無線網路多媒體系統
Wireless Multimedia System

Lecture 8: Wireless TCP

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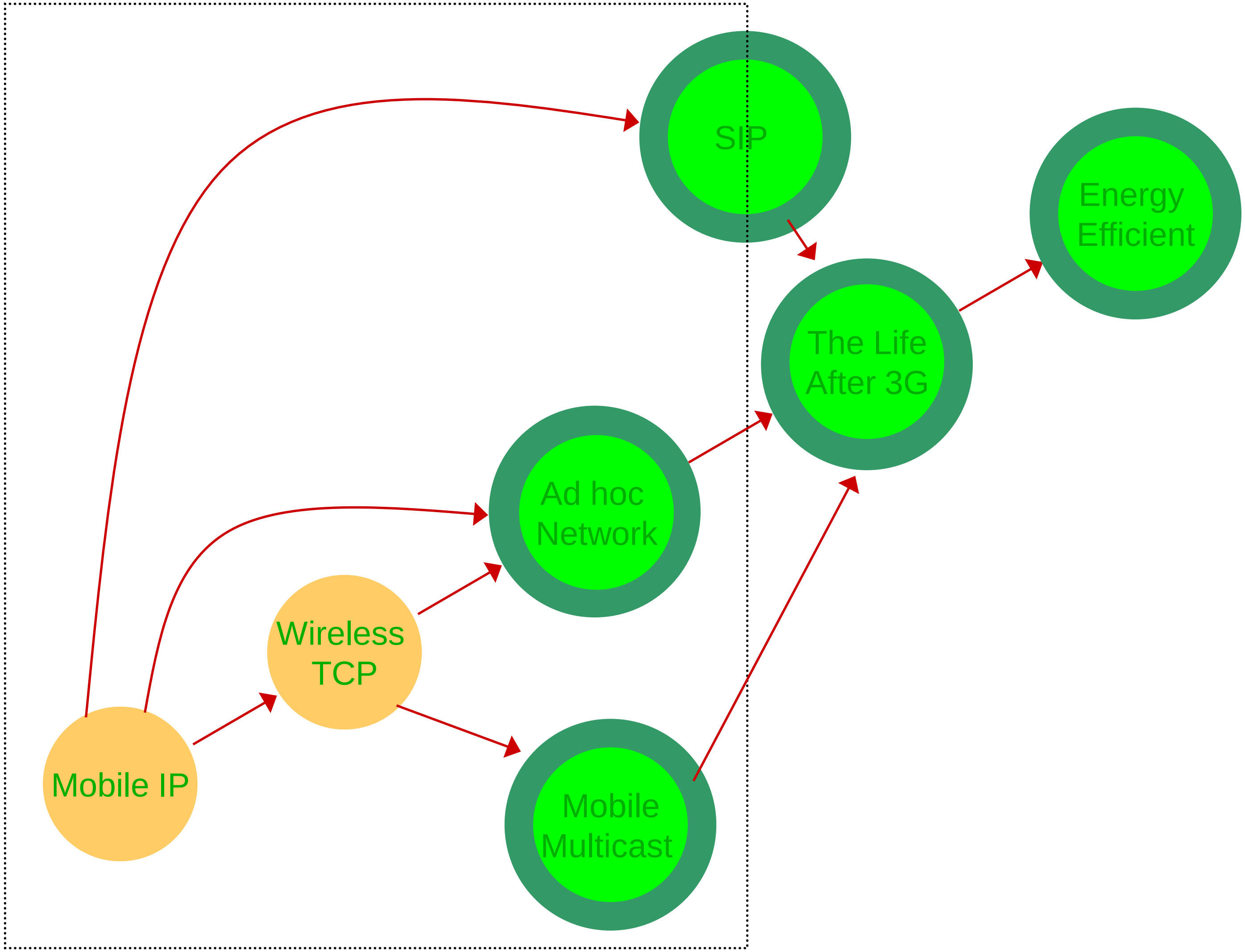
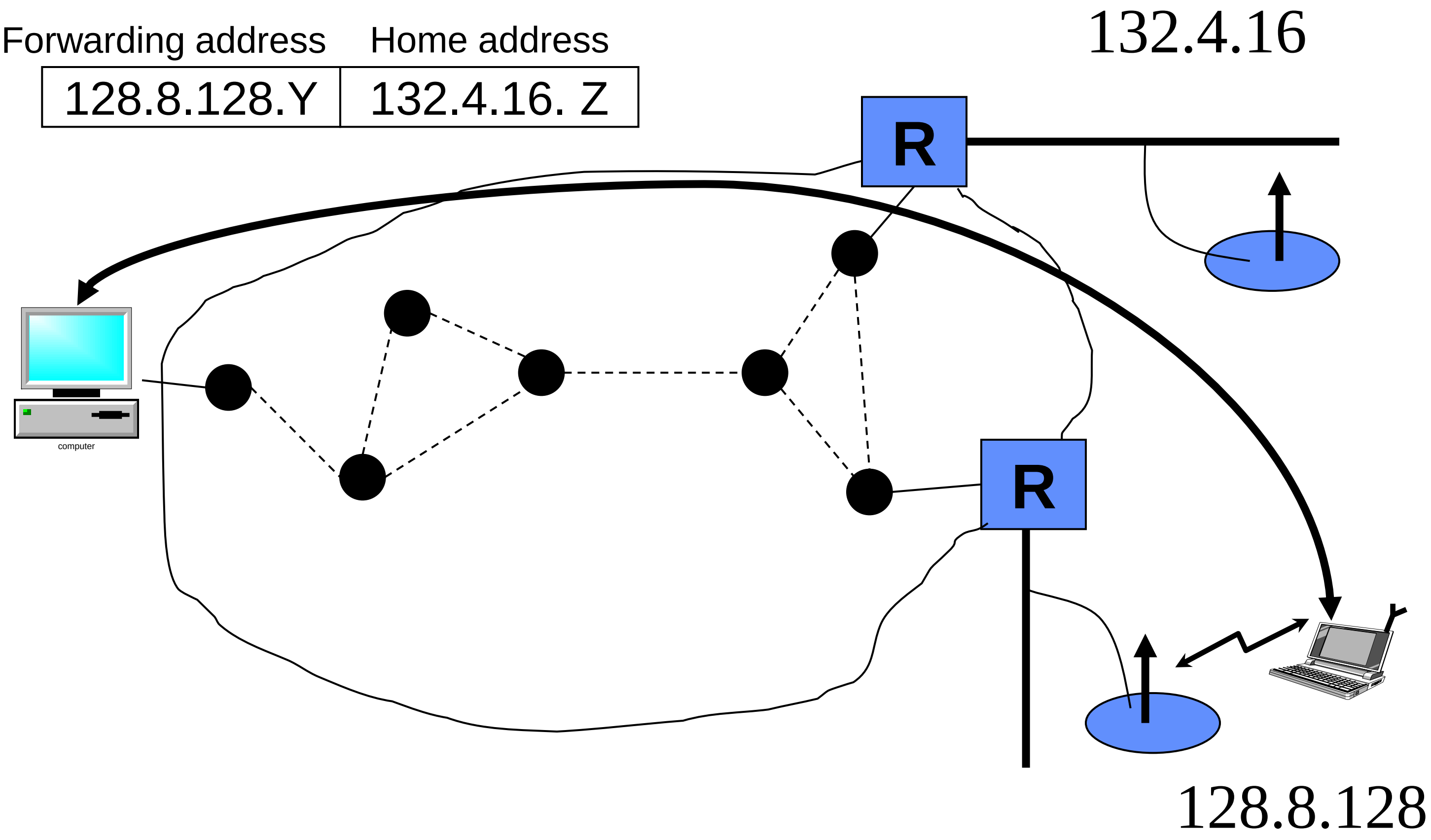
http://wmlab.csie.ncu.edu.tw/wms

Coming Issues

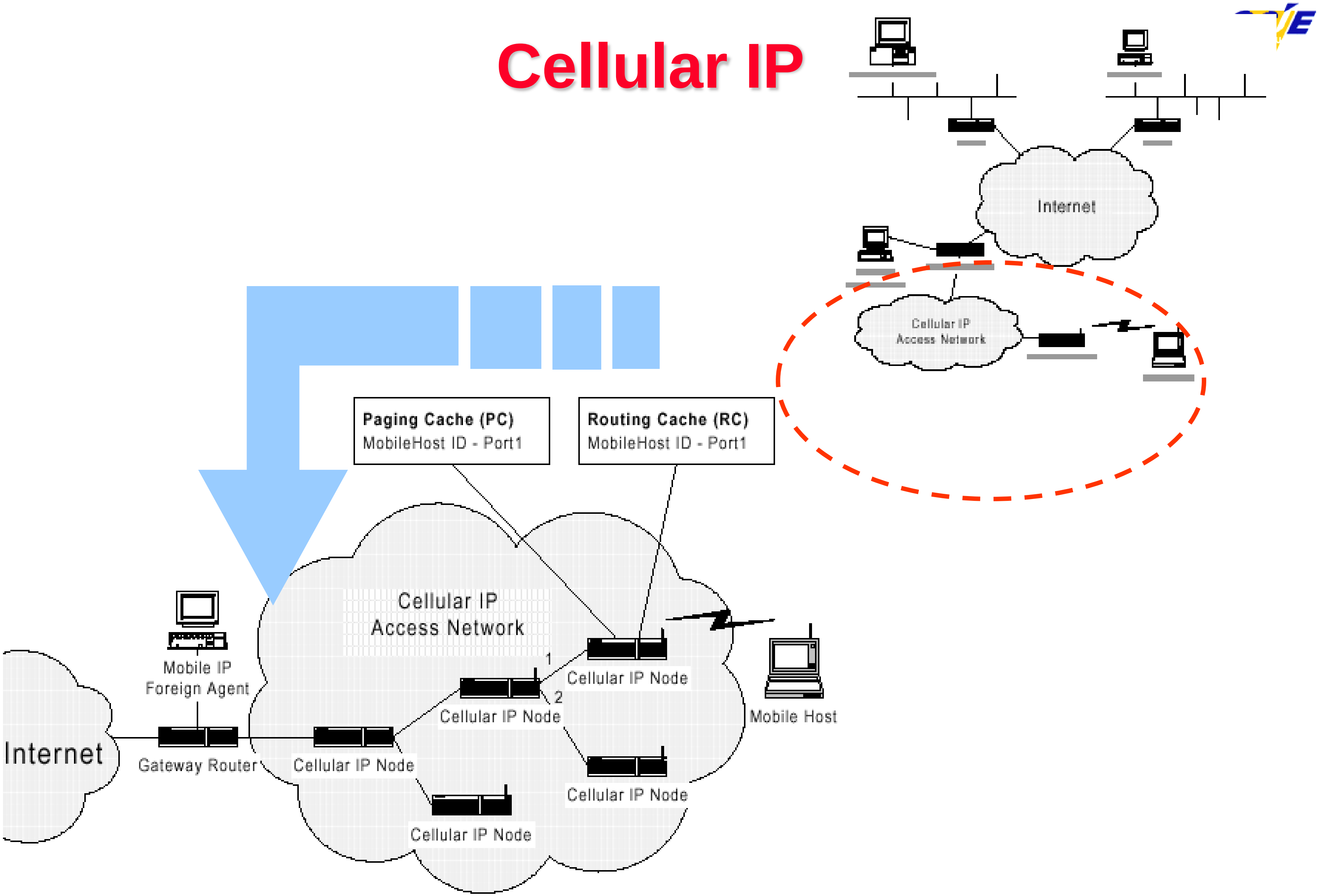


Mobile IP



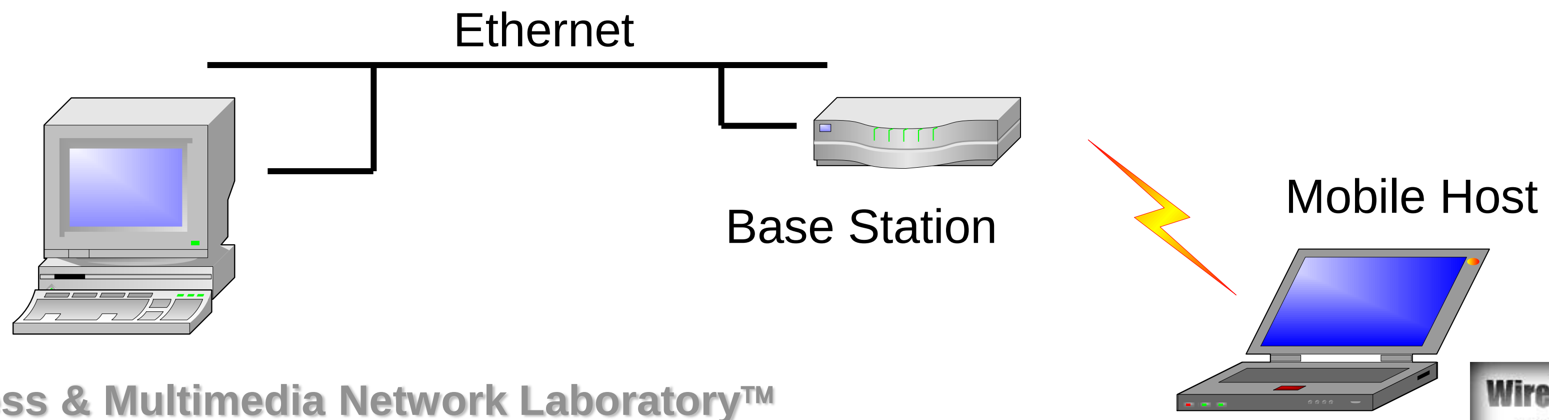
Forwarding address	Home address
128.8.128.Y	132.4.16. Z

Cellular IP


Internet
Cellular IP
Access Network
Paging Cache (PC)
MobileHost ID - Port1
Routing Cache (RC)
MobileHost ID - Port1
Cellular IP
Access Network
Mobile IP
Foreign Agent
Internet
Gateway Router
Cellular IP Node
Cellular IP Node
Cellular IP Node
Cellular IP Node
Cellular IP Node
1
2
Mobile Host

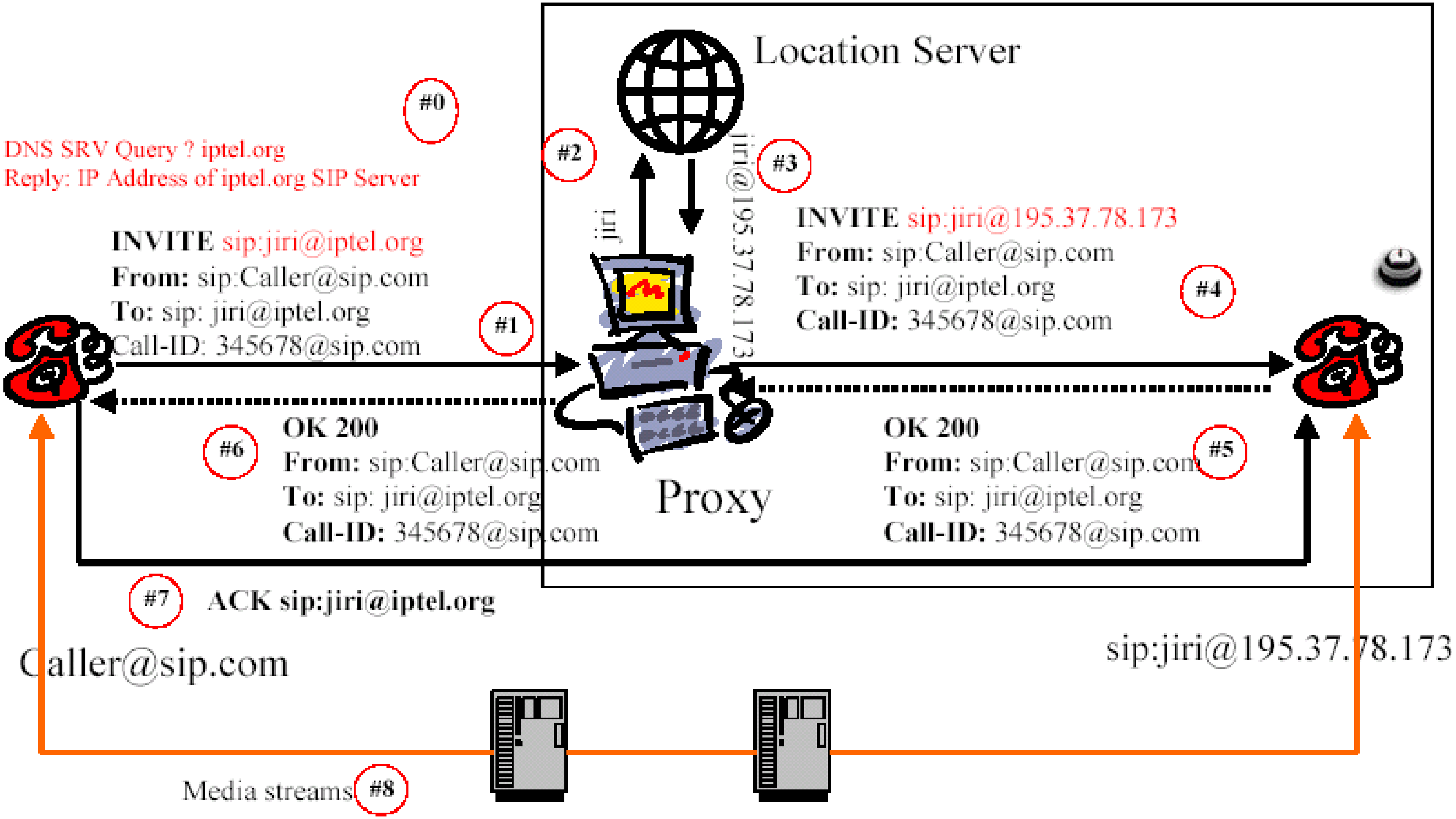
Wireless TCP

- TCP turned to perform well in traditional network where the packet losses occur mostly because of congestion.
- In the wireless environment
  - **Non-congestion** losses caused by wireless link
  - The degraded performance of TCP is mostly due to **mistaking wireless losses for congestion**.



SIP Protocol

Mobility support



DNS SRV Query ? iptel.org
Reply: IP Address of iptel.org SIP Server

INVITE sip:jiri@iptel.org
From: sip:Caller@sip.com
To: sip: jiri@iptel.org
Call-ID: 345678@sip.com

INVITE sip:jiri@195.37.78.173
From: sip:Caller@sip.com
To: sip: jiri@iptel.org
Call-ID: 345678@sip.com

OK 200
From: sip:Caller@sip.com
To: sip: jiri@iptel.org
Call-ID: 345678@sip.com

OK 200
From: sip:Caller@sip.com
To: sip: jiri@iptel.org
Call-ID: 345678@sip.com

ACK sip:jiri@iptel.org

Mobile Multicast

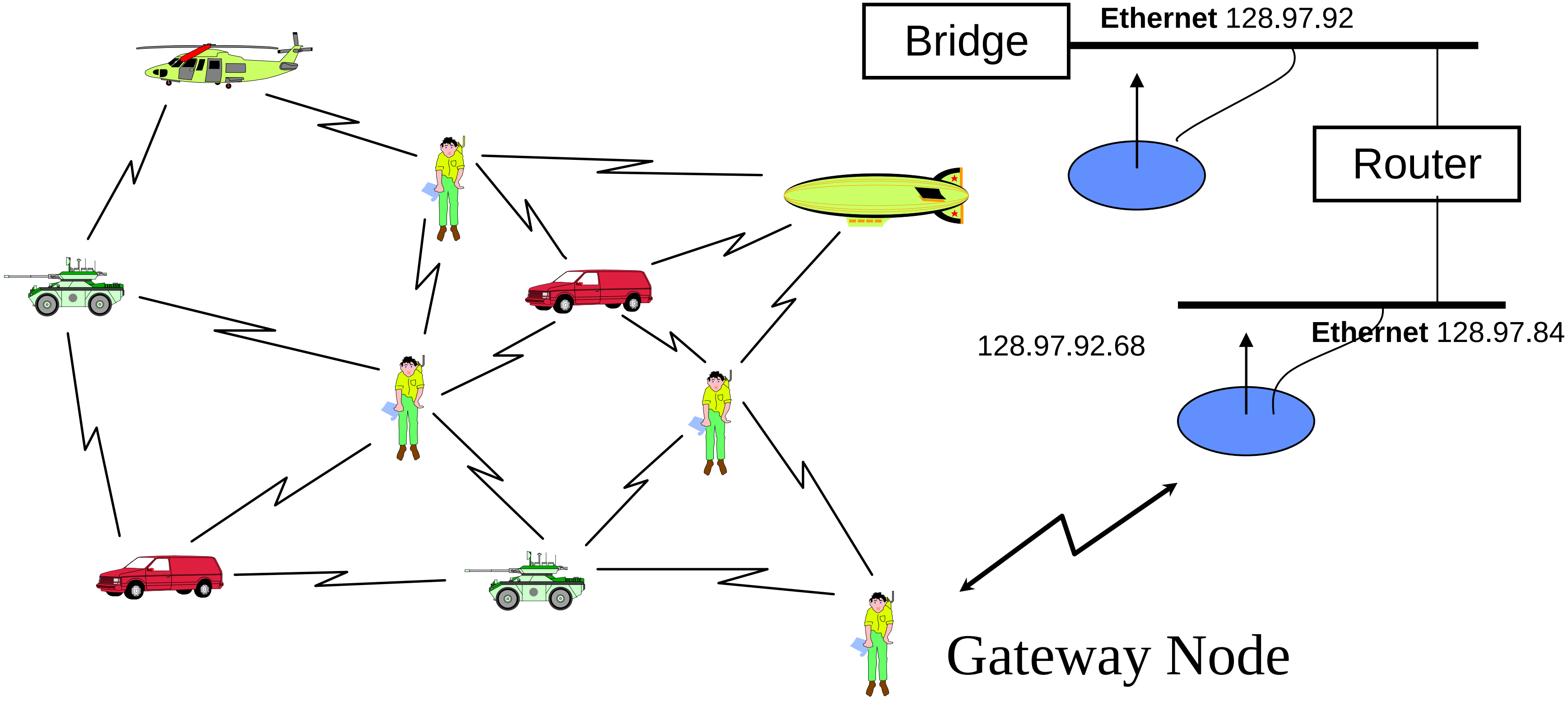
- Mobile Network~ Mobile IP
- Application Requirements: updates to replicated databases, Inter-process communication among cooperating processes
- Resource Conservations~ Single Copy in…Multicast IP

Mobile Multicast

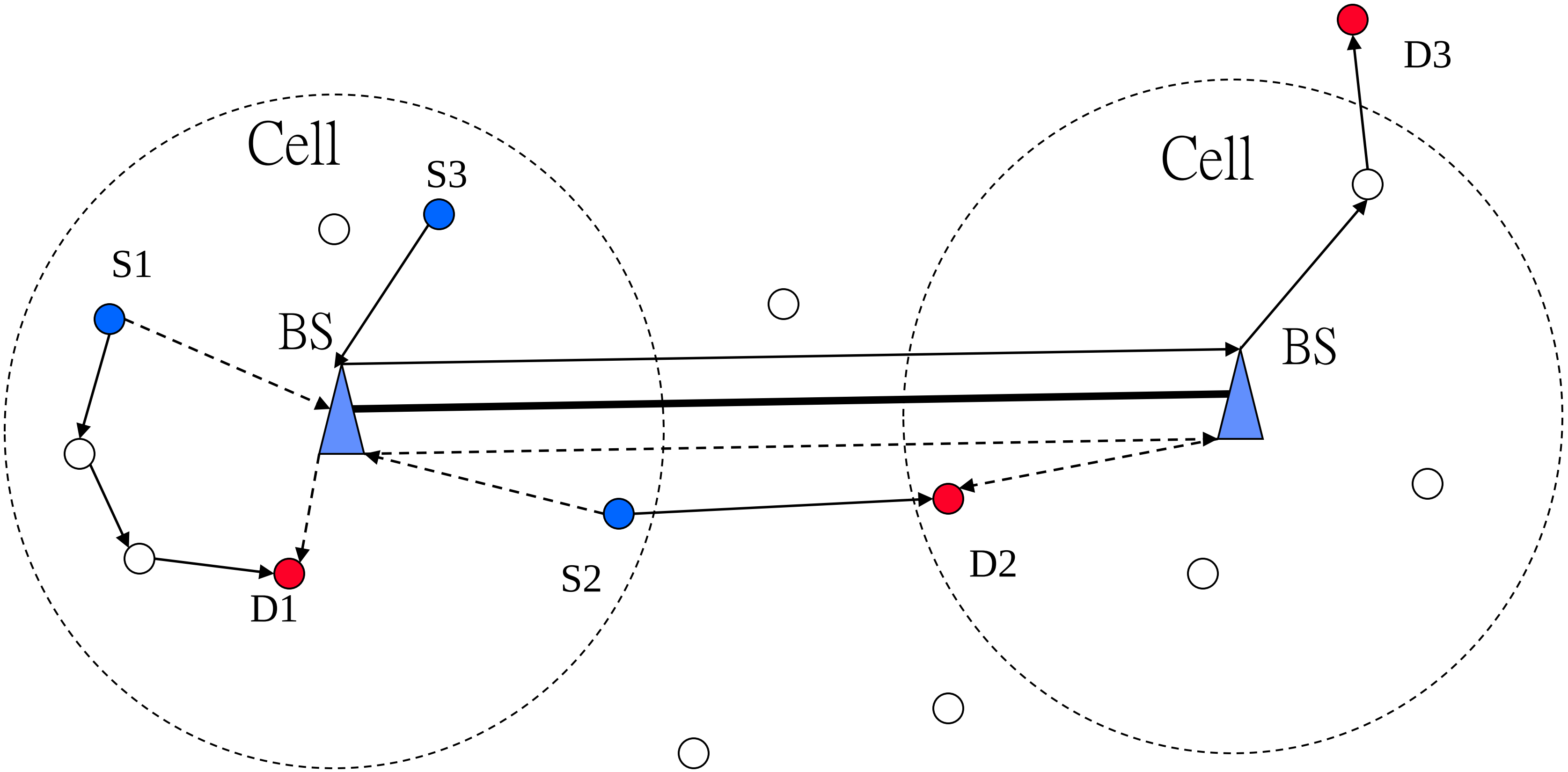
One to Many Mobile Multicasting Services

Internet Interconnection and Mobile IP

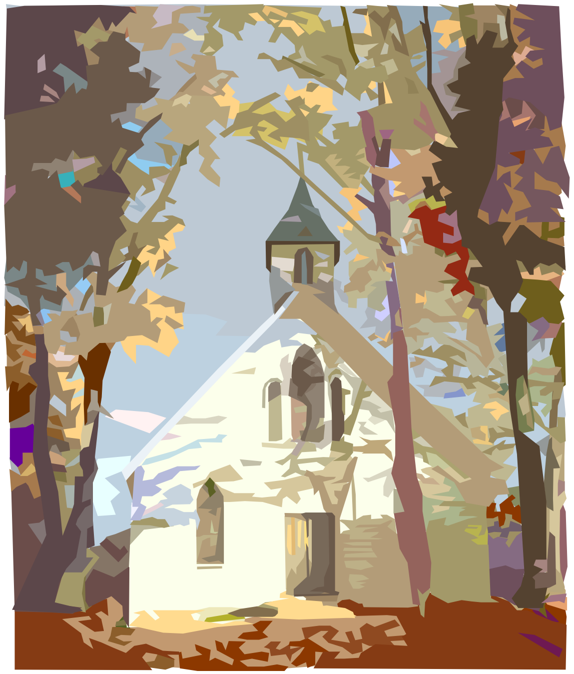
- DSR support the seamless interoperation between an ad hoc network and the Internet



Ad hoc & Cellular System



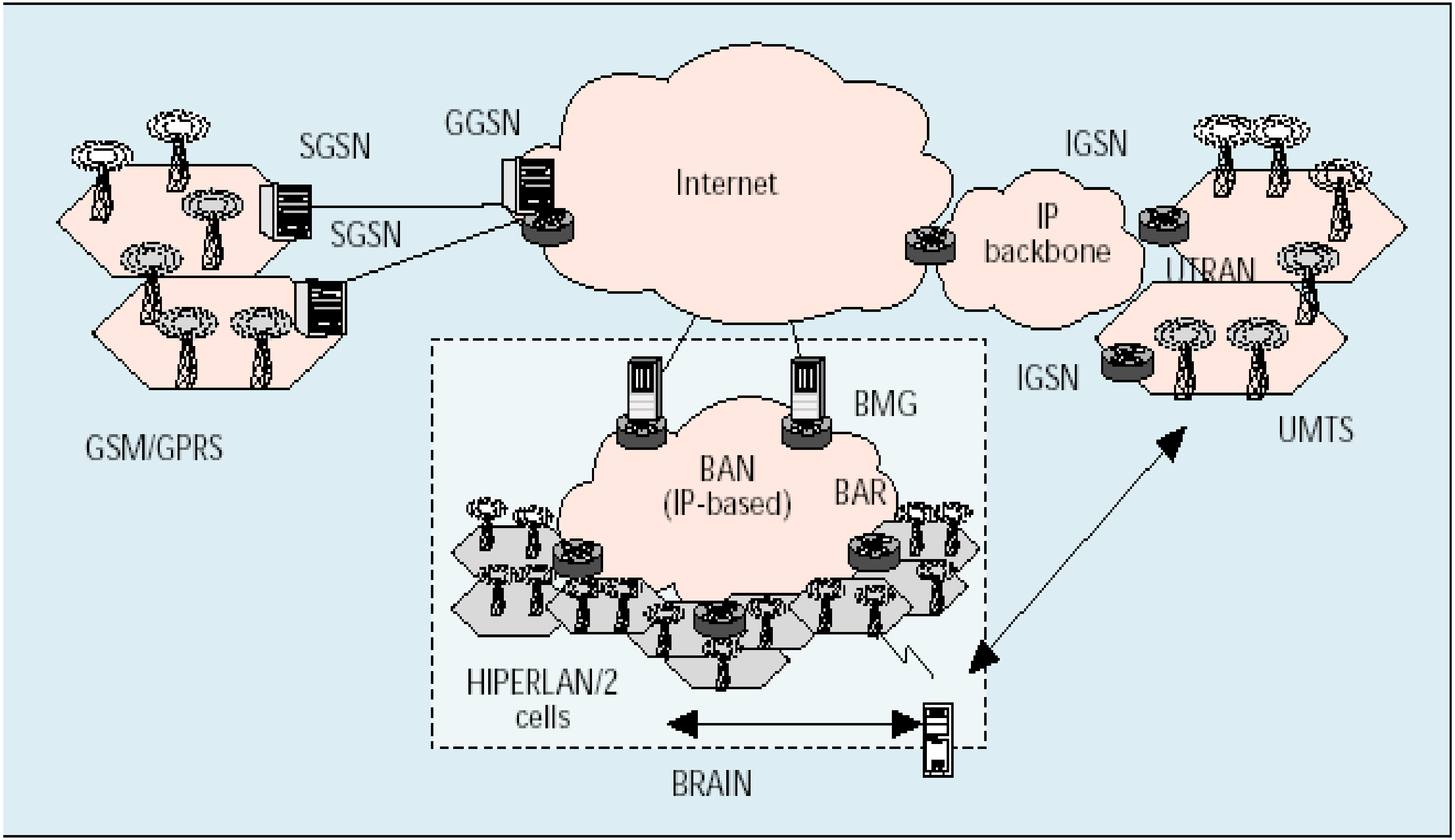
QoS Support for an All-IP System Beyond 3G



BRAIN

- Broadband Radio Access for IP-Based Networks
  - Cellular systems, fixed networks, and wireless LANs
  - Personal mobility, adapted for the terminal and link bandwidth
  - End-to-end QoS
  - A new QoS model for applications (BRENTA)
  - The radio link improvements
- IP-aware RAN (Radio Access Network)
  - Better support to IP applications
  - IP infrastructure will be widely available
- Protocol must be redesigned
  - Resource Management
  - Terminal mobility
  - RAN and terminal must have IP Stack

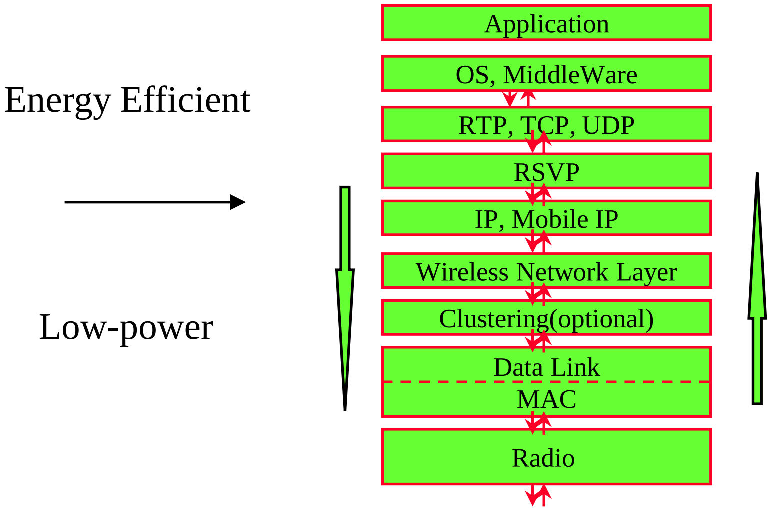
BRAIN (Broadband Radio Access for IP-based Network)



Energy and Power Efficient

- As wireless networks become an integral component of the modern communication infrastructure, energy efficiency will be an important design consideration due to the limited battery life of mobile terminals.

- This paper presents a comprehensive summary of recent work addressing energy efficient and low-power design within all layers of the wireless network protocol stack.



Energy Efficient

Low-power

Application

OS, MiddleWare

RTP, TCP, UDP

RSVP

IP, Mobile IP

Wireless Network Layer

Clustering(optional)

Data Link

MAC

Radio

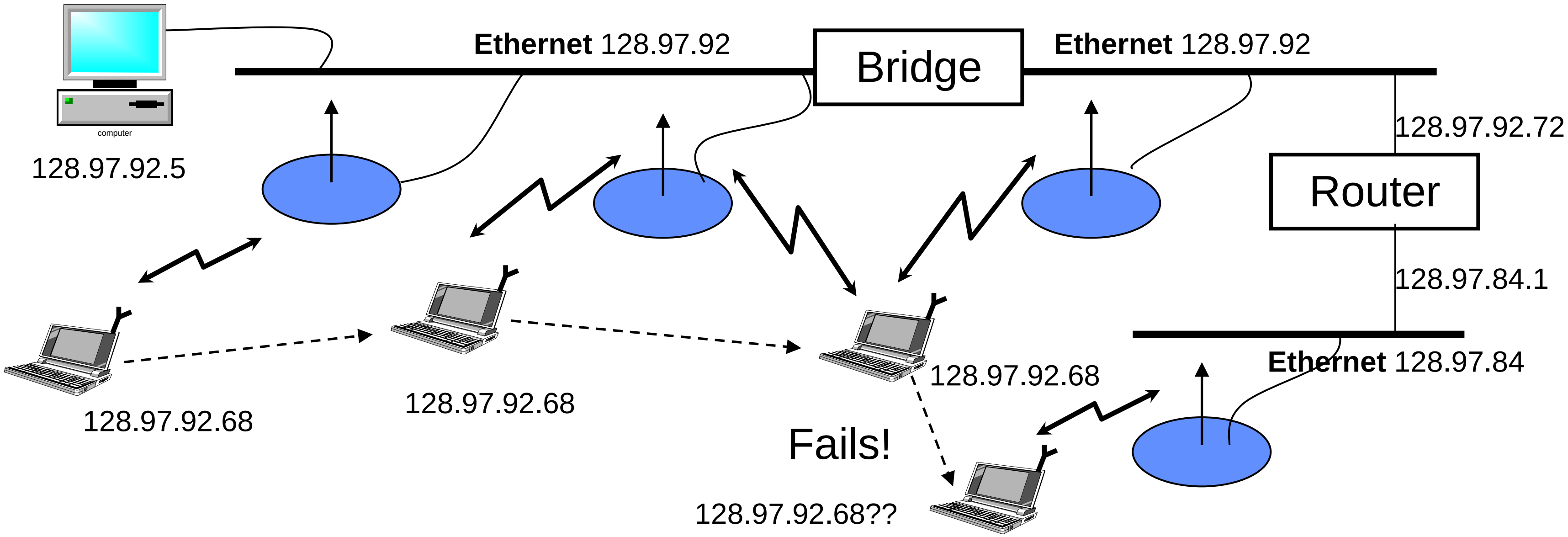
Agenda

- Basic TCP
- Impact of Mobility & Wireless on TCP performances
- Solutions for Wireless TCP
- Midterm (next week)

Reading

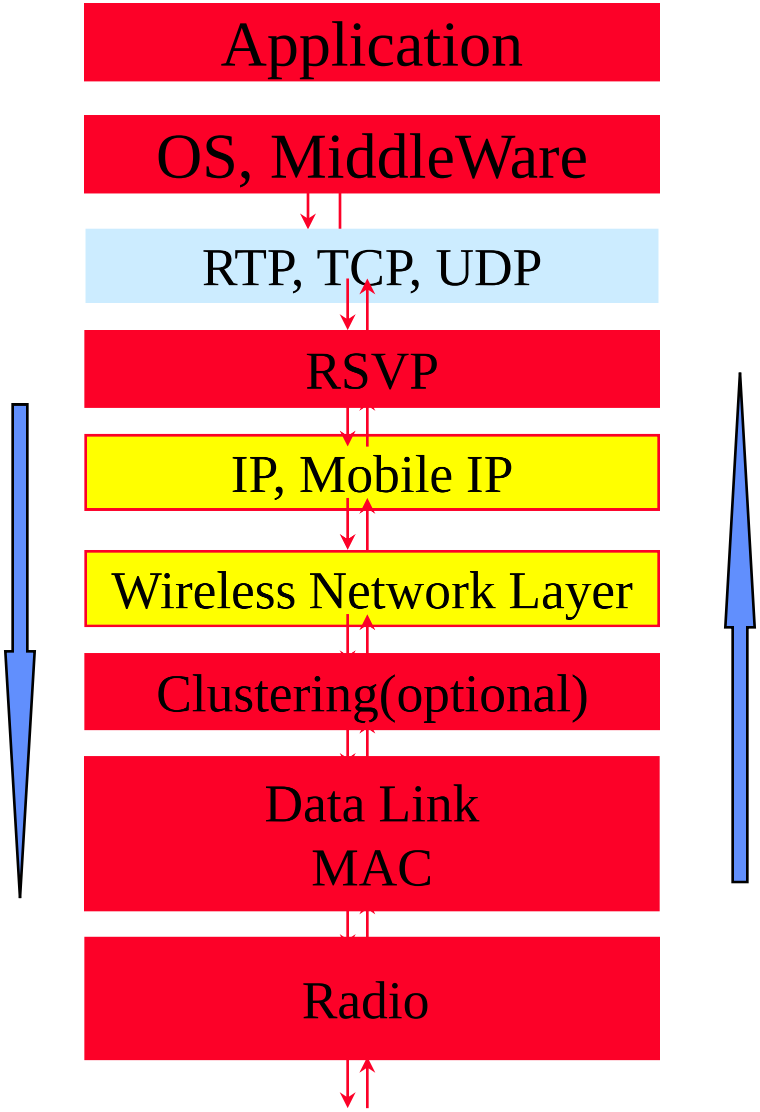
- [Balakrishnan95], Harri Balakrishnan, Srinivasan Seshan, Elan Amir and Randy H. Katz, “Improving TCP/IP Performance over Wireless Networks”, ACM Mobicom95
- [Balarkrishnan97], Harri Balarkrishna, Venkat N, Padmanabhan, Srinivasan Seshan and Randy Katz, “A Comparison of Mechanisms for Improving TCP Performance over Wireless Links”, IEEE JSAC 97.
- Reference: Ka-Cheong Leung and Victor O. K. Li, “Transmission Control Protocol(TCP) in Wireless Networks: Issues, Approaches, and Challenges”, IEEE Communications Survey 2006

Mobility in Wireless LANs: Basestation as Bridges



- Basestations are bridges(layer 2) – i.e. they relay MAC frames
  - Smart bridges avoid wasted bandwidth
- Works the within an ethernet(or other broadcast LAN)
  - Fails across network boundaries, and in switched LANs(e.g. ATM)

QoS and Multimedia Traffic Support



Application

OS, MiddleWare

RTP, TCP, UDP

RSVP

IP, Mobile IP

Wireless Network Layer

Clustering(optional)

Data Link
MAC

Radio

Adaptive
Algorithm

by QoS
Requirement

Mobility
Unpredictable
channel

by QoS
Information

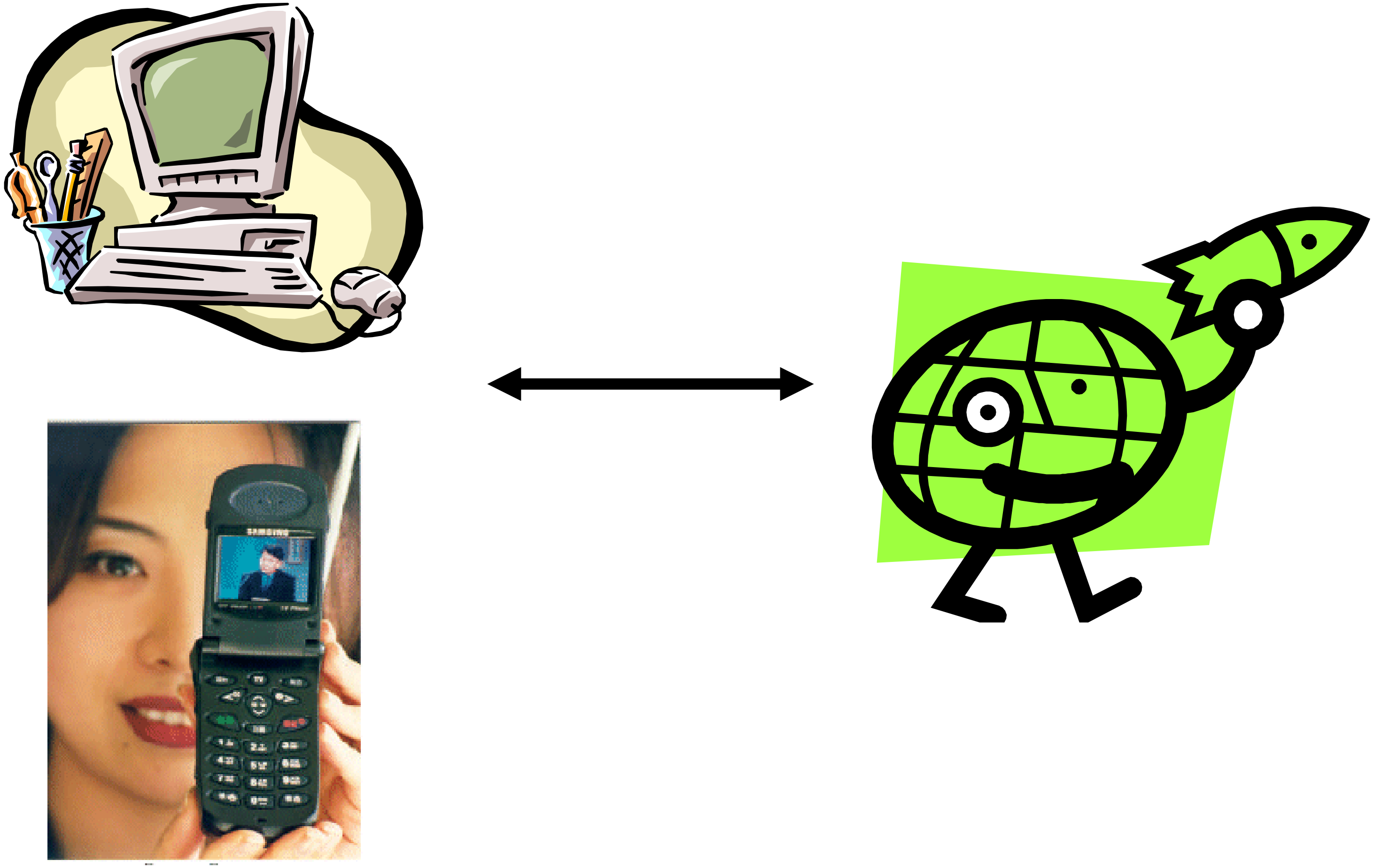
Background

- With the growth of wireless device, wireless network access will become popular, but…
- Import the protocol from the wire network to wireless network…
- Packet losses occur in wireless due to the lossy links, not network congestion
- In traditional TCP, it can not distinguish the difference between that lossy link and network congestion

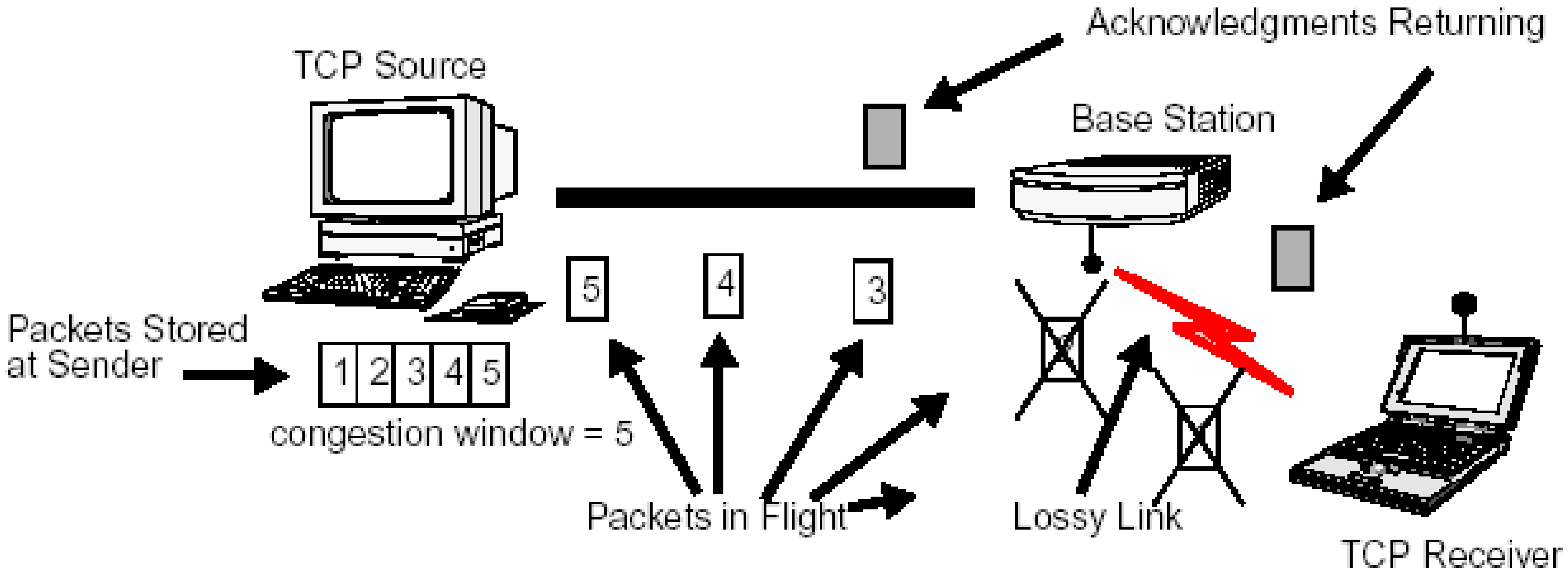
Characteristics of Wireless & Mobility

- Limited Bandwidth
  - Small frame sizes (MTU) to keep latency small
- High bit error rates
  - Small frame sized to keep packet loss probability small
- Time varying bit error rate
  - Fading, frequency collisions etc.
- QoS (loss rate, delay) degradation during hand-off
  - Due to network layer rerouting
  - Due to link layer procedures
- QoS degradation after hand-offs
  - Lack of resource at new basestation
  - Less optimal route

Basic End-to-End Control (Transport)



Typical loss situation



UDP (Connectionless, Unreliable)

Possible Multicast, Real Time Traffic, TCP-Friendly

Impact on Connectionless, Unreliable Transport Protocol

- Example: effect on UDP applications
- Increase in end-to-end packet losses
  - Error on wireless link
  - Packet loss during hand-offs
- Drop in application throughput
  - Errors on wireless link
  - Packet loss during hand-off
- Pauses in interactive applications
  - Burst errors on wireless link
  - Packet loss during hand-off
  - Delay increase due to buffering & re-sequencing during hand-offs
- Application level impact is much more complex!

TCP (Connection Oriented, Reliable)

Data Transmission, WWW, flow control, error control

TCP and Congestion Control

- Terms:
  - advertised window

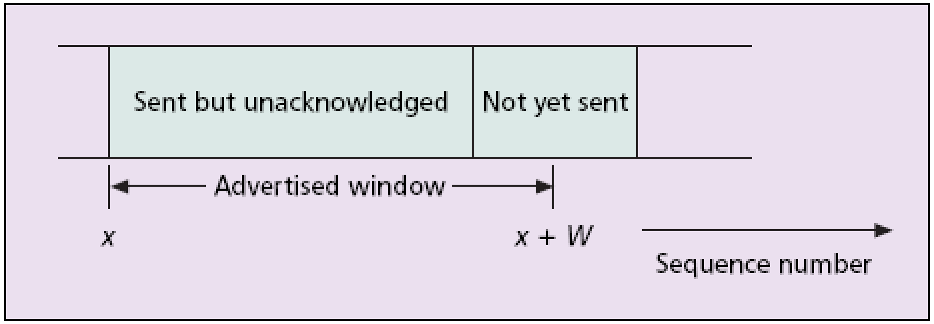


Figure 1. *An illustration of the source sequence number space and advertised window.*

  - congestion avoidance
  - congestion window

TCP Basics

- Sliding window protocol: Go-Back N ARQ
  - Transfers a byte stream in “segments”, not fixed user blocks, logical timer associated with each segment that is sent
  - 32-bit sequence number indicated byte number in stream
    - Window is max number of outstanding unACK’ed bytes in network
- Cumulative acknowledgement scheme (original TCP)
  - Ack’s all bytes up through n
  - Piggybacked on data packets in reverse direction
- Control of sender’s window size
  - Min (receiver’s advertized window, congestion window)
  - Three goals
    - Flow control to avoid receiver buffer overflow
    - Congestion control to react to congestion in network layer & below
    - Congestion avoidance
- Segment loss is assumed to be a result of congestion in routers
  - Reasonable for wired network since BER on fiber is better than 10^{-12}

TCP’s End to End Congestion Control

- Window-based congestion control
  - Cwnd: congestion window size
  - Ssthresh: slow start threshold (for slow down of increase)
- Timeout is an indicator of segment loss
- Timeout value
  - Using estimated average of ACK delay and expected deviation
- On timeout
  - Segment is assumed lost and is attributed to congestion
  - One-half of current window Is recorded in ssthresh
  - Cwd is reduced to 1
  - Timeout value is increased in case packet was delayed

TCP's End-to-end Congestion Control

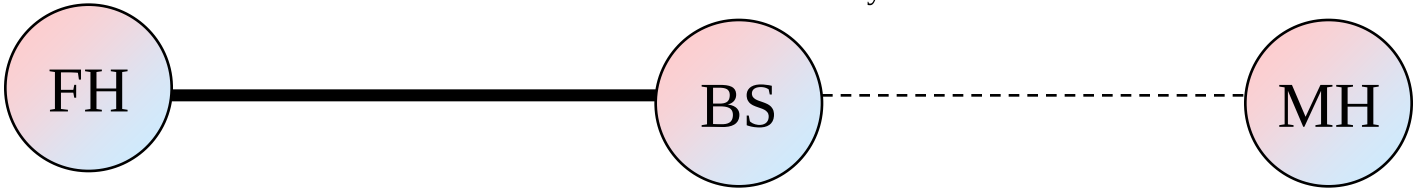
- On new ACK
  - Everything okay, so allow larger congestion window
  - Two ways of increasing cwnd
    - Phase1: slow start until cwnd <= ssthresh
      - Fast (exponential) increase of cwd
    - Phase2: congestion avoidance
      - Slow (additive) increase of cwnd
- Duplicate ACKs
  - Two causes: lost segment, misordered segment
  - >=3 duplicate ACKs in a row are a good indication of a lost segment but data is still flowing
  - Fast Retransmit and Fast Recovery
    - Missing segment is retransmitted without waiting for timeout
    - One half of current window is recorded in ssthresh
    - Congestion avoidance is done but not slow start

Challenges of Mobility and Wireless on Network Performance

TCP Performance

The Problem

- In Wireless and mobile networks, segment loss is likely not due to congestion
  - Packet corruption due to high BER on wireless link (noise, fading)
  - Packet delay and losses during handoffs
- But, TCP invokes congestion control nevertheless
- Mistaking wireless errors and handoffs for congestion causes
  - Significant reductions in throughput (window size decreases, slow start)
  - Unacceptable delays (low resolution TCP times ~500ms, back-off)



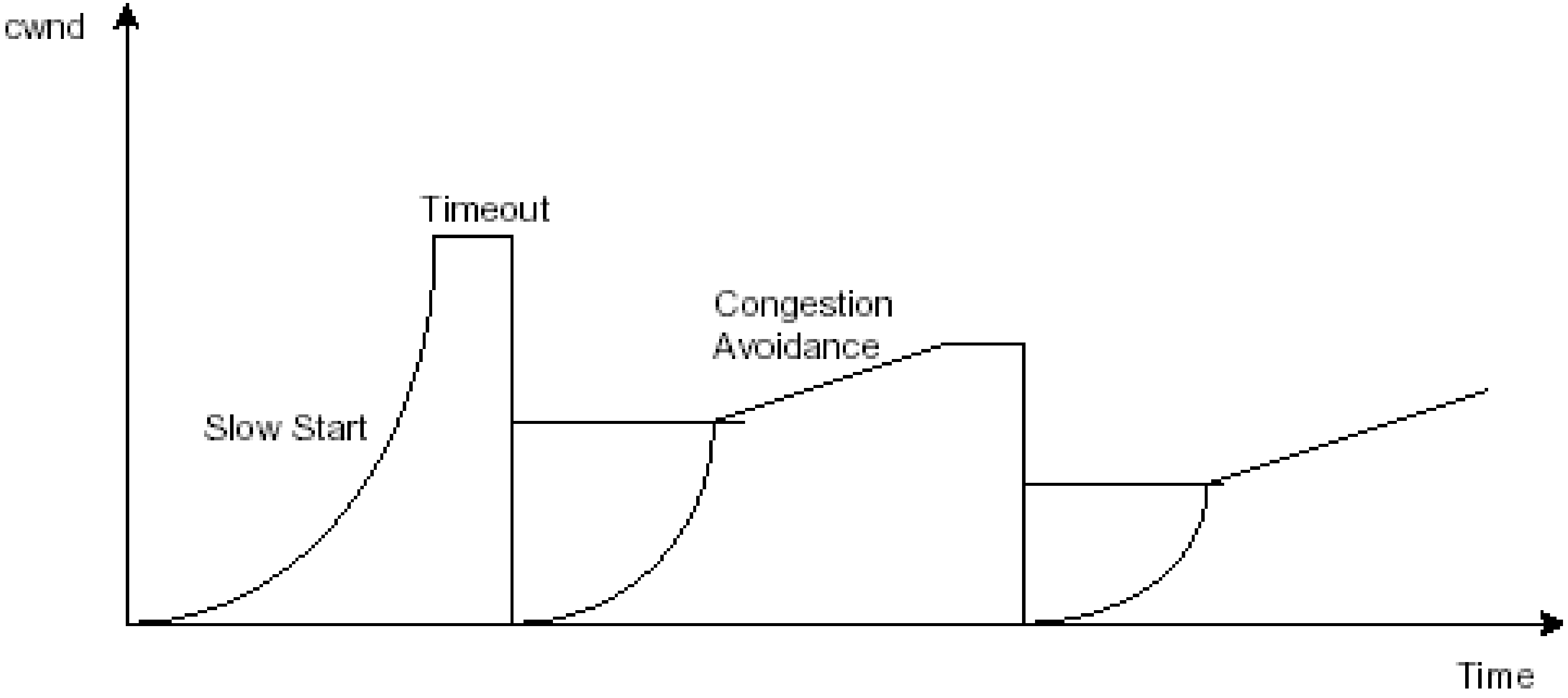
Packet loss due to congestion

Packet loss due to corruption and handoffs, excessive
Delay due to handoffs

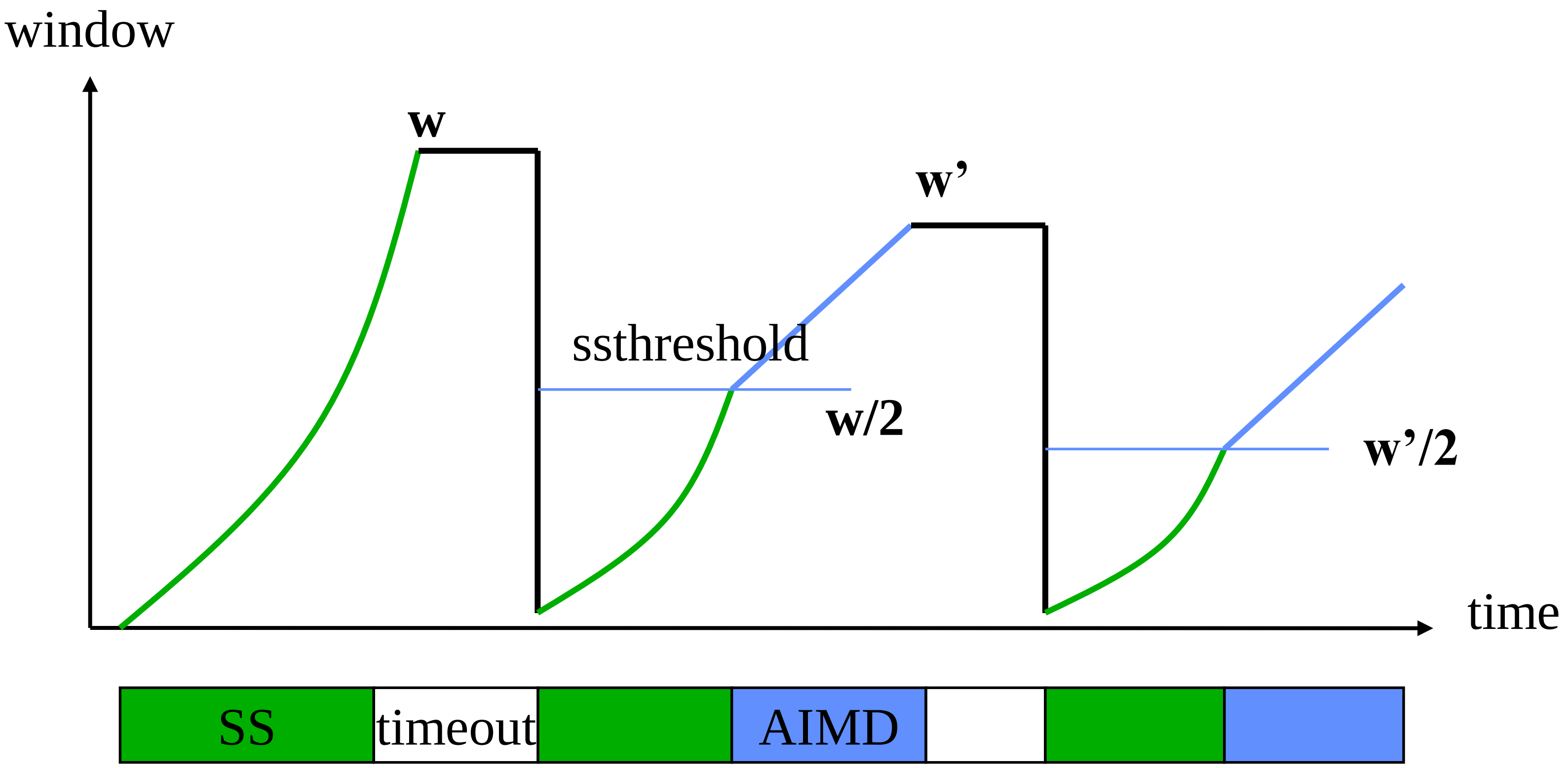
Example graph

cwin<=ssthresh → slow start

cwin>ssthresh → congestion avoidance

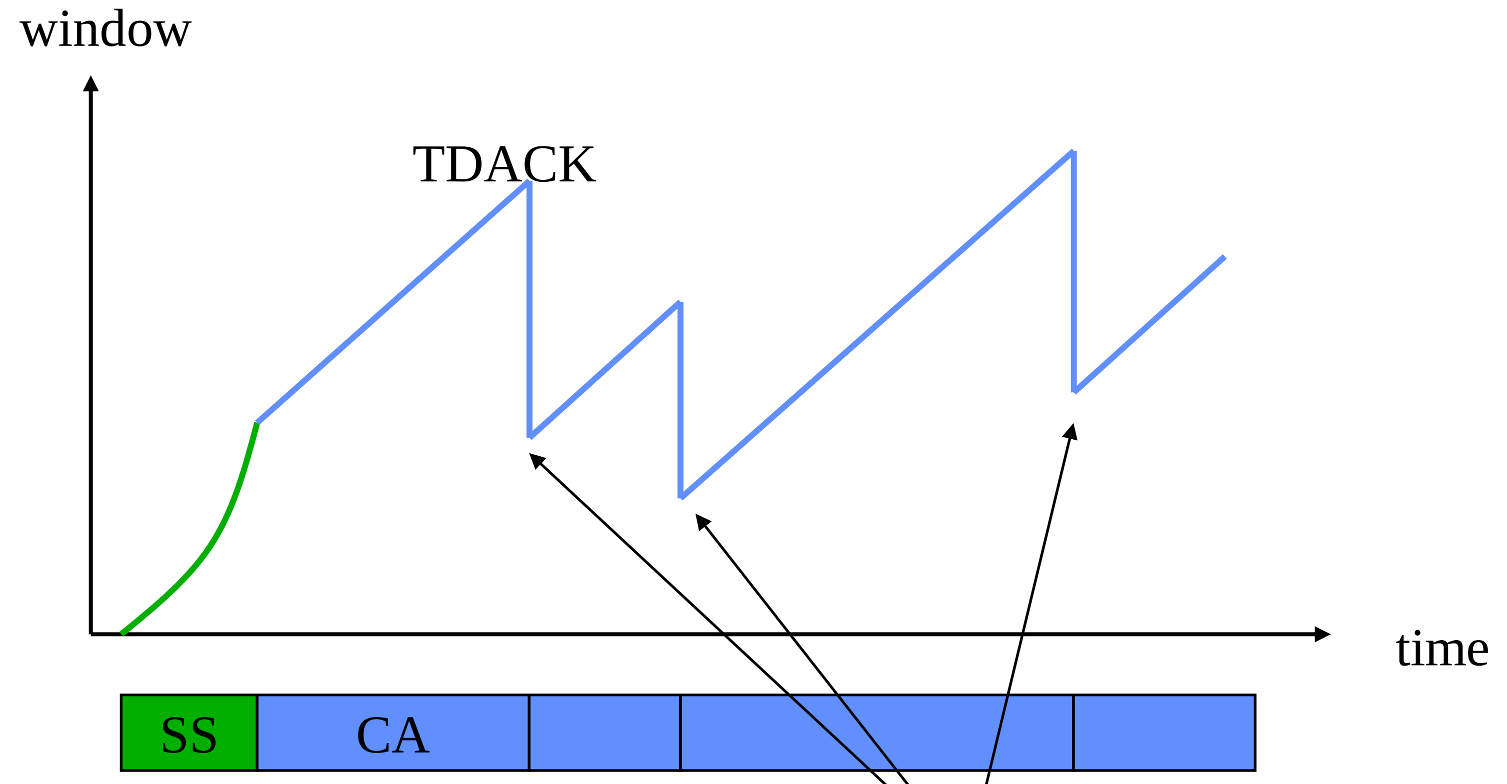


Slow Start of TCP Reno



ssthreshold : slow-start threshold

Congestion Avoidance of TCP Reno



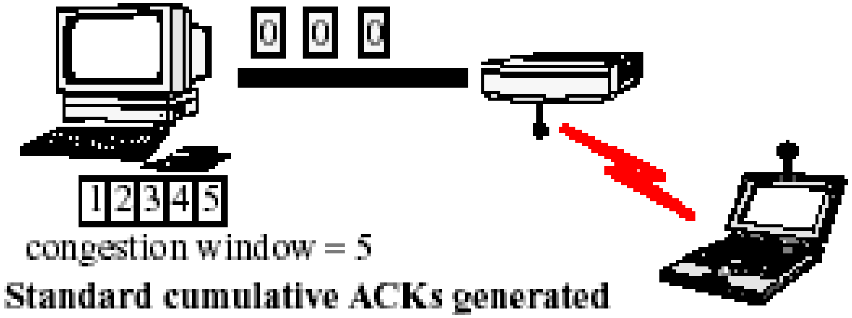
SS: slow start
CA: congestion avoidance

Fast retransmission / Fast recovery

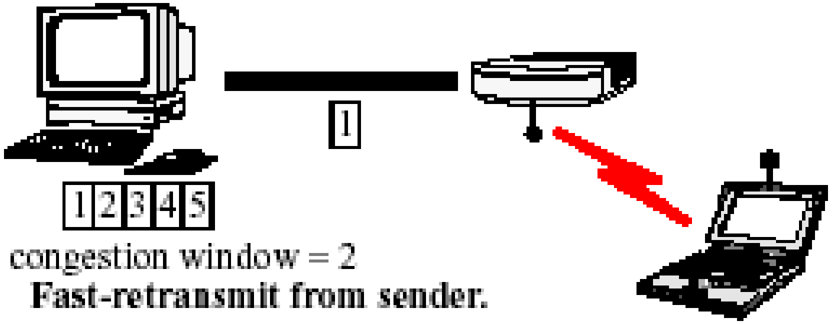
Fixes?

- Fix TCP
  - TCP really a hack in many ways..
  - Separate congestion control from error control
  - Move away from cumulative ACK
- Fix lower layer to make TCP work better
  - Improve the wireless link
- Use something different
  - Something totally new
  - Something different for the wireless part

Normal TCP

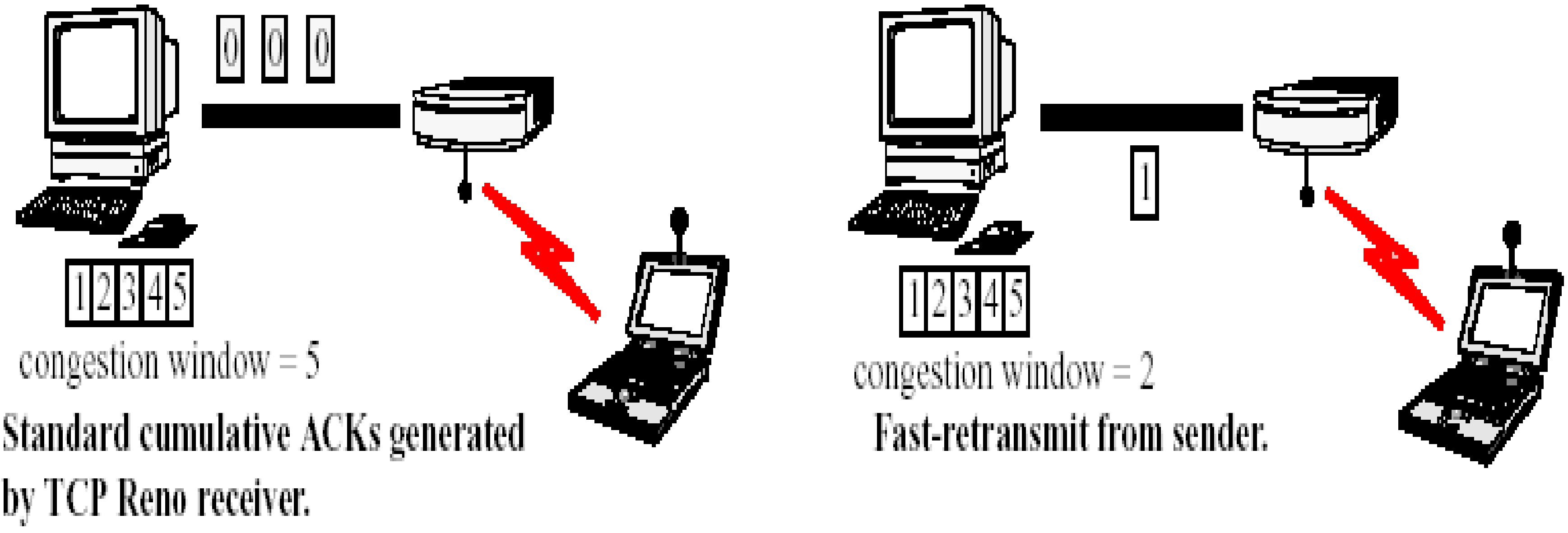


Standard cumulative ACKs generated by TCP Reno receiver.



Fast-retransmit from sender.

Fast-Retransmit Scheme



Standard cumulative ACKs generated by TCP Reno receiver.

Fast-retransmit from sender.

Solutions for WTCP (I)

Split the connection into two parts

Split Connection Approaches

- Main Idea: split MH ↔ FH connection into two MH ↔ BS & BS ↔ FH
  - Separate flow control and reliable delivery mechanisms
  - Intermediate higher layer agent at the base-station
  - Session layer hides the split connection
- Two approaches:
  - Both FH ↔ BS & BS ↔ MH segments use TCP: Rutger’s Indirect-TCP
    - e.g. uses MTCP (Multiple TCP) over BS ↔ MH
  - BS ↔MH uses specialized protocol
    - e.g. uses SRP (Selective Repeat) over BS ↔MH
    - Error and flow control optimized for lossy wireless link

Pros & Cons of Split-Connection Approaches

- Pros
  - FH is shielded from wireless link behavior
  - Handoff is transparent to FH
  - Relative easy to implement
  - Requires no modification to FH
  - Can use specialized protocol over wireless link
- Cons
  - Loss of end-to-end semantics
  - Application relink with new library
  - Software overhead: efficiency and latency
  - Large handoff latency

Solutions for WTCP (II)

Lower layer to make TCP work better

Link-level Error Control

- FEC and ARQ on wireless link to increase its reliability
  - Improves performance independent of transport protocol
- Disadvantage
  - Coupling between link level and end-to-end retransmission may lead to degraded performance at high error rates
  - Does not address the delay and losses due to handoffs

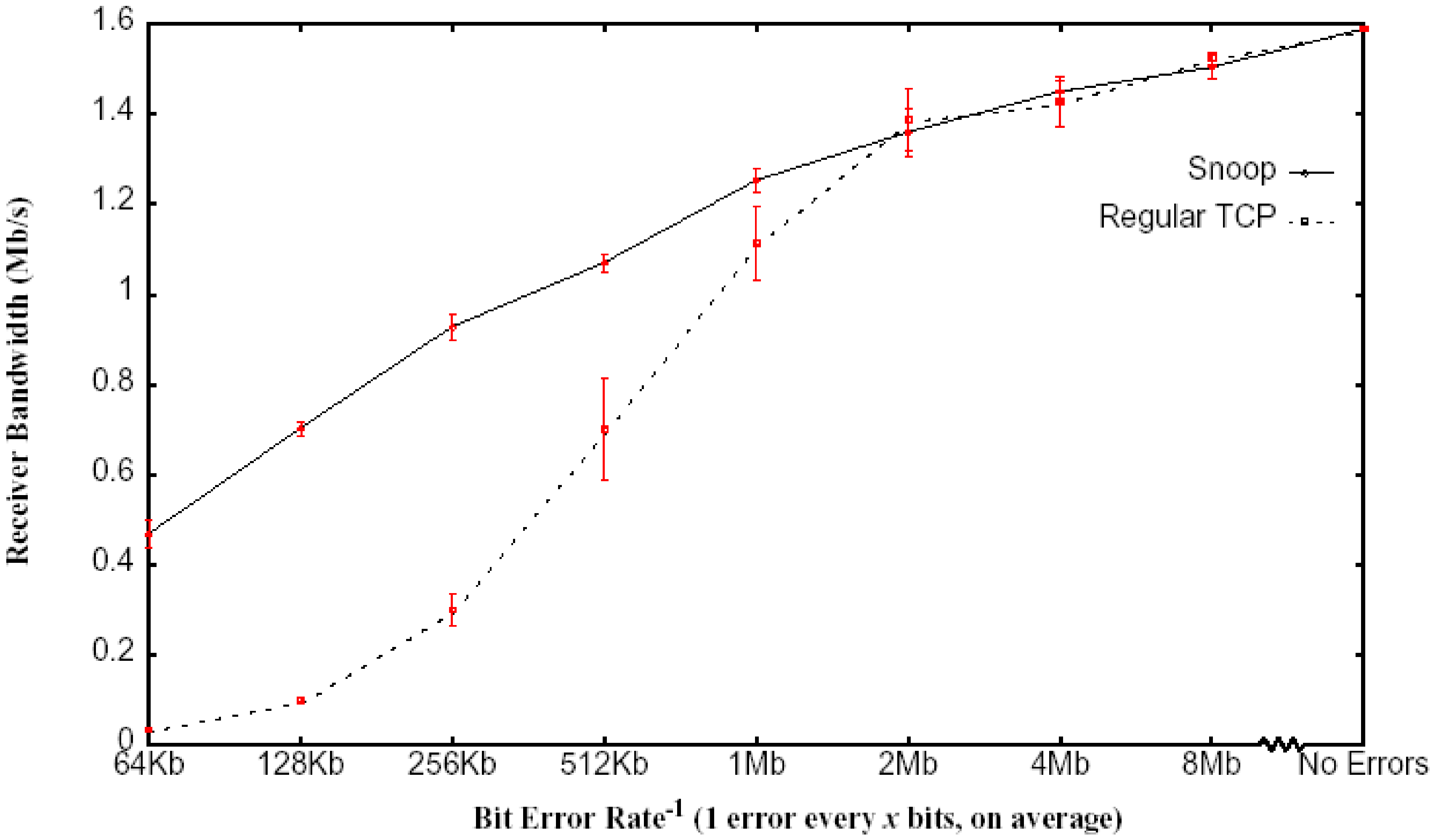
Solutions for WTCP (III)

Snoop, Make it look like!

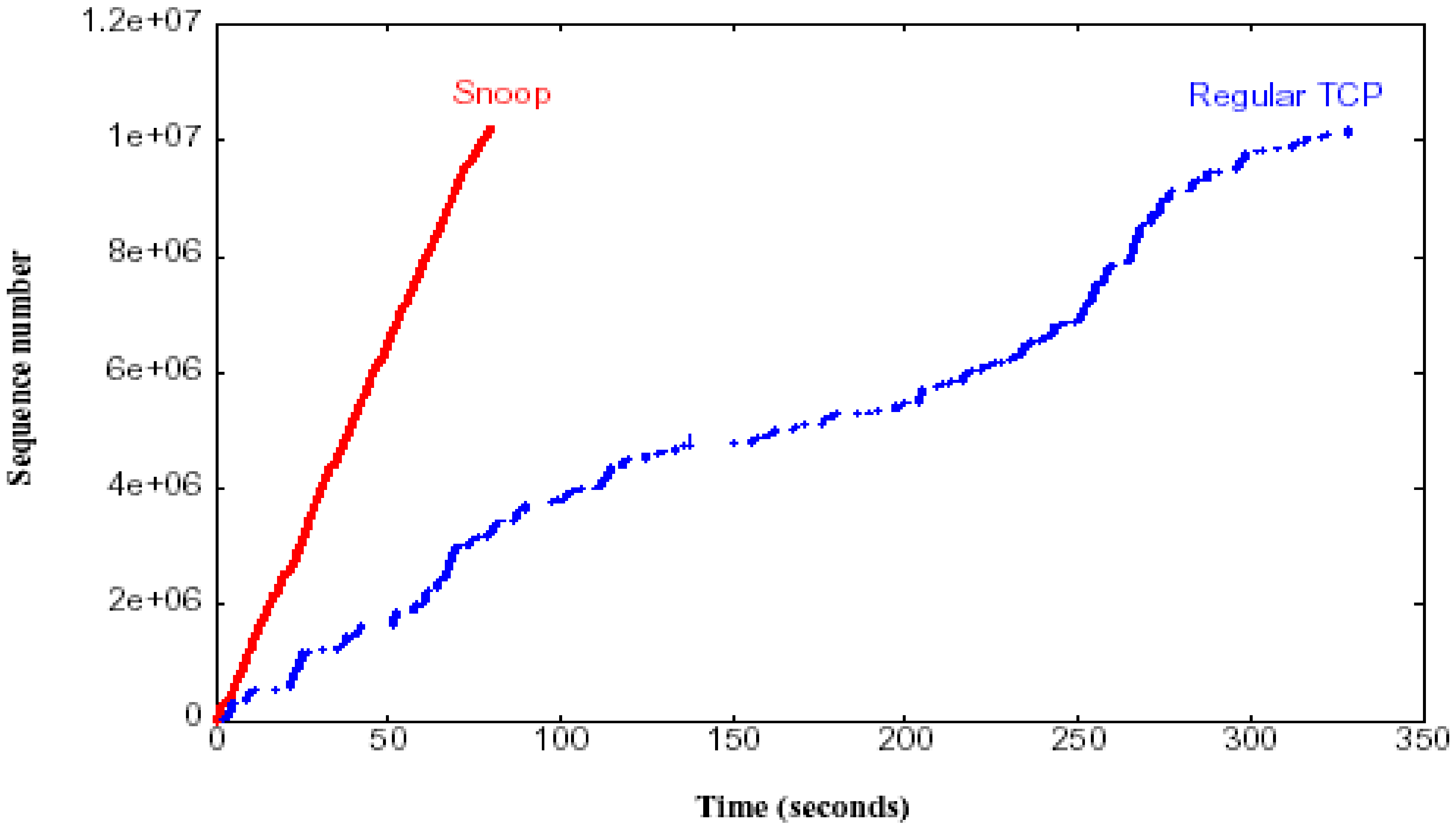
Snoop TCP

- Basic Idea for transfer of data to MH
  - Snoop Module: Modify network layer routing code at BS
  - Cache un-acknowledged TCP data going to MH at BS
  - Perform local retransmissions over wireless link
    - Policies to deal with ACKs from MH and timeout
    - Used duplicate ACKs to identify packet losses
  - Shields sender from wireless link
    - Transient conditions of high BER, temporary disconnection
- Basic idea for transfer of data from MH
  - BS detects missing packets and generated NACKs for MH, expoits SACK option for TCP
  - MH re-sends the packets, requires modifying TCP code at MH
- Features
  - Speedups of up to x20 over regular TCP depending on bit error rate
  - Maintain end-to-end semantics
  - Does not address the handoff problem

Performance of the Snoop Mechanism



Performance of the Snoop Mechanism



Comparison of Wireless TCP Techniques

- End-to-End proposals
  - Selective ACKs
    - Allows sender to recover from multiple packet losses without resorting to course timeout
  - Explicit Loss Notification (ELN)
    - Allow sender to distinguish between congestion vs. other losses
- Split-connection proposal
  - Separate reliable connection between BS & MH
    - May use standard TCP or, special techniques such as SACK, or NACK
- Link-layer proposal
  - Hide link-layer losses via general local retransmission and FEC
  - Make link-layer TCP aware
    - Snoop agent to suppress duplicate ACKs

Main Conclusions of [Balakrishnan97]

- Simple link layers do not quite work
  - Adverse interaction of times is actually a minor problem
  - Fast retransmission and associated congestion control gets triggered and cause performance loss
- Reliable link layer with TCP knowledge works well
  - Shielding sender from duplicate ACKs due to wireless losses improves throughput by 10-30%
- No need to split end-to-end connections
  - I-TCP does as bad because sender stalls due to buffer space limit at BS
  - Using SAK or BS-MH link works well
- SACK and ELN helps significantly
  - Help avoid timeous
  - e.g. ELN helped throughput by x2 over vanilla TCP-Reno
  - But still do 15% to 35% worse than TCP-aware link layer schemes

Introduction

- TCP Westwood (TCPW) is a sender-side modification of TCP Reno in wire as well as wireless network
- TCPW can estimate the E2E b/w and the improvement is most significant in wireless network with lossy links
- TCPW sender monitors the ACK reception and from it estimates the data rate
- The sender uses the b/w estimate to properly set the cwin and ssthresh

Filtering the ACK reception rate

- Sample of bandwidth

$$b_k = \frac{d_k}{t_k - t_{k-1}}$$

- We employ a low-pass filter to average sampled measurements

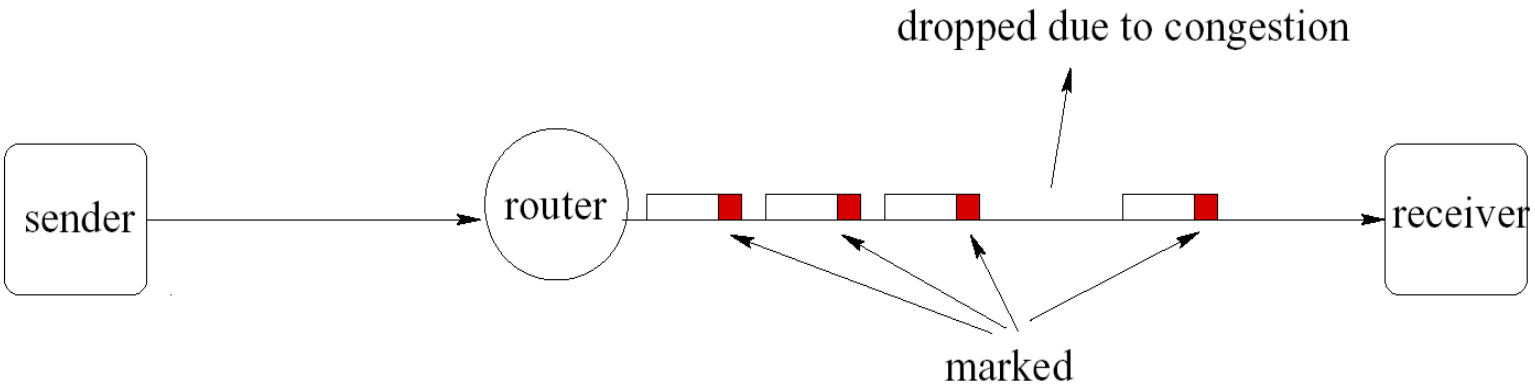
$$\hat{b}_k = \alpha_k \hat{b}_{k-1} + (1 - \alpha_k)\left(\frac{b_k + b_{k-1}}{2}\right)$$

```
if (3 DUPACKs are received)
    ssthresh = (BWE * RTTmin) / seg_size;
    if (cwin > ssthresh) /* congestion avoid. */
        cwin = ssthresh;
    endif
endif
```

Congestion Coherence

Chnlei Liu, and Raj Jain, “*Requirements and Approaches of Wireless TCP Enhancements*,".

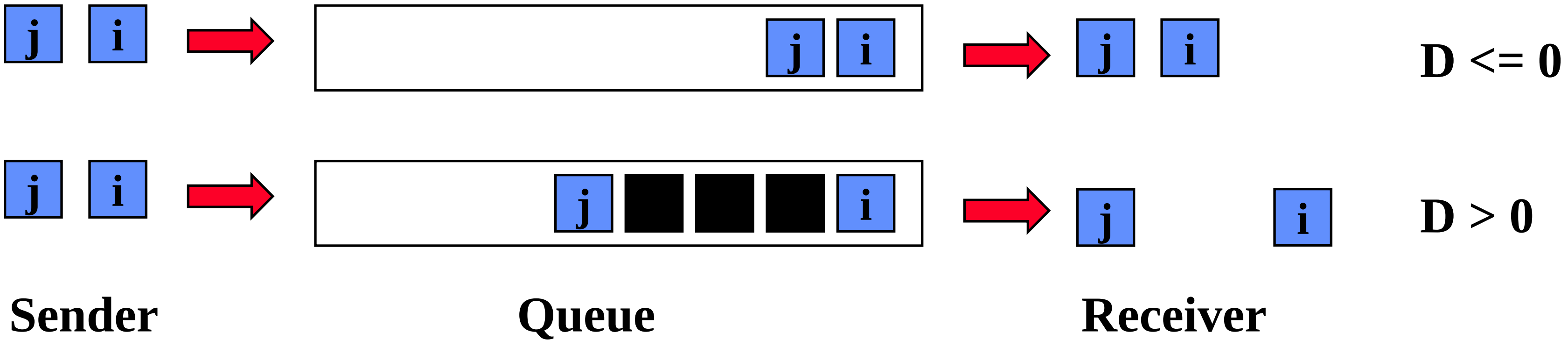
- This paper proposes a new enhancement approach that use Explicit Congestion Notification (ECN) to signal network congestion and use the sequential coherence of ECN marks to distinguish wireless and congestion losses.



inter-arrival jitter

- [RFC 1889] The difference D is packet spacing at the receiver compared to the sender for a pair of packets.
- The D (sec) is called inter-arrival jitter.

$$D(i, j) = (R_j - R_i) - (S_j - S_i) = (R_j - S_j) - (R_i - S_i)$$



D <= 0

D > 0

Sender **Queue** **Receiver**

Jitter ratio

Shi-Yang Chen, Eric Hsiao-Kuang Wu, and Mei-Zhen Chen, “*A New Approach Using Time-Based Model for TCP-Friendly Rate Estimation*”, 2002.

The ratio of packet queued at the router is

$$\frac{\left\lfloor \frac{1}{t_A} - B \right\rfloor}{\frac{1}{t_A}} = \frac{\left\lfloor \frac{1}{t_A} - \frac{1}{t_D} \right\rfloor}{\frac{1}{t_A}} = \frac{t_D - t_A}{t_D}$$

$$\approx \frac{(R_j - R_i) - (S_j - S_i)}{R_j - R_i} = \frac{D}{R_j - R_i}$$

Jitter ratio

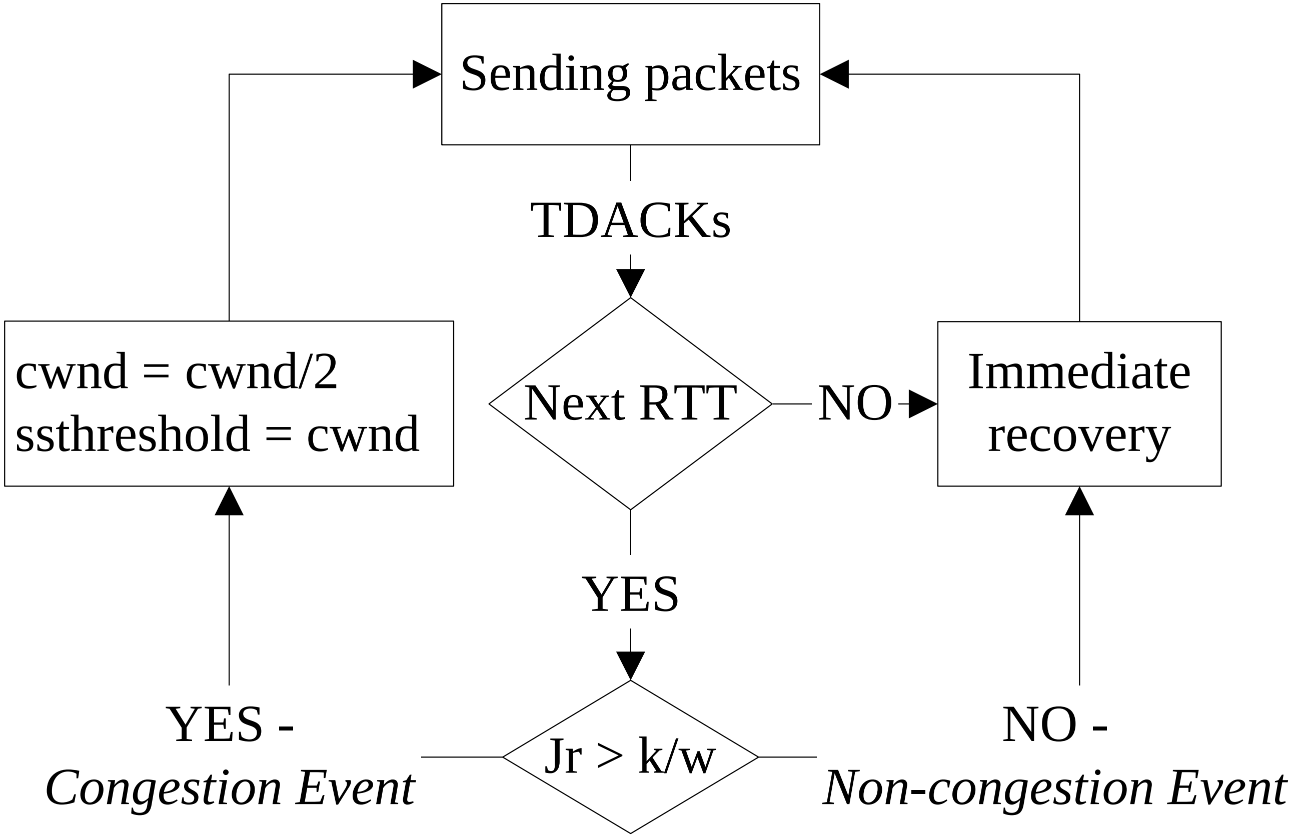
$$Jr = \frac{D}{R_j - R_i}$$

t_A : the packet-by-packet delay of the packets arrival at the router

t_D : the delay of the packets depature from the router

B : the service rate of the router

JTCP action after n duplicate ACKs



Sending packets

TDACKs

Next RTT

NO

Immediate recovery

cwnd = cwnd/2
ssthreshold = cwnd

YES

Jr > k/w

YES - *Congestion Event*

NO - *Non-congestion Event*

Next RTT: *The time between recent and previous TDACKs is longer than one RTT*

Example

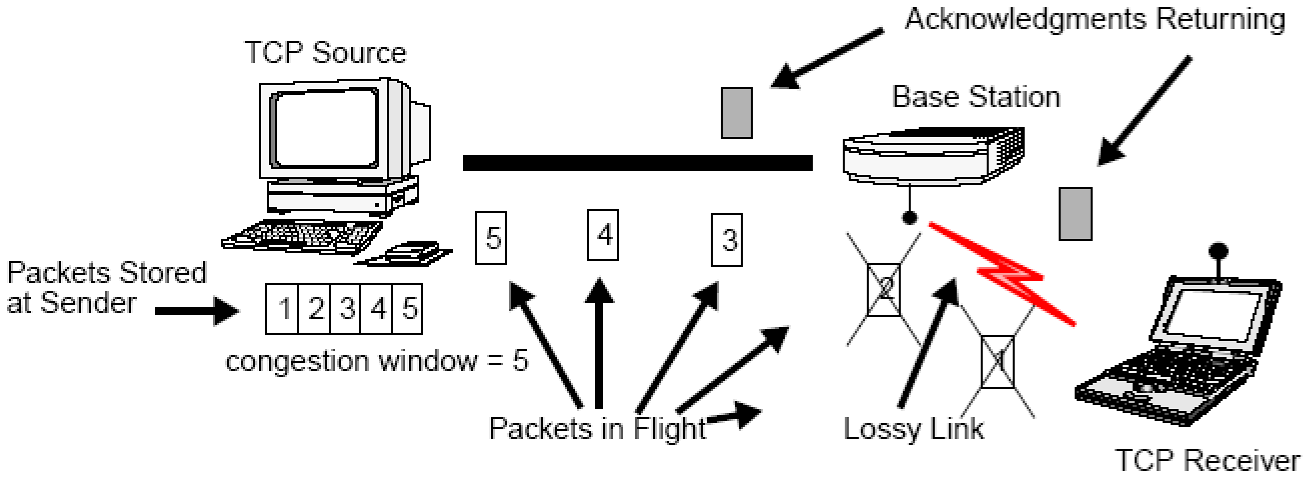
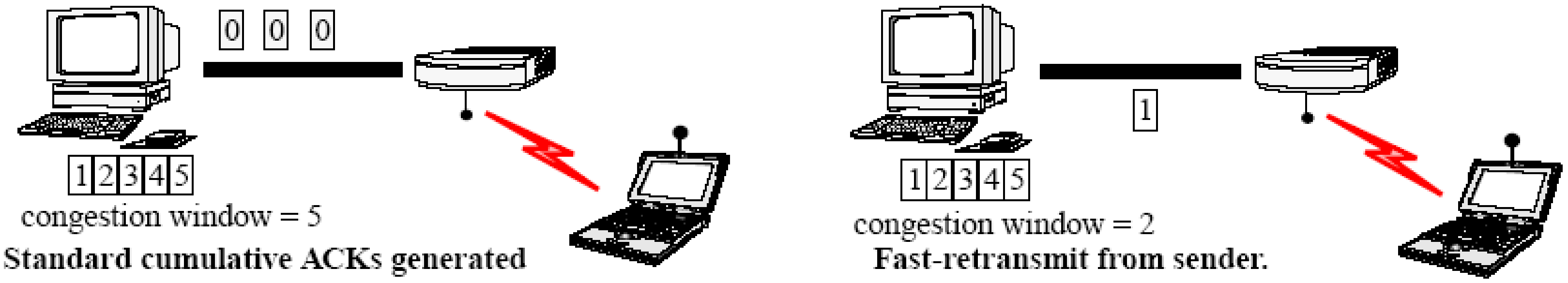


Figure 1. A typical loss situation



Standard cumulative ACKs generated by TCP Reno receiver.

Fast-retransmit from sender.

Figure 2. Normal TCP

Enhanced Solution

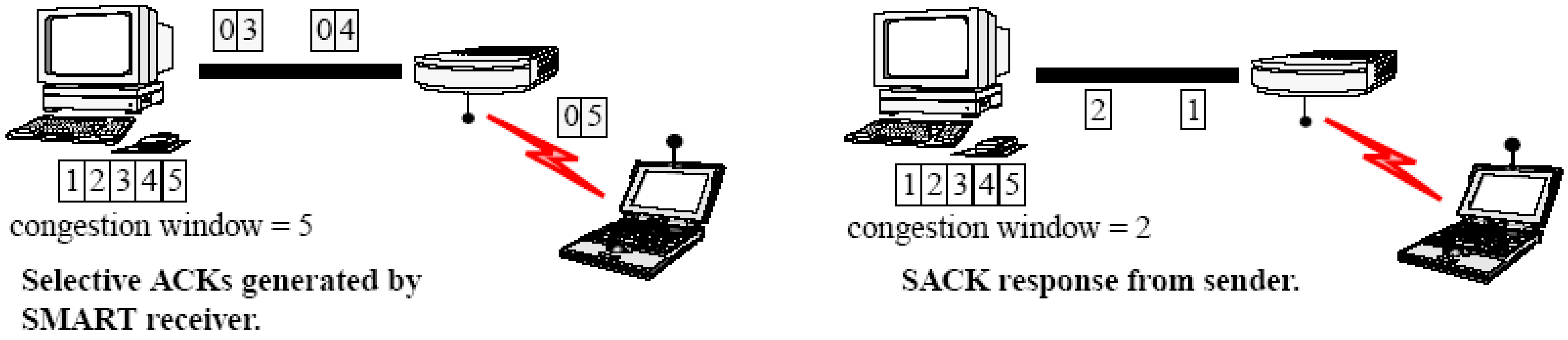


Figure 3. TCP with SMART-based selective acknowledgements

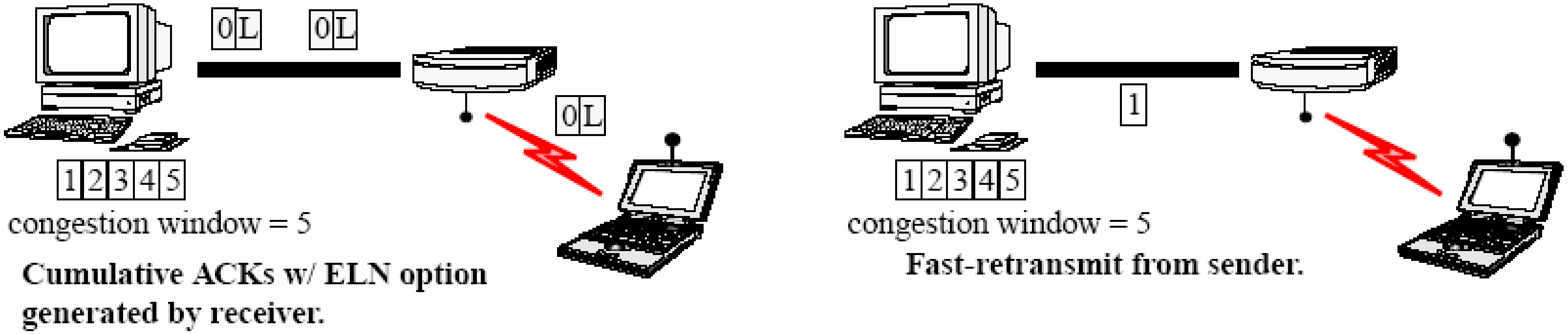
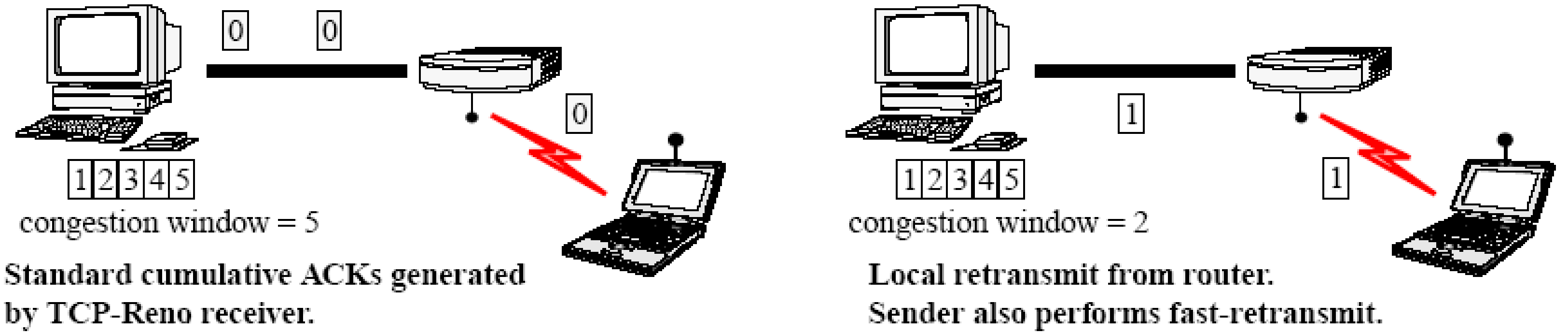


Figure 4. TCP with ELN

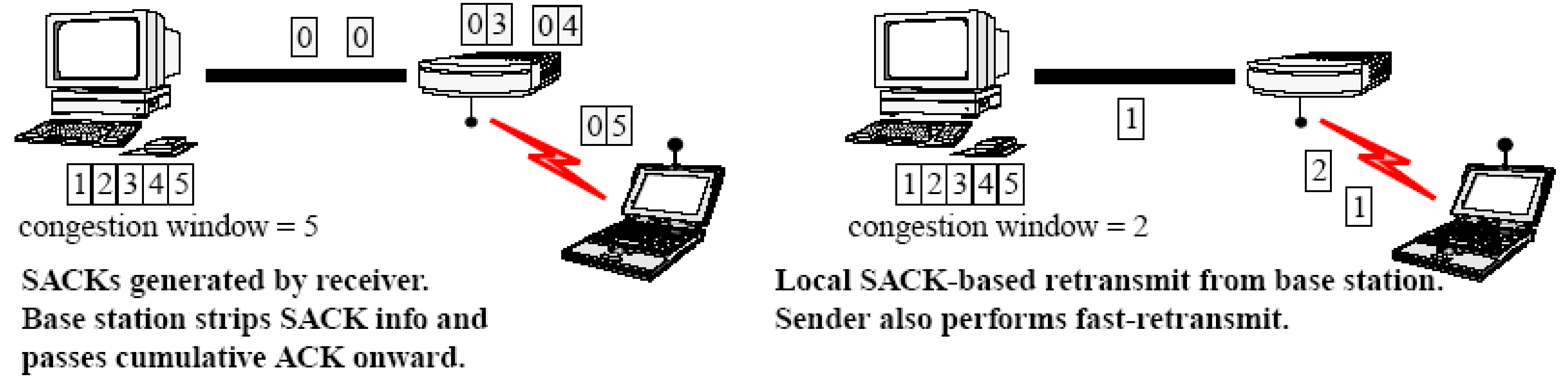
Enhanced Solution



Standard cumulative ACKs generated by TCP-Reno receiver.

Local retransmit from router.
Sender also performs fast-retransmit.

Figure 5. Basic Link-Layer protocol (LL)

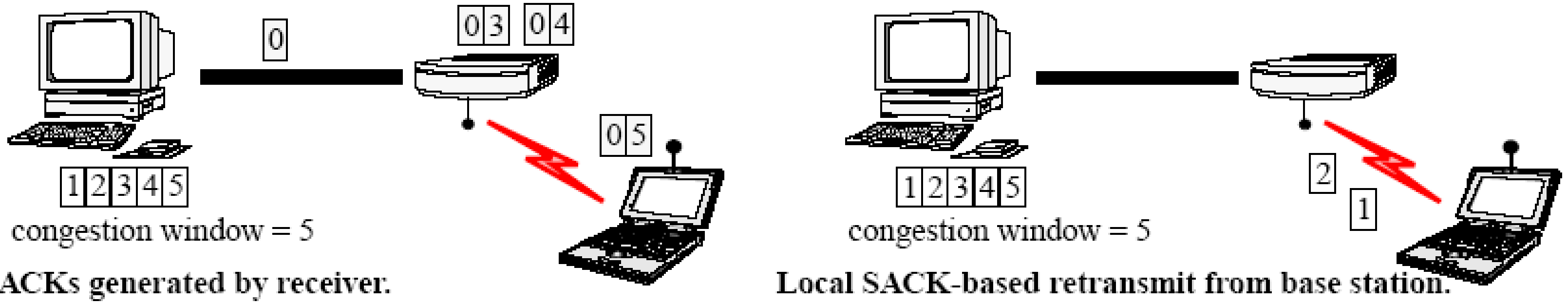


SACKs generated by receiver.
Base station strips SACK info and passes cumulative ACK onward.

Local SACK-based retransmit from base station.
Sender also performs fast-retransmit.

Figure 6. Link-Layer with SMART-based selective acknowledgments

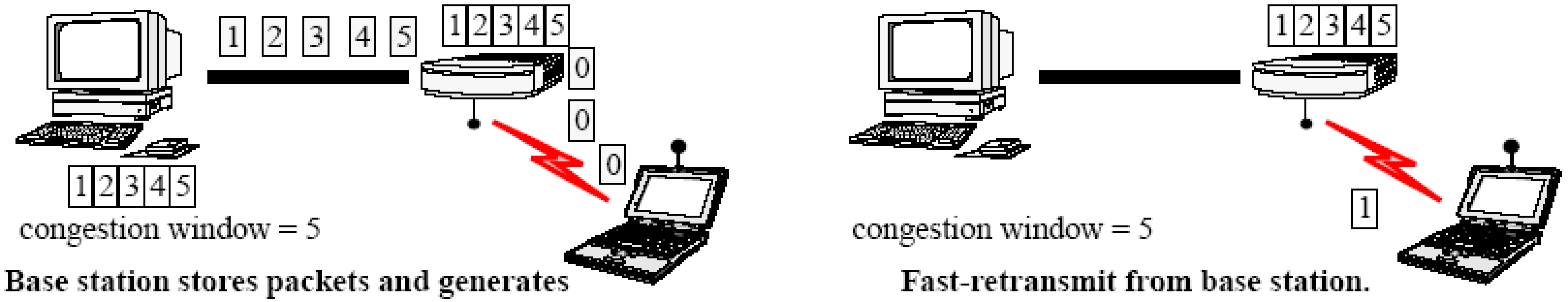
Enhanced Solution



SACKs generated by receiver.
Base station strips SACK info and suppresses any duplicate ACKs.

Local SACK-based retransmit from base station.
Sender sees no duplicate ACKs.

Figure 7. Link-Layer with SMART-based selective acknowledgments and TCP awareness



Base station stores packets and generates cumulative ACKs.
Receiver generates cumulative ACKs too.

Fast-retransmit from base station.
Sender frees packets from TCP stack.

Figure 8. Split-Connection

Taxonomy of Solutions for TCP in Wireless Networks

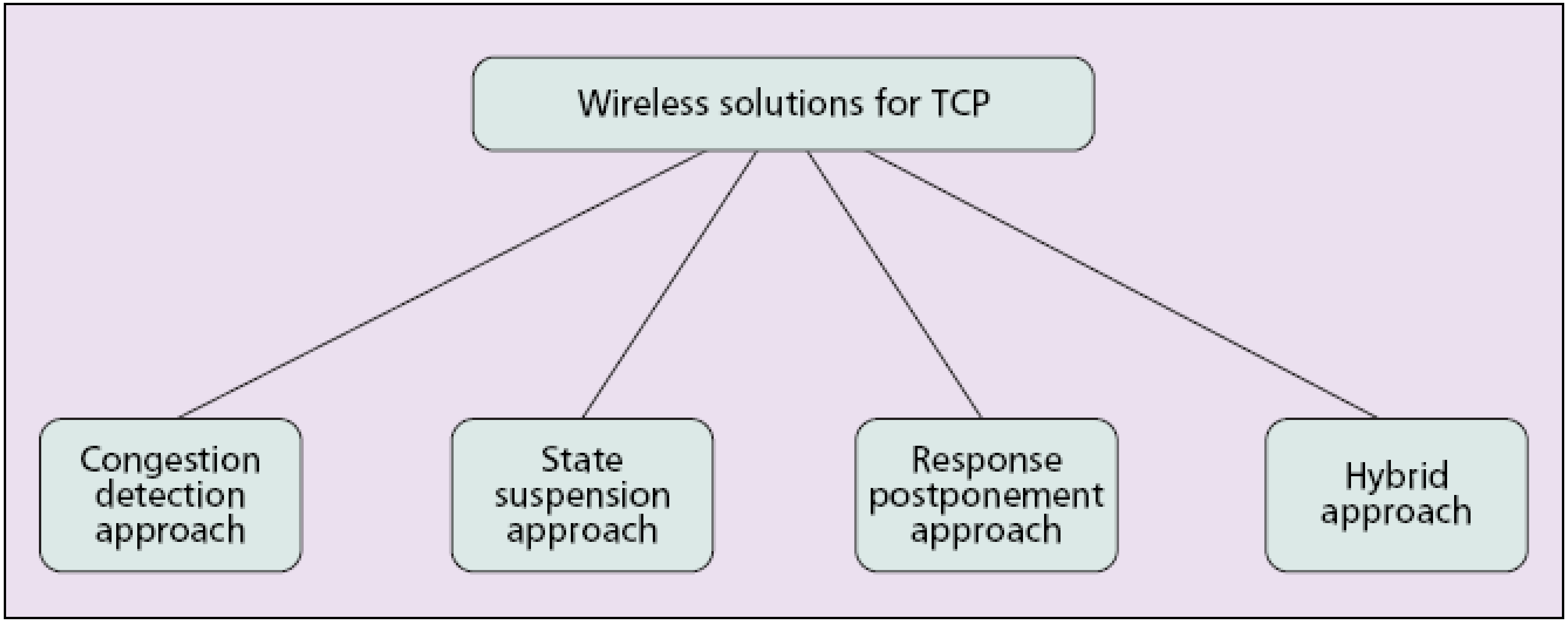
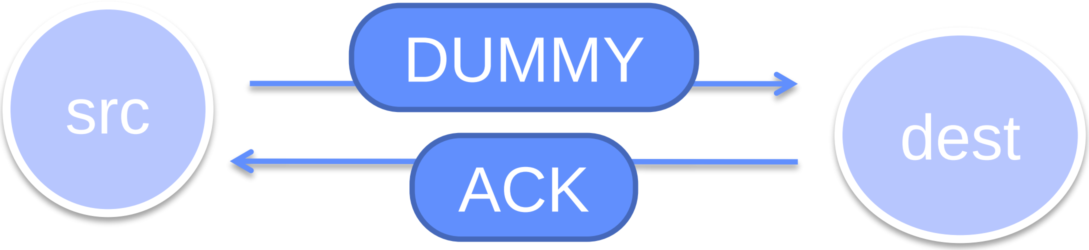


Figure 2. *The taxonomy of solutions for TCP in wireless networks.*

TCP-Peach

- Success dummy transmission
  - Unused network resources exist
  - Transmission rate can then be increased.

DUMMY SEGMENT
low-priority



If wdsn =0, cwnd+1
If wdsn !=0, wdsn-1

TCP-Peach (2/3)

- **Sudden start** :

  open up congestion window faster.

  - wdsn ←0, transmit dummy packets within one RTT.
  - cwnd can quickly be raised to the achievable value.
- **Rapid recovery** : alleviate the performance degradation due to link error.
  - wdsn ← cwnd ← ½ cwnd
  - If received ACK, cwnd +1.

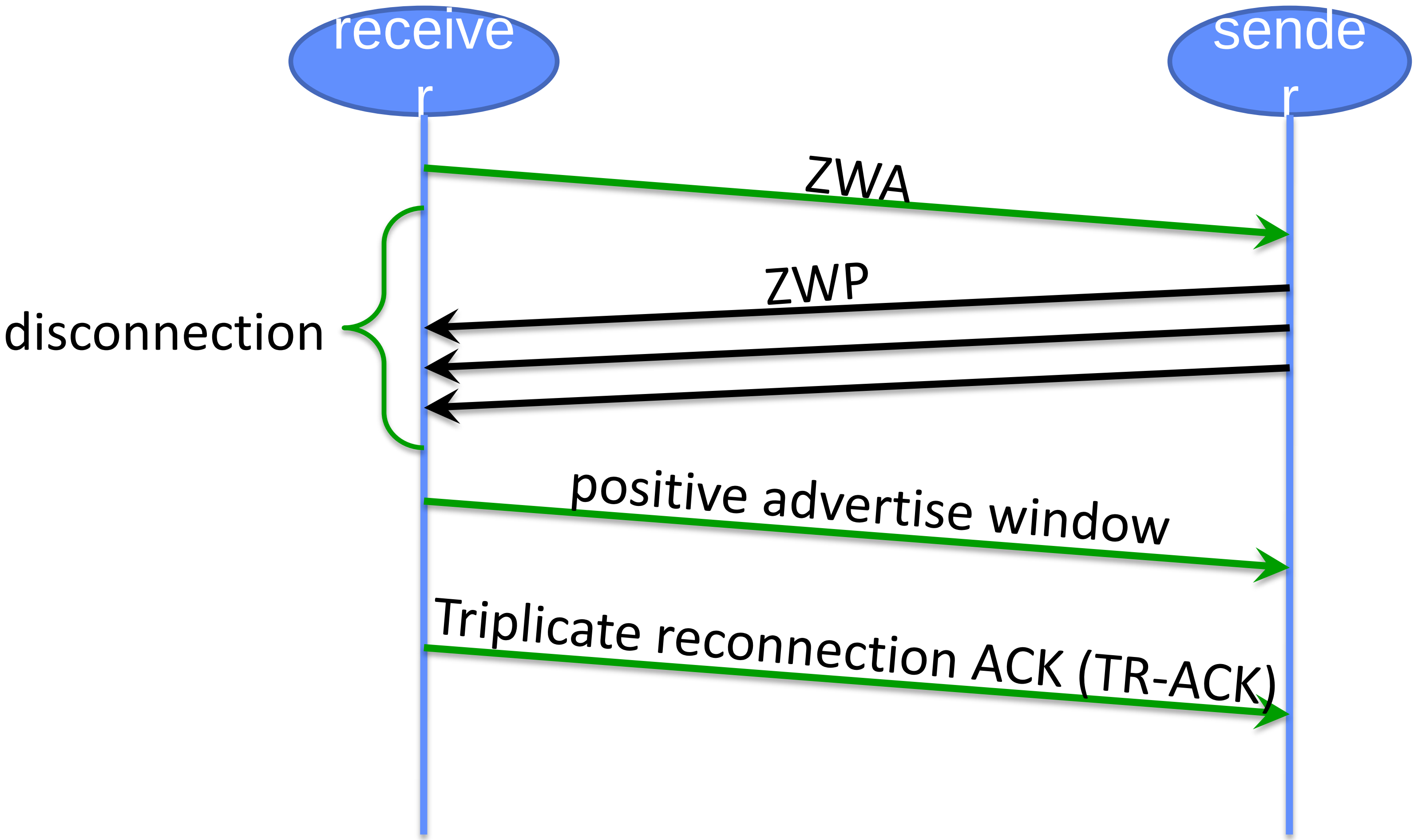
TCP-Peach (3/3)

- Advantage
  - Maintain ACK-clocking
- Disadvantage:
  - Assume: when congestive loss happens, more than half of dummy segments are lost. -> cwnd could be reclaimed.
  - dummy segment increase the traffic load, even lead to congestion.
  - Routers must distinguish segments with priorities.

Freeze-TCP (1/3)

- Receiver monitors the signal strengths of its wireless antennas and detects any impending handoffs.
- Destination(Receiver) sends “ACK with ZWA” to force the source into the persist mode and to prevent it from dropping its congestion window.

Freeze-TCP (2/3)



Freeze-TCP (3/3)

- Five shortcomings
  - Must be aware of mobility so that come cross-layer information exchanges are needed.
  - Needs to predict when a disconnection is going to happen.
  - Fails to predict an upcoming disconnection if it happens at a wireless link along the transmission path.
  - There’s no guarantee that the available bandwidth of a connection after a disconnection is the same as the previous one.
  - Can only avoid performance degradations due to disconnections.

ATCP (1/4)

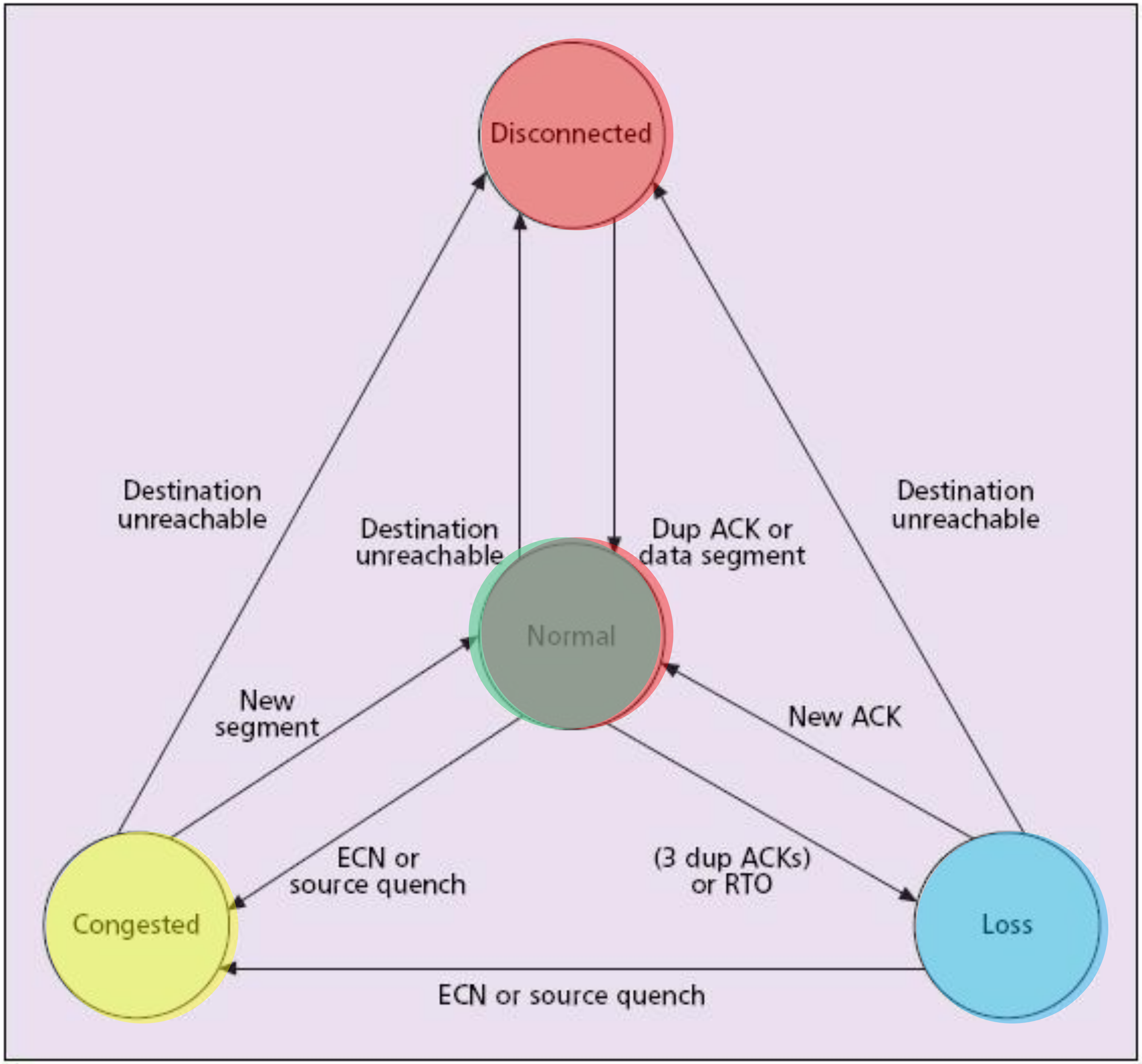
- Introduce “ATCP layer” between TCP and IP at the sender’s protocol stack
- so that the ATCP layer
  - monitors the current TCP state and
  - spoofs TCP from triggering its congestion control mechanisms inappropriately
- for problems specific to ad hoc networks.

ATCP (2/4)

- ECN

  end-to-end notification of network congestion without dropping packets.

- ICMP
  - One of the core protocols of the Internet Protocol suite.
  - Used by networked computers OS to send error messages.



■ Figure 6. *The state transition diagram for ATCP.*

ATCP (4/4)

- Drawbacks
  - Inefficient in using the available bandwidth for data transmission in wireless networks with the presence of frequent route changes and network partition.
  - Require MH to be aware of and be implemented with ECN. A destination is also required to interpret the ECN flag.
  - Does not allow source to send new data segments to a destination when it’s in the loss state as the source is in the persist mode.

TCP Fairness over 802.11