

無線網路多媒體系統 Wireless Multimedia System

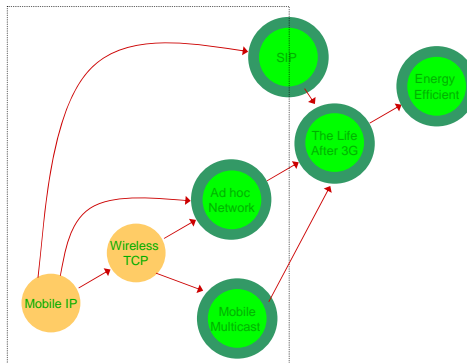
Lecture 8: Wireless TCP

吳曉光博士

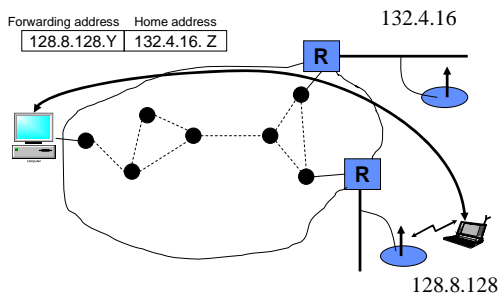
<http://inrg.csie.ntu.edu.tw/wms>



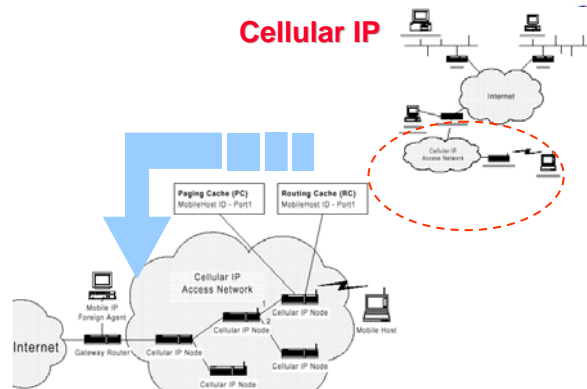
Coming Issues



Mobile IP

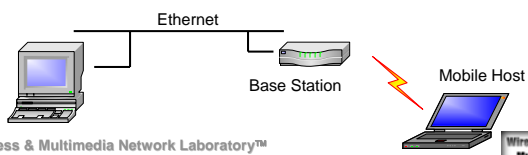


Cellular IP



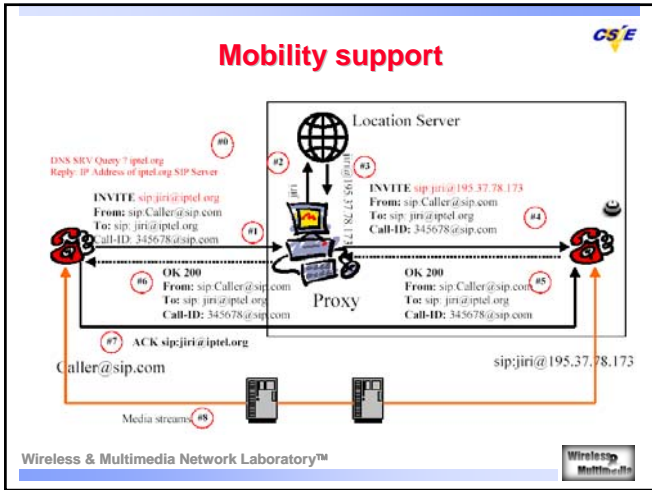
Wireless TCP

- 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

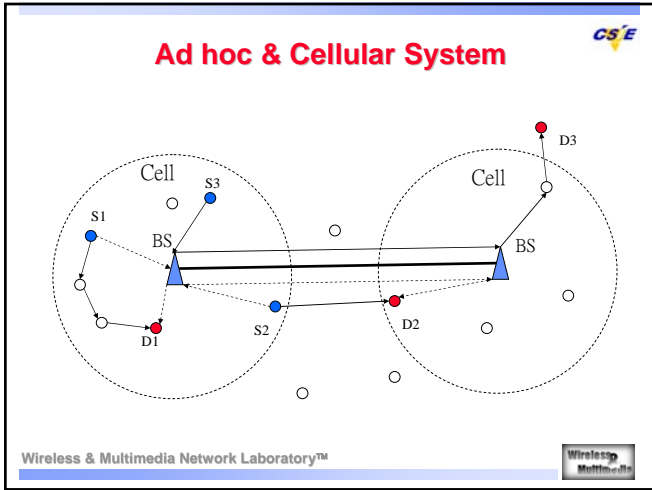
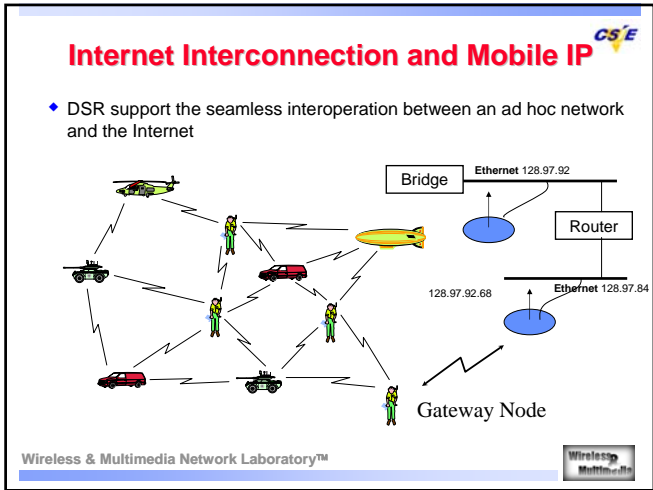




Mobile Multicast

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

Wireless & Multimedia Network Laboratory™



QoS Support for an All-IP System Beyond 3G

Wireless & Multimedia Network Laboratory™

BRAIN

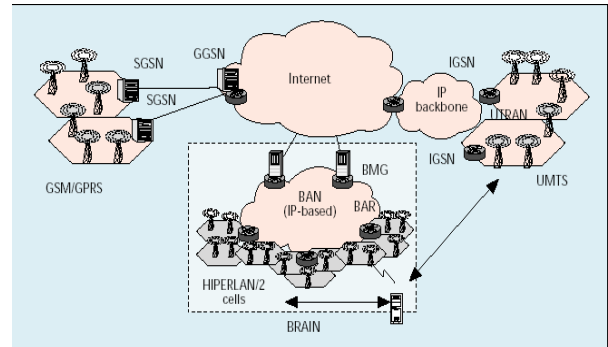


- ◆ Broadband Radio Access for IP-Based Networks
 - Cellular systems, fixed networks, and wireless LANs
 - Personal mobility, adapted for the terminal and link bandwidth
 - End-to-end QoS
 - A new QoS model for applications (BRENTA)
 - The radio link improvements
- ◆ IP-aware RAN (Radio Access Network)
 - 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

Wireless & Multimedia Network Laboratory™



BRAIN (Broadband Radio Access for IP-based Network)



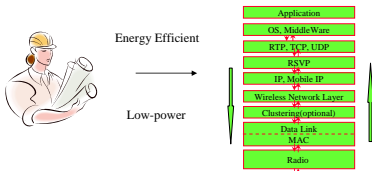
Wireless & Multimedia Network Laboratory™



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.



Wireless & Multimedia Network Laboratory™



Agenda



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



Wireless & Multimedia Network Laboratory™



Reading



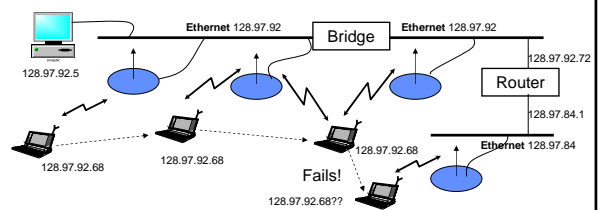
- ◆ [Balakrishnan95], Harri Balakrishnan, Srinivasan Seshan, Elan Amir and Randy H. Katz, "Improving TCP/IP Performance over Wireless Networks", ACM Mobicom95
- ◆ [Balakrishnan97], Harri Balakrishnan, Venkat N, Padmanabhan, Srinivasan Seshan and Randy Katz, "A Comparison of Mechanisms for Improving TCP Performance over Wireless Links", IEEE JSAC 97.
- ◆ Reference: [Mario2001], Saverio Mascolo, Claudio Casetti, Mario Gerla, Renwang "TCP Westwood: Bandwidth Estimation for Enhanced Transport over Wireless Links", Mobicom2001



Wireless & Multimedia Network Laboratory™



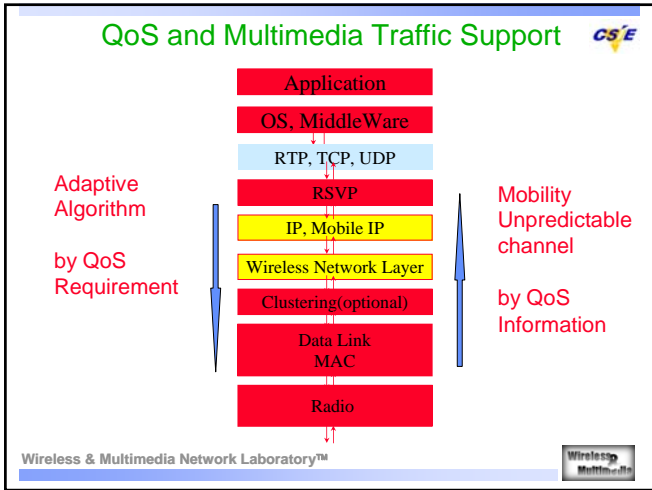
Mobility in Wireless LANs: Basestation as Bridges



- ◆ 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)

Wireless & Multimedia Network Laboratory™



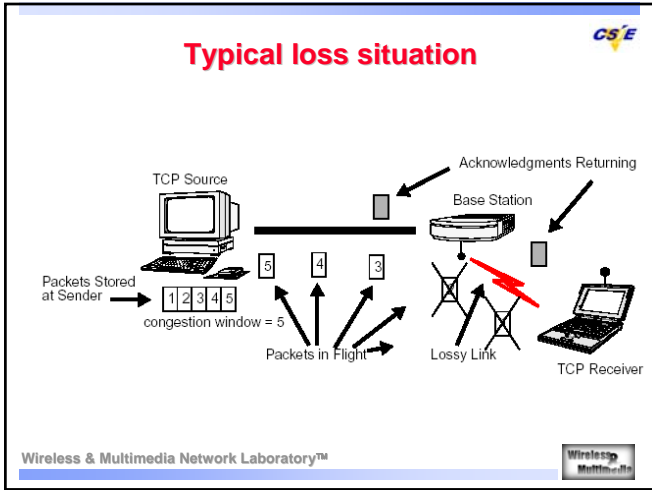
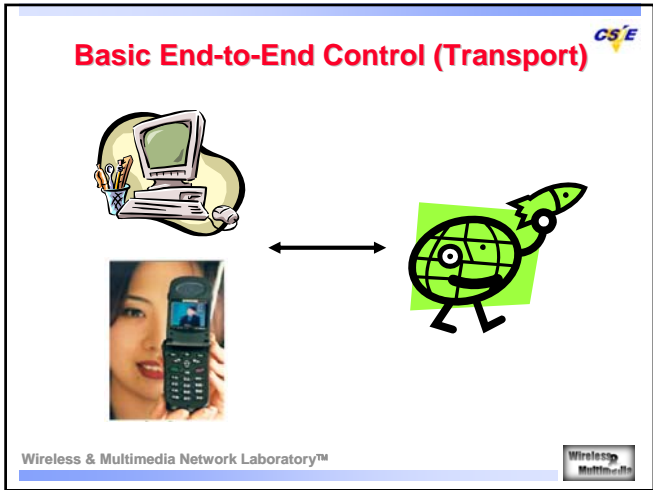


Background CS'E

- ◆ 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

Wireless & Multimedia Network Laboratory™ Wireless Multimedia

- ### Characteristics of Wireless & Mobility CS'E
- ◆ 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
- Wireless & Multimedia Network Laboratory™ Wireless Multimedia



UDP (Connectionless, Unreliable) CS'E

Possible Multicast, Real Time Traffic, TCP-Friendly

Wireless & Multimedia Network Laboratory™ Wireless Multimedia

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!

Wireless & Multimedia Network Laboratory™



TCP (Connection Oriented, Reliable)



Data Transmission, WWW, flow control, error control

Wireless & Multimedia Network Laboratory™



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}

Wireless & Multimedia Network Laboratory™



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

Wireless & Multimedia Network Laboratory™



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 $cwnd \leq ssthresh$
 - Fast (exponential) increase of cwnd
 - ◆ 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

Wireless & Multimedia Network Laboratory™



Challenges of Mobility and Wireless on Network Performance



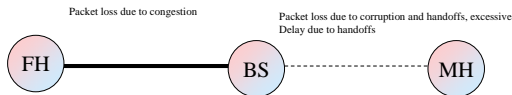
TCP Performance

Wireless & Multimedia Network Laboratory™



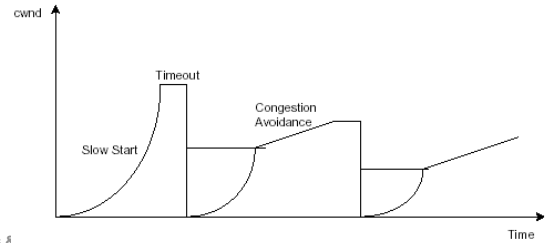
The Problem

- 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)

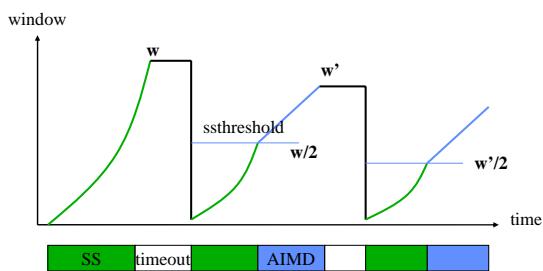


Example graph

$cwin \leq ssthresh \rightarrow$ slow start
 $cwin > ssthresh \rightarrow$ congestion avoidance

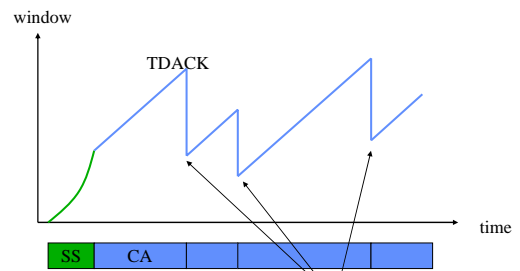


Slow Start of TCP Reno



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

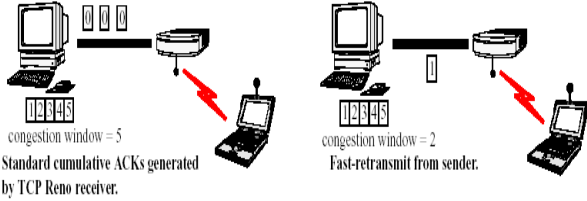


Normal TCP



Fast-Retransmit Scheme

CS'E



Wireless & Multimedia Network Laboratory™

Wireless
Multimedia

Solutions for WTCP (I)

CS'E



Split the connection into two parts

Wireless & Multimedia Network Laboratory™

Wireless
Multimedia

Split Connection Approaches

CS'E

- ◆ 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: Rutgers'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

Wireless & Multimedia Network Laboratory™

Wireless
Multimedia

Pros & Cons of Split-Connection Approaches

CS'E

- ◆ 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

Wireless & Multimedia Network Laboratory™

Wireless
Multimedia

Solutions for WTCP (II)

CS'E



Lower layer to make TCP work better

Wireless & Multimedia Network Laboratory™

Wireless
Multimedia

Link-level Error Control

CS'E

- ◆ 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

Wireless & Multimedia Network Laboratory™

Wireless
Multimedia

Solutions for WTCP (III)

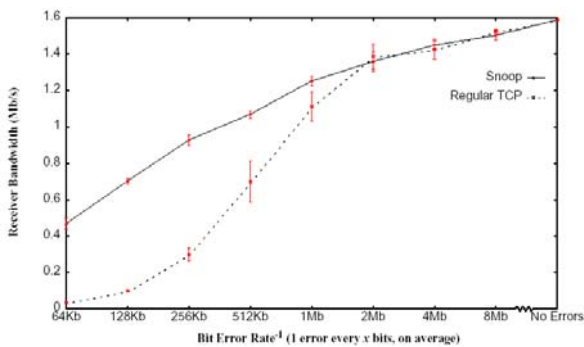


Snoop, Make it look like!

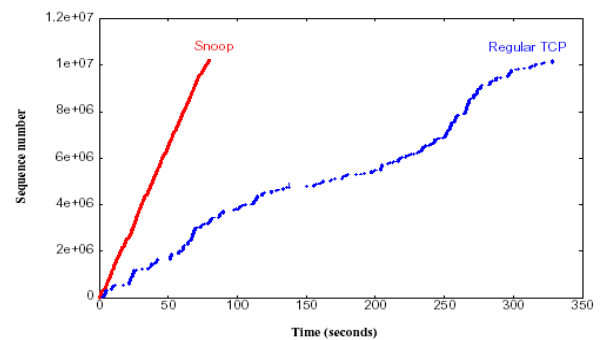
Snoop TCP

- ◆ 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, exploits 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 timeouts
 - 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 (BWE, Bandwidth Estimation)

We use
$$b_k = \frac{d_k}{t_k - t_{k-1}}$$
 to average sampled

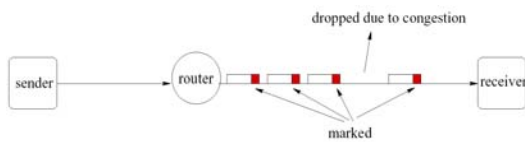
```

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."

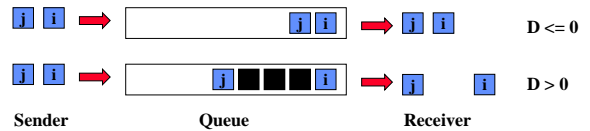
- This paper proposes a new enhancement approach that use Explicit Congestion Notification (ECN) to signal network congestion and use the sequential coherence of ECN marks to distinguish wireless and congestion losses.



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.

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



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

$$\frac{\frac{1}{t_A} - B}{\frac{1}{t_A}} = \frac{\frac{1}{t_A} - \frac{1}{t_D}}{\frac{1}{t_A}} = \frac{t_D - t_A}{t_D}$$

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

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

t_D : the delay of the packets departure from the router

B : the service rate of the router

Example

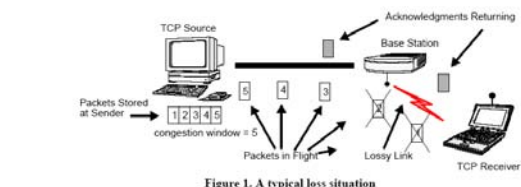


Figure 1. A typical loss situation



Figure 2. Normal TCP

Enhanced Solution

congestion window = 5
Selective ACKs generated by SMART receiver.

congestion window = 5
Cumulative ACKs w/ ELN option generated by receiver.

Figure 3. TCP with SMART-based selective acknowledgements

congestion window = 5
Standard cumulative ACKs generated by TCP-Reno receiver.

congestion window = 2
Local SACK-based retransmit from base station. Sender also performs fast-retransmit.

Figure 4. TCP with ELN

Figure 5. Basic Link-Layer protocol (LL)

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

Wireless & Multimedia Network Laboratory™ Wireless Multimedia

Enhanced Solution

congestion window = 5
SACKs generated by receiver. Base station strips SACK info and suppresses any duplicate ACKs.

congestion window = 5
Local SACK-based retransmit from base station. Sender sees no duplicate ACKs.

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

congestion window = 5
Base station stores packets and generates cumulative ACKs. Receiver generates SACKs.

congestion window = 5
Fast-retransmit from base station. Sender frees packets from TCP stack.

Figure 8. Split-Connection

Figure 9. Split-Connection with SMART-based selective acknowledgements

Wireless & Multimedia Network Laboratory™ Wireless Multimedia

Enhanced Solution

congestion window = 5
Base station stores packets and generates cumulative ACKs. Receiver generates SACKs.

congestion window = 5
SACK-based retransmit from base station. Sender frees packets from TCP stack.

Figure 9. Split-Connection with SMART-based selective acknowledgements

Wireless & Multimedia Network Laboratory™ Wireless Multimedia

TCP Fairness over 802.11

Wireless & Multimedia Network Laboratory™ Wireless Multimedia

Enhanced Solution

congestion window = 5
Base station stores packets and generates cumulative ACKs. Receiver generates SACKs.

congestion window = 5
SACK-based retransmit from base station. Sender frees packets from TCP stack.

Figure 9. Split-Connection with SMART-based selective acknowledgements

Wireless & Multimedia Network Laboratory™ Wireless Multimedia