# Introduction to Wireless TCP

Choong Seon Hong

Kyung Hee University
cshong@khu.ac.kr

# Contents

- ✓ Background
- ✓ Introduction
- ✓ Problems of Original TCP in Mobile Environments
- ✓ Strengths and Drawbacks of Existing Solutions
- ✓ Our Proposed Solution: Adaptive TCP
- ✓ Conclusions

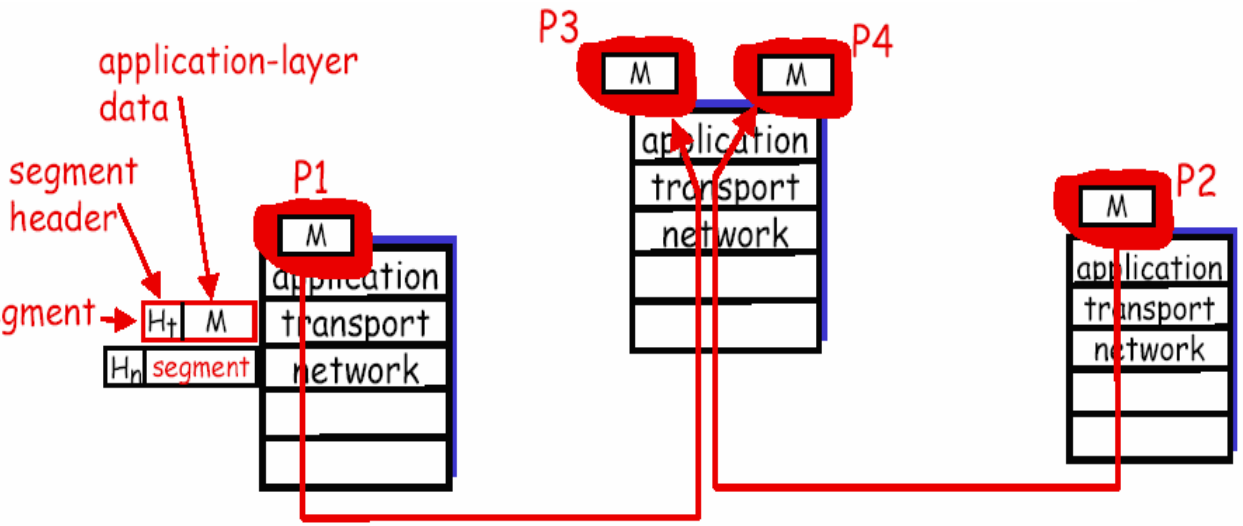
# Background: IP Protocol Stack

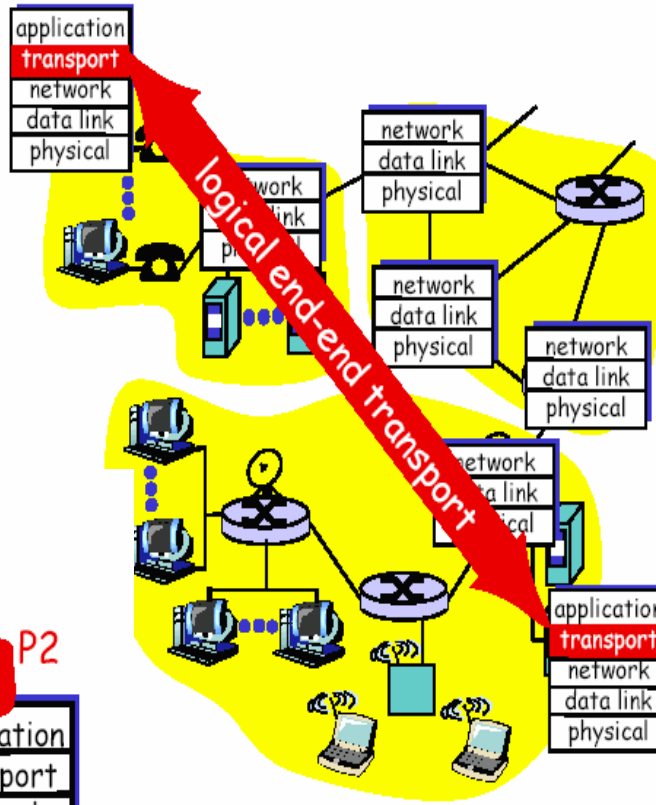
- Network Layer (Layer 3) :
  - Internet Protocol (IPv4, IPv6)
  - Packet (IP datagram) transmission between end-systems [hosts] (packet size up to 65535 bytes, often restricted by Layer 2 protocols)
  - Routing using 32 bit adresses (v4)
  - Unreliable, connectionless transmission: loss, duplication, reordering can occur
- **Transport Layer (Layer 4):**
  - Most frequent transport protocols
    **Transmission Control Protocol (TCP)**
    User Datagram Protocol (UDP)
- Application Layer/Services (Layer 5-7)
  - TCP based:
    HTTP (HyperText Transfer Protocol),
    FTP (File Transmission Protocol),
    SMTP (Simple Mail Transfer Protocol), Telnet, ...
  - UDP based:
    DNS (Domain Name Service),
    Streaming media, VoIP, ...
    SNMP(Simple Nework Management Protocol)

# Background :Transport Layer Protocols

**Goal: data transfer between application (processes) in end-systems**

- support of multiplexing/de-multiplexing
  e.g. socket API



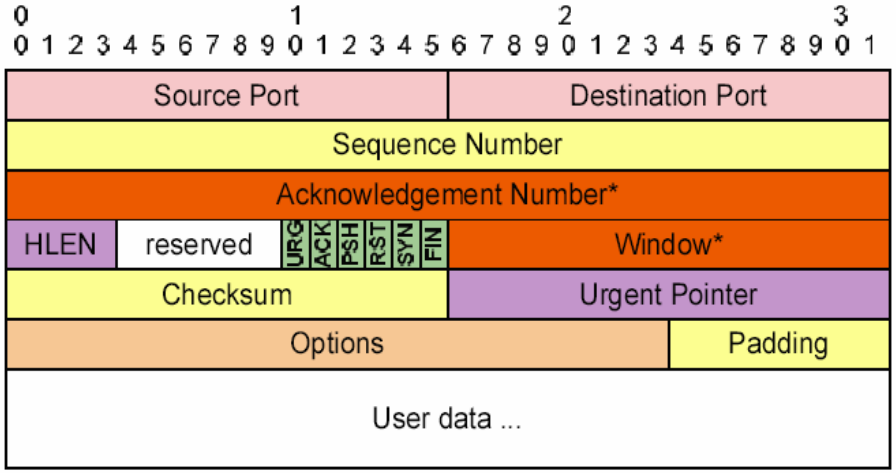

ata stream/connection identified by:
two IP addresses, protocol number, two port numbers

# Background :Transport Layer Protocols

- ✓ User Datagram Protocol (UDP) : RFC 768
  - ☞ Connectionless
  - ☞ Unreliable
  - ☞ No flow/congestion control
- ✓ Transmission Control Protocol (TCP) : RFC 793, 1122, 1323, 2018, 2581
  - ☞ Connection-oriented (full duplex)
  - ☞ Reliable, in-order byte-stream delivery
  - ☞ Flow/congestion control
- ✓ Stream Control Transport Protocol (SCTP)
  - ☞ Connection oriented (full-duplex associations)
  - ☞ Reliable message delivery, support of multiple streams
  - ☞ Support of multi-homing, flow/congestion control
- ✓ Real-Time Transport Protocol (RTP)
  - ☞ Uses UDP
  - ☞ Provides: Time-stamps, sequence numbers
  - ☞ Supports: codecs, codec translation, mixing of multi-media streams

# TCP: Basics

- ✓ Point-to-point, bi-directional connections (between end-systems)
- ✓ Reliable, in-order transport of byte–stream using
  - ☞ Sequence Numbers
  - ☞ Acknowlegements
- ✓ Flow/Congestion Control: Prevent flooding of
  - ☞ Receiver
  - ☞ Intermediate Systems

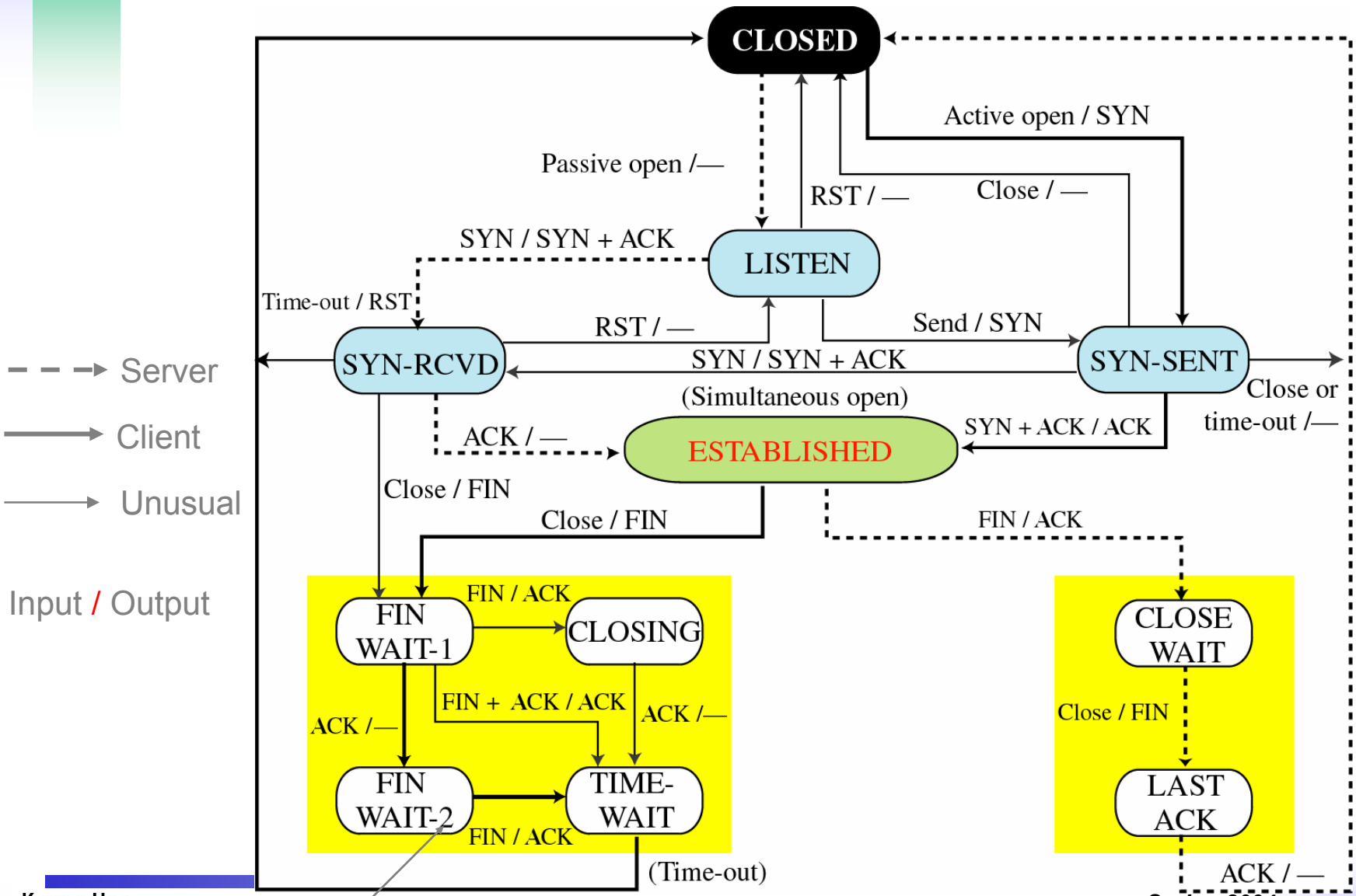



Source: RFC793 (September 1981)

* Field refers to data transmission in reverse direction

- ✓ Important ‚new' Header Fields
  - ☞ Sequence number: number of first data byte transmitted in the segment
  - ☞ ACK number: number of next byte expected in the reverse data flow
  - ☞ Window size: number of bytes host is willing to accept in reverse data flow

# A state transition diagram for TCP

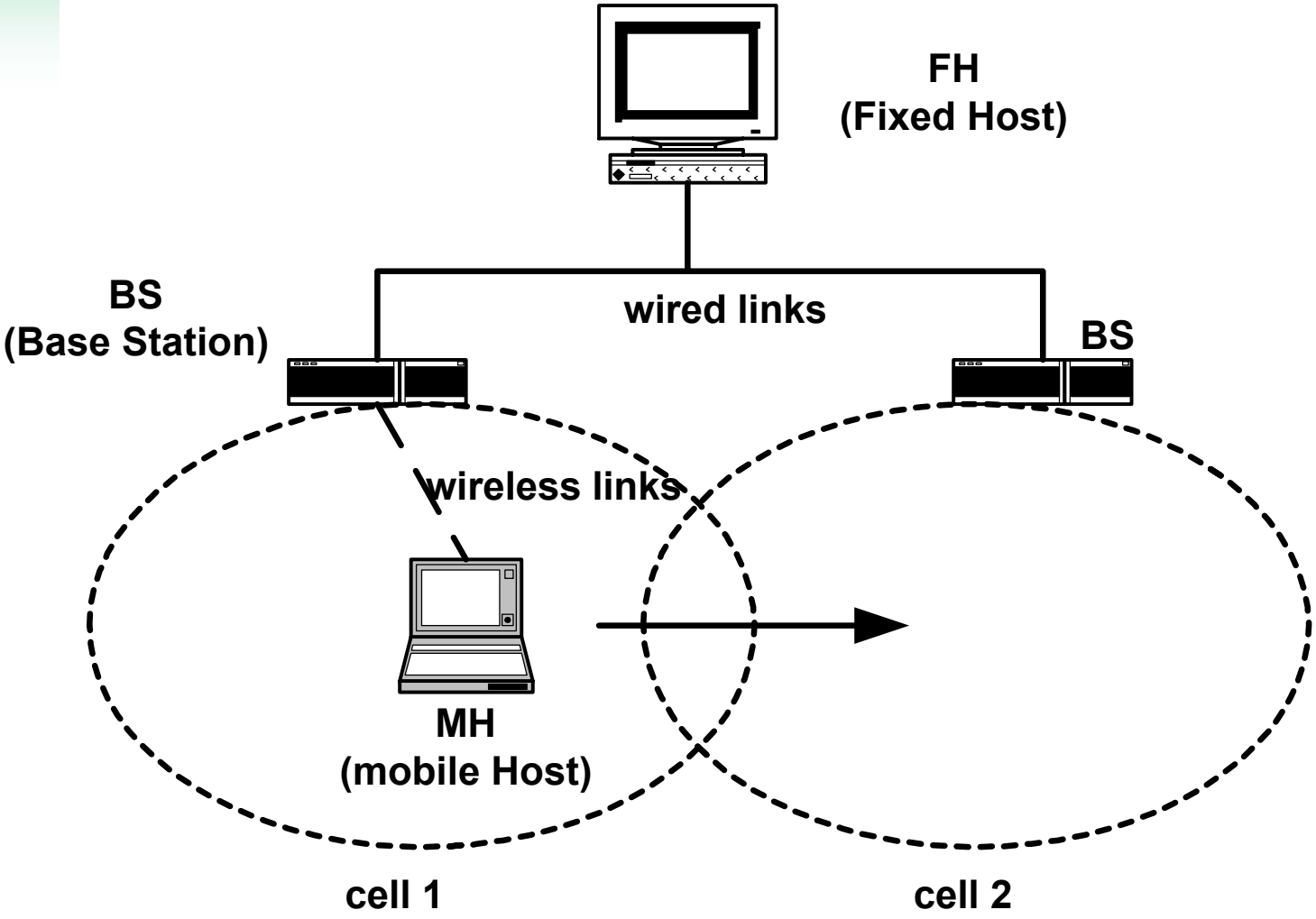



Now connection is closed in one direction

# Introduction

- ✓ Internet access and wireless access are resulting in a strong combination.
- ✓ TCP is a transport layer protocol designed for the wired links.
- ✓ It will incur end-to-end performance degradation in mobile environments.

# Introduction (cont'd) :Mobile Environment



# Introduction(cont'd)

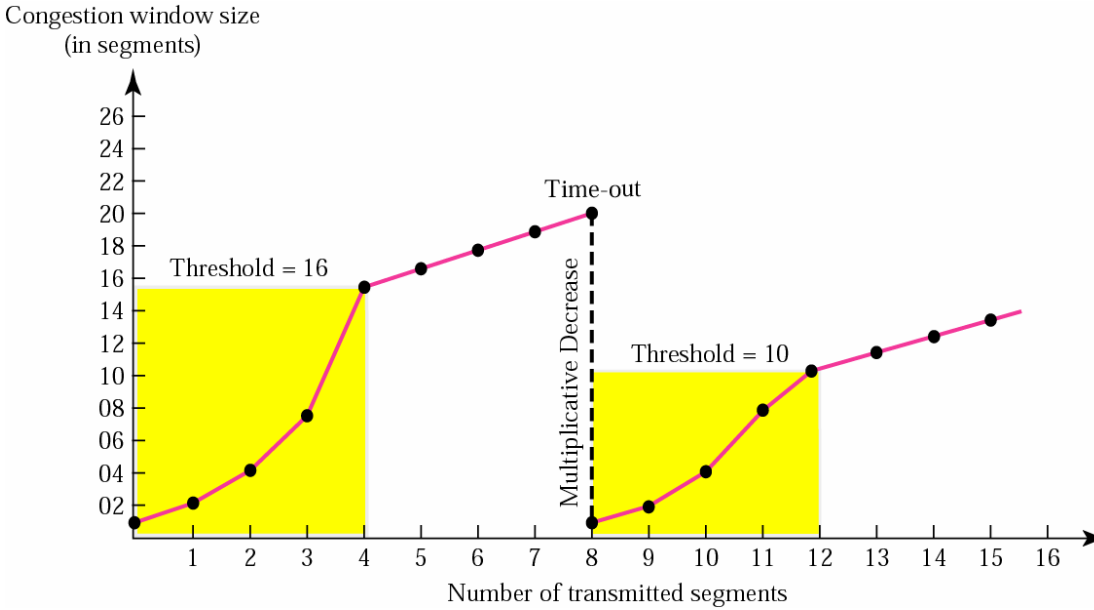
- ✓ The challenges for TCP in mobile environments are:

1. High Bit Error Rates(BER)
2. Long time disconnections
3. Frequent disconnections

# Problems of original TCP(cont'd)

For High-Bandwith Links:

- ✓ CWND doubles after each round-trip time (RTT) in **slow-start phase**
- ✓ CWND increases by one segment size in each RTT during **congestion avoidance phase**




Congestion detected:

- ✓ **timeout** → set ssthresh to cwnd/2, perform slow-start
- ✓ **three dup Acks** → half cwnd, ssthresh=cwnd (Fast Retransmit/Recovery)

**Throughput** = CWND*MSS / RTT
(for high-bandwidth links)

# Problems of original TCP(cont'd)

- ✓ The idle time T of the sender in slow start stage is given by:

$$T=P(RTT)-(2^P-1)S/R$$

- S means the MSS(maximum segment size) is S bits.
- RTT is the round-trip time.
- R denotes the transmission rate of the link from the sender to the receiver.
- P=min{Q,K-1}
  - . K is the number of windows that cover the object
  - . Q is the number of times the sender would stall

# Problems of original TCP(cont'd)

- If the slow-start scheme is not triggered, the number of extra packets that can be transferred

$$\text{Extra Segments} = W^2/8 + W\lg W - 5W/4 + 1;$$

- W is the unACKed packets can be sent in a congestion window.

* The wrong assumption on packet loss in mobile environment will definitely decrease the performance of TCP

# Wireless (Infrastructure) Networks: Challenges

- ✓ Wireless links tend to have the following properties:
  - ☞ Large delays
  - ☞ Low throughput
  - ☞ Bit errors / packet losses due to poor channel conditions (noise, interference, fading)
- ✓ Impact of mobility
  - ☞ Delay/losses due to hand-over events
- ✓ Protocols in IP family are not originally designed for such links
  - ☞ Increased volume due to headers
  - ☞ Deficiencies of TCP flow/congestion control
  - ☞ ... many more (e.g. applications HTTP→WAP)
- ✓ Protocol Enhancements are being developed, e.g.
  - ☞ Robust Header Compression (RoHC)
  - ☞ Enhancements for Wireless TCP

# TCP-mechanisms in wireless settings

- ✓ TCP assumes congestion if packets are dropped
  - ☞ possibly wrong in wireless networks, here we often have packet loss due to *transmission errors*
  - ☞ furthermore, *mobility* itself can cause packet loss (handover losses) or temporary connection disruptions (timeouts or even broken TCP connections)

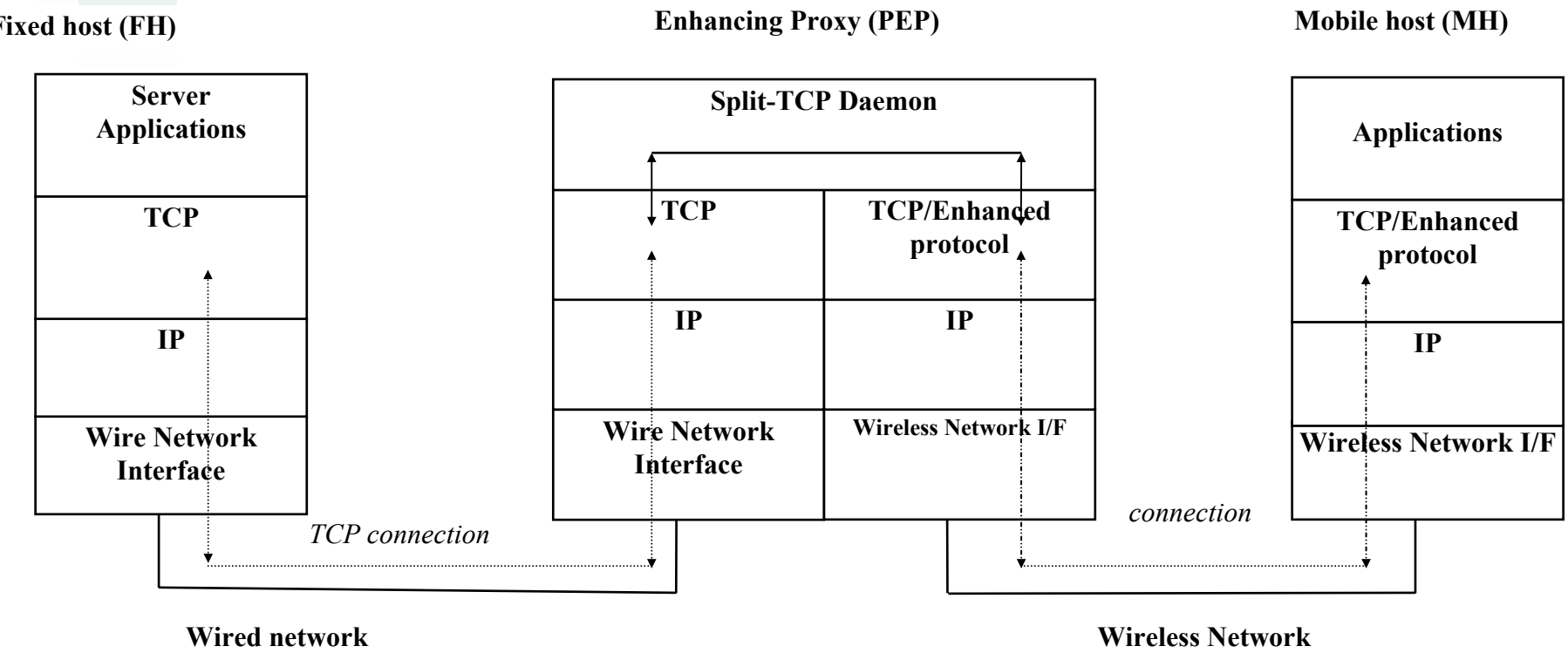
→ performance of an unchanged TCP degrades severely

- ☞ however, TCP cannot be changed fundamentally due to the large base of installation in the fixed network, TCP for mobility has to remain compatible
- ☞ the basic TCP mechanisms are needed to for congestion control in the wired network parts

# Wireless TCP: Common Approaches for Enhancement

- ✓ Link-Layer Approach
  - ☞ Local Retransmission of lost packets
  - ☞ Hide losses from sender
- ✓ Explicit Notification Approach
  - ☞ Explicitly notify TCP sender of the condition of the network / type of the loss
- ✓ End to End Approach
  - ☞ Enhance TCP Protocol stack at sender and receiver to achieve better throughput (e.g. TCP SACK)
- ✓ Split-Connection Approach
  - ☞ End-to-End flow control terminated before wireless link

# Wireless TCP: Split Connection




✓Proxy is located between the 2 end-hosts to split the TCP connection into 2 parts

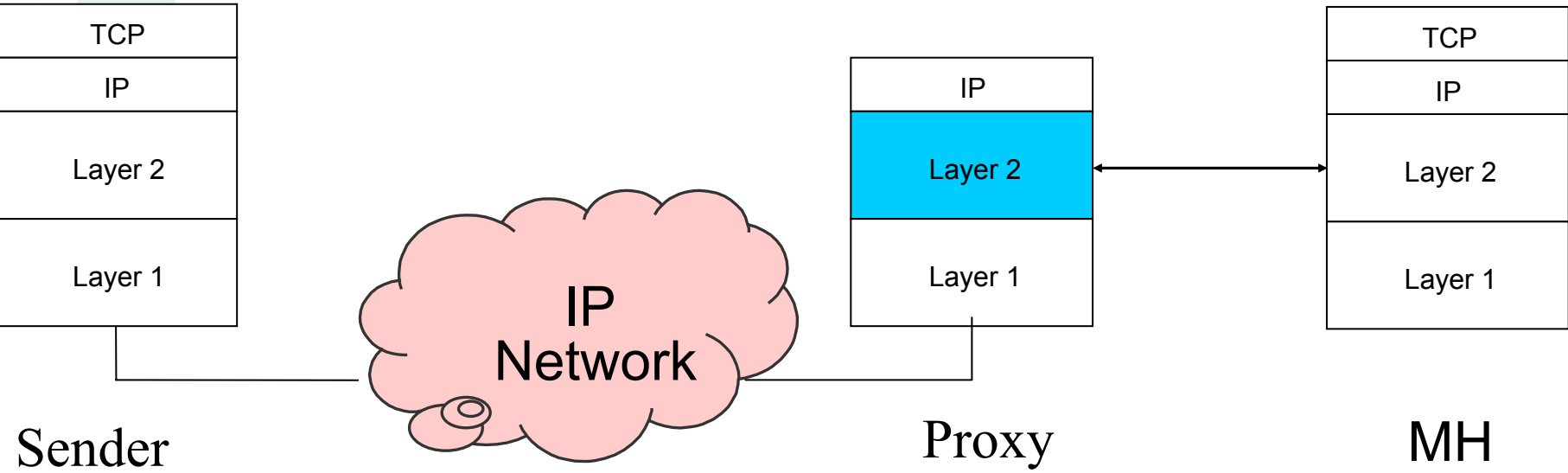
✓Different implementations: Indirect TCP (state-full), Mobile TCP (stateless, send recv=0 when disconnection detected)

# Wirless TCP: Split Connection (cont`d)

- ✓ Advantages
  - ☞ No Changes in wired network and correspondent host necessary
  - ☞ Shields the end-host in the wired network from the wireless network characteristics: Wireless Local Recovery by Proxy
  - ☞ Possibly reduced header size for optimized transport protocol over wireless link
  - ☞ Allows for 'Smaller' and simpler wireless protocol between MH and Proxy
- ✓ Disadvantages
  - ☞ Loss of end-to-end TCP semantics
  - ☞ Not usable with end-2-end encryption (e.g. IPsec), since access to the TCP header needed

  For 'state-full' versions:
  - ☞ Requires buffer management at Proxy
  - ☞ Requires state transfer when hand-over to different proxy occurs
  - ☞ Hard state: Failures of proxy can result in loss of data

# Wireless TCP: Link-Layer Approach




- ✓ Proxy detects losses over the wireless link
- ✓ Proxy does local retransmission before the sender timeouts. Hides the wireless losses from the Sender
- ✓ TCP-unaware approaches: local retransmission
- ✓ TCP-aware approaches: e.g. SNOOP (but: filtering of dup Acks!)

# Wirless TCP: Link-Layer Approach

- TCP-aware approach: SNOOP
  - **Modify the IP layer in the BS, and let BS cache the TCP packets sending from CN to the MN**
  - **If the packet lost on wireless link, IP layer on the BS will retransmit the packet**
  - **BS suppress DUPACKs sent from MN to CN**
  - **BS use shorter local timer for local timeout**

# Wirless TCP: Link-Layer Approach(cont'd)

- Changes are restricted to BS and optionally to MN as well
- A (snoop) layer is added to the routing code at BS which keep track of packets in both directions
- Packets meant to MN are buffered at BS, and if needed, retransmitted in the wireless link

Discussion: Link-Layer Approaches

✓ Advantages
- No modification to TCP layer in end hosts
- Prevent propagation of losses/errors to TCP source

✓ Disadvantages
- TCP-aware link layer solutions cannot be used with IPSec
- Link-layer retransmission cause RTT variations (and thus possibly TCP time-outs)
- Not usable if data and Ack traverse different paths)

# Wirless TCP: End-to-end approach

- ✓ TCP Protocol Stack at Sender and Receiver enhanced
  e.g. SACK, FACK, D-SACK, Eifel, Freeze TCP
- ✓ Possible enhancements
  - ☞ Differentiate Losses
    e.g. no slow-start for wireless losses
  - ☞ Efficient Utilisation of Bandwidth
    e.g. no initial slow-start
  - ☞ Detection of Multiple Losses
- ✓ Advantages
  - ☞ End-to-End semantics and layered architecture of network protocols are preserved
  - ☞ IP packet encryption can be used
- ✓ Disadvantage
  - ☞ Modification at end host

# End-2-End Enhancements: SACK

TCP Reno inefficient for multiple packet losses within congestion window

→Extension: Selective Acknowledgement (SACK)

SACK principles:

- ✓ Several (3) SACK blocks mark successfully received sets of data (in TCP Option header extension)
- ✓ Sender maintains scoreboard of successfully transmitted packets
- ✓ Special treatments of partial Acks during Fast Recovery

→ Allows retransmission of more than one segment per RTT

# End-2-End Enhancements: Freeze TCP

- ✓ Principles
  - ☞ Freeze-TCP does not need help from base station
  - ☞ The receiver sends Zero Window Advertisement (ZWA)
  - ☞ End-to-end enhancement
  - ☞ TCP receiver monitors signal strengths and detects an impending handoff
  - ☞ Advertise a zero window size to force the sender into the ZWP mode and prevent it from dropping its congestion window
  - ☞
- ☞ Zero Window Probe (ZWP)
  - ☞ An advertised window size is zero –> the sender freeze all retransmit timers and enter a persist mode
  - ☞ Sender sends ZWPs until the receiver's window opens up
  - ☞ The interval between successive probes grows exponentially until it reaches 1 minute
- ☞ Receiver sends 3 DUPACKs when route is re-established

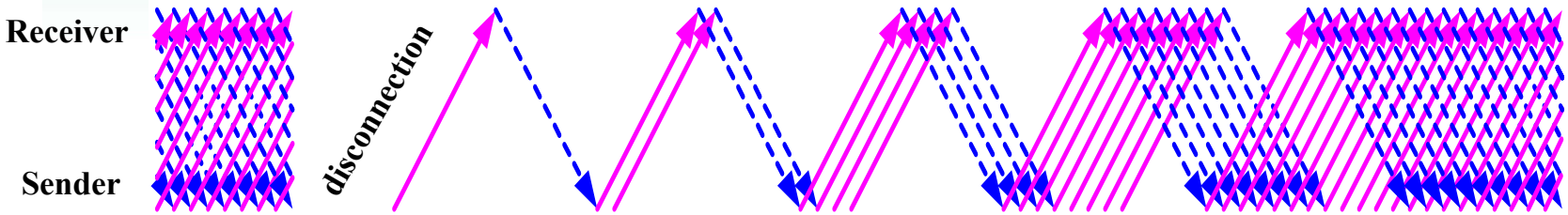
# End-2-End Enhancements: Freeze TCP

- ✓ TR-ACKs
  - ☞ Prevent substantial idle time after a reconnection (ZWP is exponentially backed off)
  - ☞ As soon as a connection is re-established, the receiver sends 3 copies of the ACK for the last data segment it received prior to the disconnection
- ✓ Advantages
  - ☞ It is a true end-to-end signalling scheme and does not require any intermediaries (such as base stations) to participate in the flow control
  - ☞ Changes to TCP code are confined entirely to the receiver side and are easy to implement

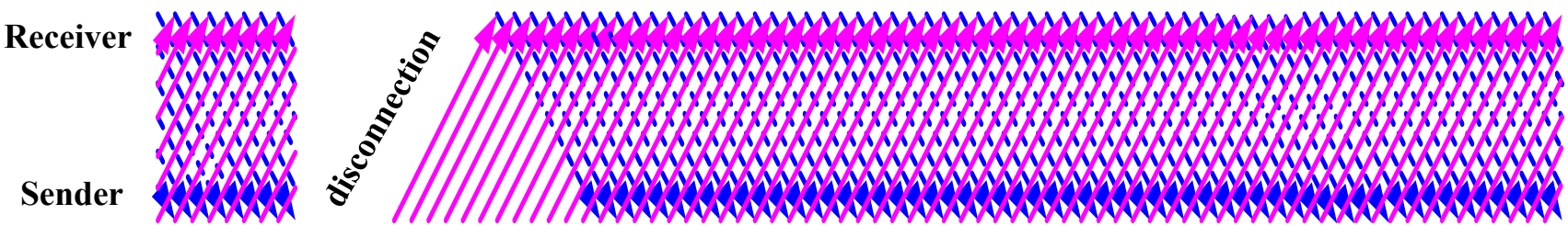
# End-2-End Enhancements: Freeze TCP

- ✓ Disadvantages
  - ☞ Whether it is appropriate to restart transmission at the full rate with the old window size upon entering a new, unknown environment?
  - ☞ It needs the receiver to predict impending disconnection

# End-2-End Enhancements: Freeze TCP




Regular TCP




Freeze TCP

# Existing Solutions - Summary

- ✓ Indirect TCP(I-TCP) [A.Bakre 1995]
- ✓ Mobile TCP (M-TCP) [K.Brown 1997]
- ✓ Explicit bad-state notification(EBSN) [N.Vaidya 1999]
- ✓ Snoop protocol[H.Balakrishnan 1995]
- ✓ New Snoop protocol [ Jian-Hao Hu 2000]
- ✓ Freeze-TCP [Goff 2000]
- ✓ TCP HACK:TCP Header Checksum Option [R.K.Balan 2001]
- ✓ Adaptive Bandwidth Share Estimation [R. Wang 2002]

# Strengths and Drawbacks of Existing Solutions

| | I-TCP | M-TCP | Snoop | New Snoop | EBSN | Freeze-TCP | ABSE | TCP Hack |
|---|---|---|---|---|---|---|---|---|
| End-to-end TCP semantics? | N | Y | Y | Y | N | Y | Y | Y |
| Require the intermediate node to modify TCP? | Y | Y | Y | Y | Y | N | N | N |
| Handle encrypted traffic? | N | N | N | N | N | Y | Y | Y |
| Need symmetric routing? | Y | Y | Y | Y | Y | N | N | N |
| Handle long disconnections? | Y | Y | N | Y | Y | Y | N | N |
| Handle frequent disconnections? | Y | Y | N | Y | Y | Y | N | N |
| Handle high bit error rate? | Y | Y | Y | Y | N | N | Y | Y |

# Drawbacks of using Performance Enhancing Proxies (PEPs)

- The intermediary will become the bottleneck
- Add the third point of failure besides the endpoints themselves
- Cannot handle end-to-end encrypted traffic
- Need a symmetric routing

# Proposed Solution:Extended TCP HACK

- ✓ The special ACK in TCP HACK may be lost.
- ✓ Extended TCP HACK:
  - ☞ Add a buffer in the TCP receiver(denoted s_buffer).
  - ☞ Then, save all sequence numbers into s_buffer and these sequence numbers are recovered from those packets transmitted in the same window (Data are corrupted but the sequence numbers in headers can be recovered.)
  - ☞ Send special ACK to the sender containing all the sequence numbers in the s_buffer.
  - ☞ Sequence numbers in the s_buffer will be cleared if the retransmitted packets are received correctly or the timers expire.

# Extended TCP HACK(cont'd)

| | | |
|---|---|---|
| Kind=14 | Length=4 | 1's complement checksum of TCP header and pseudo-IP header |

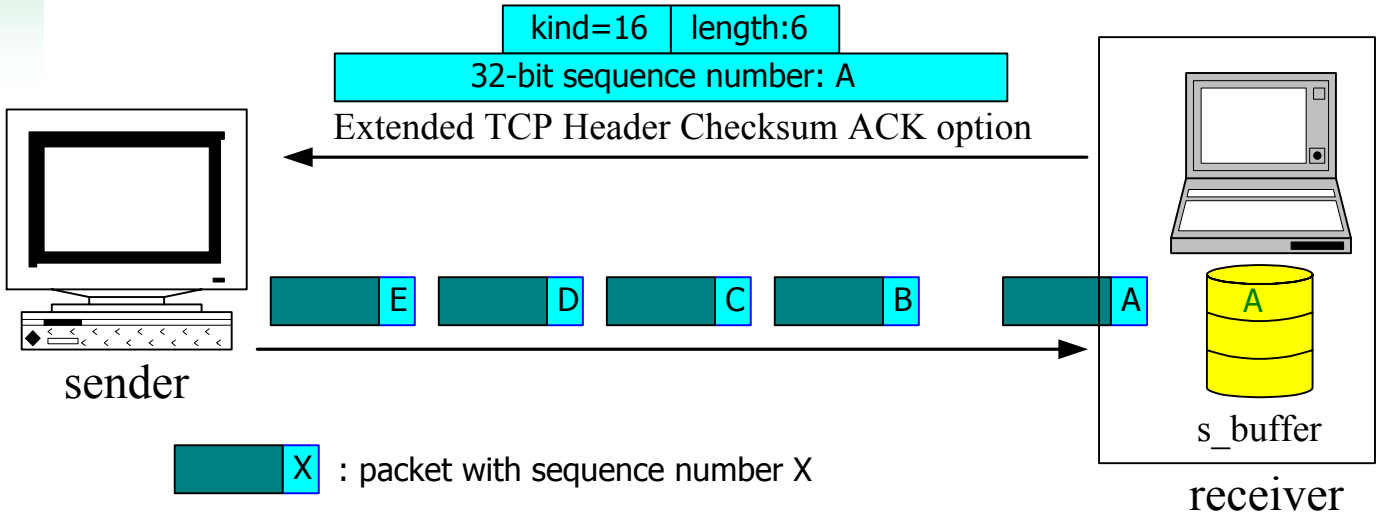
**TCP Header Checksum option**

| | |
|---|---|
| **Kind=16** | **Length: Variable** |

| |
|---|
| **1st 32-bit sequence number of corrupted segment to resend** |
| **2nd 32-bit sequence number of corrupted segment to resend** |
| **….** |
| **nth 32-bit sequence number of corrupted segment to resend** |

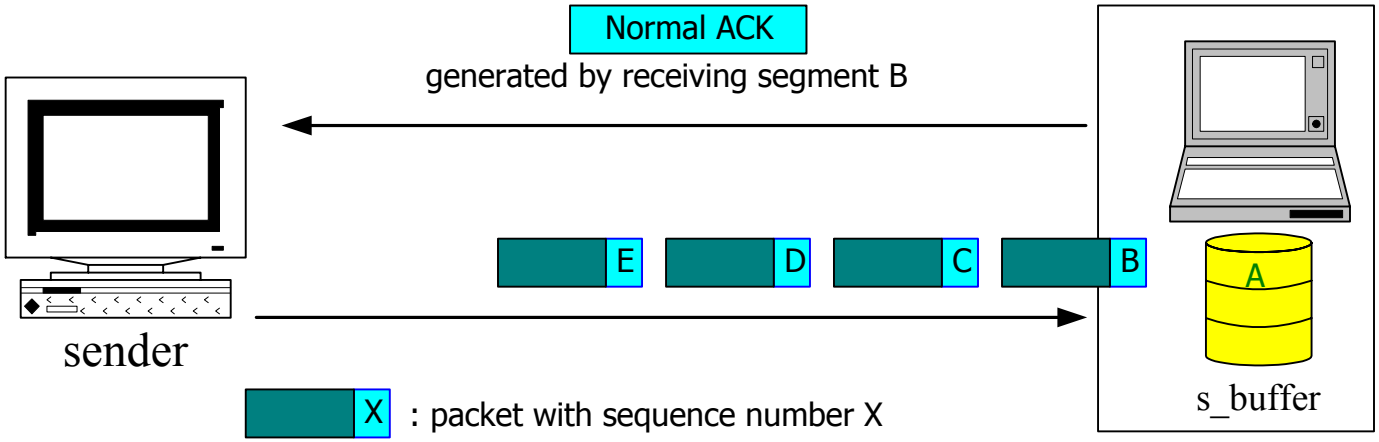
**Extended TCP header Checksum ACK option**

# Extended TCP HACK(cont'd)



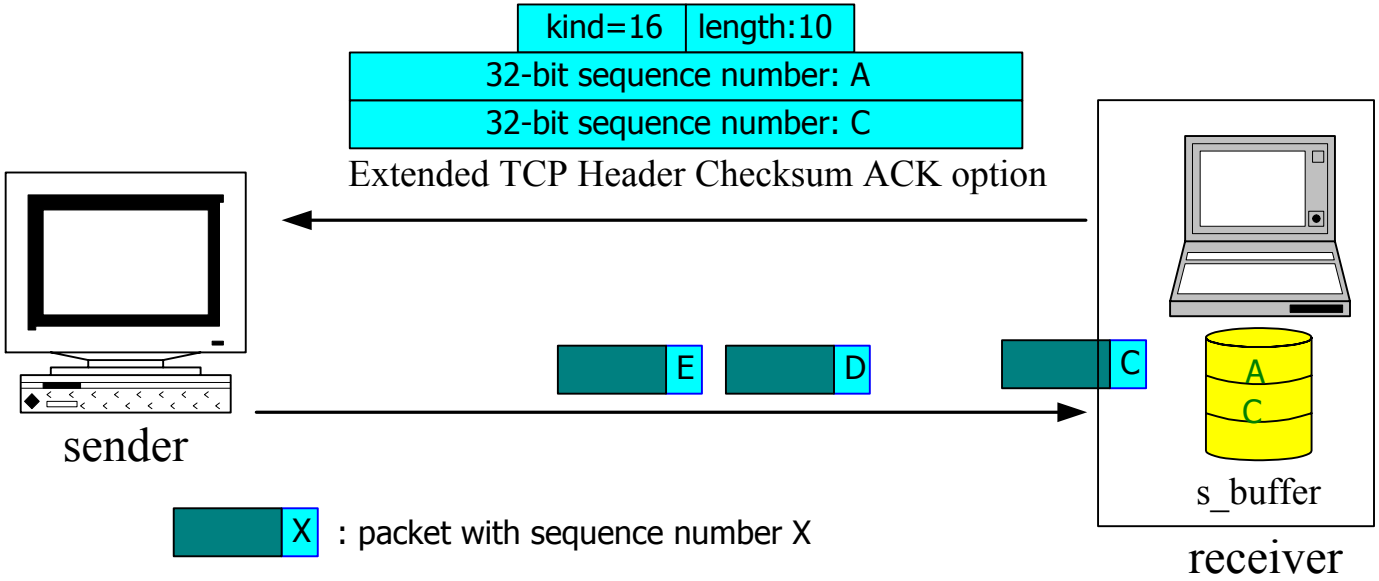

- The segments with sequence A, C and E are data corrupted but their headers can be recovered.
- The segment with sequence B is correct
- The segment with sequence D is corrupted in the header.

# Extended TCP HACK(cont'd)



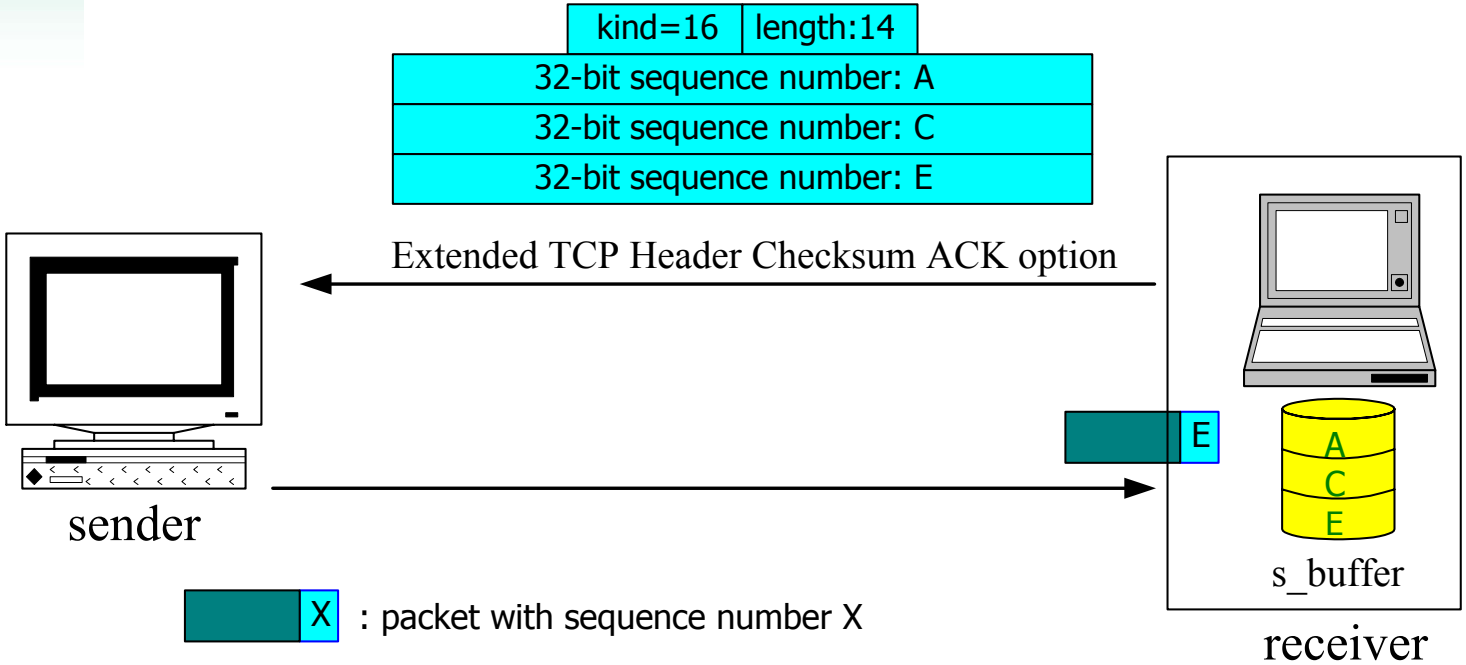

**The process of extended TCP HACK when receiving the segment with sequence number B**

# Extended TCP HACK(cont'd)



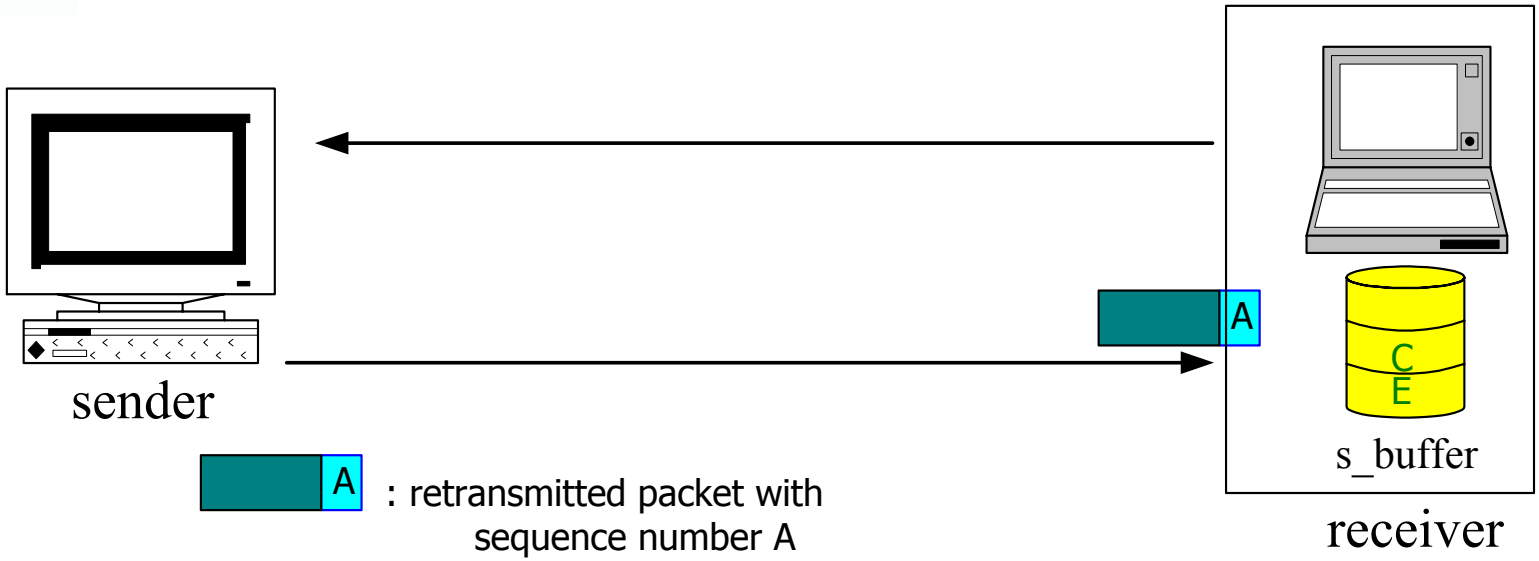

**The process of extended TCP HACK when receiving the segment with sequence number C**

# Extended TCP HACK(cont'd)



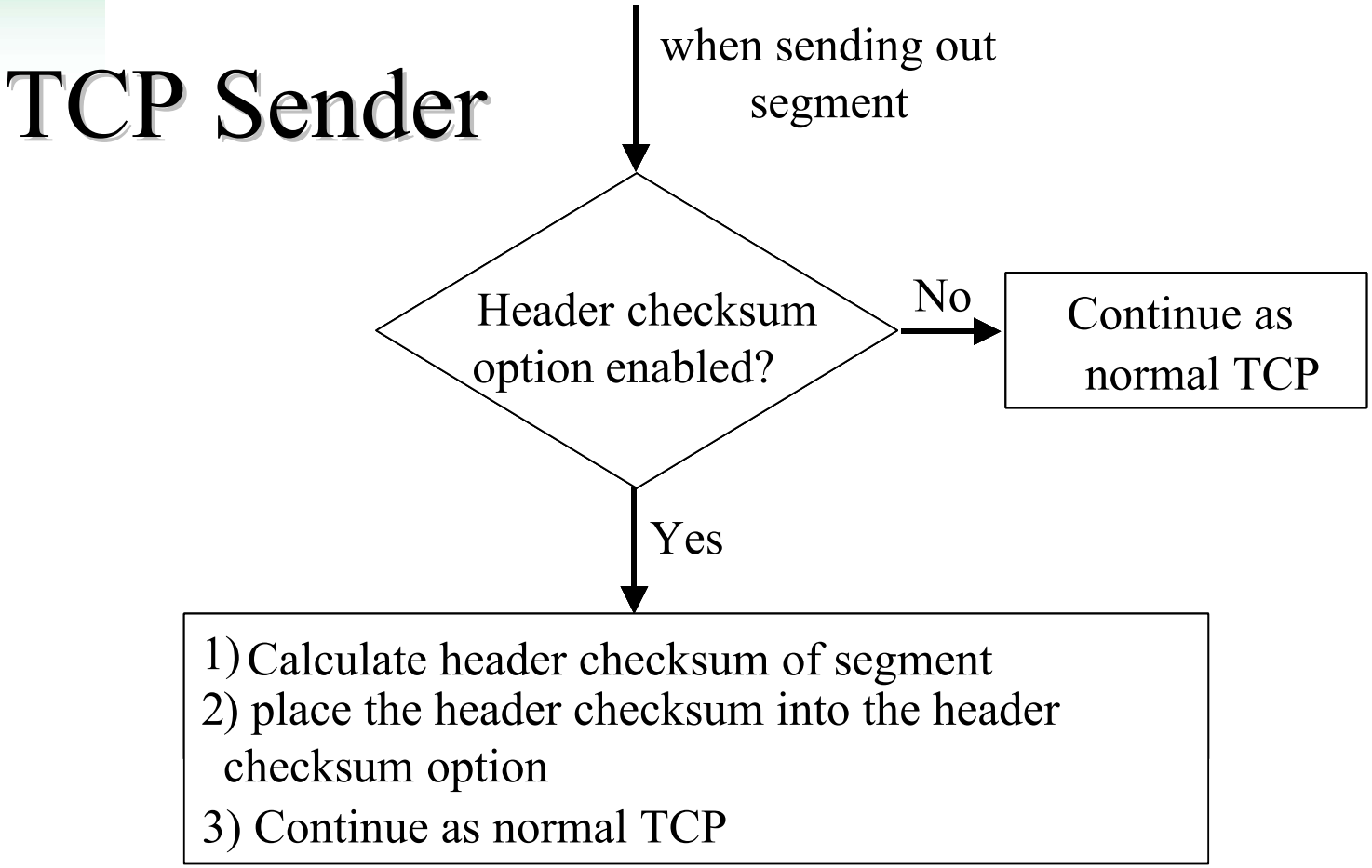

**The process of extended TCP HACK when receiving the segment with sequence number E**

# Extended TCP HACK(cont'd)




**The process of extended TCP HACK when receiving the retransmitted segment with sequence number A**

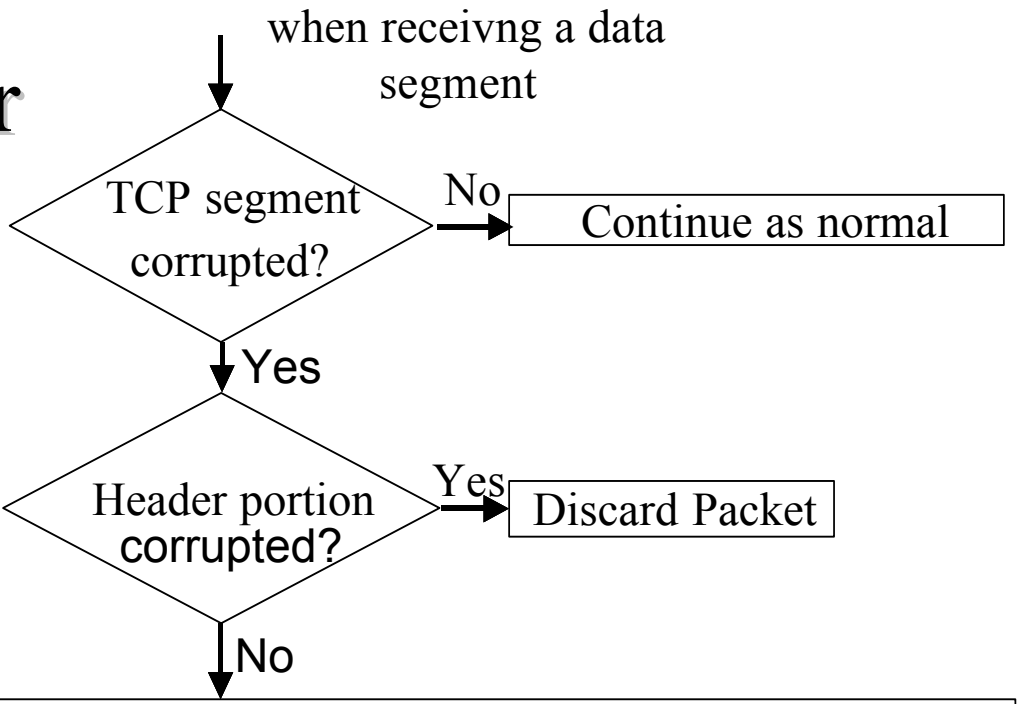
# Extended TCP HACK(cont'd)




**Modifications to the TCP sender**

# Extended TCP HACK(cont'd)

## TCP Receiver

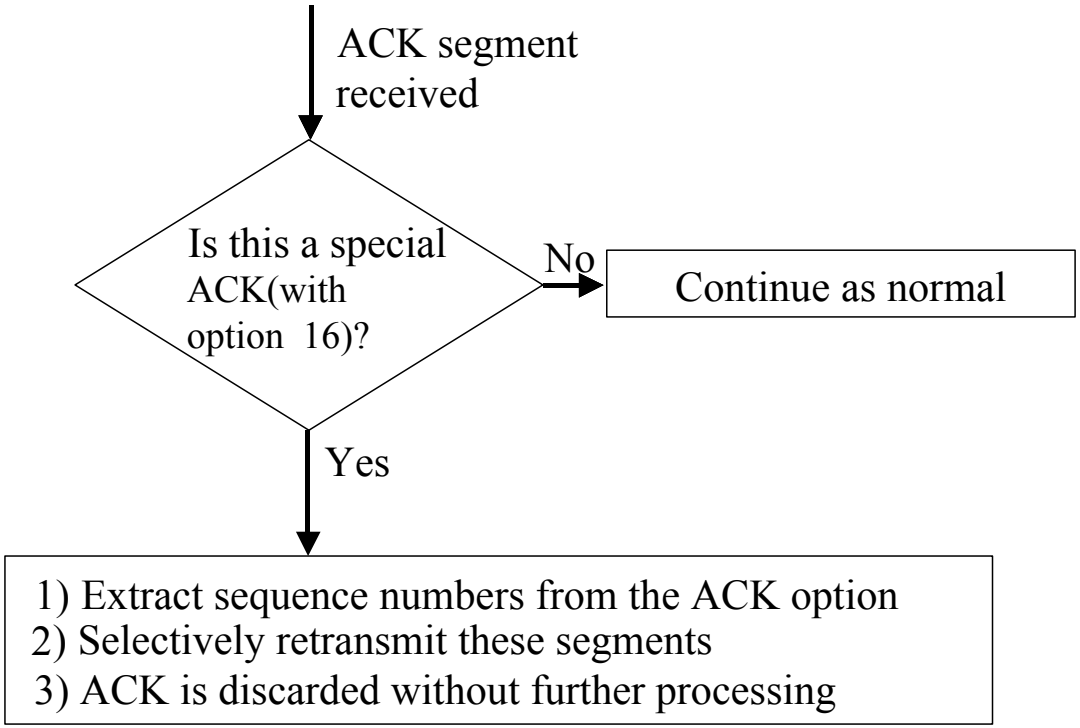



1) Recover sequence number of corrupted segment from header.
2) Save this sequence number in the s_buffer
3) Generate special ACK containing all the sequence numbers in the s_buffer.

**Modifications to the TCP receiver**

# Extended TCP HACK(cont'd)

## ✓ACK Processing




**Modification to the ACK processing**

# Improved Freeze-TCP

- Problem of Freeze-TCP
  - Since the ZWPs(Zero Window Probe) are exponentially backed off, there is the possibility of substantial idle time after a reconnection.
  - If the disconnection period was long and the reconnection happened immediately after losing a ZWP from the sender. The sender will go into a long back-off before sending the next probe.
  - Meantime the receiver has already reconnected, but the connection remains idle until the sender transmits its next probe.

# Improved Freeze-TCP (cont'd)

- Solution of Freeze-TCP:
  - As soon as a connection is re-established, the receiver sends 3 copies of the ACK for the last data segment it received prior to the disconnection.
  - This causes the sender to immediately re-transmit one segment, which eliminates the waiting period.
  - Fast re-transmit /fast recovery algorithms will set the congestion window to a half of its current window
  - This will degrade the performance of TCP

# Improved Freeze-TCP (cont'd)

- Our solution
  - Use the extended TCP header checksum ACK option proposed in Extended TCP HACK
  - As soon as a connection is re-established, the receiver sends at least one copy of the special ACK with option kind,16, but no data in the ACK option.
  - When sender receives the special ACK with no data, it restarts to send the packets,does not shrink its congestion window. Then discards these special ACK without further processing.

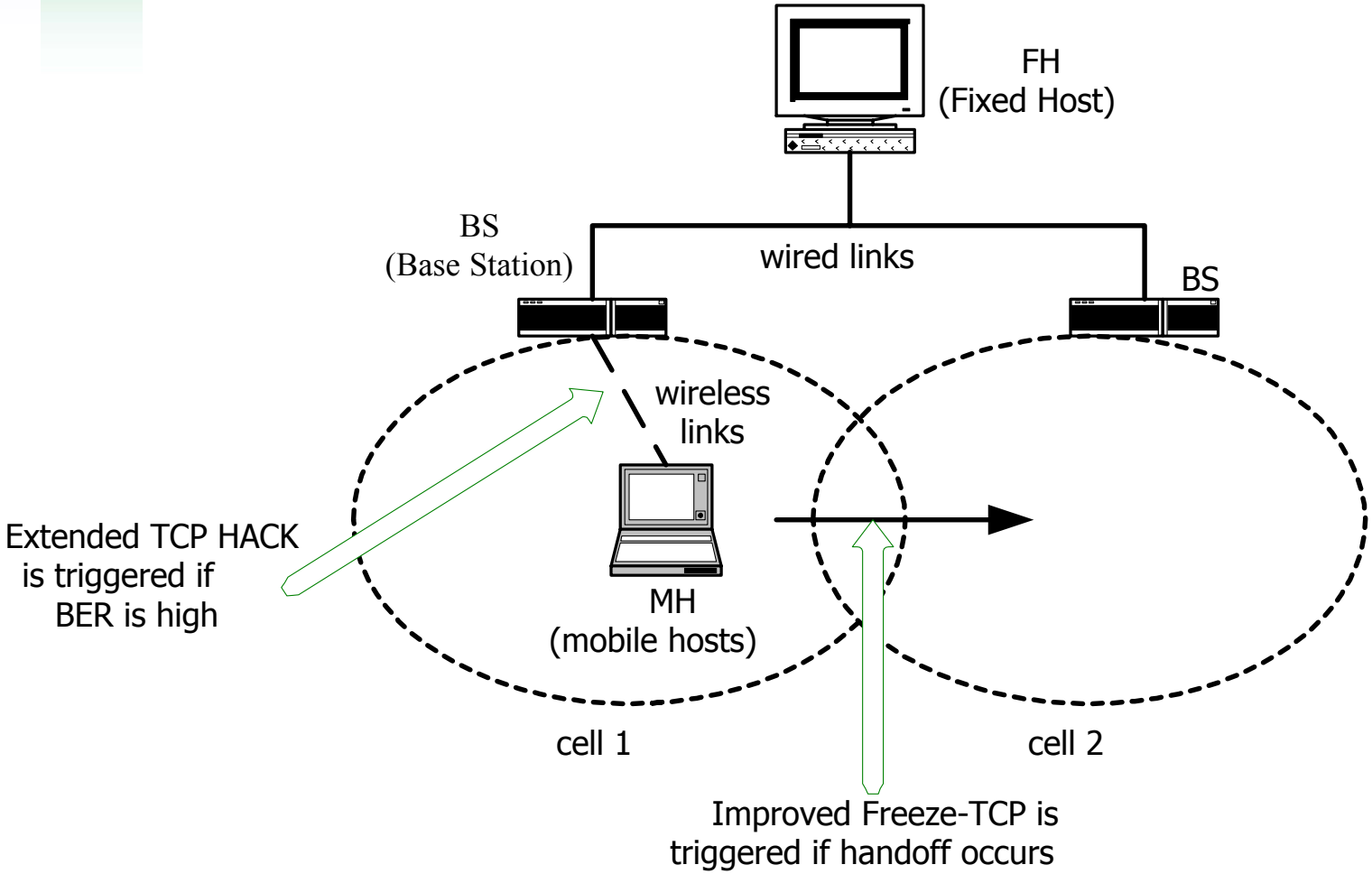
# Improved Freeze-TCP (cont'd)


kind=

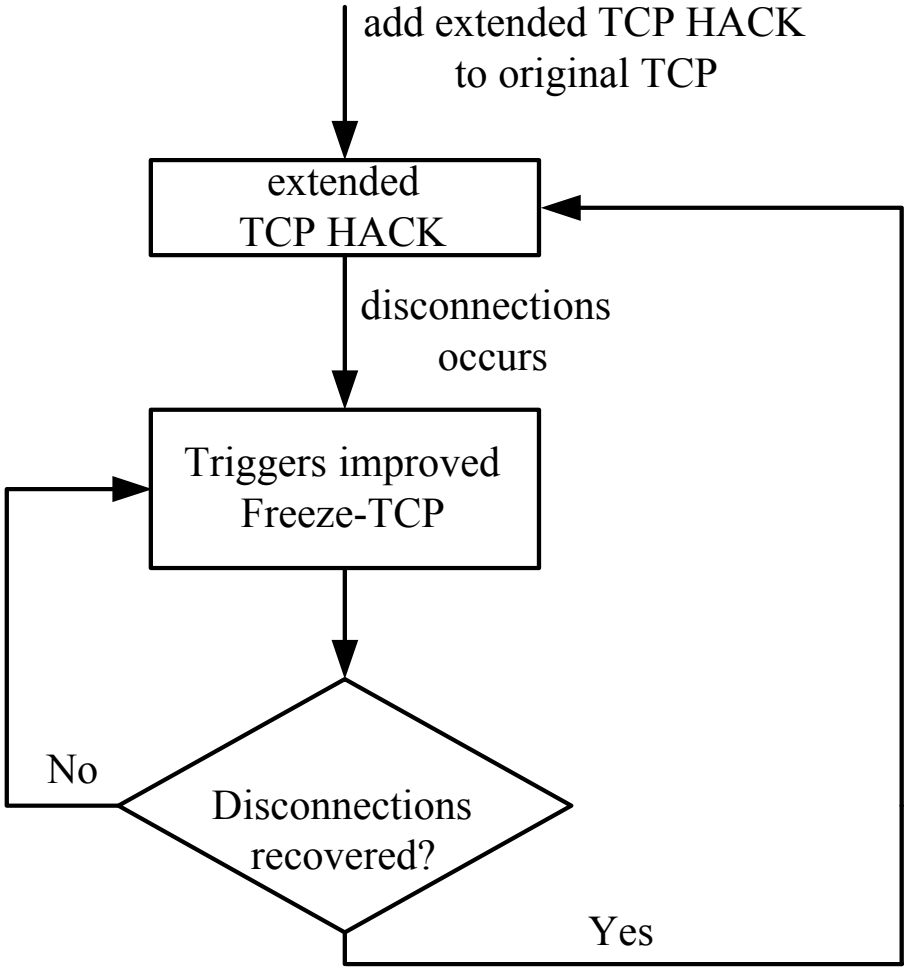
**The process of improved Freeze- TCP HACK when connection is re-established**

Extended TCP H

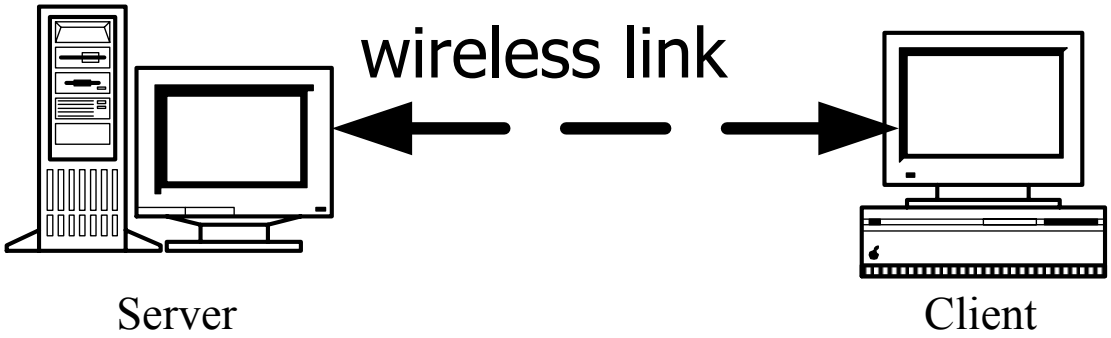
# Adaptive TCP



# Work flow of adaptive TCP



# Simulation Model




Simulation Parameters

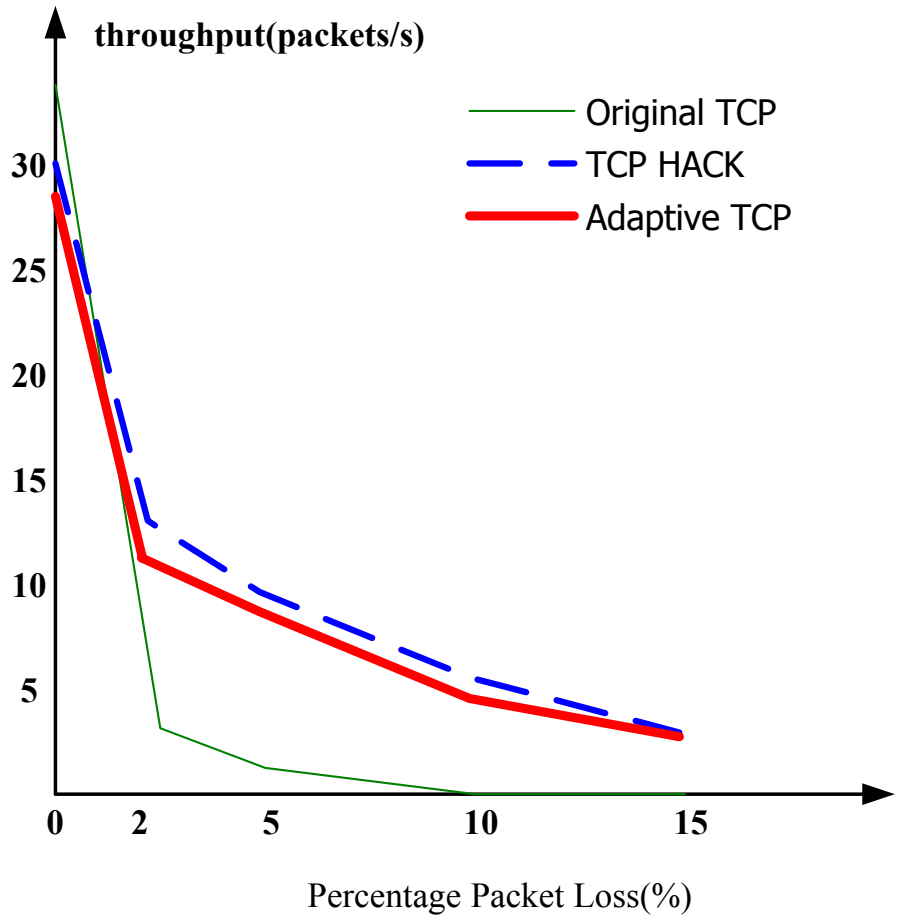
(simulation tool: OPNET modeler v8.0)

Bandwidth of wireless link: 384Kbytes MSS: 536bytes

Burst length : 3 packets Size of s_buffer: 40Byte

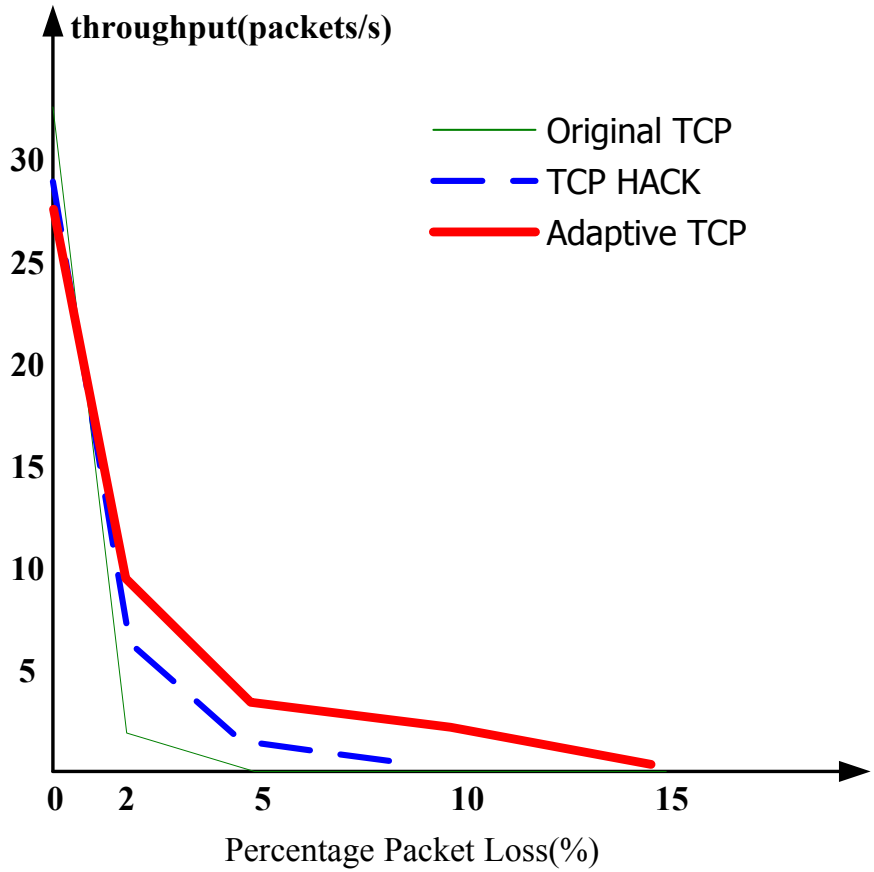
# Throughput for various packet loss rate

Packet loss only on the forward path

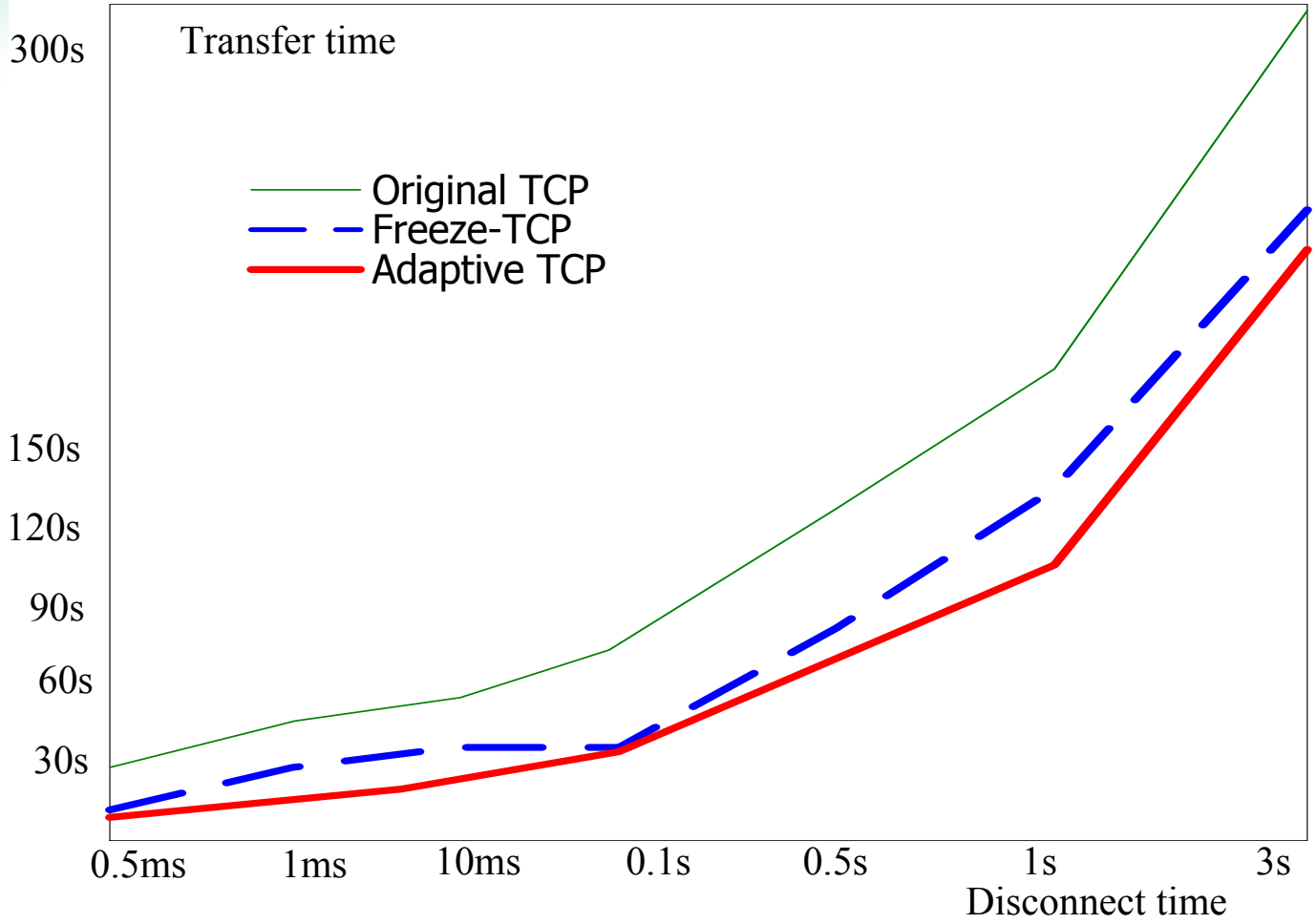


# Throughput for various packet loss rate

Packet loss on both forward and reverse paths



# Transfer time for various disconnect time



# Transfer time for various protocols

| | Time needed to finish all the transmissions (second) |
|---|---|
| Original TCP | 2200 |
| Freeze-TCP | 1300 |
| TCP HACK | 980 |
| Adaptive TCP | 320 |

# Drawbacks

- ✓ The software overload;
- ✓ The improved Freeze-TCP needs the receiver to predict an impending disconnection.

# Conclusions

- ✓ With our proposal,we can get an enhanced TCP which can work efficiently in mobile environments.
- ✓ Our proposed protocol has following characteristics:

1. An end-to-end TCP
2. Does not require an intermediate node to do TCP modifications
3. Handles end-to-end encrypted traffic
4. Does not need symmetric routing
5. Handles long time disconnections
6. Handles frequent disconnections
7. Handles high BER(bit error rate)

# References


[1] Behronz A.Forouzan, “TCP/IP protocol suite” international editions 2000,271-311

[2] Jochen Schiller, “Mobile Communications” Pearson Education Limited 2000, 290-307

[3] M.Allman,V.Paxson,and W.Stevens, “TCP congestion control”, IETF RFC 2581,1999

[4] Jiangping Pan,Jon W.Mark and Xuemin Shen, “TCP performance and its improvement over wireless links” GlobeCom2000

[5] Ajay Bakre and B.R. Badrinath, “I-TCP: Indirect TCP for mobile hosts”, Tech. Rep., Rutgers University, May 1995.

[6] H.Balakrishnan, S.Seshan, Eamir, and R.H. Katz, “Improving TCP/IP performance over Wireless Networks”, In Proc.1st ACM Conf. on Mobile computing and Networking, November 1995.

[7] Jian-Hao Hu,Kwan L.Yeung,Wiew Chee Kheong and Gang Feng, “Hierarchical Cache Design for Enhancing TCP over Heterogeneous Networks with Wired and Wireless Links” GlobeCom2000

[8] K.brown and S.Singh, “M-TCP: TCP for Mobile Cellular Networks”, ACM computer Communications Review (CCR), vol.27, no.5, 1997

[9] N.Vaidya, Overview of work in mobile-computing (transparencies).

[10] Tom Goff, James Moronski, D.S.Phatak, “Freeze-TCP: a true end-to-end TCP enhancement mechanism for mobile environment” InfoCom2000

[11] M.Mathis, J.Mahdavi, S.Floyd, A.Romanow, “TCP selective acknowledgment options” IETF RFC 2018, 1996

[12] R.K.Balan, B.P.Lee,K.R.R.Kumar, L.Jacob,W.K.G.Seah, A.L.Ananda, “ TCP HACK:TCP header checksum option to improve performance over lossy links”, InfoCom2001

[13] Hari Balakrishnan, Venkata N. Padmanabhan, Srinvasan Seshan, Mark Stemm, Elan Amir, Randy H.Katz, "TCP Improvements for Heterogeneous Networks: The Daedalus Approach”.

[14] Ramon Caceres and Liviu Iftode,”Improving the performance of reliable transport protocols in mobile computing environments” IEEE JSAC Special Issue on Mobile Computing Network,1994.

[15] James F. Kurose and Keith W. Ross, “Computer Networking” 2001 by Addison Wesley Longman, Inc. 167-260.

[16] Modeler & Radio powered by OPNET Simulation Technology. SIMUS Technologies. Inc.

[17] IT Decision Guru powered by OPNET Simulation Technology. SIMUS Technologies.Inc.

[18] IETF PILC WG homepage, http://www.ietf.org/html.charters/plic-charter.html

[19] J. Border , M. Kojo , J. Griner , G. Montenegro , Z. Shelby , “Performance Enhancing Proxies Intended to Mitigate Link-Related”. IETF RFC 3135. June 2001.

[20] Jinsheng Sun., Moshe Zukerman†, King-Tim Ko, Guanrong Chen and Sammy Chan, Effect of Large Buffers on TCP Queueing Behavior, IEEE Infocom 2004

[21] Bokyung Wang, Suresh Singh, Computational Energy Cost of TCP, IIEEE nfocom 2004

[22] Ren Wang, Giovanni Pau, Kenshin Yamada, M.Y. Sanadidi, and Mario Gerla, TCP Startup Performance in Large Bandwidth Delay Networks, IEEE Infocom 2004

[23] Rajiv Chakravorty, Sachin Katti, Jon Crowcroft, Ian Pratt, Flow Aggregation for Enhanced TCP over Wide-Area Wireless, IEEE Infocom2003

[24] Laura Galluccio, Giacomo Morabito, Sergio Palazzo, An Analytical Study of a Tradeoff Between Transmission Power and FEC for TCP Optimization in Wireless Networks

# Thanks !