Introduction to Wireless and Mobile Networking

Lecture: TCP in wireless and mobile networks

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TCP in Wireless and Mobile Networks

- References
  - K. Pentikousis, "A survey of TCP in wired-cum-wireless environments," IEEE Communications Surveys, vol. 3, 2000.
  - http://www.crhc.uiuc.edu/wireless/talks/tcp-wireless-tutorial.ppt

TCP Overview

Transmission Control Protocol

- Provide reliable transport layer mechanism
- Congestion control and avoidance
- Window-based flow control
- Use ACKs to acknowledge all received bytes
- Use byte sequence number

TCP window flow control

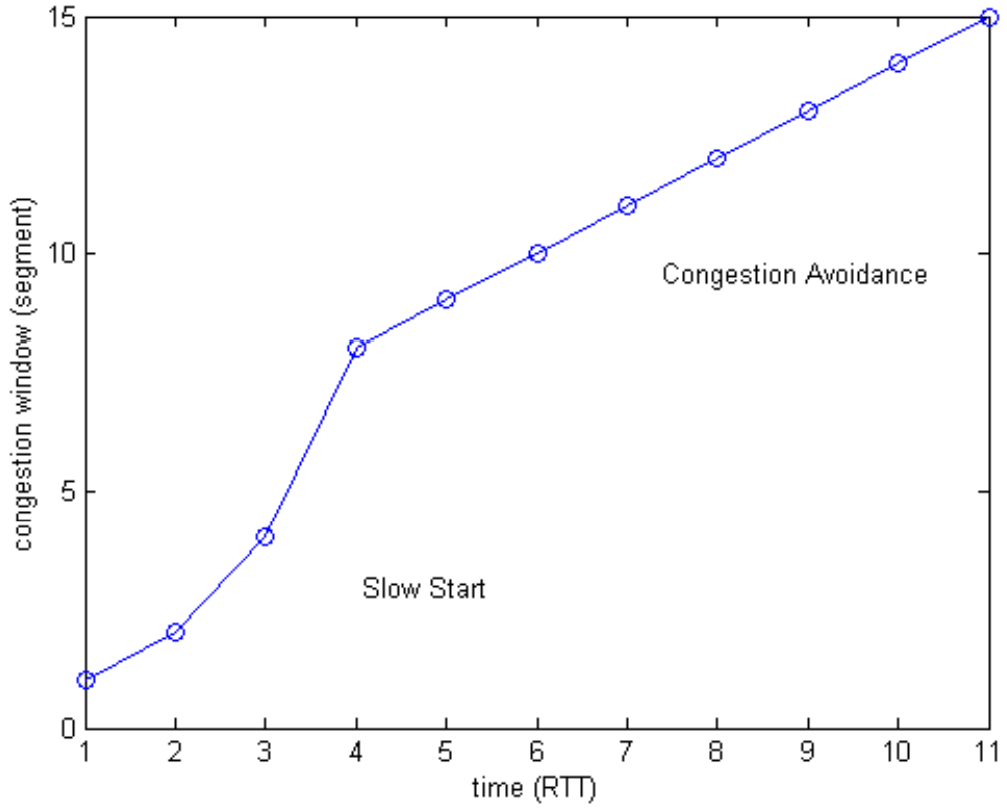
- Additive increase and multiplicative decrease
- Increase window (2 phase)
  - Slow start
  - Congestion avoidance
- Decrease window
  - When detecting packet loss
  - Assume congestion occur

Slow Start

- Additive increase
- Congestion window cwnd
  - Initial value: cwnd=1 MSS (Maximum Segment Size)
  - Receiving every ACK: cwnd=cwnd+1
  - cwnd grows exponentially
- Slow start stops when reaching slow start threshold

Congestion Avoidance

- When receive every ACK
  - cwnd = cwnd +1/cwnd



Wireless TCP

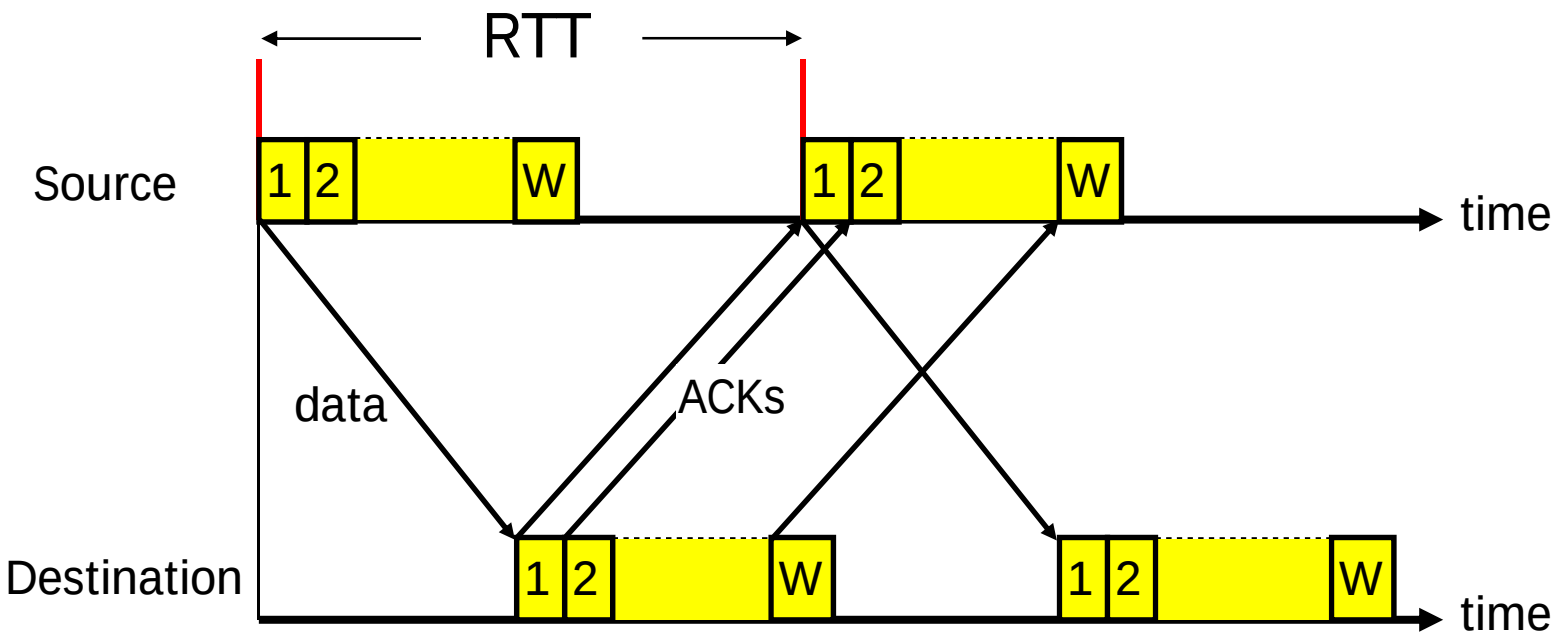
- Challenges in wireless and mobile environment
  - High BER (bit-error rate) in wireless medium
  - Mobility
- How transmission error affect TCP?
  - TCP thinks packet losses are due to congestion
    - Reduce congestion window size
    - Back off its retransmission timer
    - Reduce throughput

Variants of TCP and TCP mechanims

TCP (Transport Control Protocol)

- End-to-end transport layer protocol
- Functionalities
  - Congestion control
  - Flow control
  - Reliable transmission
  - Sequenced delivery

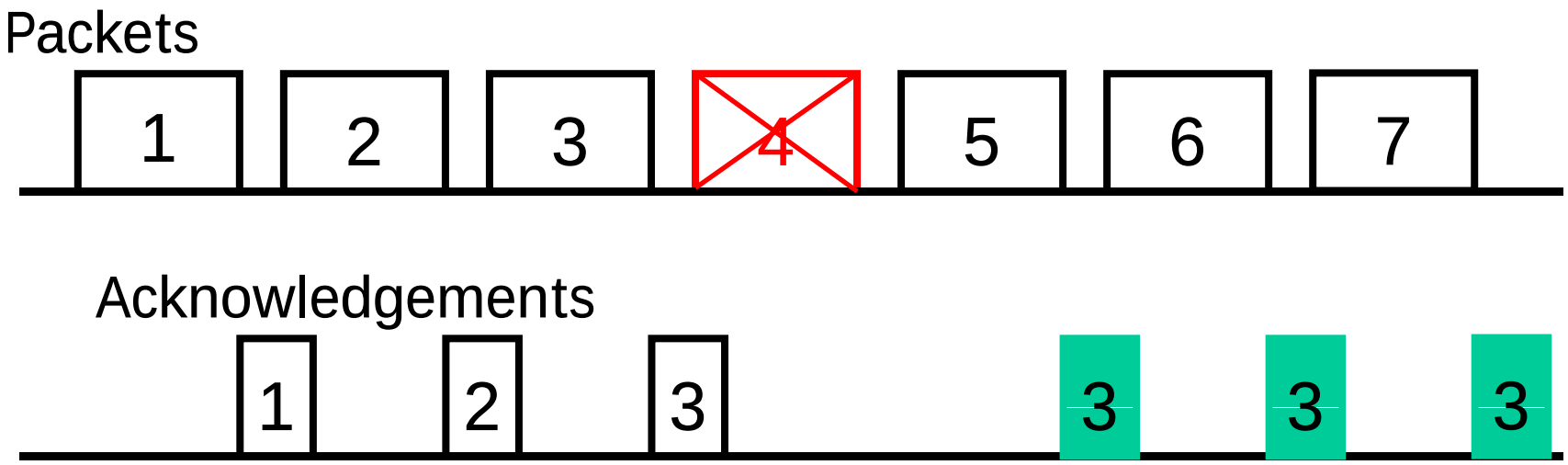
Window Flow Control



- ~ W packets per RTT
- Lost packet detected by missing ACK

Packet Loss

- Assumption: loss indicates congestion
- Packet loss detected by
  - Retransmission TimeOuts (RTO timer)
  - Duplicate ACKs (at least 3)



Issues in Wireless Environment

Wireless Transmissions

- Limited bandwidth
- Long Round Trip Time
  - Severe issue in satellite communications
  - Current 3G cellular also tries to reduce RTT
- High BER
  - Strong FEC might be inefficient
- Short Flows
  - HTTP applications need several small packet transmissions
- Power consumption
  - Long TCP session might be power inefficient

TCP with mobile hosts

- Mobile IP
  - Designed for handoff less frequent than 1 per sec
- Handoff results in packet loss
- Might need to distinguish packet losses due to congestion and mobility

Problems

- TCP considers packet losses as indication of congestion
  - Trigger congestion control
- In wireless and mobile networks, packet losses could be due to
  - High BER of wireless transmission
  - Handoff
- Frequent TCP congestion window backoff results in
  - Small window size
  - Limited throughput

Classifications of Solutions

- Link Layer
  - (1) Robust link layer
    - FEC/ARQ
  - (2) TCP-Aware Link Layer solution
    - Snoop
  - (3) TCP-Unaware Link Layer solution
    - TULIP
    - Delayed Duplicate ACK
- Split connection (Transport Layer)
  - Indirect TCP (I-TCP)
  - M-TCP

Classifications of Solutions (2)

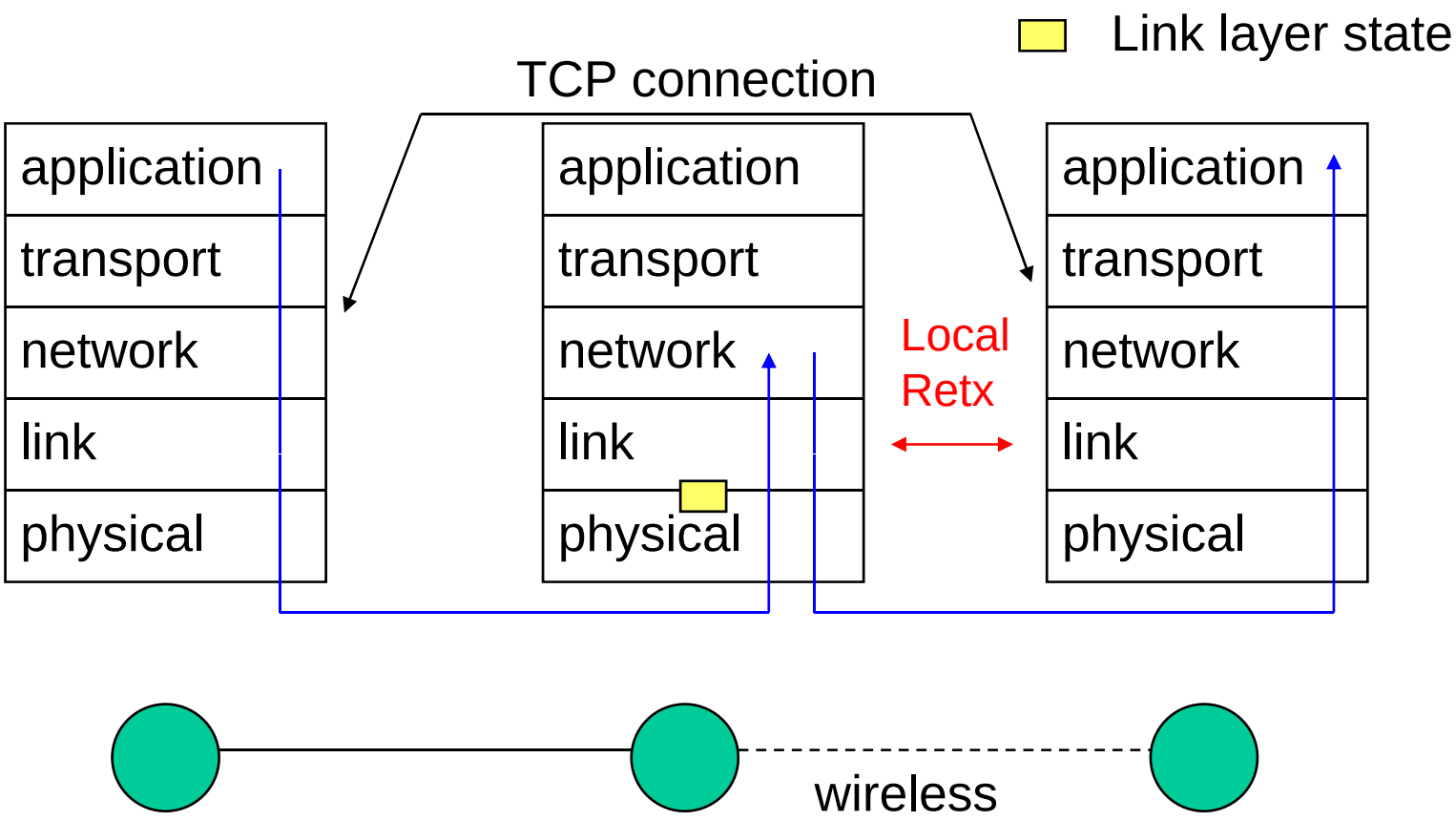
- Modified version of TCP
  - TCP SACK
  - TCP FACK
  - TCP Santa Cruz
- Other changes to TCP
  - Change ACK strategy
  - Increase TCP's Initial Congestion Window
  - Explicit Congestion Notification
  - Explicit Loss Notification
  - Fast Retransmit
- New Transport Layer
  - Wireless TCP
- WAP protocol stacks

Link Layer Solution

Link Layer Schemes

- Hide Wireless Link Error from TCP
  - Emulate a wired link
    - Reduce BER with FEC
    - Hide retransmission (L2) from L4
  - Reduce the error rate in wireless medium
    - Automatic Repeat Request (ARQ)
    - Forward Error Correction (FEC)
    - Hybrid FEC/ARQ scheme
- TCP-aware Link Layer Solution
  - Snoop

Link Level Retransmissions



Link Layer: Strength/Weakness

- Advantages
  - No connection state to be maintained at BS
  - Layered structure
  - Shielding the loss to higher-layer protocols
- Disadvantages
  - Do not solve the mobility issue
  - Small timeout value for ARQ
  - Duplicate re-transmission effort

Related work

- FEC
  - Most communication systems use FEC
- ARQ
  - Cellular system typically uses ARQ
  - In some systems, ARQ is optional (e.g. 802.16)
- AIRMAIL (1995)
  - FEC+ARQ
- Hybrid ARQ
  - FEC+ARQ
  - Soft combining
  - Promising technique in many systems

Snoop

H. Balakrishnan *et al.*

Snoop

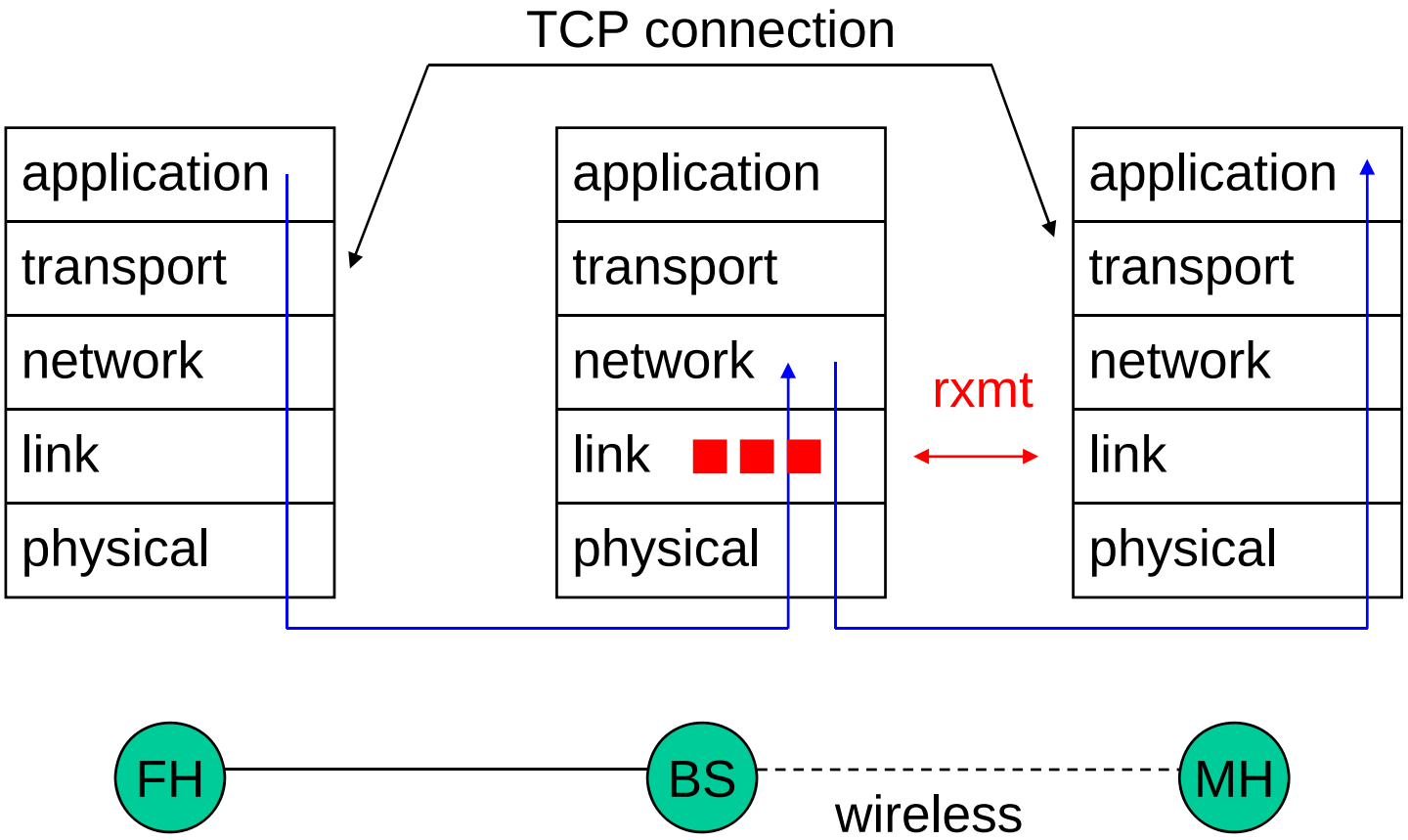
- Blakrishnan, Padmanabhan, Seshan, Katz
  - SIGCOMM 1996
- TCP-aware Link Layer solution
- Snoop Agent locates at BS
- No change required in wired network
- Snoop Agent monitors all TCP session
  - Maintain un-acknowledged TCP segment information at cache
  - Monitor both uplink/downlink
- Soft state

Snoop Agent Operation

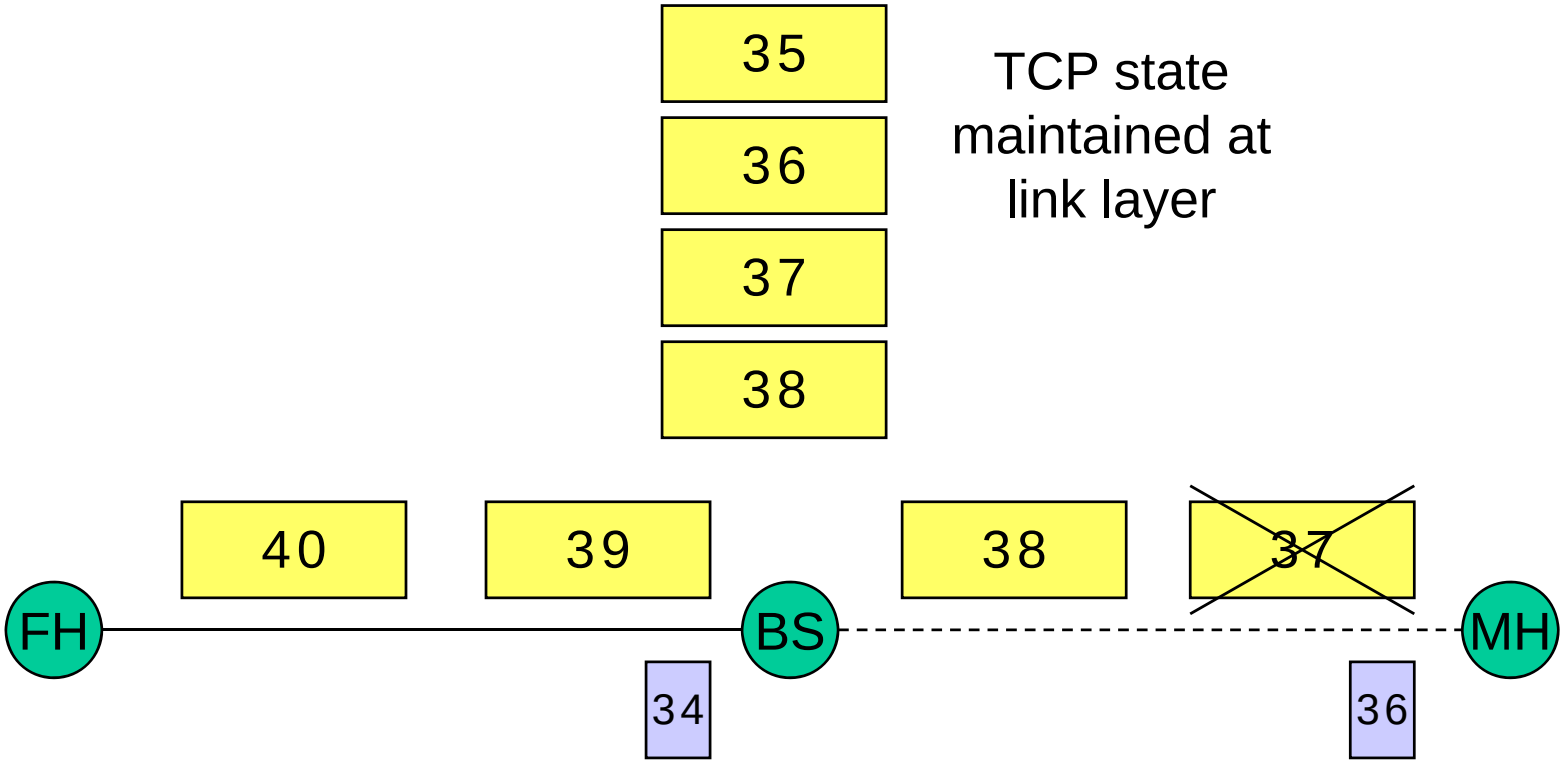
- Packet loss detection
  - Receive duplicate ACKs
  - Local timeout
- Hide the packet loss in wireless network
  - Retransmit cached packet
  - Dropping duplicate ACKs at BS to prevent from fast retransmission from source

Snoop Protocol

- Per TCP-connection state

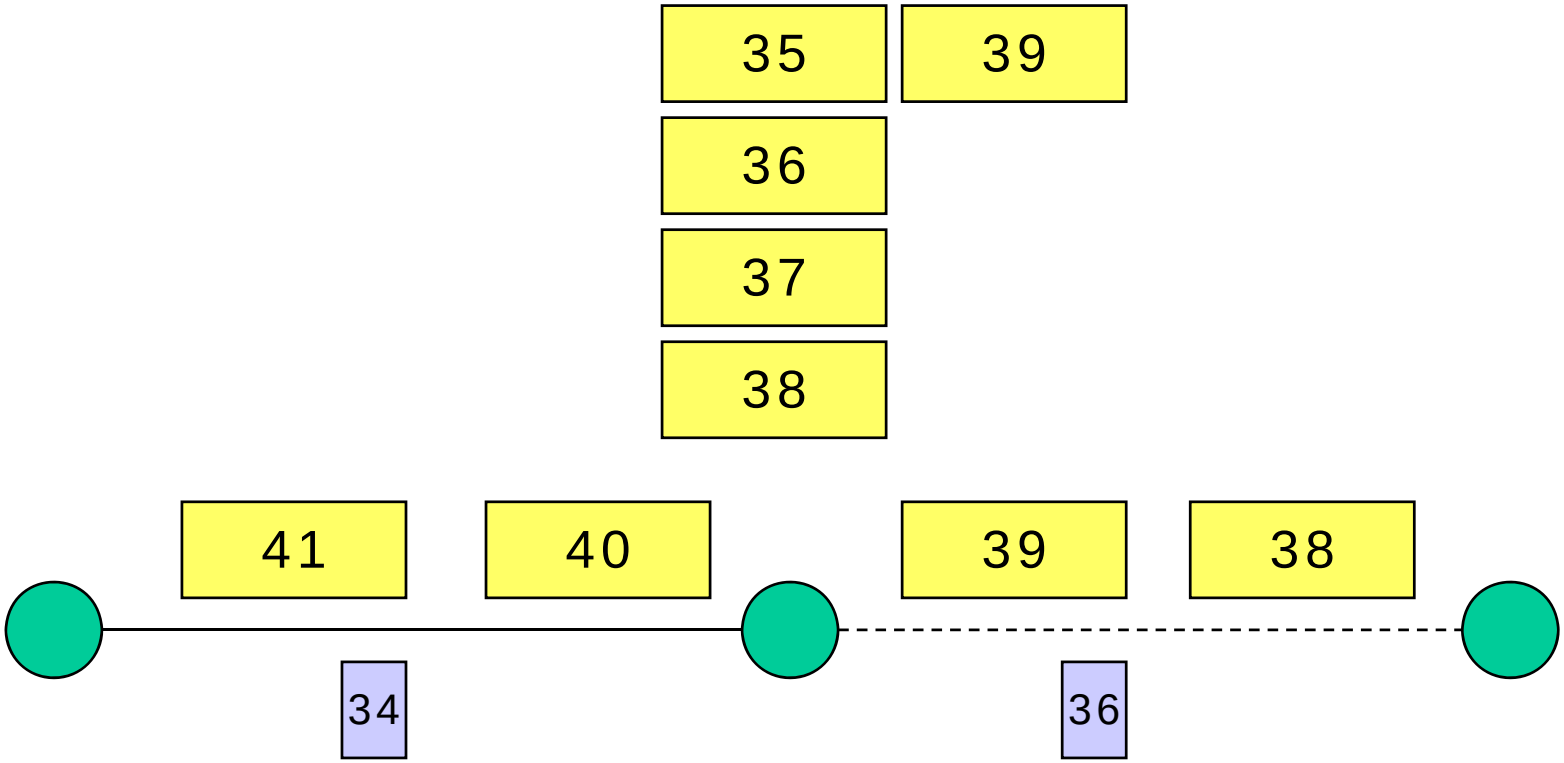


Snoop : Example



Example assumes delayed ack - every other packet ack'd

Snoop : Example



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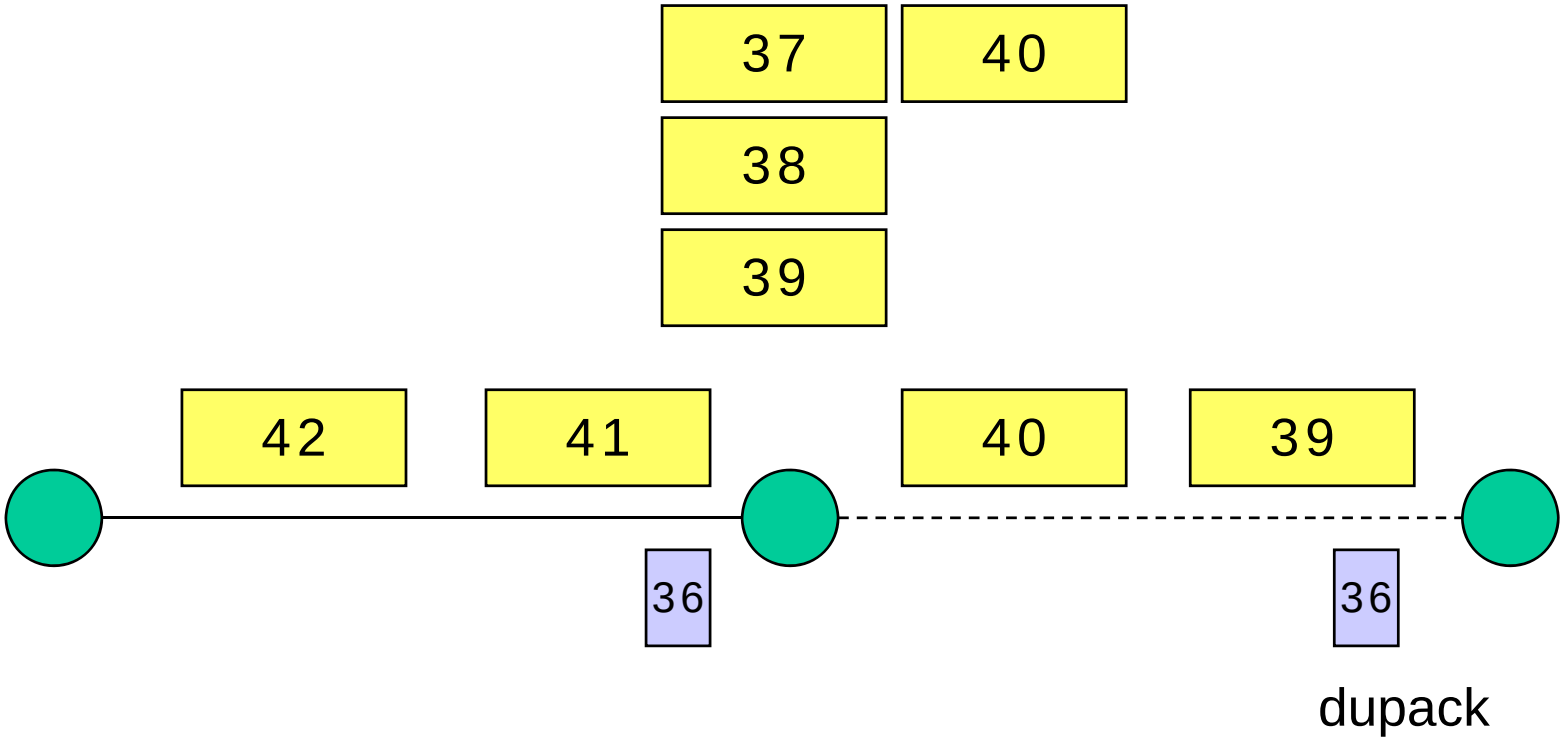
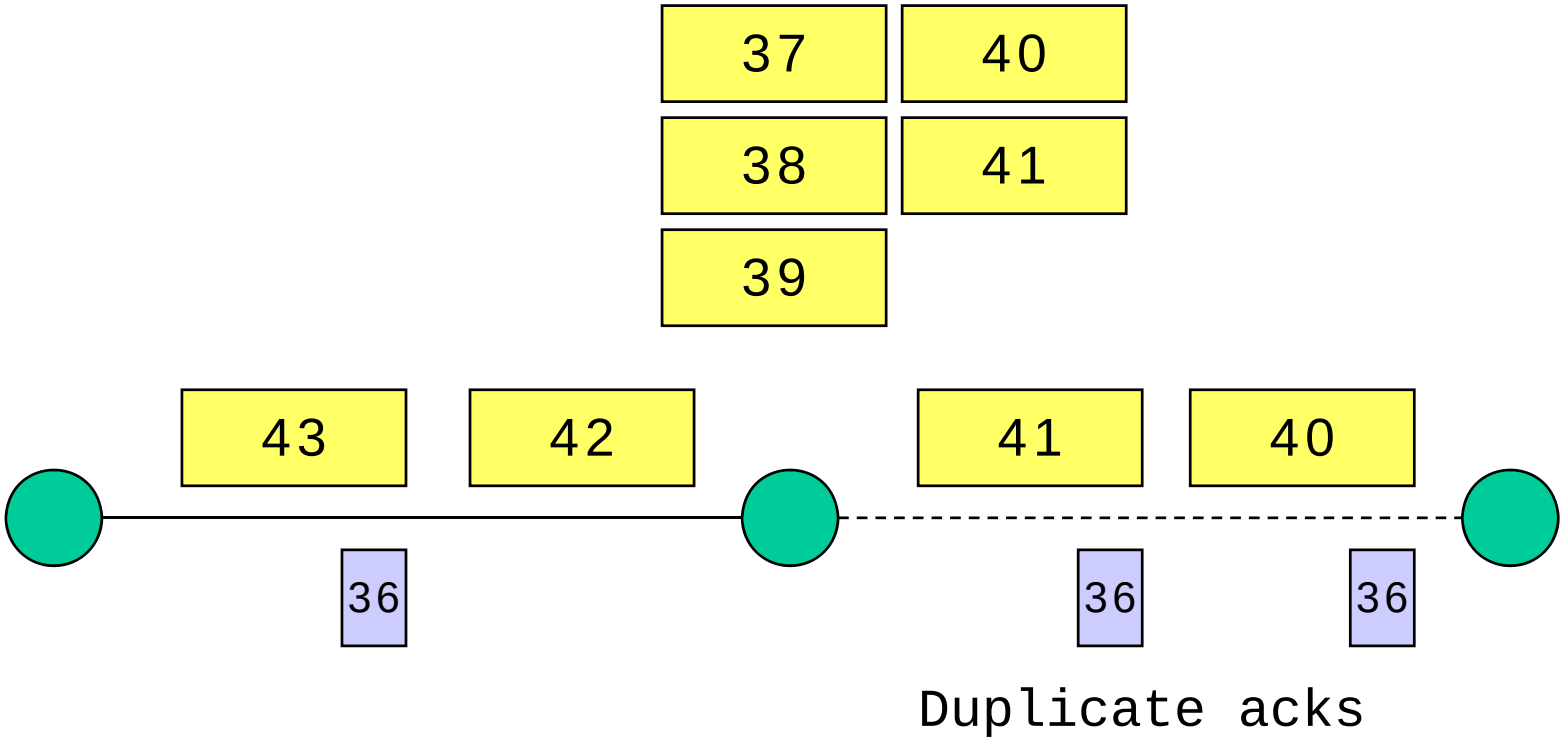


Duplicate acks are not delayed

Snoop : Example



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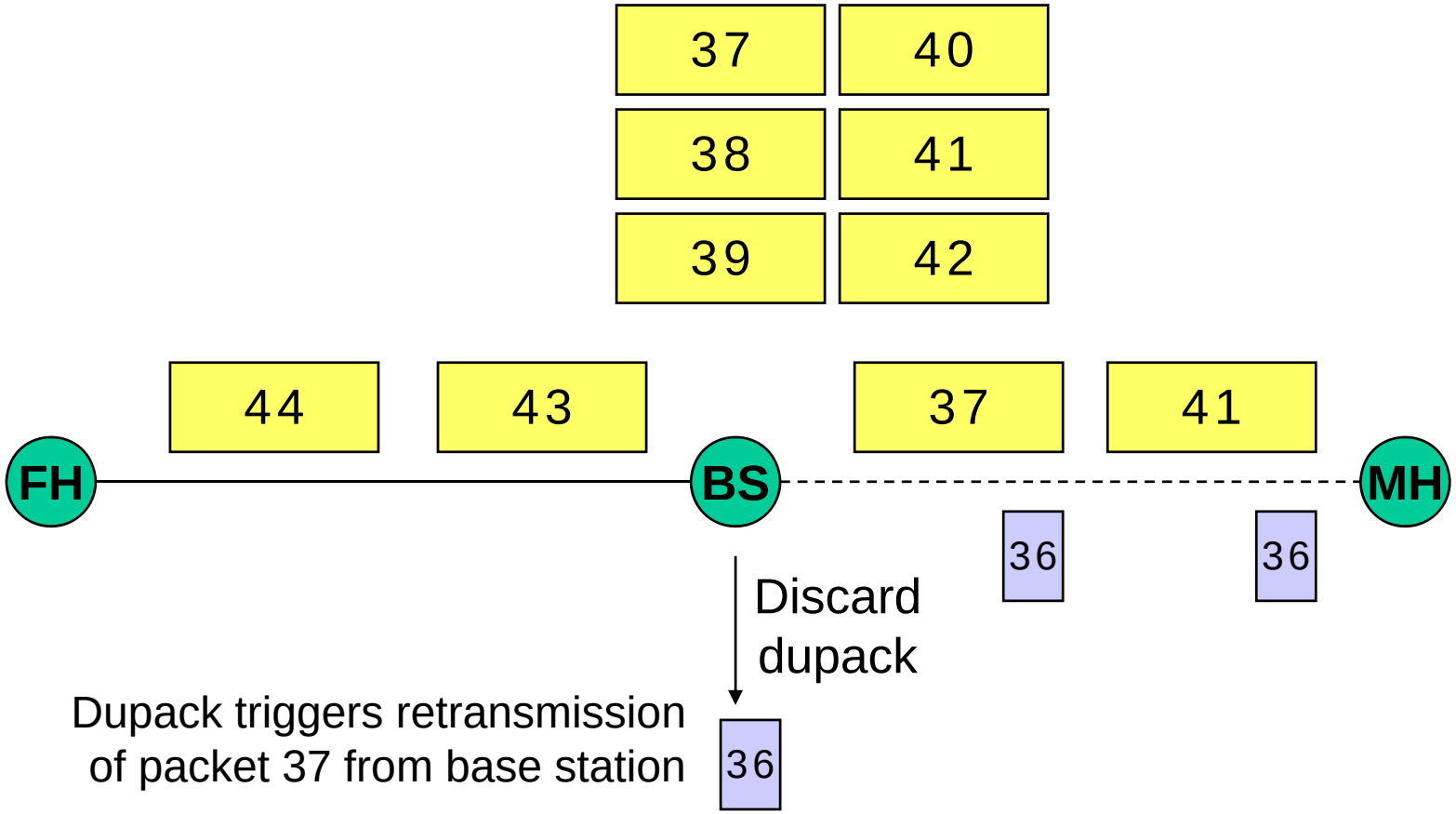

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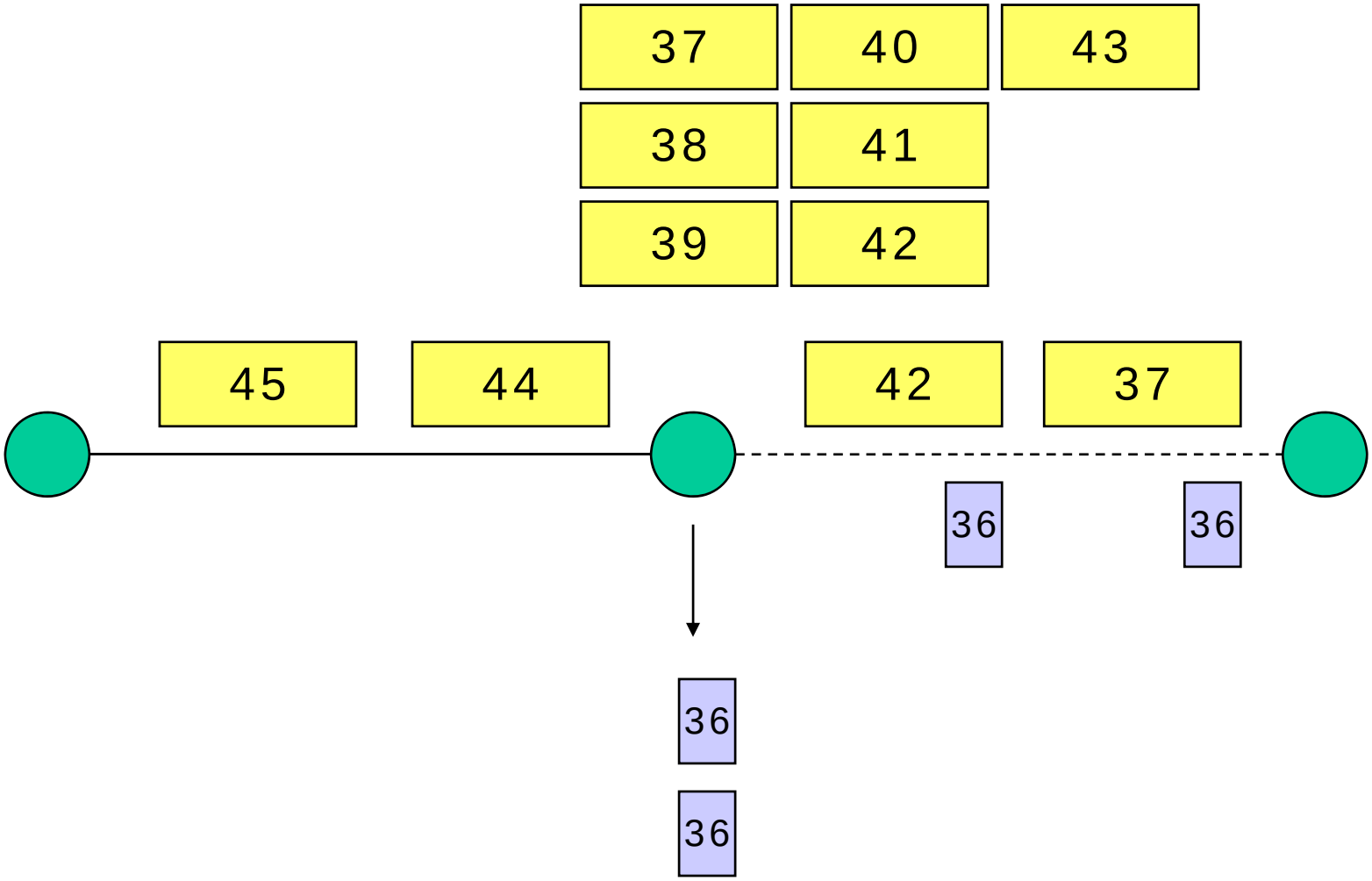

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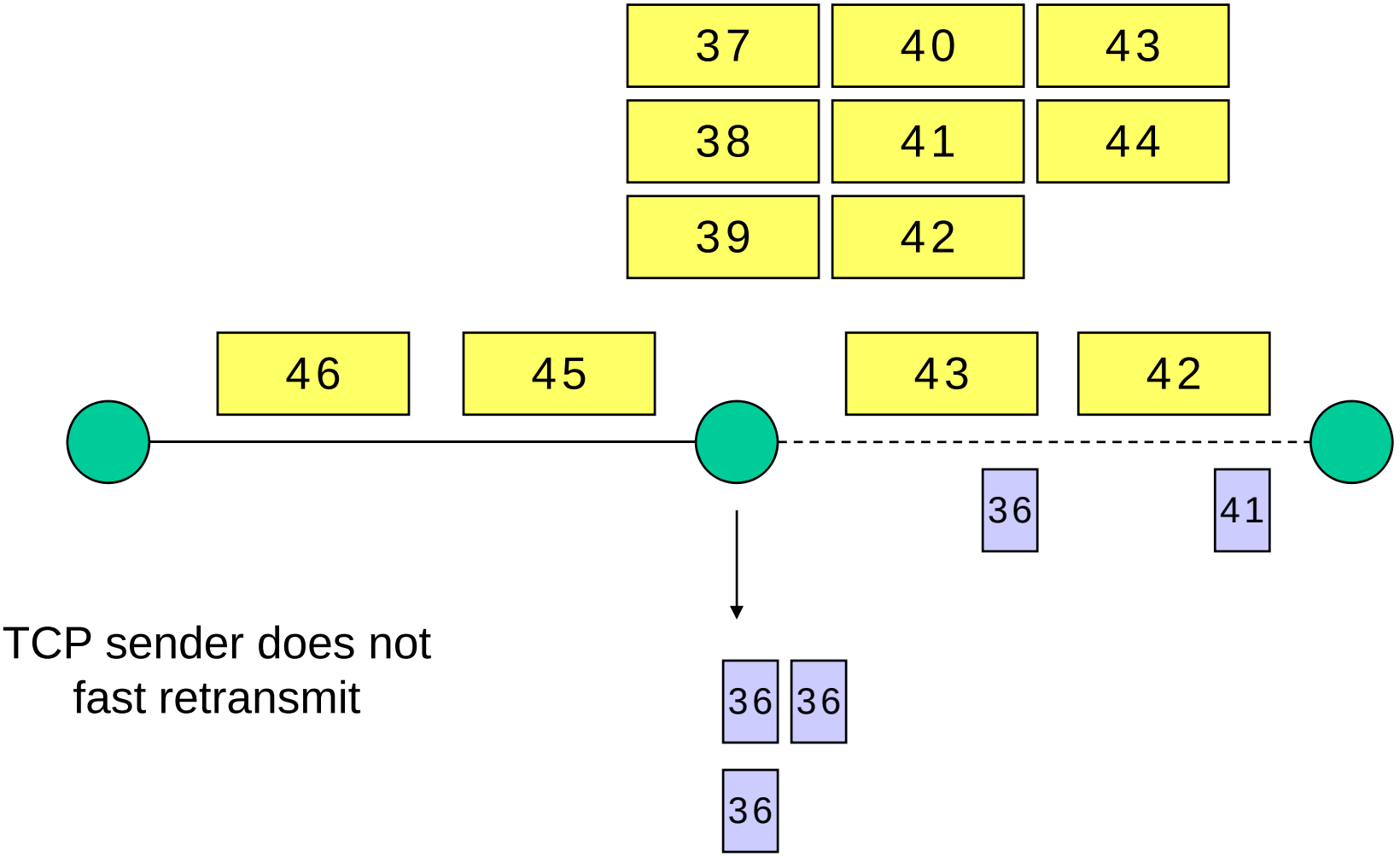
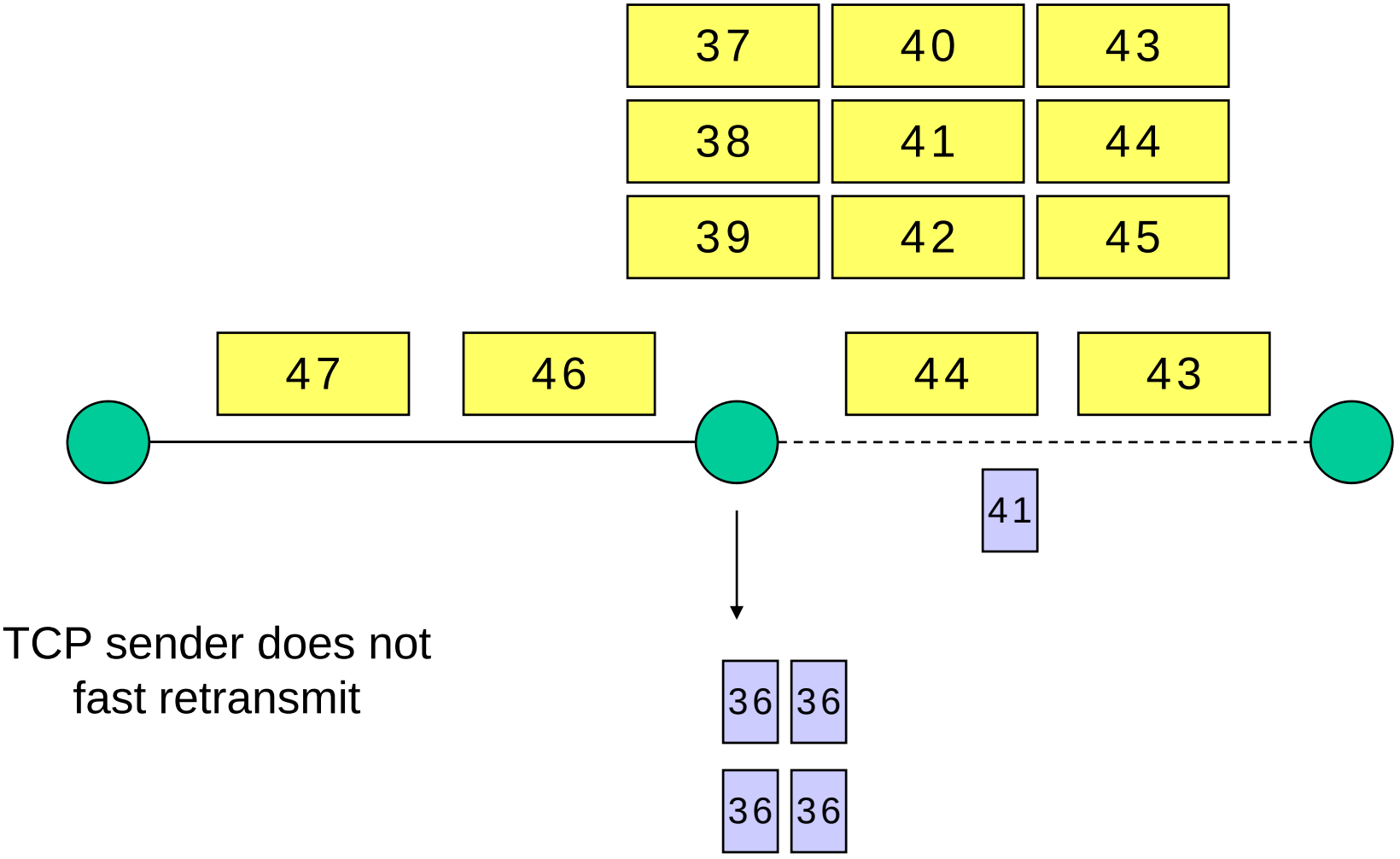


TCP sender does not
fast retransmit

Snoop : Example



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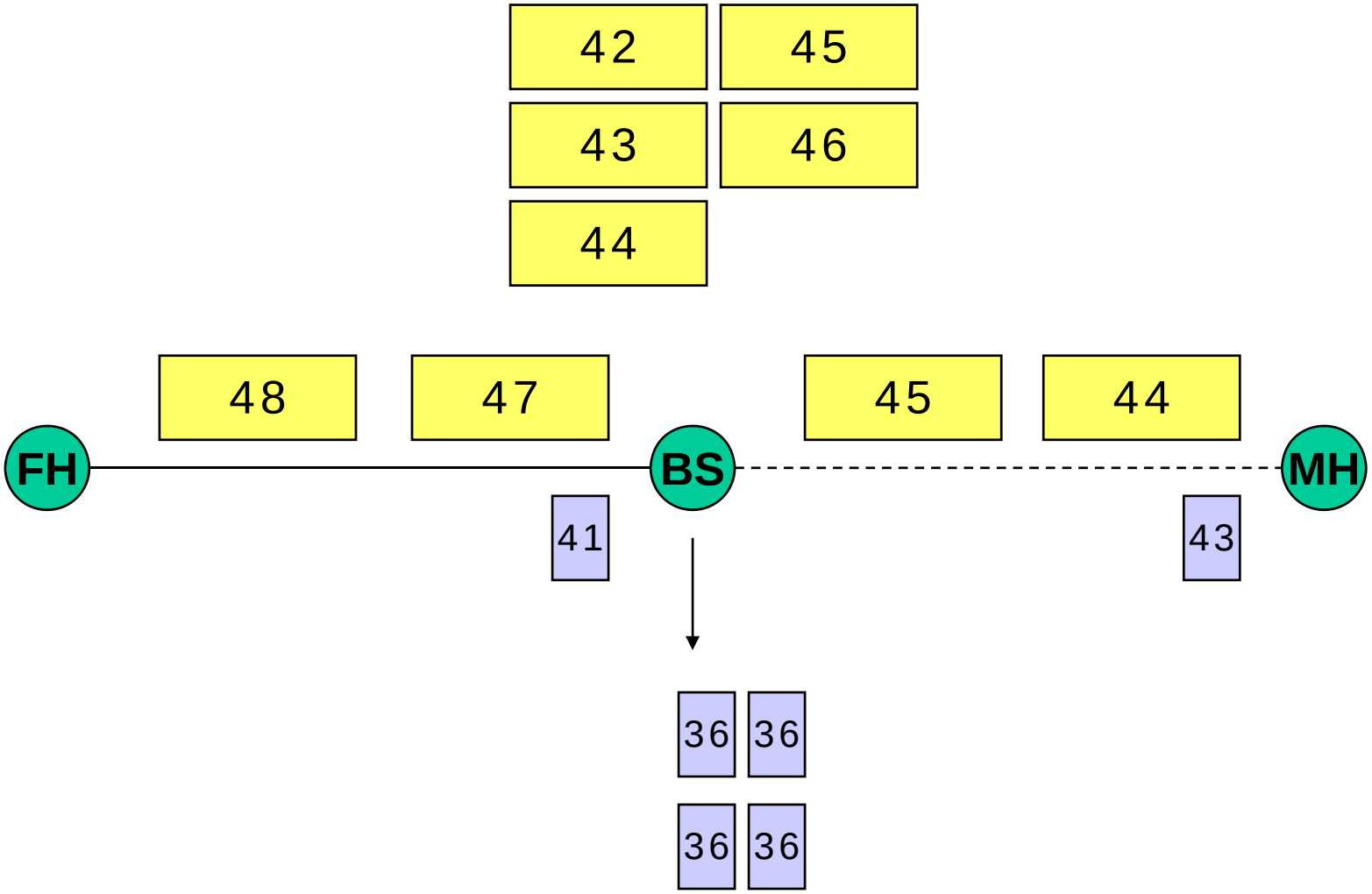


Design Goal

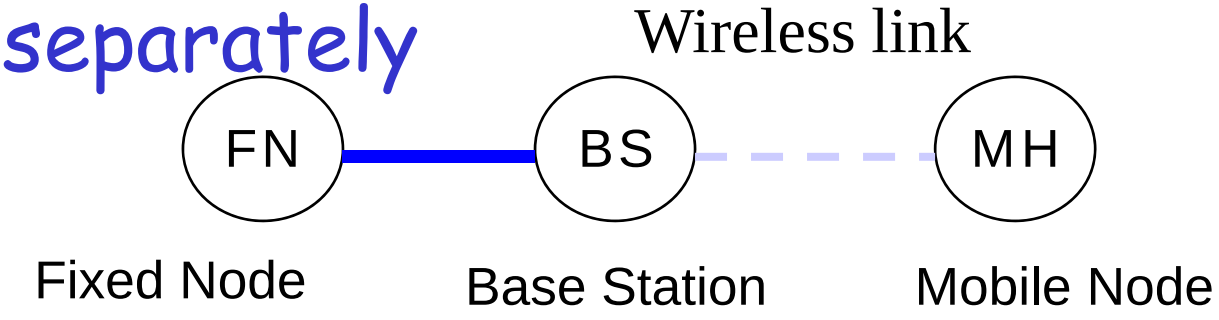
- TCP sender should not take any congestion control when encounter a packet loss due to wireless transmission error
- TCP sender should just retransmit the packet due to wireless transmission error
- Sender should be shielded by wireless transmission error

Snoop: Strength/Weakness

- Advantages
  - Shielding sender from wireless link error
  - Soft state connection is used
- Disadvantages
  - Link layer overhead
  - Violate modular layer design principle
  - Mobile-side TCP need to be modified
  - Modification at BS

Split Connection Approach

- Split TCP end-to-end connection into two connections
  - Sender to BS
  - BS to receiver
- Handle wireline and wireless TCP separately



Split Connection: I-TCP

ICDCS 95

Bakre & Badrinath

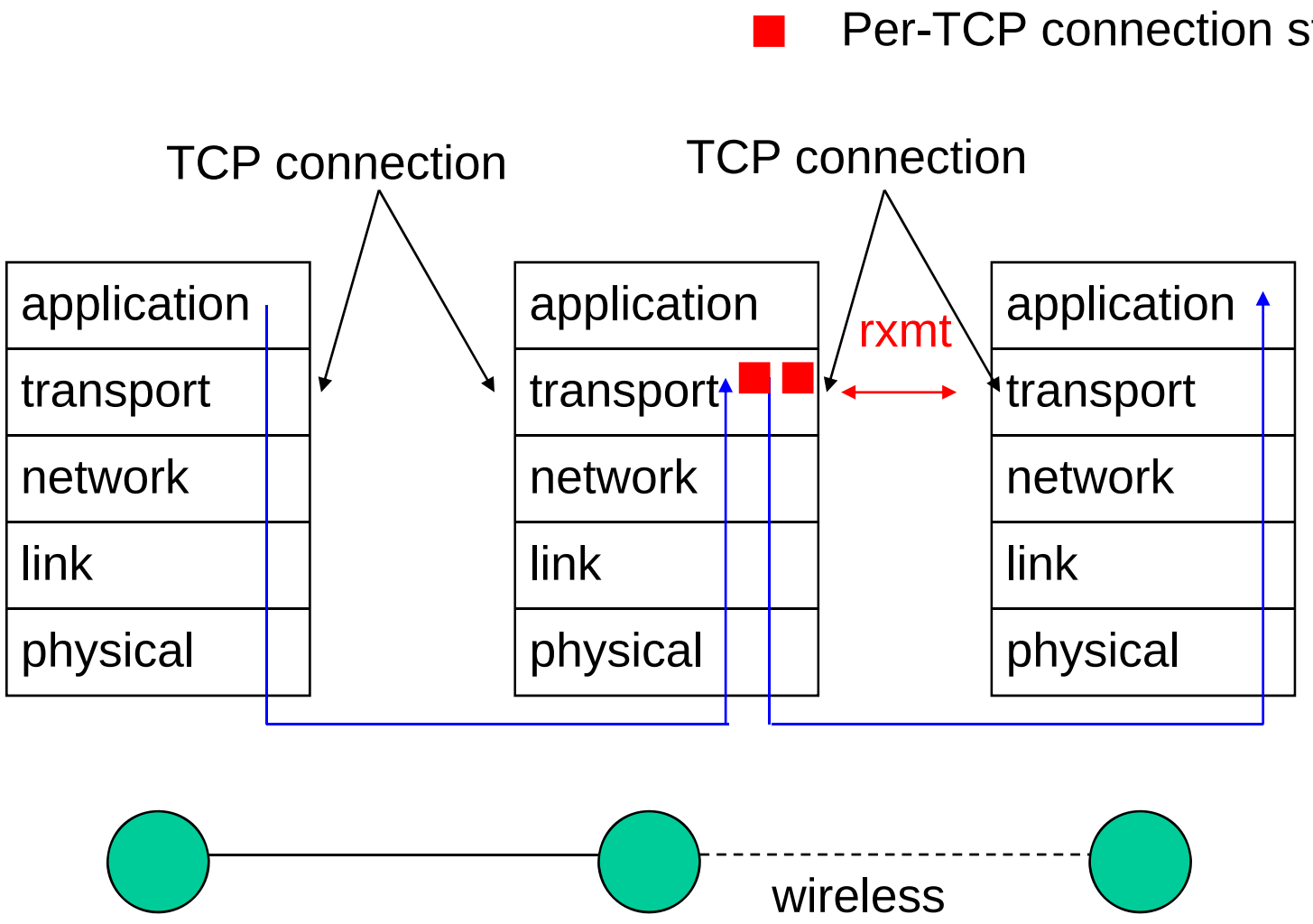
Split Connection Schemes

- Separate packet loss in wireless link and wired link
  - Independent TCP flow control in wireline and wireless linsk
  - May use special transport layer protocol and control parameters in wireless/wired link
- I-TCP (Indirect TCP)
  - Bakre and Badrinath.
    - ICDCS 95
  - Use two standard TCP connections

I-TCP

- MSR (Mobility Support Router)
  - Split TCP operation: 2 logical connections
  - MSR acknowledges on behalf of the mobile host
- Operations
  - Normal TCP between MSR and Sender
  - "wireless TCP" between MSR and mobile host
    - Separate "wireless link" and "user mobility"
- Performance
  - Sender sees more stable connection
  - Recover loss packets faster
  - Handle mobility

Split Connection Approach



Split Connection : Strength/Weakness

- Advantages
  - Do not modify wireline network
  - Possible for special TCP design in wireless network
    - Light-weighted
    - Energy-efficient
- Disadvantages
  - Modification at BS
  - Hard state maintain at BS
  - Violate TCP end-to-end paradigm
  - User mobility will cause problems

Split Connection: M-TCP

ACM CCR 97

Brown & Singh

M-TCP

- M-TCP uses TCP Persist Mode
  - When a new ack is received with receiver's advertised window = 0, the sender enters persist mode
  - Sender does not send any data in persist mode
    - except when persist timer goes off
  - When a positive window advertisement is received, sender exits persist mode
  - On exiting persist mode, RTO and cwnd are same as before the persist mode

M-TCP

- Split connection: 2 logical connections
- BS acknowledges "after" receiving ACKs from MH
- Handoff
  - Withheld ack sent with window advertisement = 0, if MH moves away (handoff in progress)
  - Sender is in persist mode during handoff
  - Sender exits persist mode after handoff, and starts sending packets using same cwnd as before handoff

Compressed M-TCP

- Modified version of M-TCP
  - Proposed by the same authors
- Apply compression to improve performance under limited bandwidth

End-to-End Approaches: ELN

End-to-End Schemes

- Explicit Loss Notification (ELN)
  - Add ELN option to TCP ACK
  - When a packet is dropped by wireless link, ELN in ACK which corresponding to the packet is set
  - When sender receives the ELN set, it retransmit packet without reducing congestion window
  - Indicate non-congestion packet loss
  - Get Link status from Link Layer
  - Useful in multi-hop networks

End-to-End : Strength/Weakness

- Advantages
  - Easily distinguish congestion loss and non-congestion loss
- Disadvantages
  - Wireline-side TCP (i.e. TCP source node) needs to be modified
  - Slow recovery of lost packets

Compared to Snooping

- Similar to Snoop
  - TCP-aware agent to observe packet loss due to wireless transmission
    - Same drawback (need to modify BS)
- Modification of TCP source node
- Protocol dependent (TCP-aware)

Conclusions

TCP in "Wireless" Networks

- Link Layer Approach
  - FEC, ARQ
- Split Approach
  - Link Layer Split (Snoop)
  - Transport Layer Split (I-TCP)
- End-to-End Approach
  - Modify TCP (TCP SACK)
  - Change ACK algorithm
  - New Transport Layer Protocol
    - New protocol suite (e.g. WAP)

TCP in "Mobile" Networks

- Techniques to alleviate TCP misbehaviors caused by "wireless" packet loss might NOT work
  - Some techniques still work
    - Decouple "packet loss == congestion"
  - Split approaches have trouble in "mobile" environment
- Reduce packet losses during handoff
  - Seamless handoff
    - Reduce handoff latency
    - Packet forwarding is useful

Other Issues

- Link Asymmetry
- Long RTT
  - TCP in 3G
- Data and ACK compete for transmission
  - E.g. 802.11
- Frequent route change
  - Ad hoc networks
  - Moving fast result in more trouble ?
    - Answer: it depends….
- 802.11-based multihop network is bad for TCP connections