無線網路多媒體系統
Wireless Multimedia System

Lecture 8: Wireless TCP

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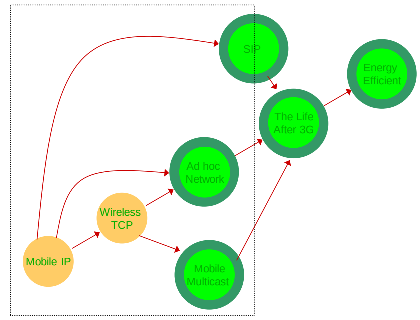
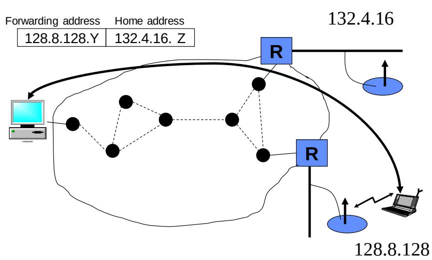
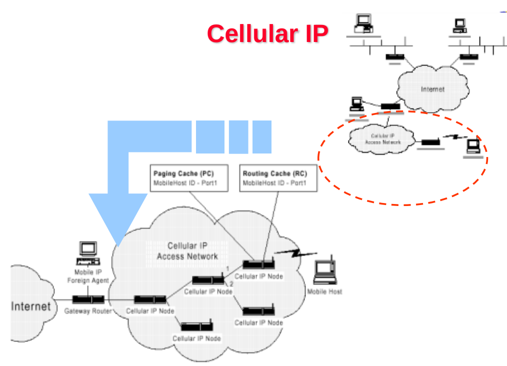
Coming Issues



Mobile IP

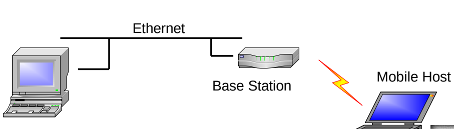


Cellular IP

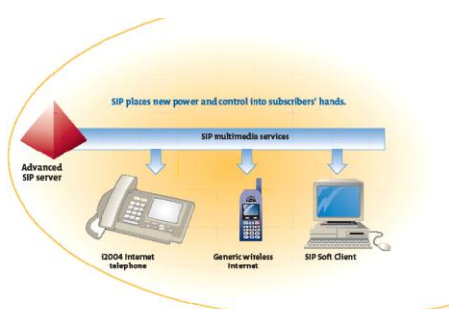


Wireless TCP

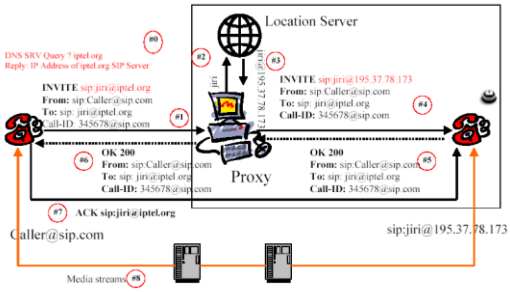
- TCP turned to perform well in traditional network where the packet losses occur mostly because of congestion.
- In the wireless environment
  - **Non-congestion** losses caused by wireless link
  - The degraded performance of TCP is mostly due to **mistaking wireless losses for congestion**.



SIP Protocol



Mobility support



Mobile Multicast

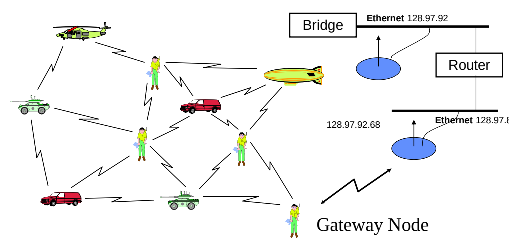
- Mobile Network~ Mobile IP
- Application Requirements: updates to replicated databases, Inter-process communication among cooperating processes
- Resource Conservations~ Single Copy in…Multicast IP

Mobile Multicast

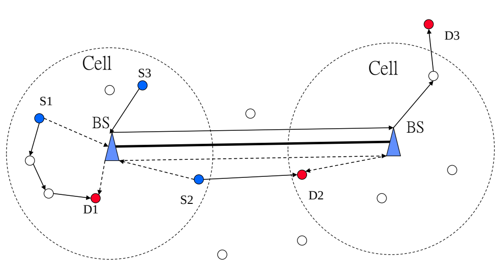
One to Many Mobile Multicasting Services

Internet Interconnection and Mobile IP

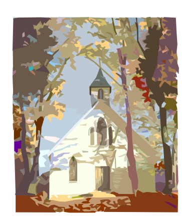
- DSR support the seamless interoperation between an ad hoc network and the Internet



Ad hoc & Cellular System



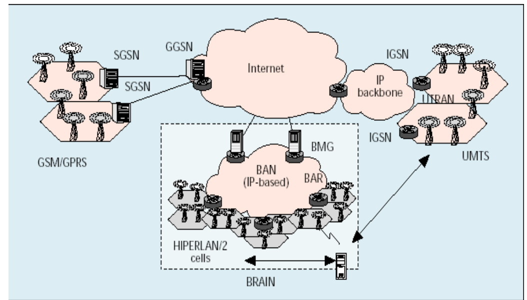
QoS Support for an All-IP System Beyond 3G



BRAIN

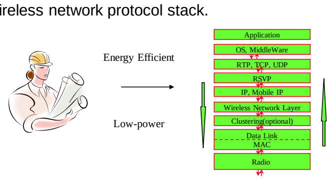
- Broadband Radio Access for IP-Based Networks
  - Cellular systems, fixed networks, and wireless LANs
  - Personal mobility, adapted for the terminal and link bandwidth
  - End-to-end QoS
  - A new QoS model for applications (BRENTA)
  - The radio link improvements
- IP-aware RAN (Radio Access Network)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



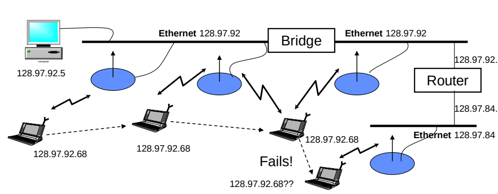
Agenda

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

Reading

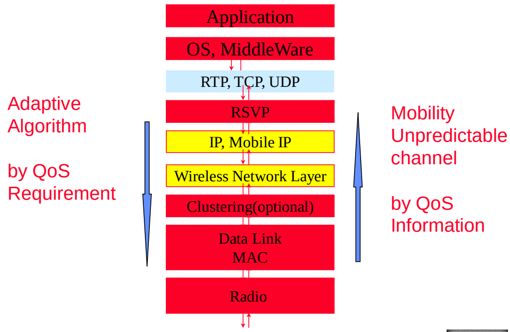
- [Balakrishnan95], Harri Balakrishnan, Srinivasan Seshan, Elan Amir and Randy H. Katz, "Improving TCP/IP Performance over Wireless Networks", ACM Mobicom95
- [Balarkrishnan97], Harri Balarkrishna, Venkat N, Padmanabhan, Srinivasan Seshan and Randy Katz, "A Comparison of Mechanisms for Improving TCP 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



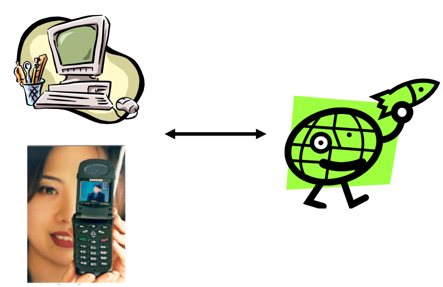
Background

- 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

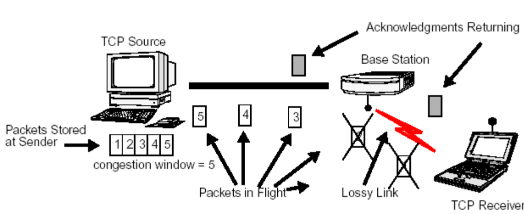
Characteristics of Wireless & Mobility

- 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

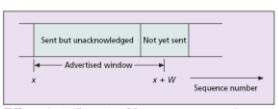


Figure 1. *An illustration of the source sequence number space and advertised window.*

  - 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

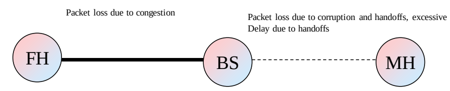
- On new ACK
  - Everything okay, so allow larger congestion window
  - Two ways of increasing cwnd
    - Phase1: slow start until cwnd <= ssthresh
      - Fast (exponential) increase of cwd
    - Phase2: congestion avoidance
      - Slow (additive) increase of cwnd
- Duplicate ACKs
  - Two causes: lost 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

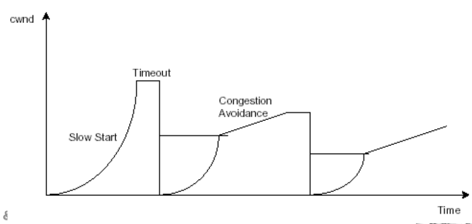
- In Wireless and mobile networks, segment loss is likely not due to congestion
  - Packet corruption due to high BER on wireless link (noise, fading)
  - Packet delay and losses during handoffs
- But, TCP invokes congestion control nevertheless
- Mistaking wireless errors and handoffs for congestion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



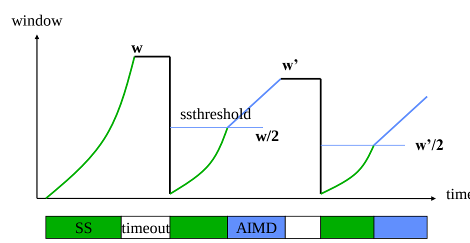
Example graph

cwin<=ssthresh → slow start

cwin>ssthresh → congestion avoidance

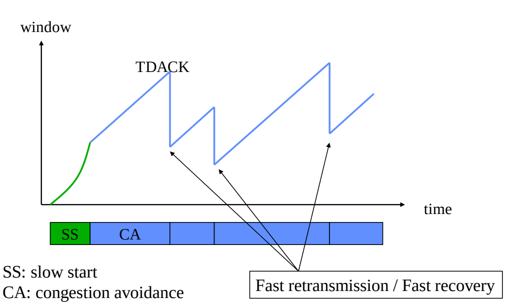


Slow Start of TCP Reno



ssthreshold : slow-start threshold

Congestion Avoidance of TCP Reno

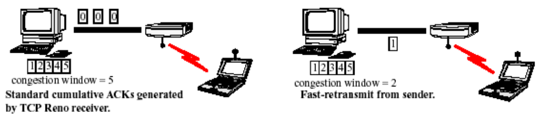


SS: slow start
CA: congestion avoidance

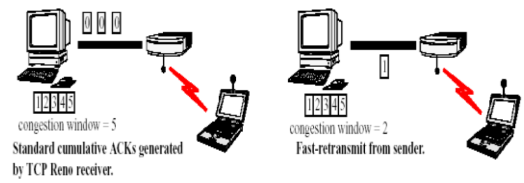
Fixes?

- 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



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

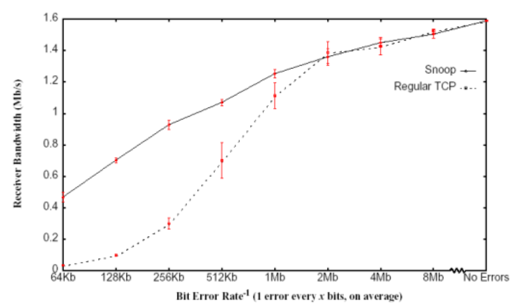
Solutions for WTCP (III)

Snoop, Make it look like!

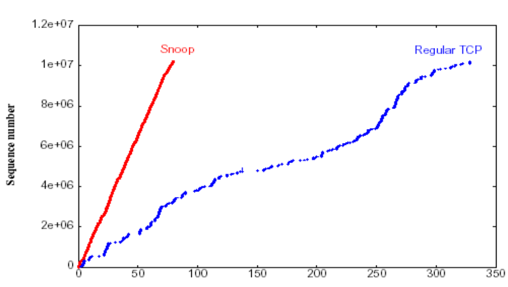
Snoop TCP

- 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 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 $b_k = \frac{d_k}{t_k - t_{k-1}}$
- We employ a low-pass filter to average sampled measurements

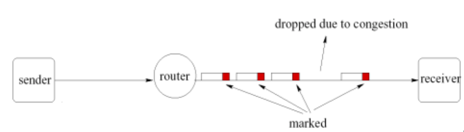
$$\hat{b}_k = \alpha_k \hat{b}_{k-1} + (1-\alpha_k)\left(\frac{b_k + b_{k-1}}{2}\right)$$

```
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*,".

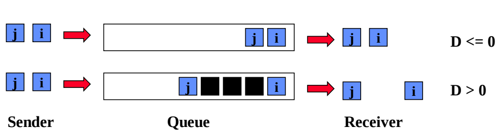
- This paper proposes a new enhancement approach that use Explicit Congestion Notification (ECN) to signal network congestion and use the sequential coherence of ECN marks to distinguish wireless and congestion losses.



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.

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



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

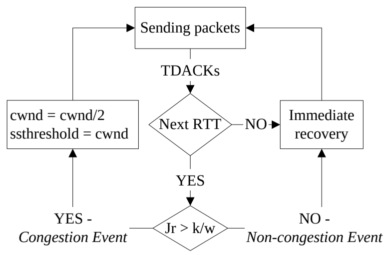
$$Jr = \frac{D}{R_j - R_i}$$

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



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

Example

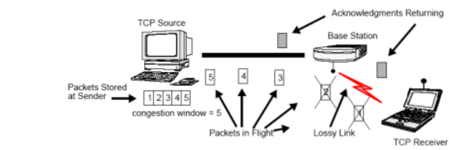


Figure 1. A typical loss situation

Figure 2. Normal TCP

Enhanced Solution

Figure 3. TCP with SMART-based selective acknowledgements

Figure 4. TCP with ELN

Enhanced Solution

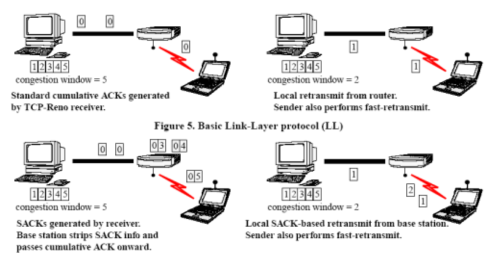


Figure 5. Basic Link-Layer protocol (LL)

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

Enhanced Solution

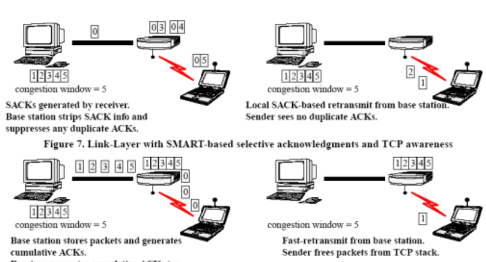


Figure 7. Link-Layer with SMART-based selective acknowledgments and TCP awareness

Figure 8. Split-Connection

Taxonomy of Solutions for TCP in Wireless Networks

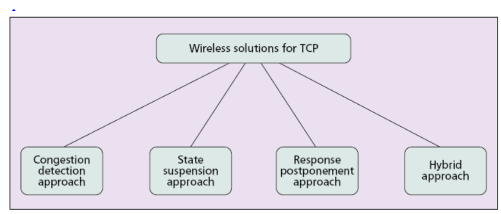


Figure 2. *The taxonomy of solutions for TCP in wireless networks.*

TCP-Peach

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

If wdsn =0, 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.

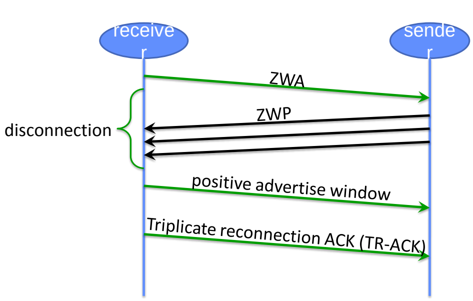
TCP-Peach (3/3)

- 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.

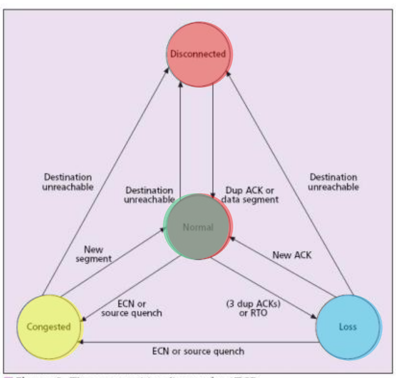


Figure 6. *The state transition diagram for ATCP.*

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