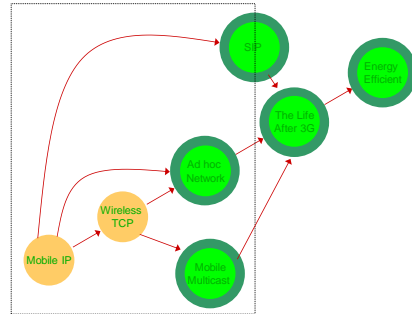


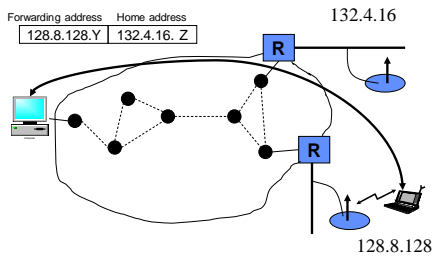
無線網路多媒體系統 Wireless Multimedia System

Lecture 8: Wireless TCP
吳曉光博士

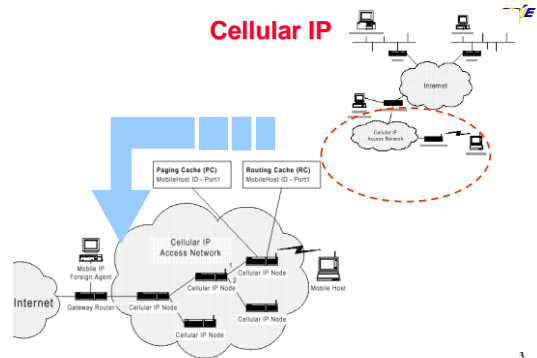
Coming Issues



Mobile IP

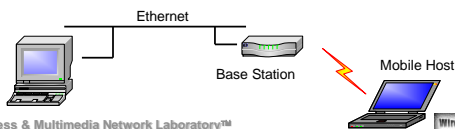


Cellular IP

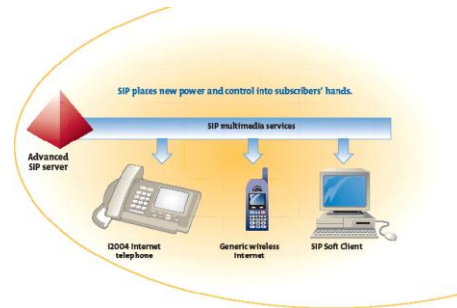


Wireless TCP

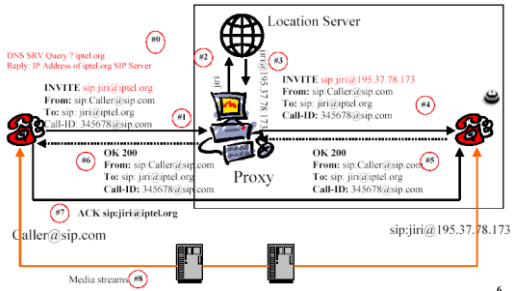
- TCP turned to perform well in traditional network where the packet losses occur mostly because of congestion.
- In the wireless environment
 - **Non-congestion** losses caused by wireless link
 - The degraded performance of TCP is mostly due to **mistaking wireless losses for congestion**.



SIP Protocol



Mobility support



Wireless & Multimedia Network Laboratory™



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



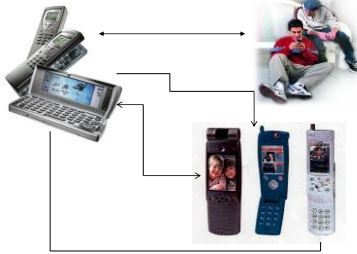
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Mobile Multicast



One to Many Mobile Multicasting Services



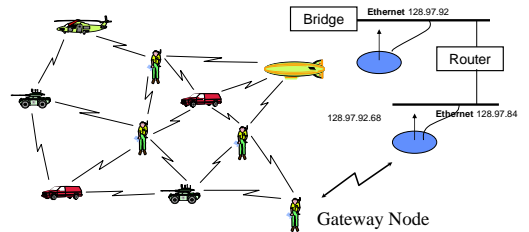
Wireless & Multimedia Network Laboratory™



Internet Interconnection and Mobile IP



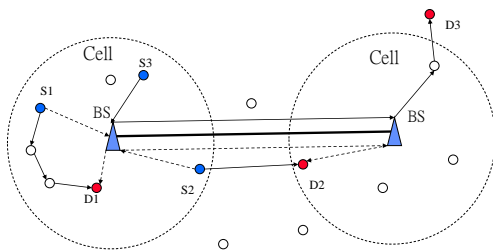
- DSR support the seamless interoperation between an ad hoc network and the Internet



Wireless & Multimedia Network Laboratory™



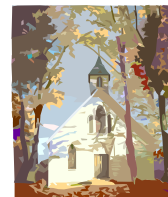
Ad hoc & Cellular System



Wireless & Multimedia Network Laboratory™



QoS Support for an All-IP System Beyond 3G



Wireless & Multimedia Network Laboratory™



BRAIN

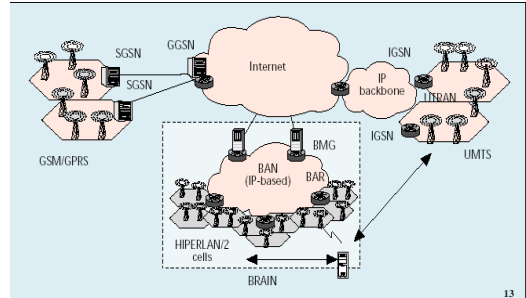


- ◆ Broadband Radio Access for IP-Based Networks
 - Cellular systems, fixed networks, and wireless LANs
 - Personal mobility, adapted for the terminal and link bandwidth
 - End-to-end QoS
 - A new QoS model for applications (BRENTA)
 - The radio link improvements
- ◆ IP-aware RAN (Radio Access Network)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

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BRAIN (Broadband Radio Access for IP-based Network)



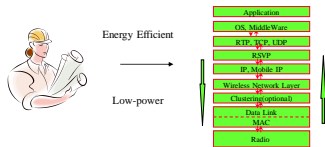
13



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.



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Agenda



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



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Reading



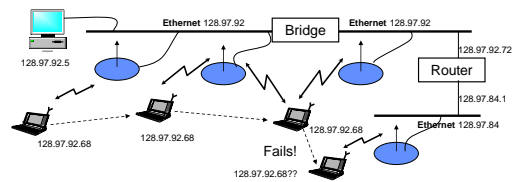
- ◆ [Balakrishnan95], Harri Balakrishnan, Srinivasan Seshan, Elan Amir and Randy H. Katz, "Improving TCP/IP Performance over Wireless Networks", ACM Mobicom95
- ◆ [Balakrishnan97], Harri Balakrishnan, Venkat N. Padmanabhan, Srinivasan Seshan and Randy Katz, "A Comparison of Mechanisms for Improving TCP Performance over Wireless Links", IEEE JSAC 97.
- ◆ Reference: Ka-Cheong Leung and Victor O. K. Li, "Transmission Control Protocol(TCP) in Wireless Networks: Issues, Approaches, and Challenges", IEEE Communications Survey 2006



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Mobility in Wireless LANs: Basestation as Bridges

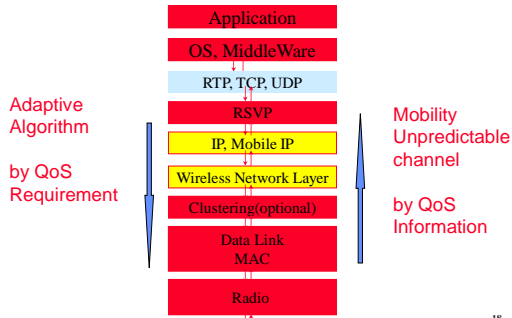


- ◆ Basestations are bridges(layer 2) – i.e. they relay MAC frames
 - Smart bridges avoid wasted bandwidth
- ◆ Works the within an ethernet(or other broadcast LAN)
 - Fails across network boundaries, and in switched LANs(e.g. ATM)

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QoS and Multimedia Traffic Support



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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

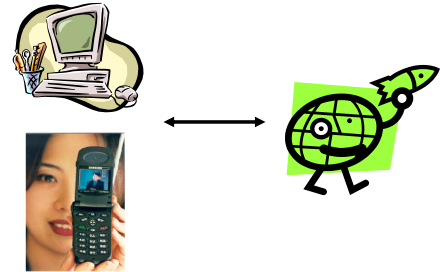
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Characteristics of Wireless & Mobility

- 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

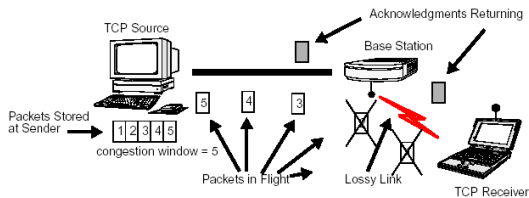
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Basic End-to-End Control (Transport)



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Typical loss situation



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UDP (Connectionless, Unreliable)



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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!

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TCP (Connection Oriented, Reliable)



Data Transmission, WWW, flow control, error control

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TCP and Congestion Control



- ◆ Terms:
 - advertised window

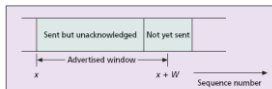


Figure 1. An illustration of the source sequence number space and advertised window.

- congestion avoidance
- congestion window

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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 by 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 advertised 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}

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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

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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

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Challenges of Mobility and Wireless on Network Performance



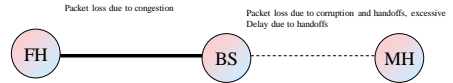
TCP Performance

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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)

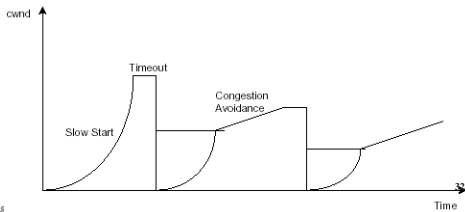


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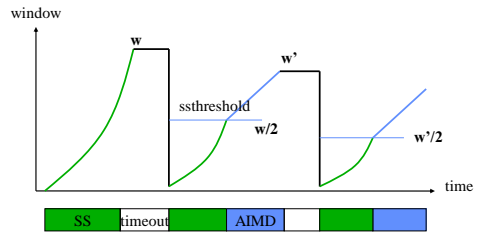


Example graph

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



Slow Start of TCP Reno

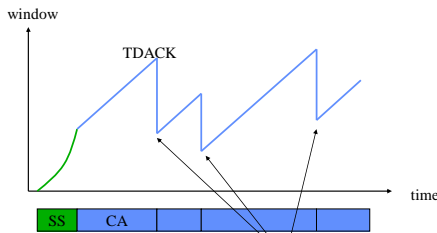


ssthresh : slow-start threshold

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Congestion Avoidance of TCP Reno



SS: slow start
 CA: congestion avoidance

Fast retransmission / Fast recovery

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Fixes?

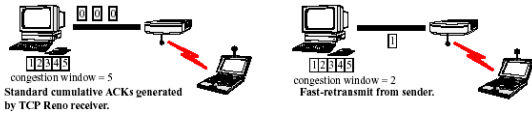
- ◆ Fix TCP
 - TCP really a hack in many ways..
 - Separate congestion control from error control
 - Move away from cumulative ACK
- ◆ Fix lower layer to make TCP work better
 - Improve the wireless link
- ◆ Use something different
 - Something totally new
 - Something different for the wireless part



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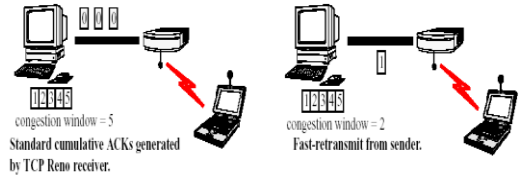
Normal TCP



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Fast-Retransmit Scheme



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Solutions for WTCP (I)



Split the connection into two parts

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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: Rutgers 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

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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

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Solutions for WTCP (II)



Lower layer to make TCP work better

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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

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Solutions for WTCP (III)



Snoop, Make it look like!

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Snoop TCP

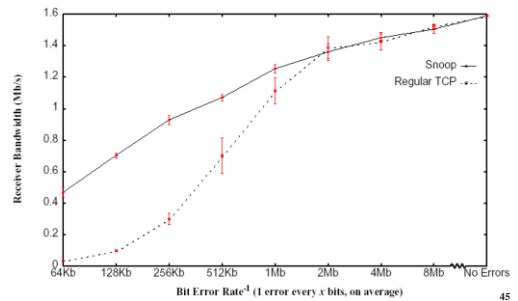


- ◆ Basic Idea for transfer of data to MH
 - Snoop Module: Modify network layer routing code at BS
 - Cache un-acknowledged TCP data going to MH at BS
 - Perform local retransmissions over wireless link
 - Policies to deal with ACKs from MH and timeout
 - Used duplicate ACKs to identify packet losses
 - 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, exports 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

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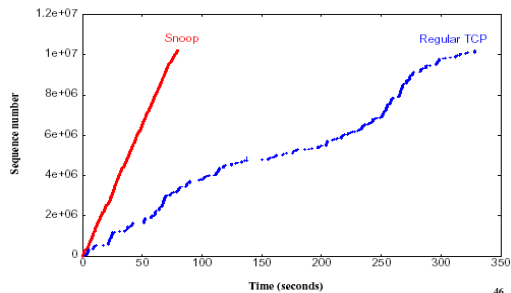
Performance of the Snoop Mechanism



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Performance of the Snoop Mechanism



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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

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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

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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

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

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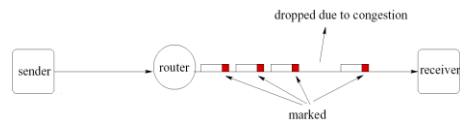
if (3 DUPACKs are received)
  ssthresh = (BWE * RTTmin) / seg_size;
  if (cwin > ssthresh) /* congestion avoid. */
    cwin = ssthresh;
  endif
endif
    
```

50

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.

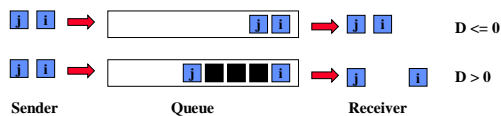


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inter-arrival jitter

- [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.

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



52

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

$$\frac{\left[\frac{1}{t_a} - B \right]}{\frac{1}{t_a}} = \frac{\left[\frac{1}{t_a} - \frac{1}{t_d} \right]}{\frac{1}{t_a}} = \frac{t_d - t_a}{t_d}$$

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

$$\Rightarrow J_r = \frac{D}{R_j - R_i}$$

Jitter ratio

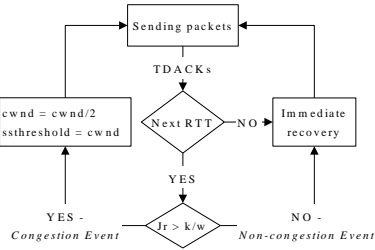
t_a : the packet - by - packet delay of the packets arrival at the router

t_d : the delay of the packets departure from the router

B: the service rate of the router

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JTCP action after n duplicate ACKs



Next RTT: The time between recent and previous

TDACKs is longer than one RTT

Example

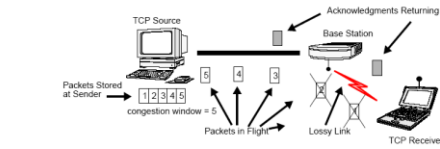


Figure 1. A typical loss situation



Figure 2. Normal TCP

Enhanced Solution



Figure 3. TCP with SMART-based selective acknowledgements



Figure 4. TCP with ELN

Enhanced Solution



Figure 5. Basic Link-Layer protocol (LL)



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

Enhanced Solution



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

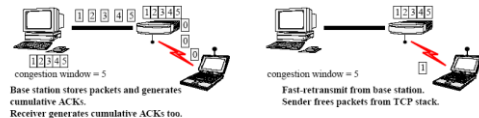


Figure 8. Split-Connection

Taxonomy of Solutions for TCP in Wireless Networks

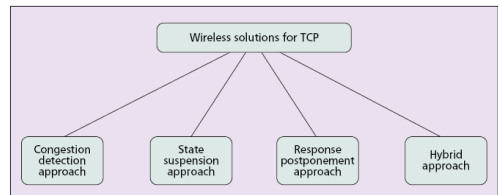


Figure 2. The taxonomy of solutions for TCP in wireless networks.

TCP-Peach



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



If $wdsn = 0$, $wnd+1$
If $wdsn \neq 0$, $wdsn-1$

60



TCP-Peach (2/3)



- Sudden start :**
 - open up congestion window faster.
 - $wdsn \leftarrow 0$, transmit dummy packets within one RTT.
 - wnd can quickly be raised to the achievable value.
- Rapid recovery :** alleviate the performance degradation due to link error.
 - $wdsn \leftarrow wnd \leftarrow \frac{1}{2} wnd$
 - If received ACK, $wnd + 1$.

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TCP-Peach (3/3)



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

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Freeze-TCP (1/3)

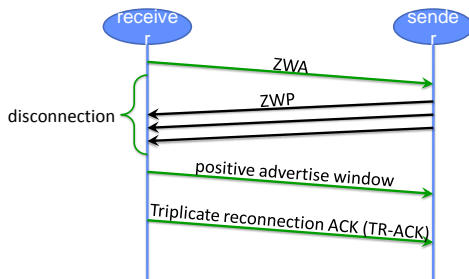


- Receiver monitors the signal strengths of its wireless antennas and detects any impending handoffs.
- Destination(Receiver) sends "ACK with ZWA" to force the source into the persist mode and to prevent it from dropping its congestion window.

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Freeze-TCP (2/3)



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Freeze-TCP (3/3)



- Five shortcomings
 - Must be aware of mobility so that some 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.

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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.

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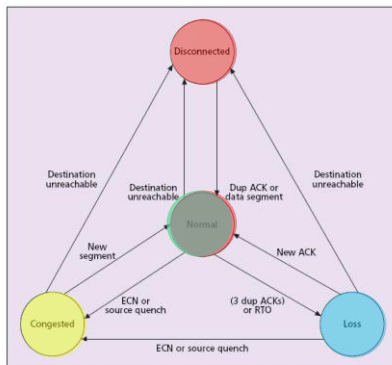


ATCP (2/4)



- ◆ 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.

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Figure 6. The state transition diagram for ATCP.



ATCP (4/4)

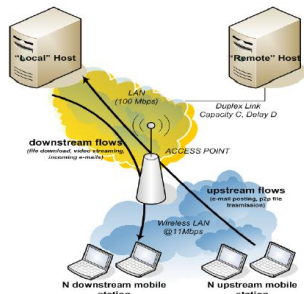


- Drawbacks
 - Inefficient in using the available bandwidth for data transmission in wireless networks with the presence of frequent route changes and network partition.
 - Require MH to be aware of and be implemented with ECN. A destination is also required to interpret the ECN flag.
 - Does not allow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

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TCP Fairness over 802.11



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