CIS 632 / EEC 687
Mobile Computing

TCP in Mobile Networks

Prof. Chansu Yu

Contents

- Physical layer issues
  - Communication frequency
  - Signal propagation
  - Modulation and Demodulation
- Channel access issues
  - Multiple access / Random access / Asynchronous
  - 802.11 / Bluetooth
  - Capacity / Energy / Fairness / Directional
- System issues
  - Embedded processor
  - Low power design
- Network issues
  - Location management
  - Mobile IP / Cellular IP
  - MANET routing / Clustering
  - Multicast
  - Interoperability
  - Network reliability (TCP)
  - Quality of service (QoS)

TCP in Mobile IP Networks

TCP in Mobile Ad Hoc Networks

2

Wireless Mobile Transport Layer

- Wireless environments are characterized by *long latencies* and *frequent interruptions*
- Problem: TCP has been optimized for wired networks
  - Wired Network: When a packet is lost, it's typically a sign of congestion → sender should slow down
  - Wireless Network: When a packet gets lost, it could be due to
    - Disconnects
    - Long latencies – slower transmission rates
    - IP tunneling while node moves to new link

    → **What can be done? By whom?**

3

TCP Issues

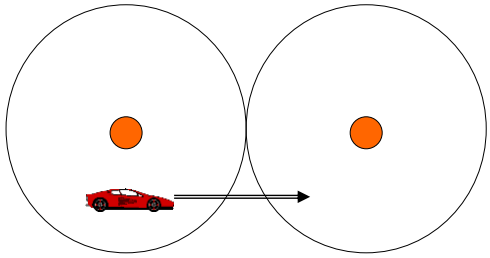
- Reducing the transmission rate is often the wrong response over wireless links.
- The sender should know the network it is transmitting over to make the right decision
- TCP issues in Mobile IP networks
  - Handoff problem
  - High transmission error rate

4

Ramon Caceres, AT&T Bell Lab.
Liviu Iftode, Princeton Univ.
IEEE Journal on Selected Areas in Communication, 1995 (cited ~425).

Hand-off Problem

- Hand-offs occur when a mobile host starts communicating with a new base station (in cellular wireless systems)



5

Hand-off Problem

- Hand-offs may result in temporary loss of route to MH
  - with non-overlapping cells, it may take a while before the mobile host receives a beacon from the new BS
- While routes are being reestablished during handoff,
  - MH and old BS may attempt to send packets to each other, resulting in loss of packets

6

Hand-off Problem

- Packet loss is mistaken as congestion
  - Drops the transmission window size
  - Slow start to restrict the windows growth rate
  - Resets the retransmission timer to a backoff interval
  - Thus, reduces the TCP throughput

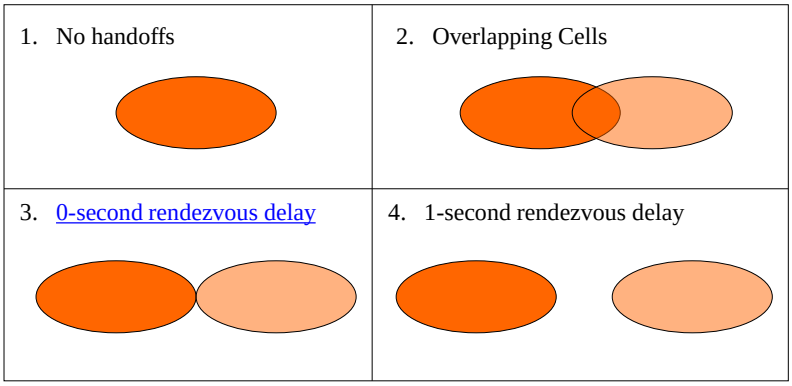
7

Hand-off Problem

- During the long delay for a handoff to complete, a whole window worth of data may be lost
  - After handoff is complete, acks are not received by the TCP sender
  - Sender eventually times out, and retransmits
  - If handoff still not complete, another timeout will occur
- Performance penalty
  - Time wasted until timeout occurs
  - Window shrunk after timeout

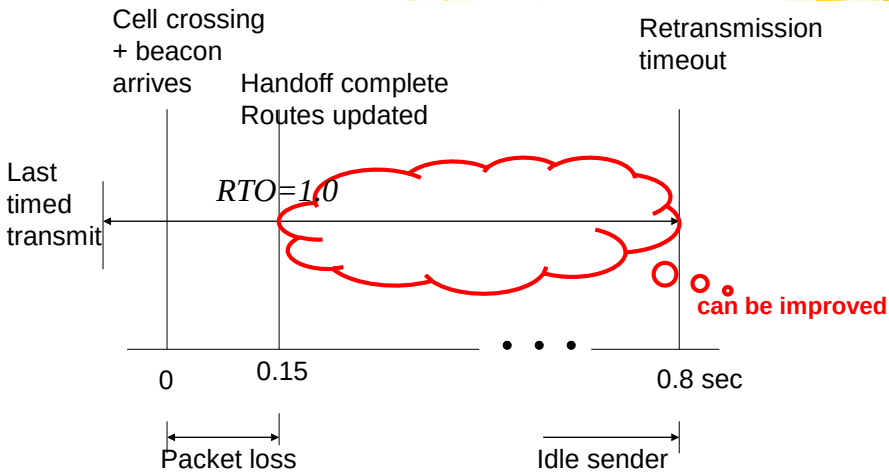
8

Mobility Scenarios



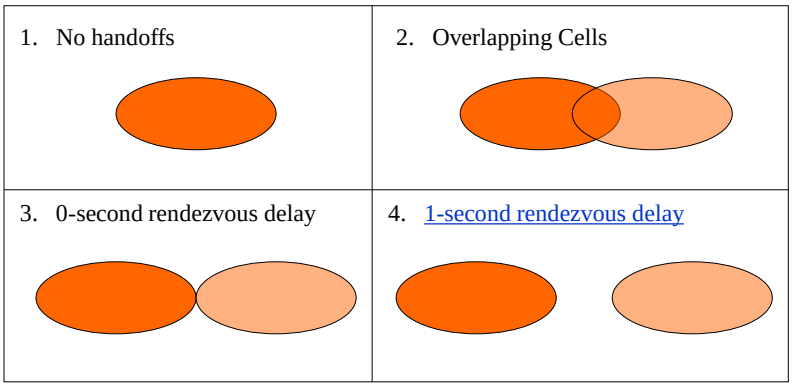
9

0-second Rendezvous Delay : Beacon arrives as soon as cell boundary crossed



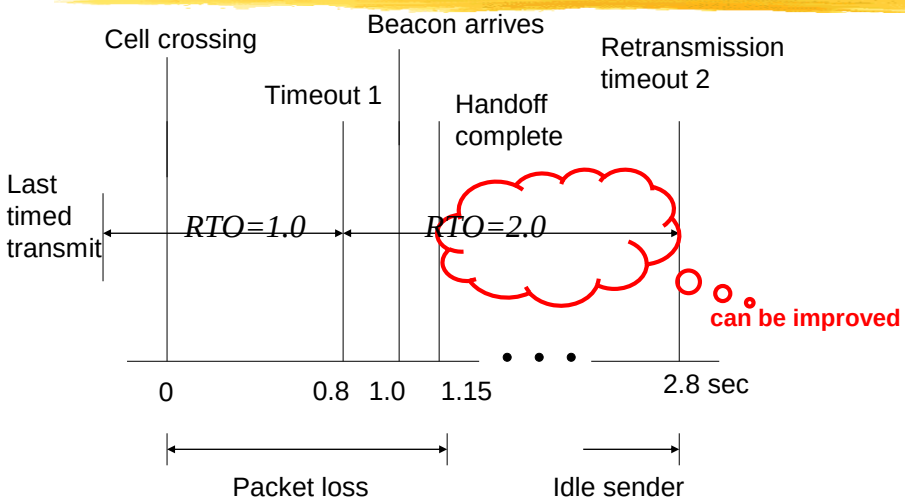
10

Mobility Scenarios



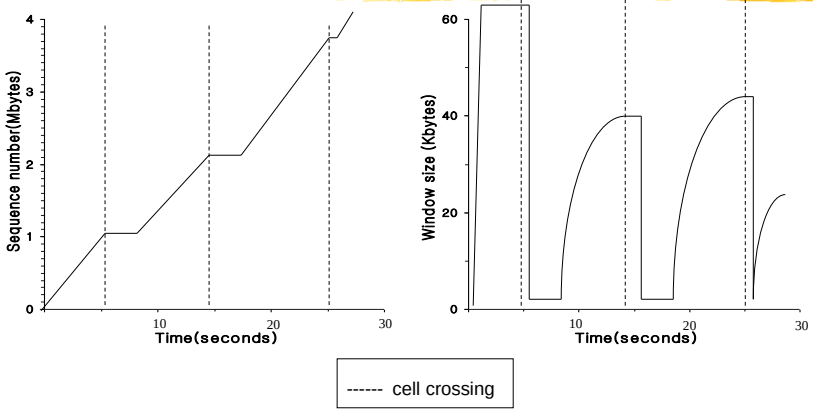
11

1-second Rendezvous Delay : Beacon arrives 1 second after cell boundary crossed



12

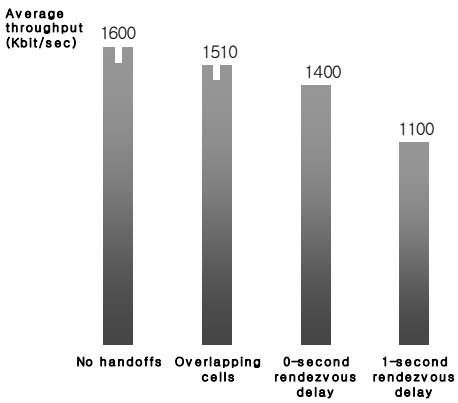
TCP Performance (1-sec delay)



<Behavior of TCP sequence number> <Behavior of TCP congestion window>

13

TCP Performance



- MH switches cells every 8 seconds
- Throughput dropped significantly in the presence of motion

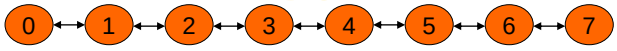
- Degradation in overlapping cells is due to *encapsulation and forwarding delay* during handoff

- Additional degradation in cases 3 and 4 due to packet loss and idle time at sender

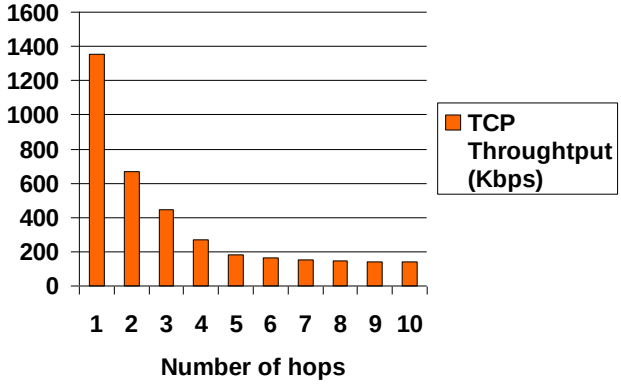
14

G. Holland and N. H. Vaidya, ACM Mobicom, 1999 (UIUC).

TCP in MANET



Connections over multiple hops are at a disadvantage compared to shorter connections, because they have to contend for wireless access at each hop

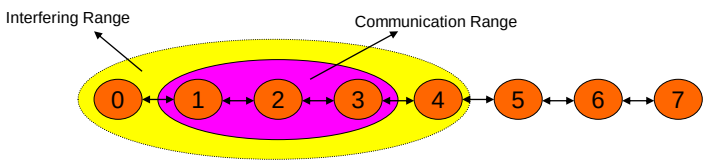


TCP Throughput using 2 Mbps 802.11 MAC

15

Why Performance Degrades?

- MAC Layer - IEEE 802.11 DCF
  - Interfering range is a little more than two times of the communication range
  - When node 2 transmits, nodes 0, 1, 3 and 4 are blocked



16

Approaches

- TCP issues in Mobile IP networks
  - Handoff problem - **Fast retransmission**
  - High transmission error rate - **Split connection**
- TCP issues in MANET (not today)
  - Impact of multiple-hop route
  - Interplay with 802.11 MAC

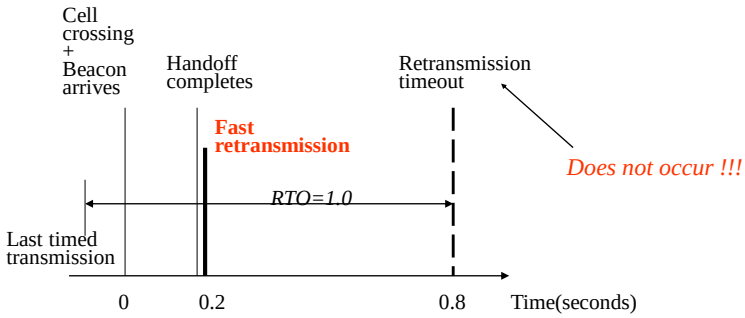
17

Handoff Problem - Fast Retransmission

- When the packet loss is due to handoff, ***who*** can make the right decision? And ***which action*** can be taken?
- When MH is the TCP receiver: after handoff is complete, it sends 3 dupacks to the sender
  - this triggers fast retransmit at the sender
  - instead of dupacks, a special notification could also be sent
- When MH is the TCP sender: invoke fast retransmit after completion of handoff

18

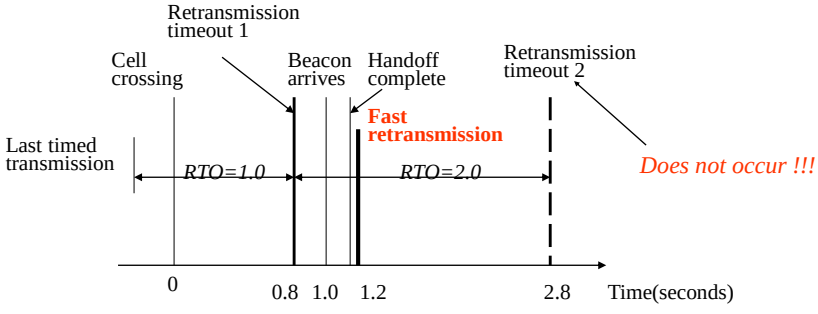
0-second Rendezvous Delay Improvement using Fast Retransmit



Fast retransmission after a handoff with a 0-second rendezvous delay

19

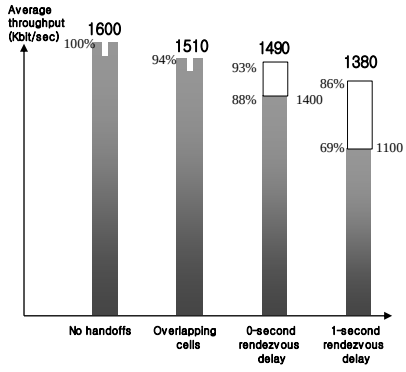
1-second Rendezvous Delay Improvement using Fast Retransmit



Handoff latency and related packet losses with a 1-second rendezvous delay

20

TCP Performance Improvement



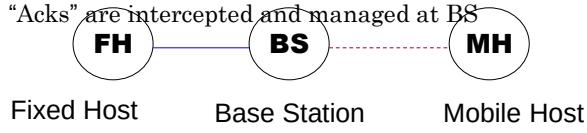
- No change in the first two cases as expected
- Improvement for non-overlapping cells
  - Some degradation still remains
  - fast retransmit reduces congestion window
- **Do we need to change TCP software ?**

Approaches

- TCP issues in Mobile IP networks
  - Handoff problem - **Fast retransmission**
  - High transmission error rate - **Split connection**
- TCP issues in MANET
  - Impact of multiple-hop route
  - Interplay with 802.11 MAC

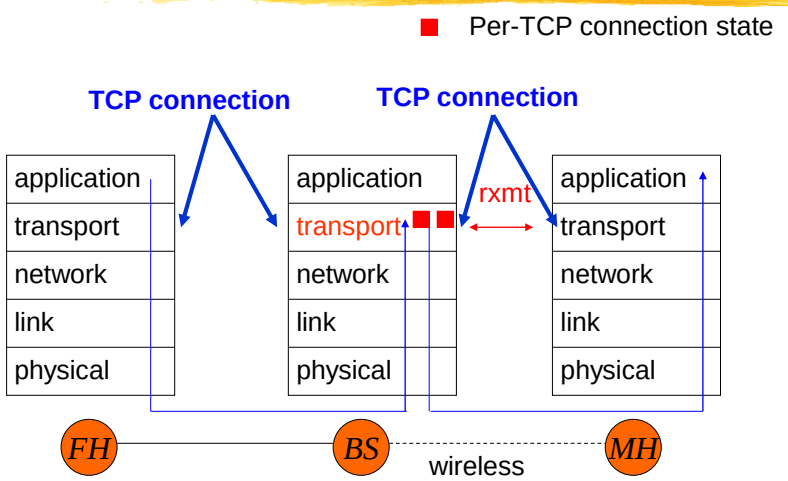
High Transmission Error Rate - Split Connection Approach

- Ho can we address the problem of ***high error rate over wireless links***?
- End-to-end TCP connection is broken into one connection on the wired part of the route and one over wireless part of the route
- A single TCP connection split into two TCP connections
  - FH-MH = FH-BS + BS-MH
  - "Acks" are intercepted and managed at BS



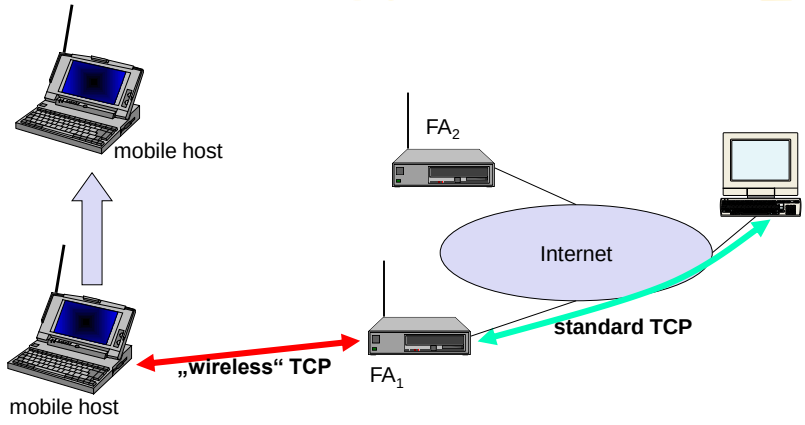
23

Split Connection Approach



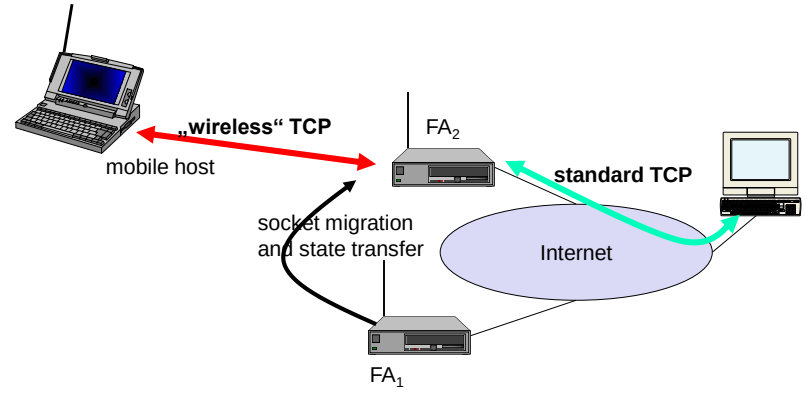
24

Split Connection Approach: What happen if move



25

Split Connection Approach: State Migration



26

Split Connection Approach

- BS terminates the standard TCP connection acting as a proxy
- Old BS (FA) must migrate buffered packets (already acknowledged to FH) as well as socket of the proxy to new BS
- The socket contains the current state of the TCP connection
  - Sequence number, addresses, port number
  - Last packet transmitted to MH
  - Last packet acknowledged by MH
  - Next expected acknowledgement and expected number of duplicated acknowledgements
  - Round-trip time estimate of wireless link

27

Split Connection Approach: Variations

- Indirect TCP
  - FH - BS connection : Standard TCP
  - BS - MH connection : Standard TCP
- Selective Repeat Protocol (SRP)
  - FH - BS connection : standard TCP
  - BS - MH connection : selective repeat protocol on top of UDP
- Asymmetric transport protocol (Mobile-TCP)
  - Low overhead protocol at wireless hosts such as header compression, simpler flow control, No congestion control
- Mobile-End Transport Protocol
  - BS-MH link can use any arbitrary protocol optimized for wireless link

28

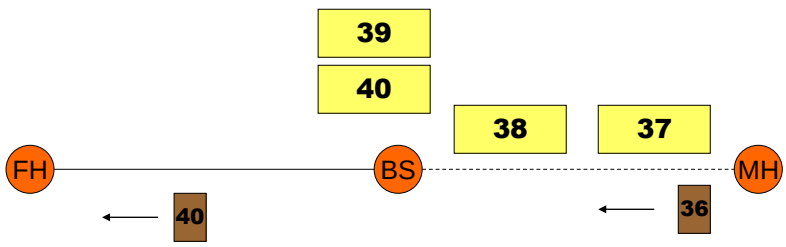
Split Connection Approach : Advantages

- BS-MH connection can be optimized independent of FH-BS connection
  - Different flow / error control on the two connections
- Local recovery of errors
  - Faster recovery due to relatively shorter RTT on wireless link
- Good performance achievable using **appropriate** BS-MH protocol
  - Standard TCP on BS-MH performs poorly when multiple packet losses occur per window (timeouts can occur on the BS-MH connection, stalling during the timeout interval)
  - **Selective acks improve performance for such cases**

29

Split Connection Approach : Disadvantages

- End-to-end semantics violated
  - ack may be delivered to sender, before data delivered to the receiver



30

Split Connection Approach : Disadvantages

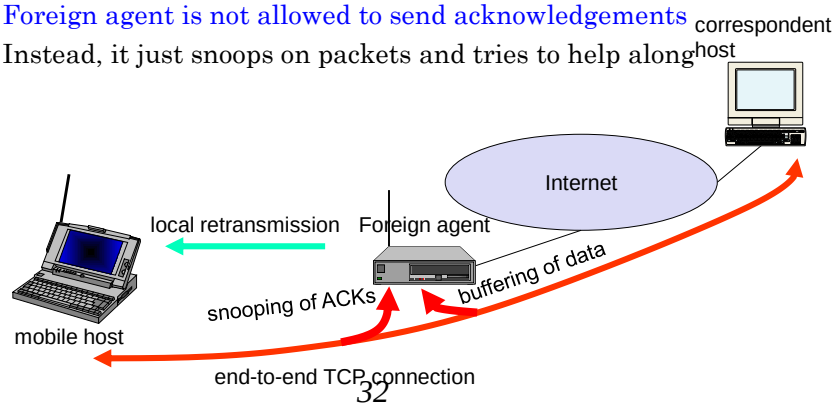
- BS retains hard state
  - BS failure can result in loss of data (unreliability)
    - If BS fails, packet 40 will be lost
    - Since it is ack'd to sender, the sender does not buffer 40
  - Hand-off latency increases due to state transfer
    - Data that has been ack'd to sender, must be moved to new base station
- Buffer space needed at BS for each TCP connection
  - BS buffers tend to get full, when wireless link slower (one window worth of data on wired connection could be stored at the base station, for each split connection)
- Extra copying of data at BS
  - copying from FH-BS socket buffer to BS-MH socket buffer (at TCP layer)
  - increases end-to-end latency

31

Snoop Protocol: TCP-Aware Link Layer

Tries to restore the end-to-end semantics of TCP:

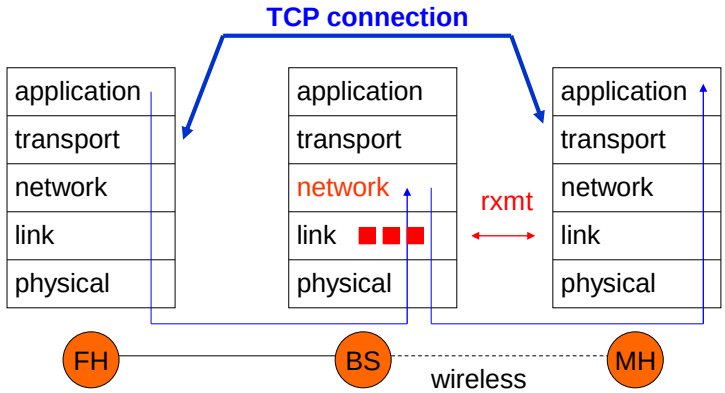
- Foreign agent is not allowed to send acknowledgements
- Instead, it just snoops on packets and tries to help along



32

Snoop Protocol: TCP-Aware Link Layer

■ Per TCP-connection state



33