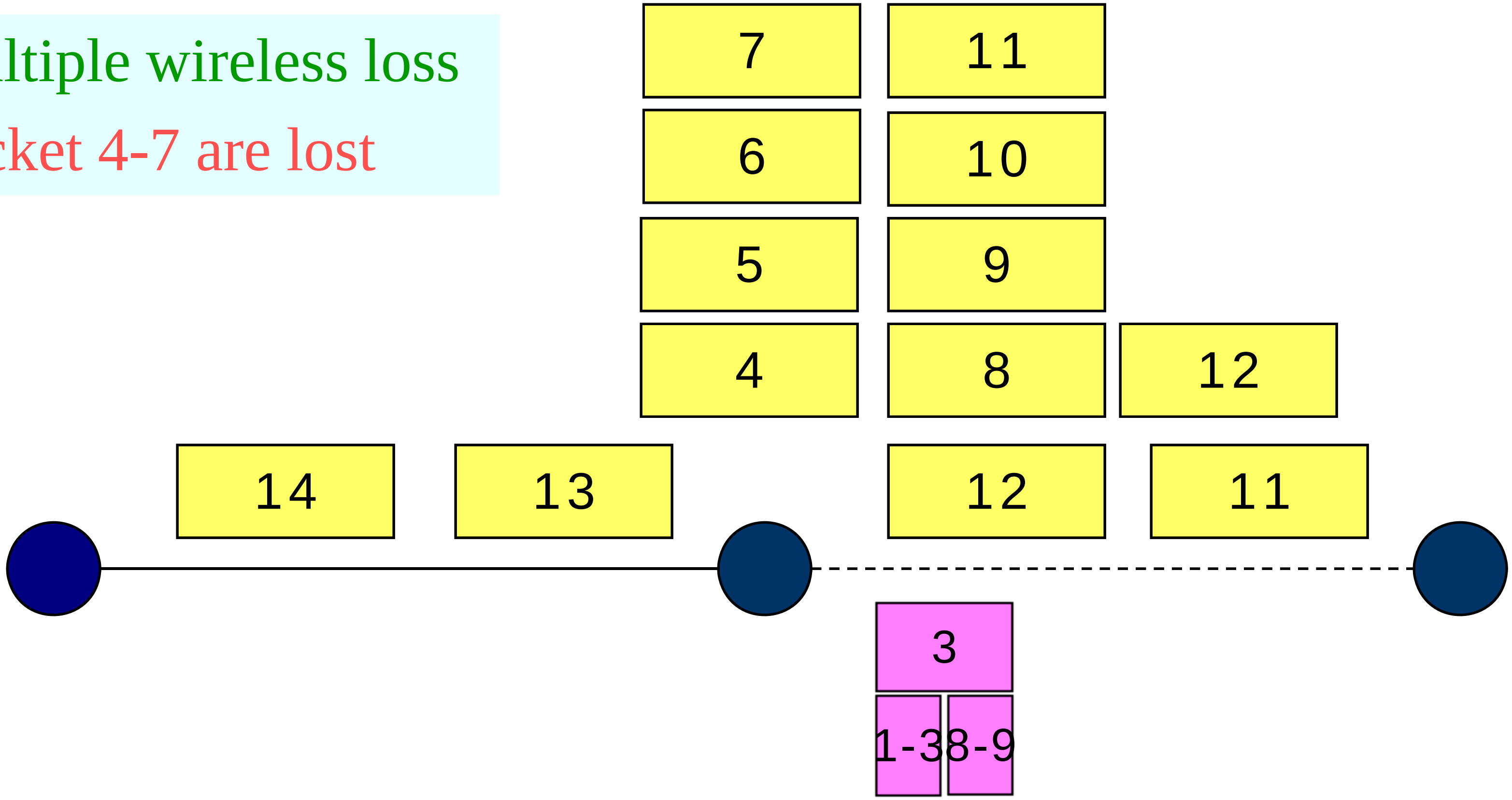




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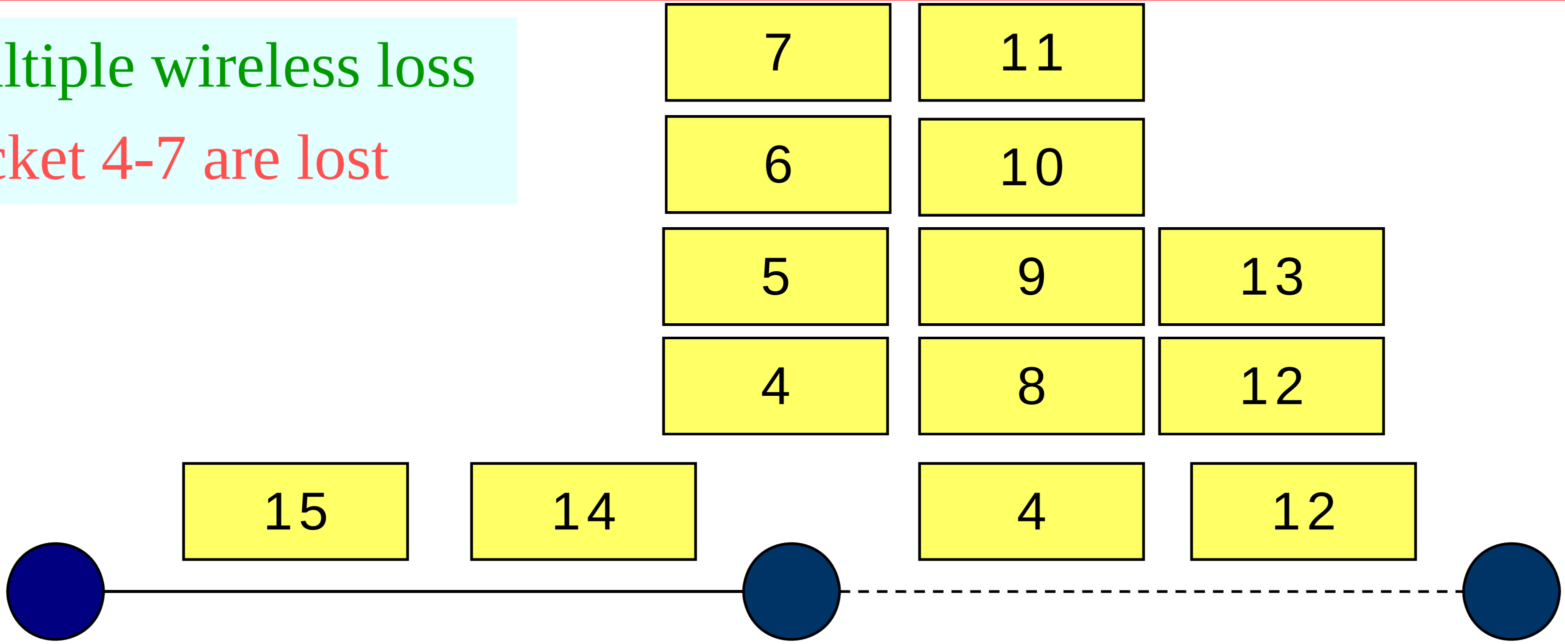




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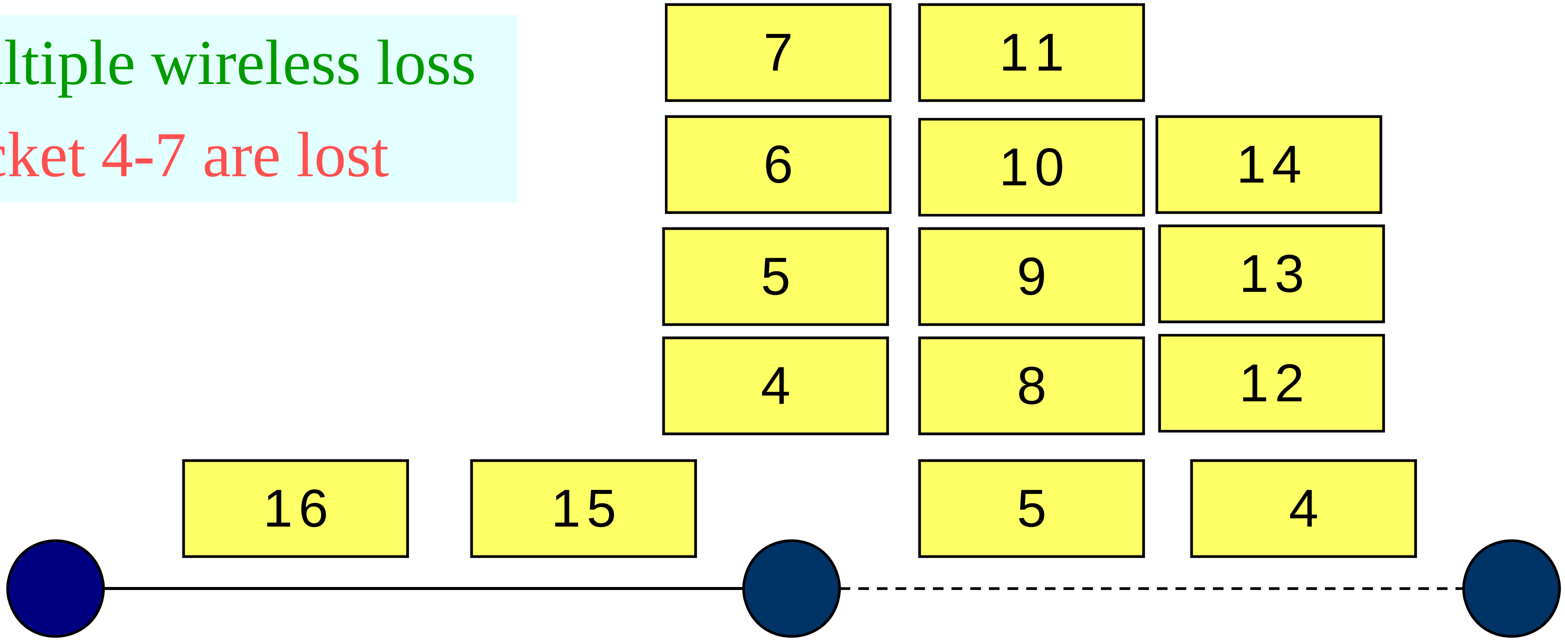




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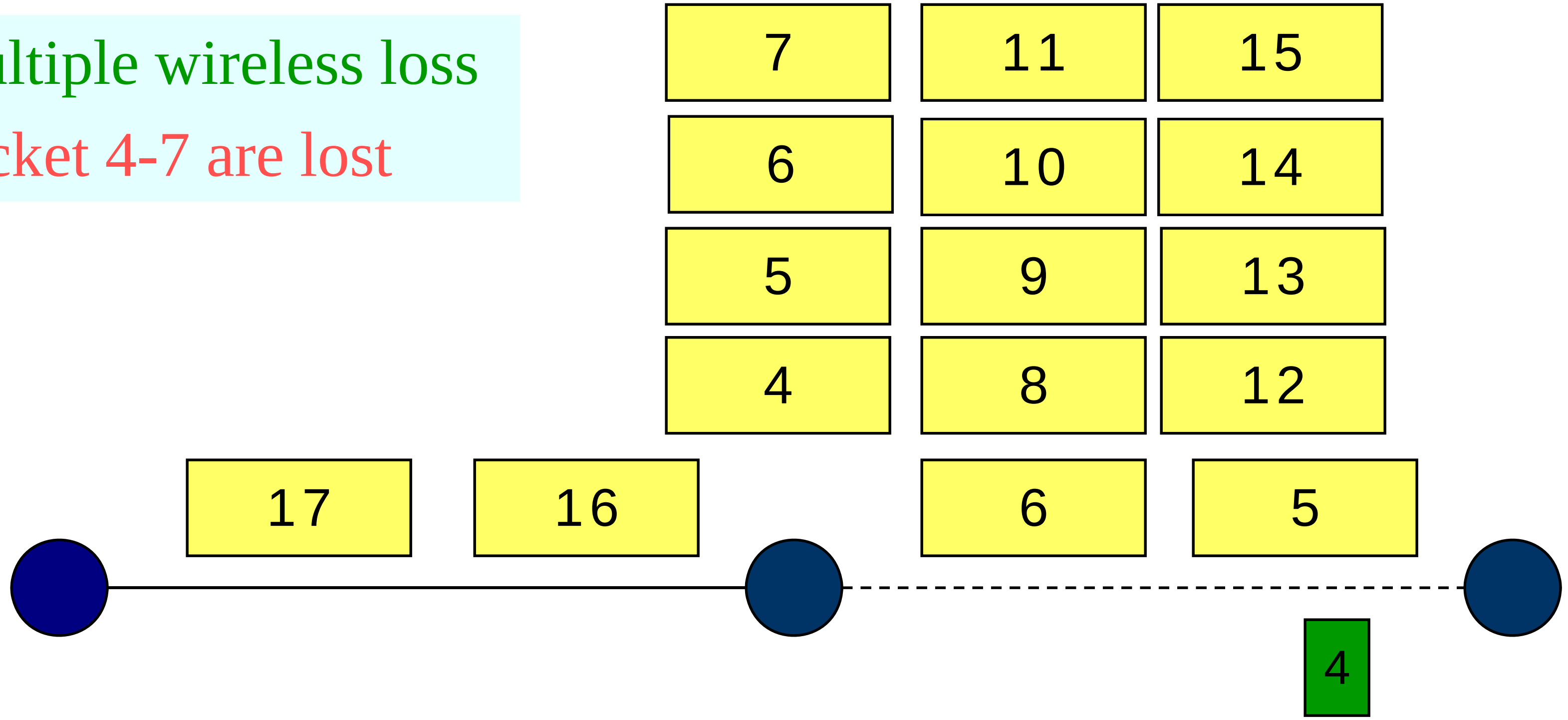




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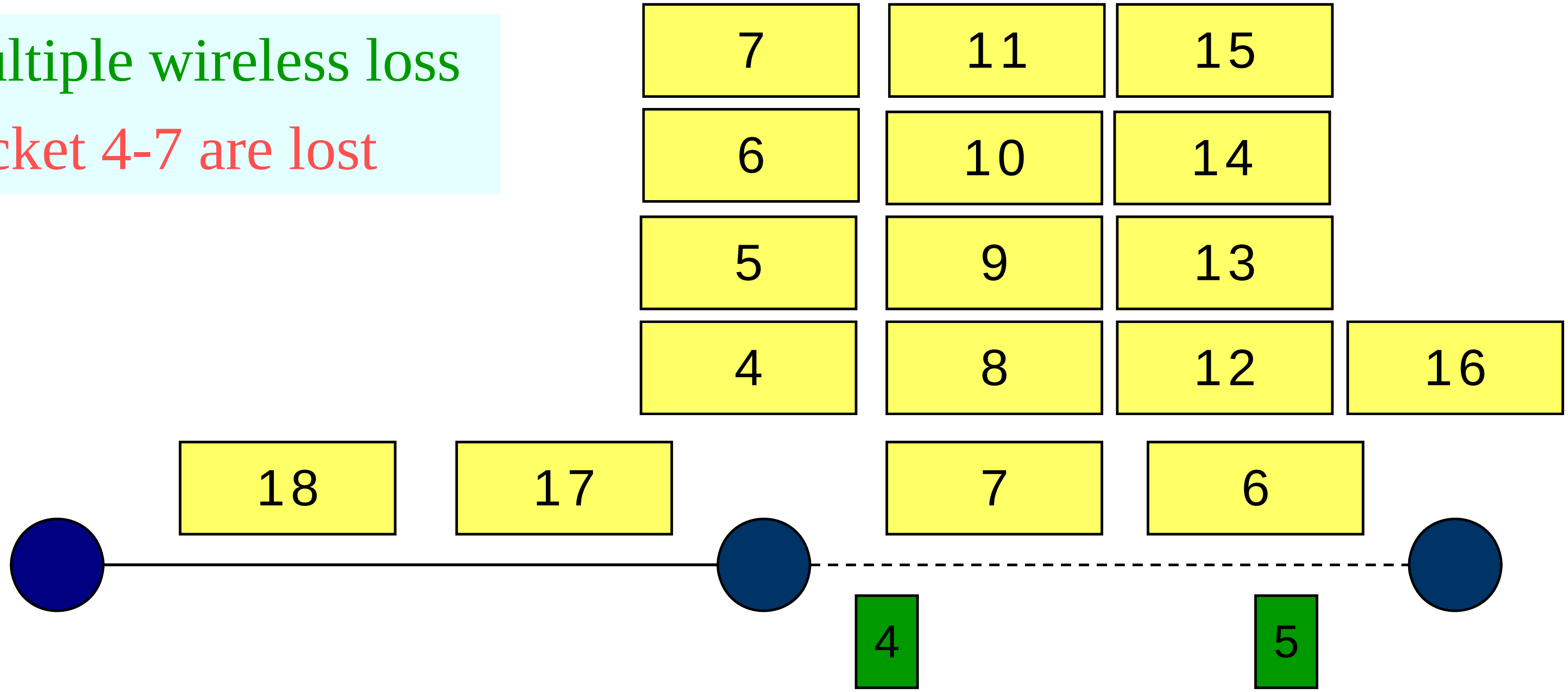




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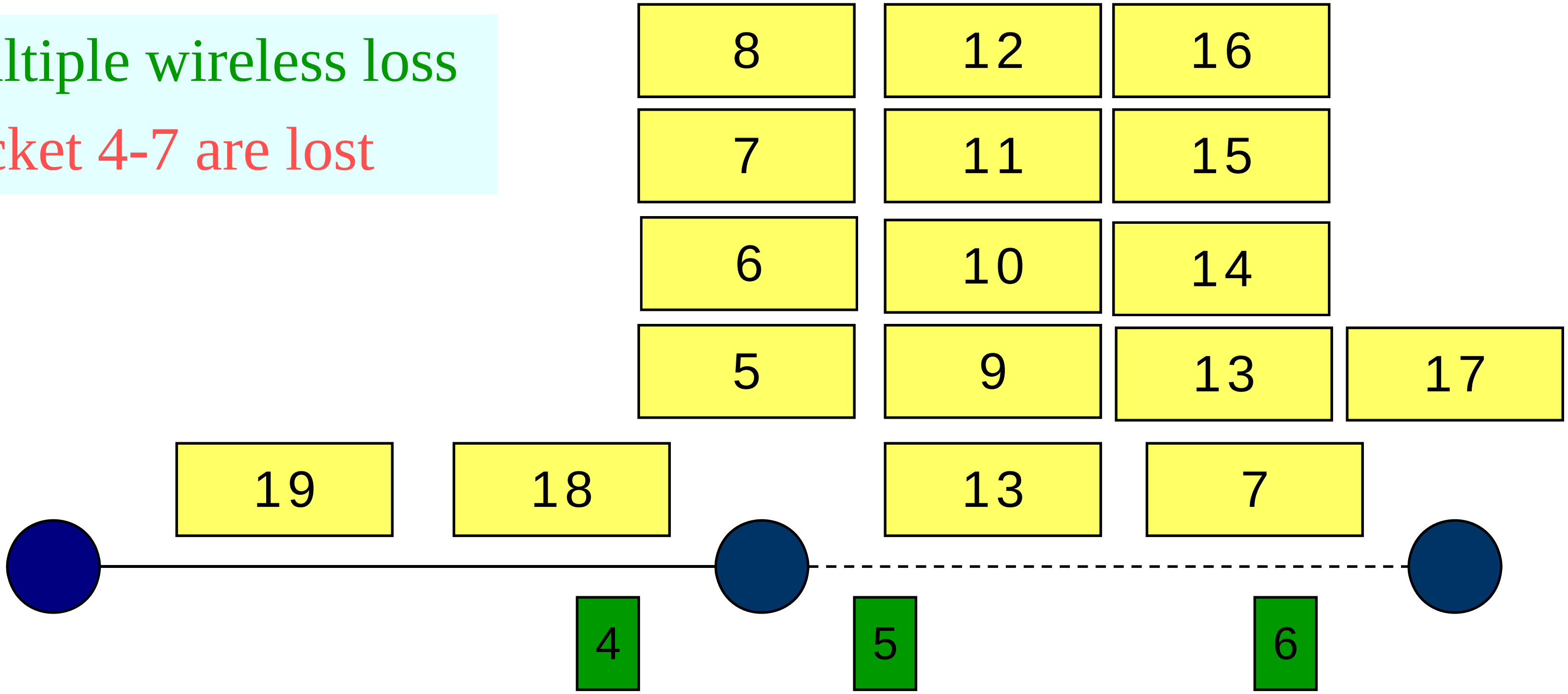




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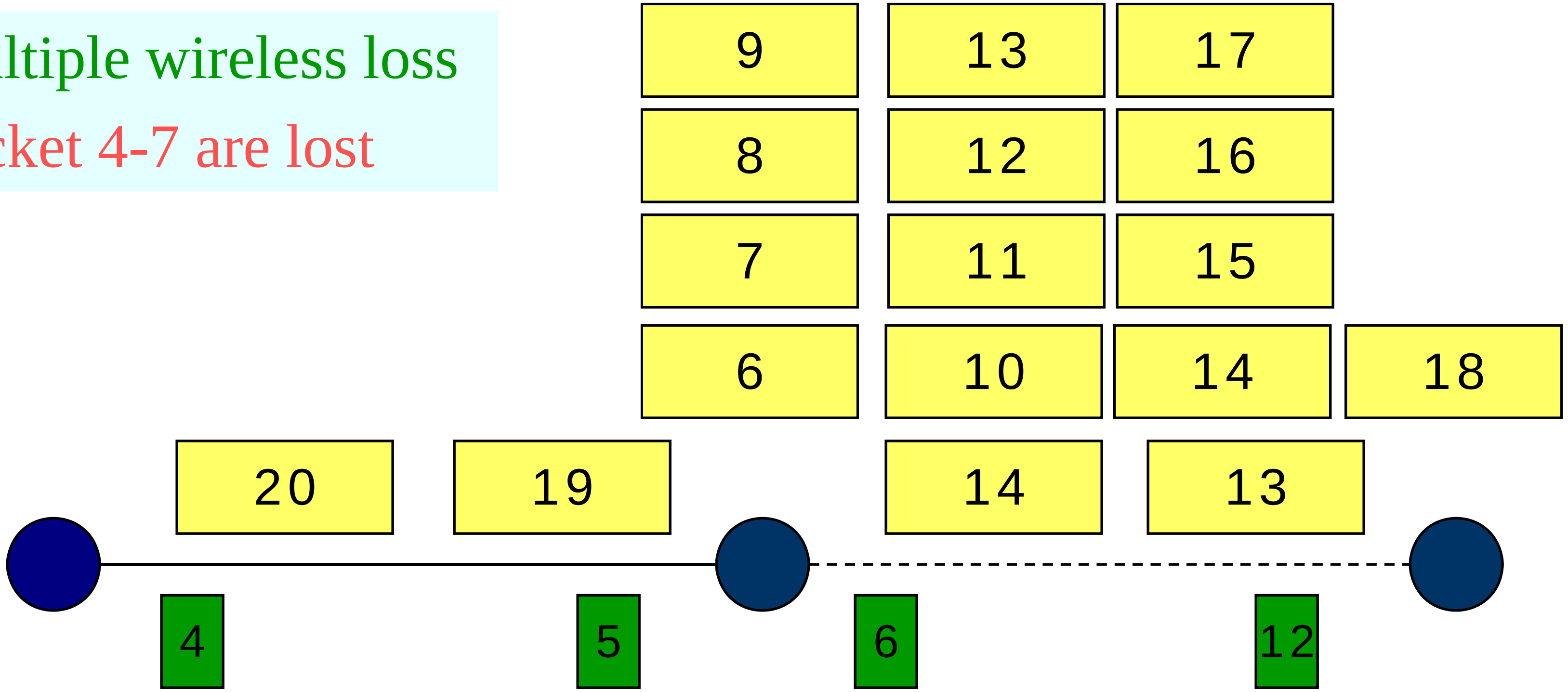




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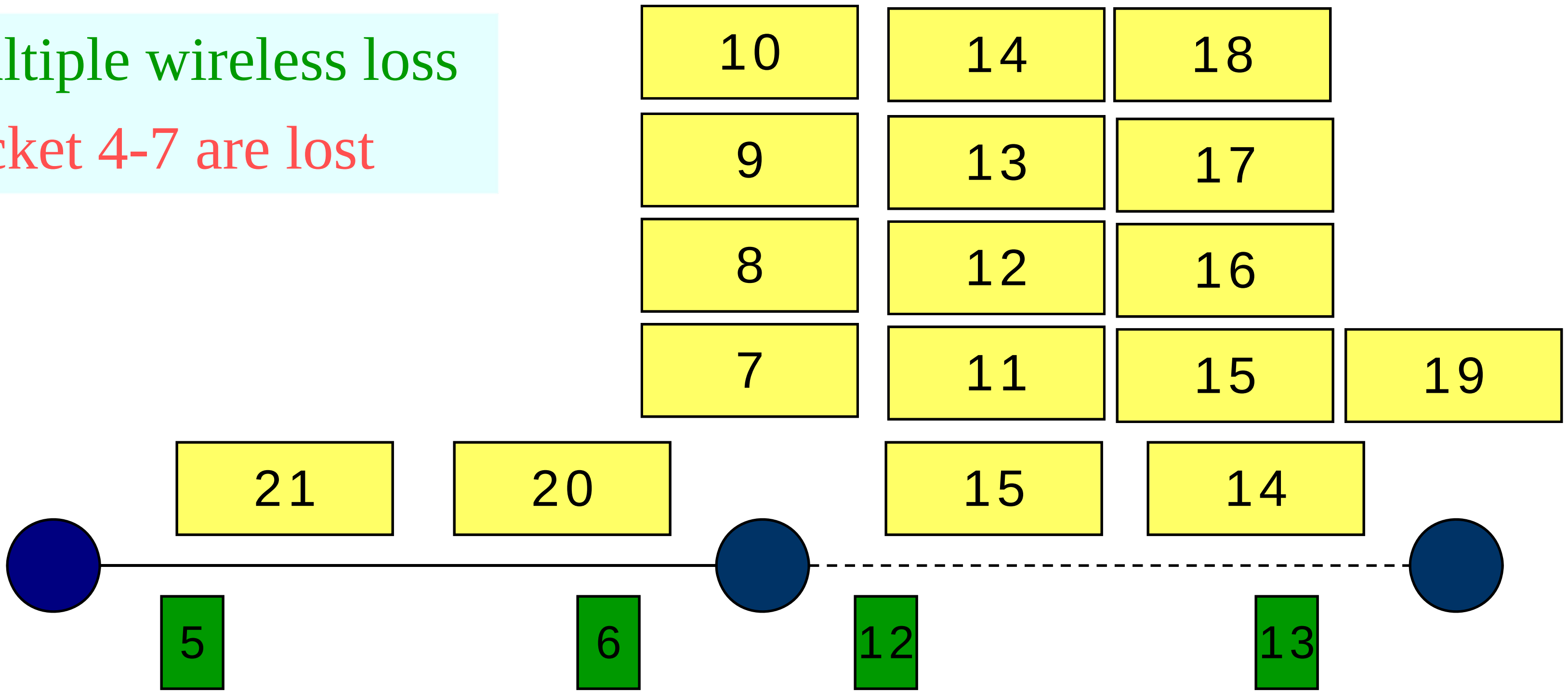




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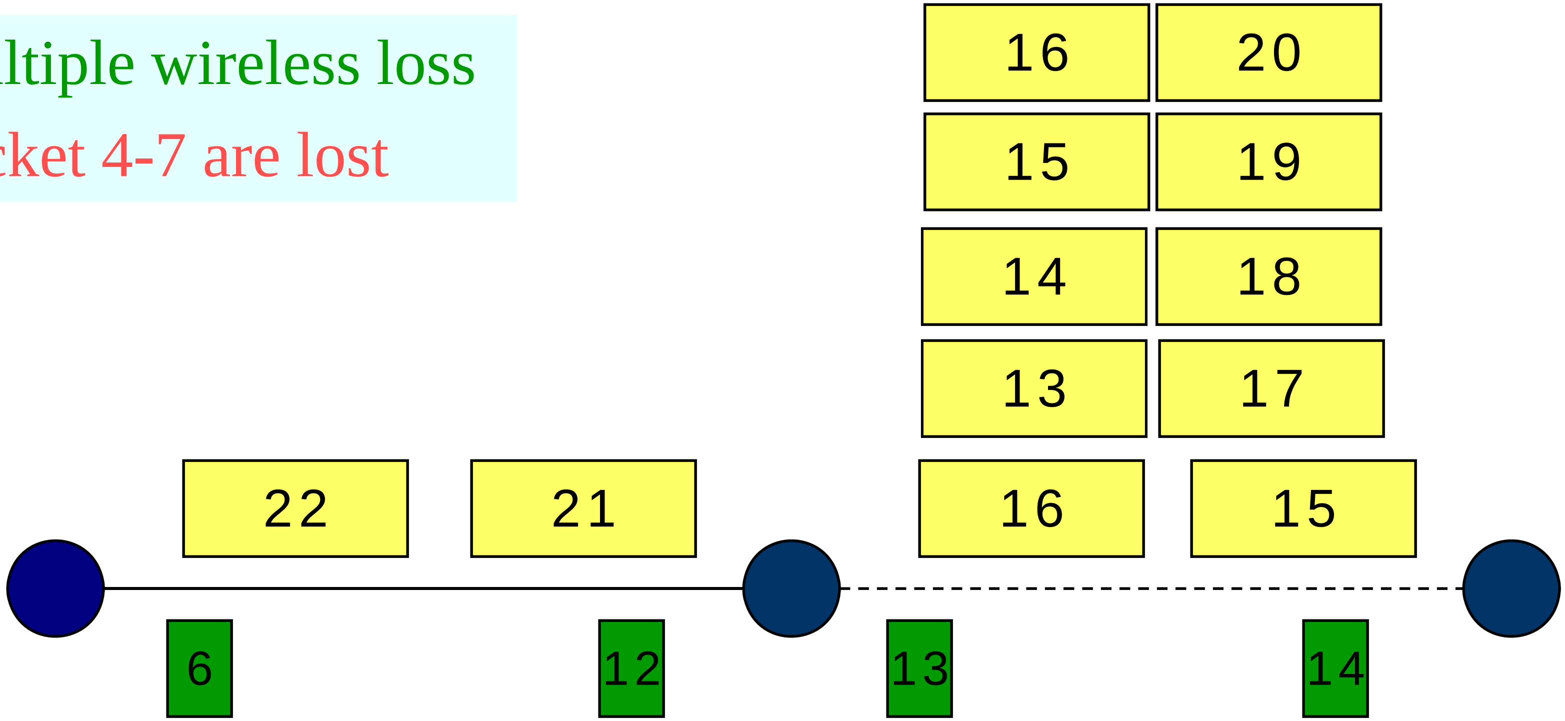




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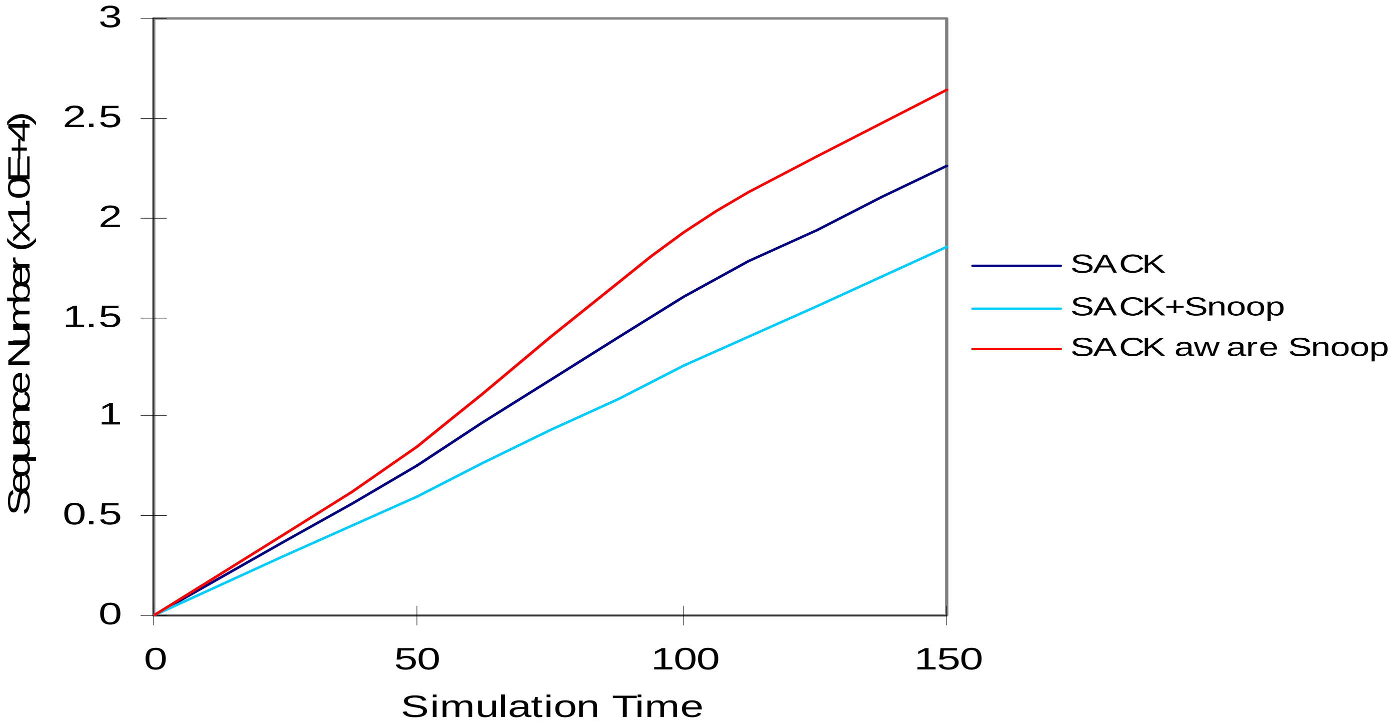
# TCP SACK-Aware Snoop

- Wireless channel is of 2 Mbps capacity with negligible delay
- Wireless channel modeled as two state marcov model with good state 97 msec and bad state 3 msec yielding steady state packet error rate of 5%



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# Summary

***It is difficult to create a "one size fits all" TCP for Last Hop Wireless Networks***

# Challenges

- Try to minimize effect of high BER
  - ***Localization may be preferred***
- Provide real time handoff and roaming facility
  - ***Try caching at higher level of network hierarchy***
- Share wireless bandwidth efficiently between different classes of traffic
  - ***Your protocol must be fair to other transport protocols***
  - ***Use some fairness index***

# Challenges

- Reduce number of retransmission
  - ***Required for battery powered devices***
  - ***Hard to do***
  - ***Give little attention***

- Do not become too aggressive while increasing congestion window to avoid congestion

- Do not become too conservative while decreasing congestion window to keep the pipe full



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