End to End Bandwidth Estimation in TCP to improve Wireless Link Utilization

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Outline

- Introduction
- TCP Westwood overview
- Performance Evaluation in Wireless scenarios
- Internet Measurements
- Conclusion

Introduction

- TCP Tahoe - Slow-start and Congestion avoidance
- TCP Reno -Fast Retransmission and Fast Recovery
- Problems

In Wireless lossy links, the sporadic losses are not due to congestion thus it leads to unnecessary window and transmission rate reduction

Common TCP terms

- Slow Start   Exponential increase from cwnd =1, increase in window for every Ack received.
- Fast Retransmission Retransmission sooner then timeout after 3 acks
- Congestion/ Slow Start Threshold - Window resulting from multiplicative decrease
- Faster Recovery – Avoids slow start and starts from the congestion window at half the value. Linear increase
- Congestion avoidance - Linear increase, Increase in window for every RTT time.

TCP Westwood

- Sender side only modification of TCP Reno Congestion control that exploits end to end bandwidth estimation.
- The bandwidth is estimated by low pass filtering the rate of returning acks.
- The bandwidth is used to compute congestion window and slow start threshold.

TCP Westwood Overview

- Slow Start and Congestion window aware of Bandwidth at time of congestion
- The increase after congestion is additive but decrease Adaptive (AIAD) as compared to AIMD (Additive Increase Multiplicative decrease) of Reno

TCPW implementation

- Sender side Bandwidth Estimation by measuring and low pass filtering the rate of returning acks

- When 3 DUPACKS are received
  ssthresh=(Bandwidth*RTT)/seg_size   c*wnd* =ssthresh

- When a coarse timeout expires
  ssthresh =(B*RTT)/seg_size   c*wnd* =1

- When acks are successfully received TCPW increases cwnd according to Reno's congestion control algorithm

TCPW Advantage over Reno

- In case of sudden increase in bottleneck load, reduction can be more drastic then a reduction by half and can be less drastic in other cases. This features improves stability and utilization

TCP Westwood convergence to fair share

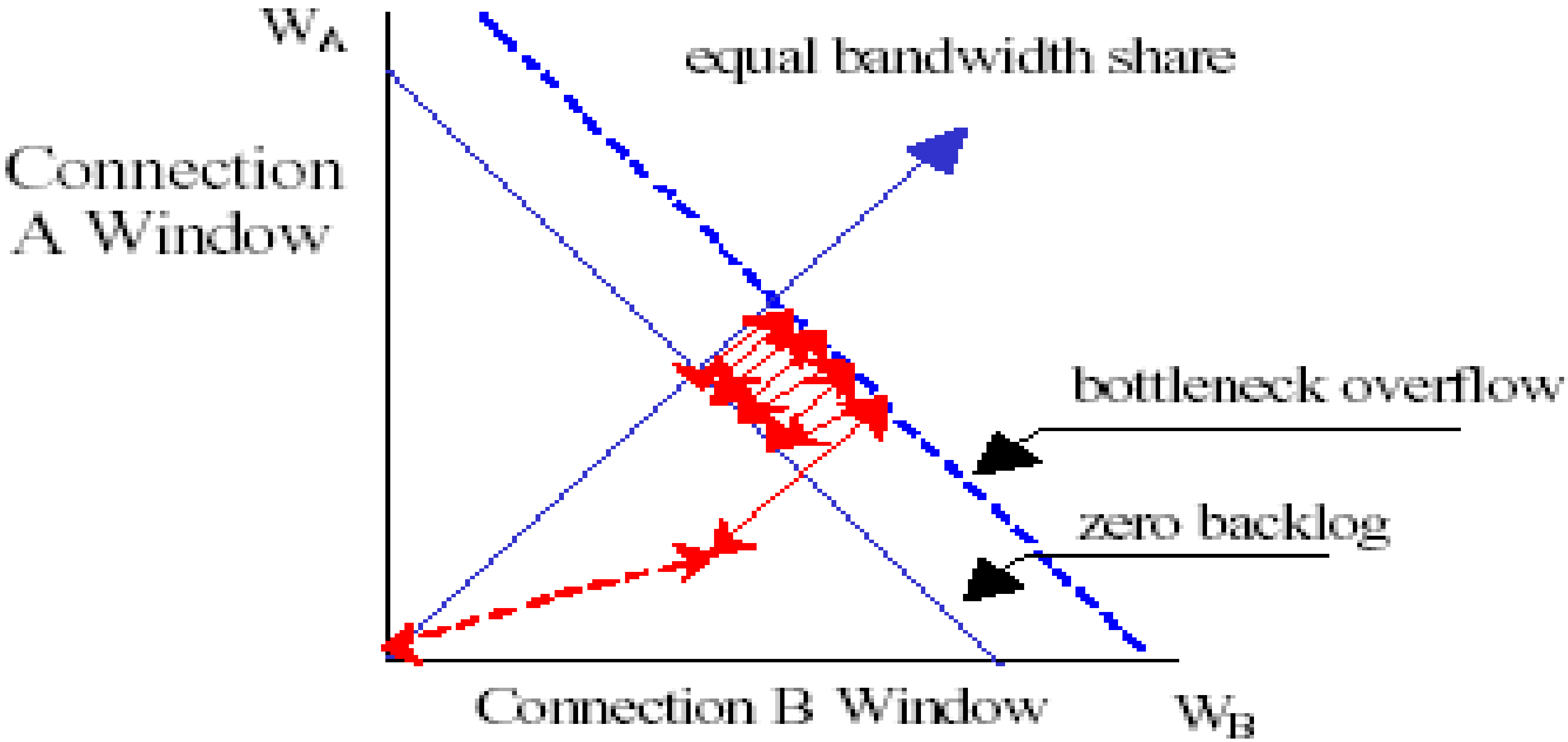


Figure 2. Convergence toward fair bandwidth sharing.

TCPW convergence to fair share

- Suppose 2 connections with the same round trip time. One connection starts first then the other connection first in slow start mode and then in congestion avoidance. In congestion avoidance the window, grows at the same rate 1 segment per RTT.

- When the bottleneck link overflows , the window at the overflow is Wi = Ri (b/C +RTT), for i = A,B;where R is the achieved rate (i.e., BWE); b is the bottleneck buffer size; and C is the bottleneck trunk capacity.

- After buffer overflow, the new TCP Window reduces to new value as Wi'= Ri (RTT) for i = A, B

The ratios of window A & B Wb/ Wa are preserved after overflow. The ratio increases during congestion avoidance, then B overflows and its window is reduced. After a while A's window is reduced.
This keeps on happening until equilibrium is reached with Wb=WA

Bandwidth estimation effectiveness

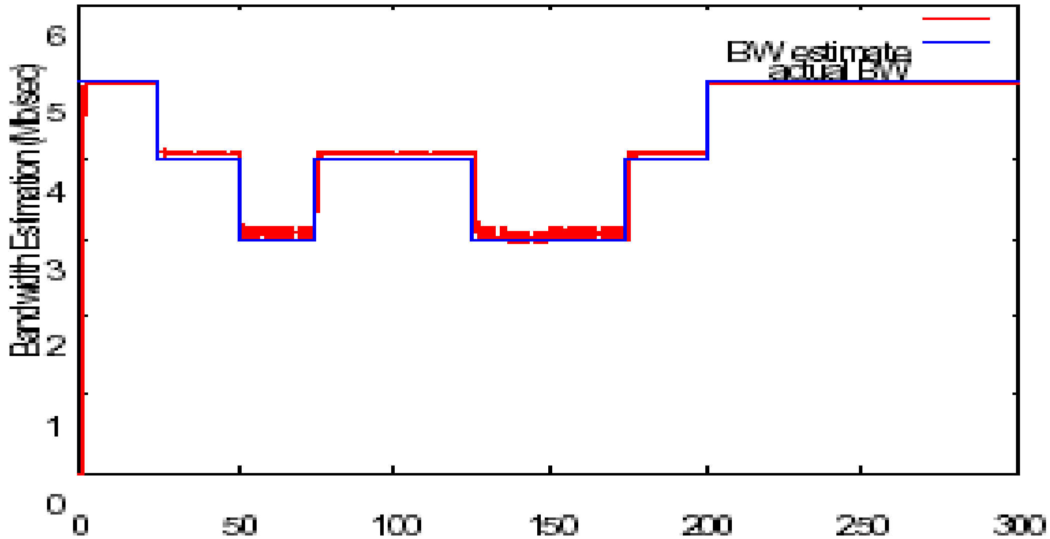


Figure 3. TCPW with concurrent UDP traffic: bandwidth estimation

One TCP connection and 2 UDP 1Mbps ON-OFF connections .
After 25 sec 1 UDP connection is turned on, after 50 the other UDP connection is turned on
The second UDP connection folows OFF,ON,OFF at 75,125,175
Boththe connection are turned off at 200 sec

TCPW Friendliness

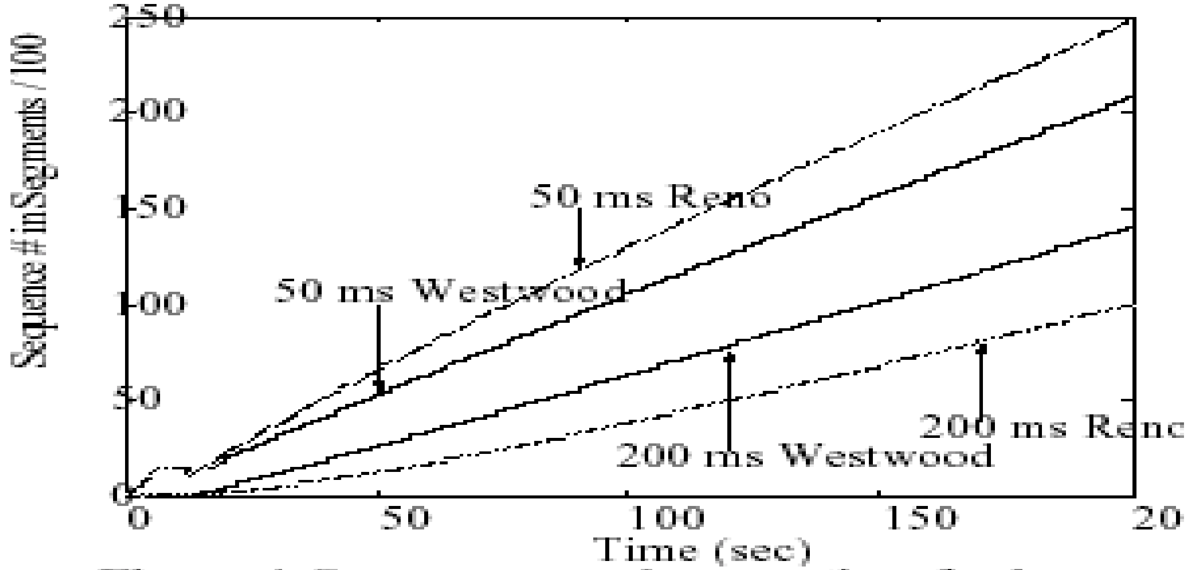


Figure 4. Sequence numbers vs. time for long and short RTT connections without RED

Connection subject to 50 ms and 200 ms RTT.
The short connection progresses faster for TCP Reno
The superior fairness for long connection is due to less reduction of cwnd and ssthresh for TCPW.

TCPW fairness with Reno

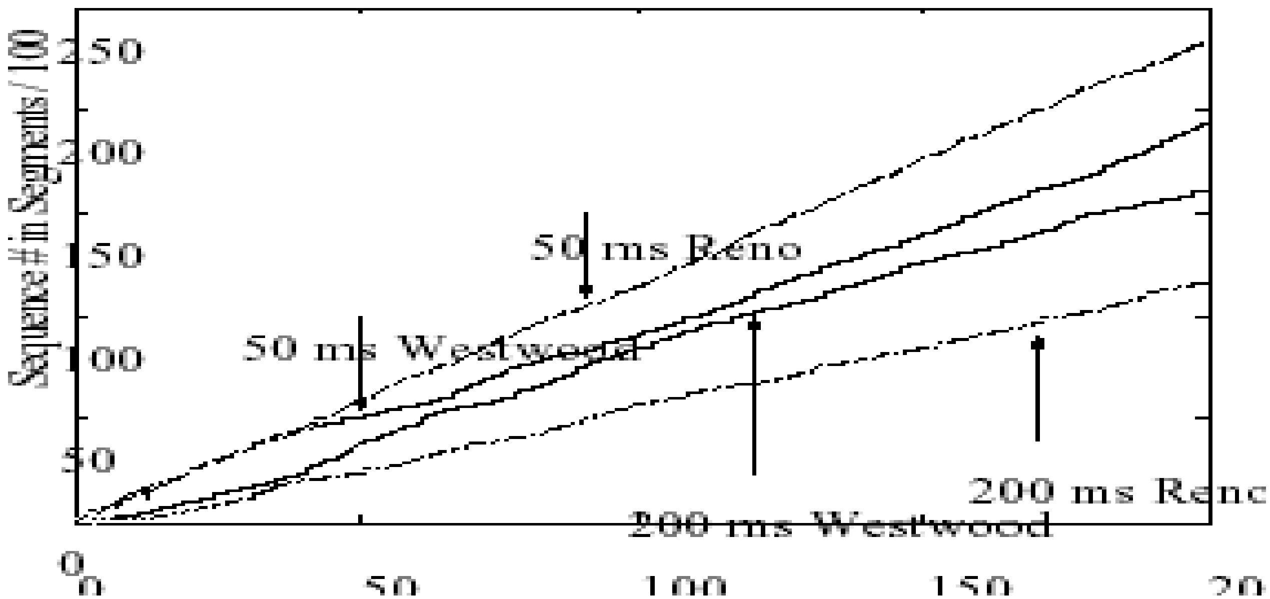


Figure 5. Sequence numbers vs. time for long and short RTT connections with RED

The TCPW performance improvement is more with RED

TCPW friendliness

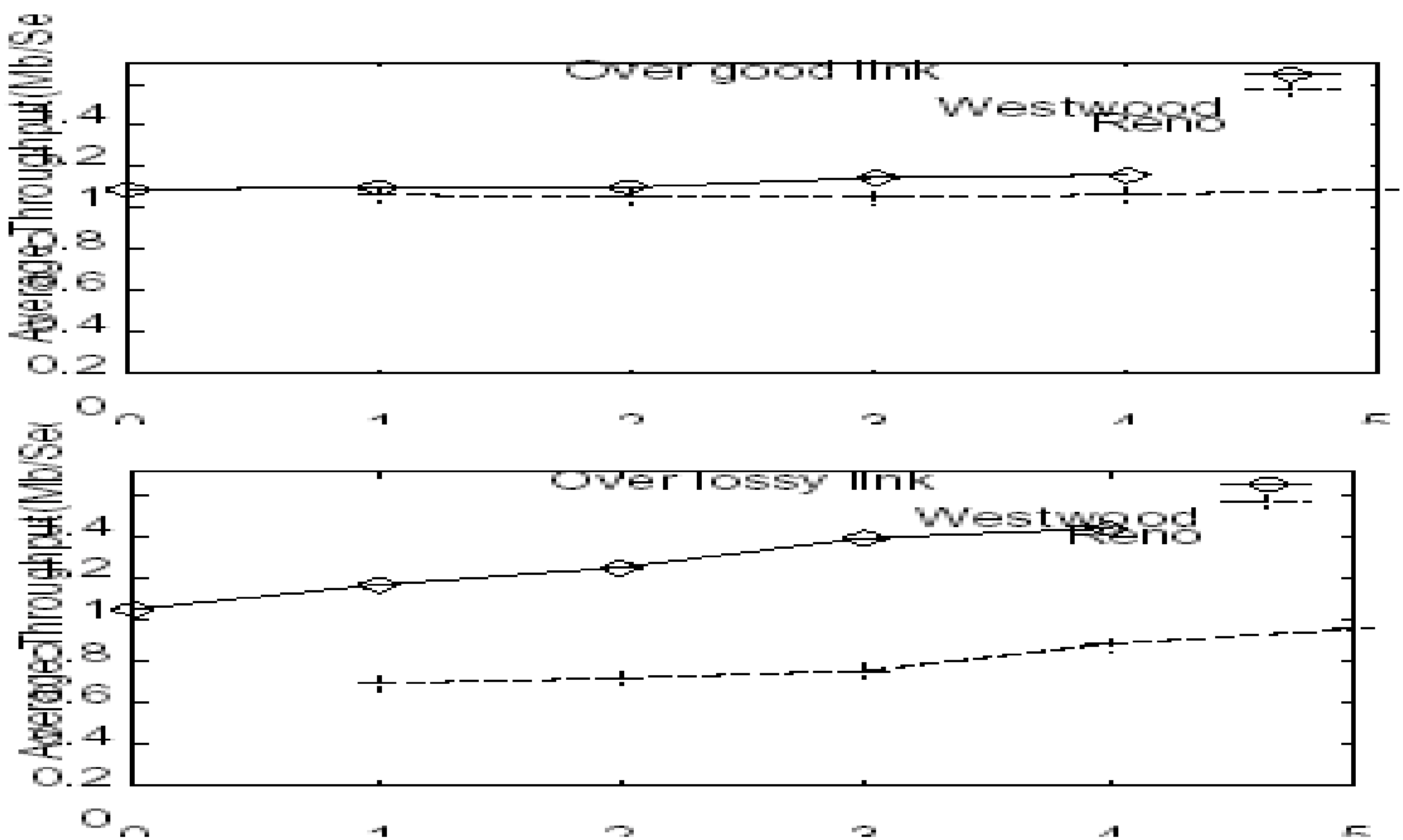


Figure 7. Average throughput vs. No. of Reno connections over good and lossy link (5 connections total)

Performance Evaluation in Wireless Scenarios

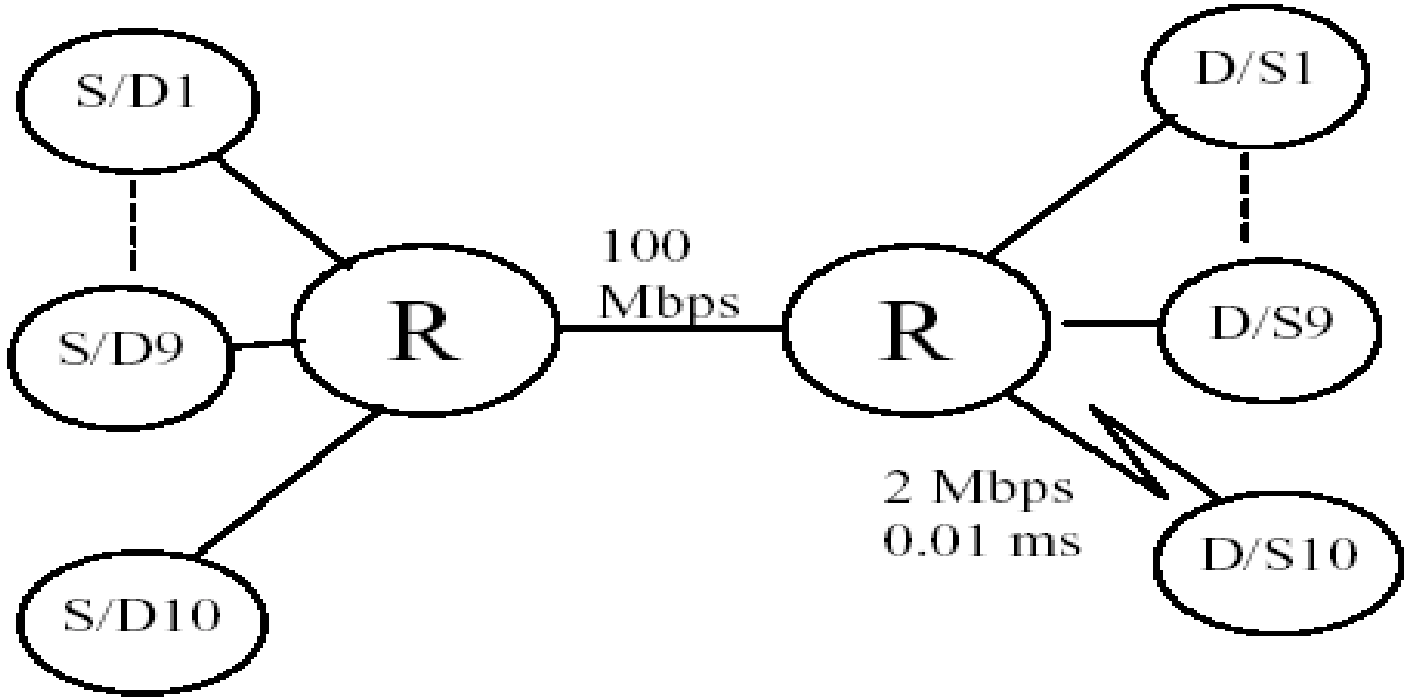


Figure 1. Mobile client or mobile server

Simulation scenarios

- Mobile client connected through a last hop wireless link to the internet
- Mobile server connected through a last hop wireless link to the internet
- Geo Satellite bottleneck link shared by TCP connections.

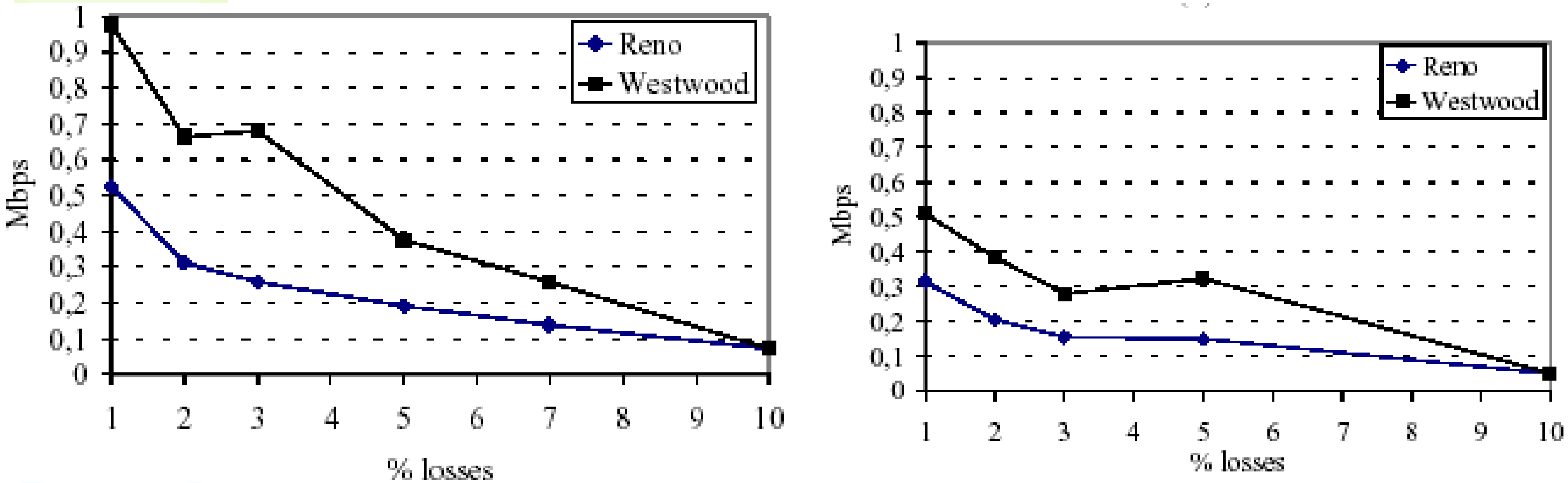
Mobile Client

- A single connection going through a wired portion including a 100 Mbps link between source node and a base station. A propagation time of 62 ms. Wireless portion 2 Mbps link with propagation time .01 msec

- A single bottleneck topology with 9 wired Reno connections and the rest as above.

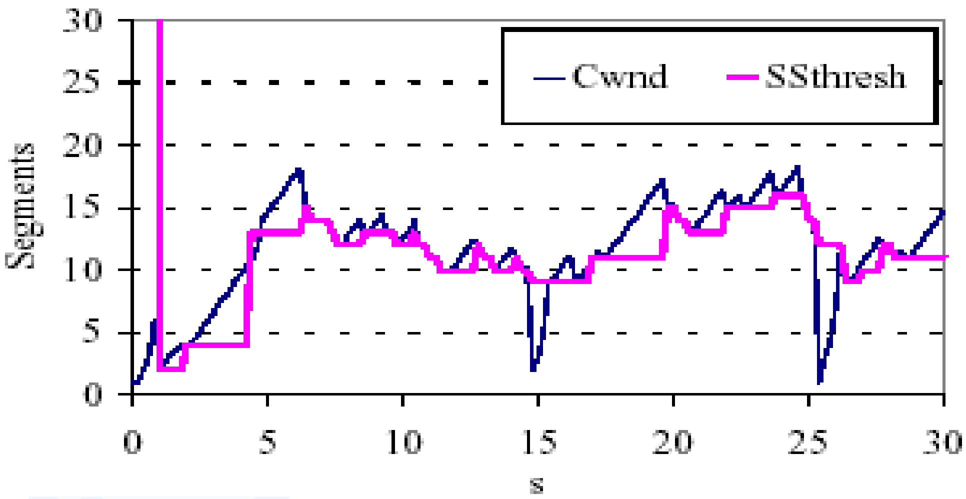
Independent Error Model

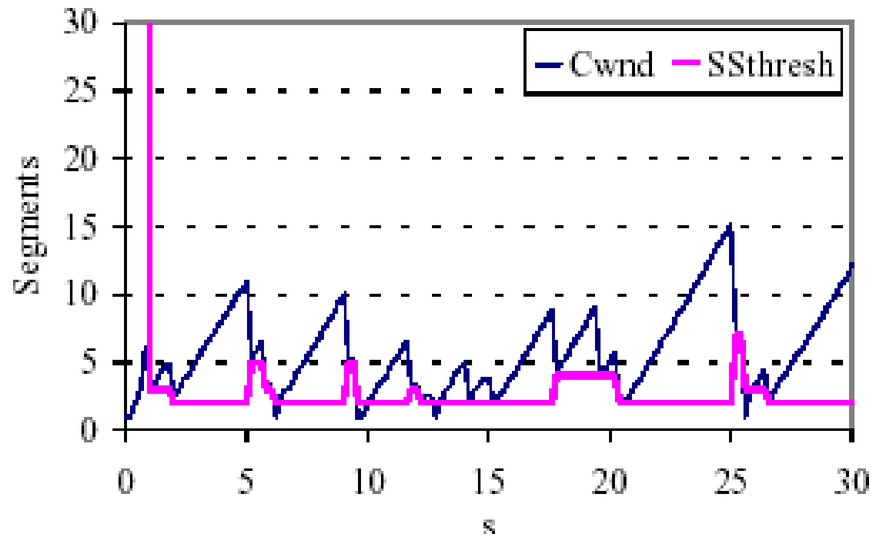
- Bernoulli Error model with 1% to 10% packet loss probability
- The time between successive errors is exponentially distributed



Average throughput under independent lossy condition
a) Single connection b) Multiple connection

TCPW improves throughput up to 163% with respect to TCP Reno in single connection and 116% in multiple connection





Congestion Window and Slow start Threshold behaviors Westwood(left) and Reno(Right)

Westwood is efficient than Reno in wireless links since losses are not due to congestion which keep the values of *cwnd* and *ssthresh* for Reno much lower then Westwood

Burst Error Models

- We use a 2-stat Markov model

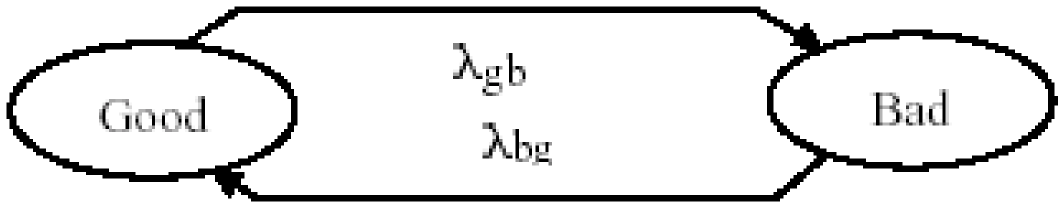
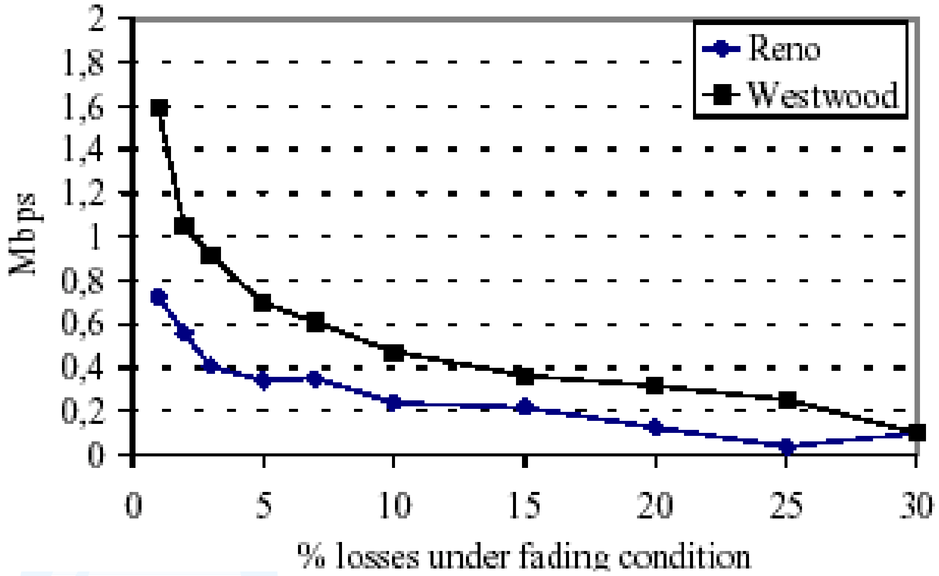


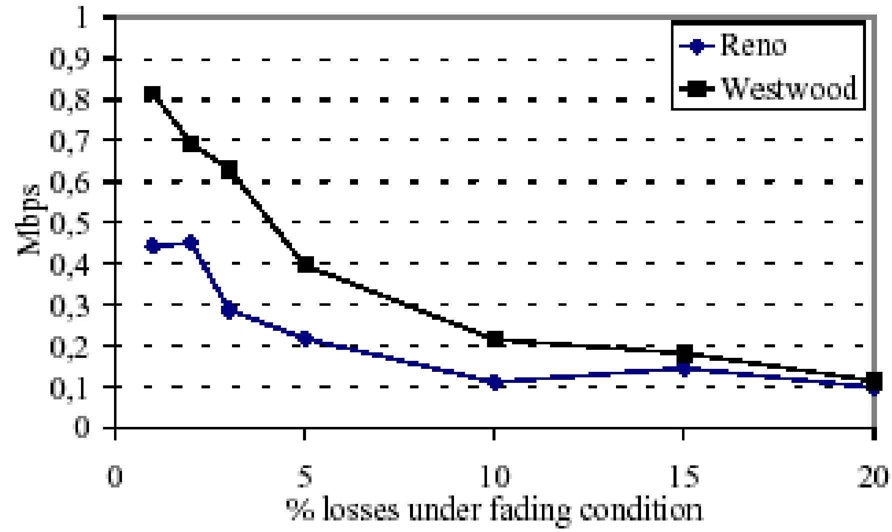
Figure 5. Two-State Markov Model for Burst Error Characterization

The wireless link is in 2 states .

In good and bad Bernoulli model is assumed for packet error. The rate of error in bad state is much higher.

Interval between packet error are exponentially distributed. The link stays in good state or bad state for a time interval that is exponentially distributed.



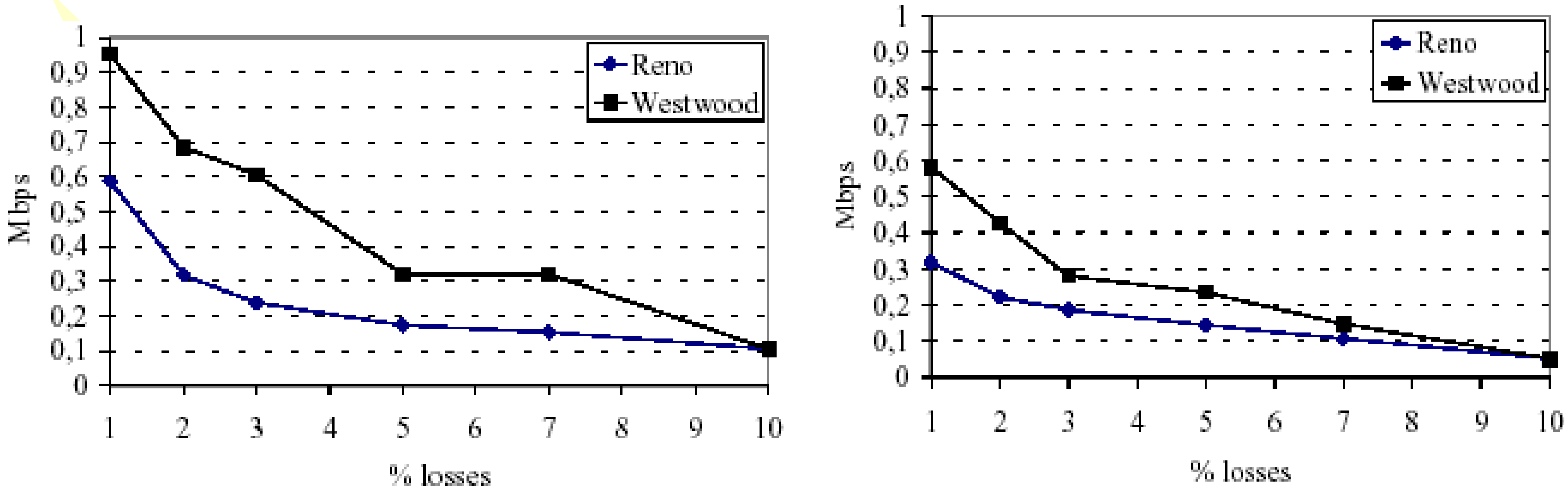


In Bad state packet loss is varied from 0 to 30%. Throughput improvement In single connection is from 66 to 578%

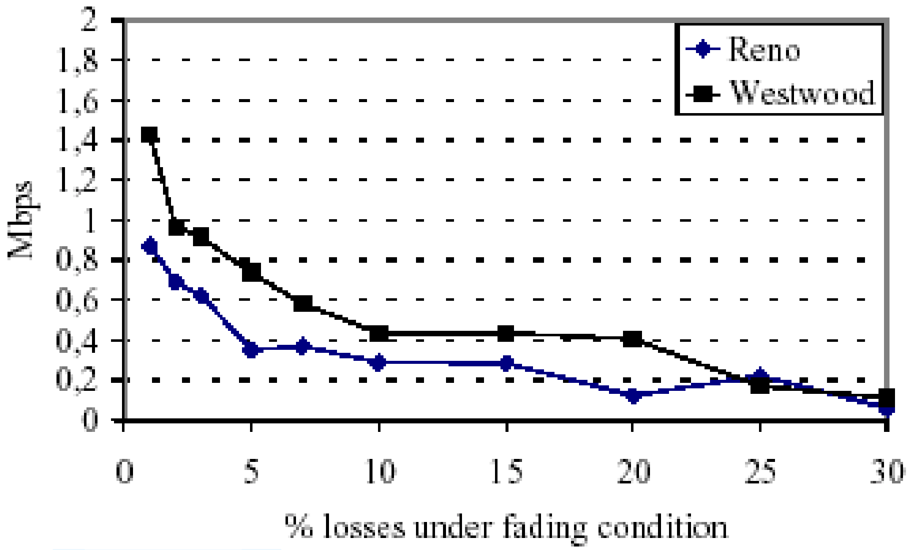
For loss rate greater than 20% TCPW and Reno tend to the same throughput

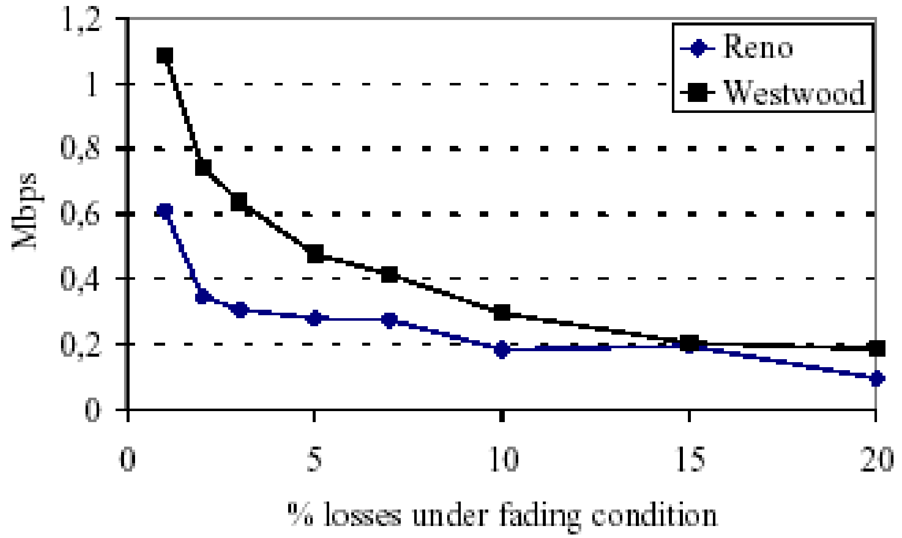
Mobile server

- The mobile node is now the server



Independent Error Model. Avg throughput under lossy condition.
a) Single Connection b) Multiple connection

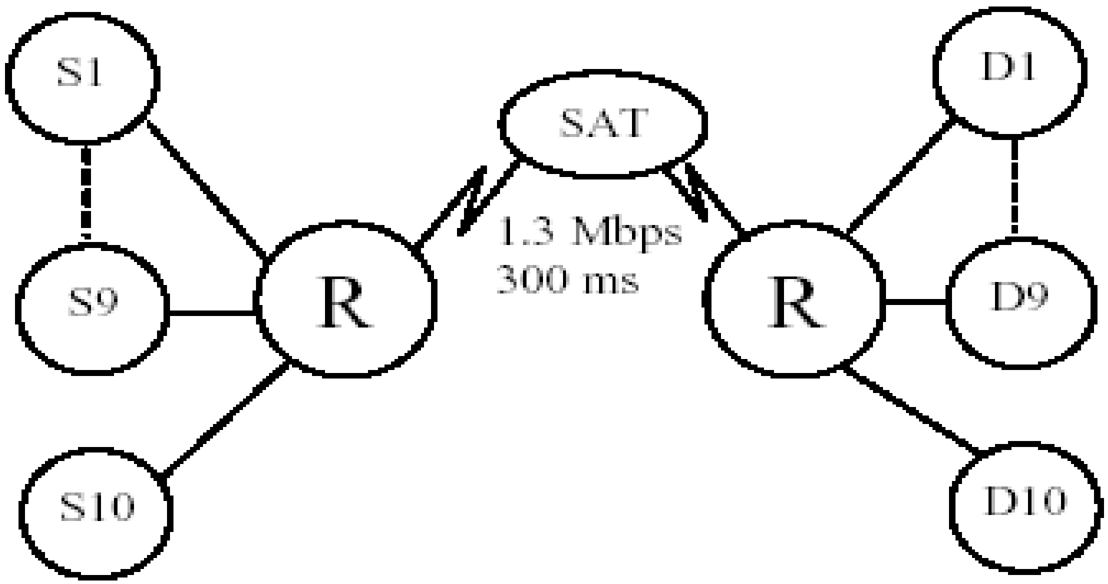




Burst Error model. The improvement of TCPW ranges from 40% to 222% For single connection and for multiple connection ranges from 60% to 115%.

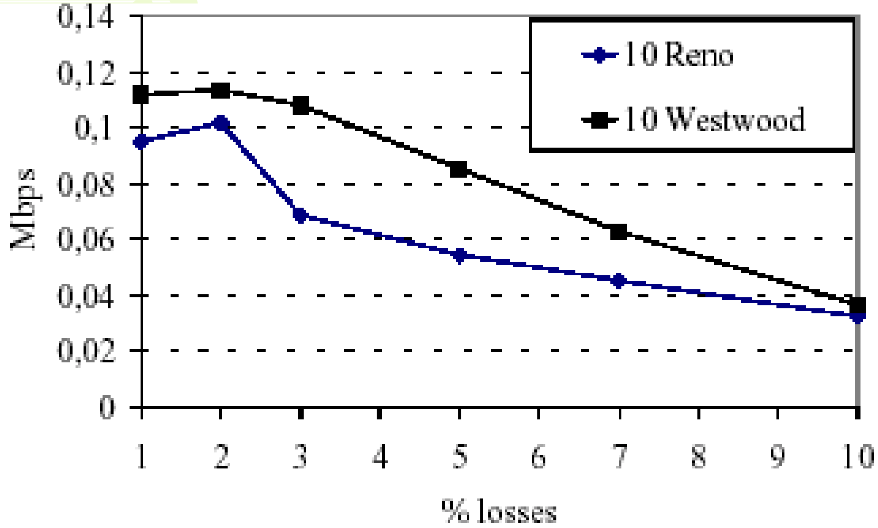
For loss rate greater then 20% TCPW and Reno converge to the same output.

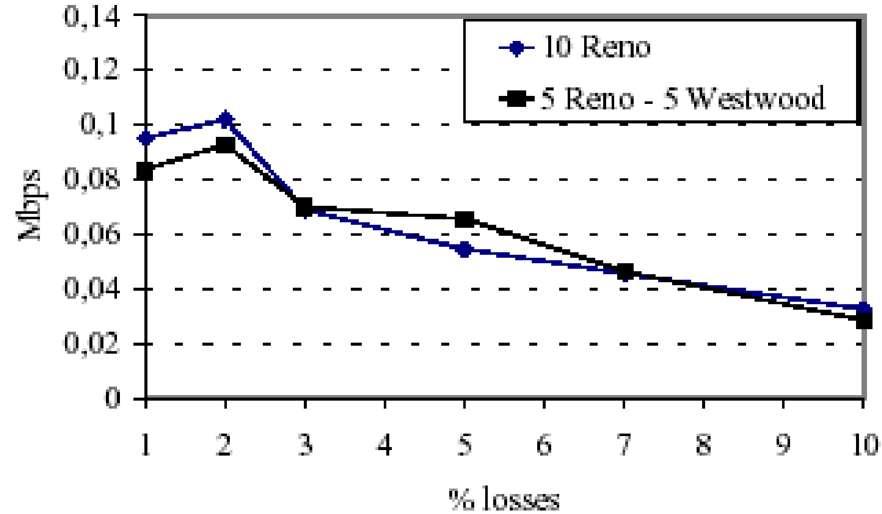
Geo Satellite scenario



A bottleneck scenario in which 10 TCP sources are sharing the Geo Satellite link The bandwidth is 1.3 Mbps and RTT 600 msec.

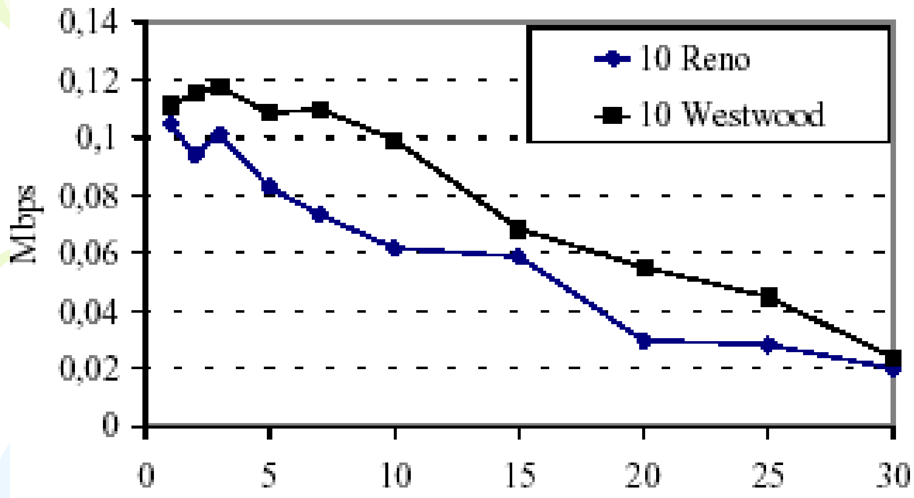
We compare mean throughput of 10 TCPW and 10 Reno
And 5 Reno and 5 Westoood sharing the link at the same time.

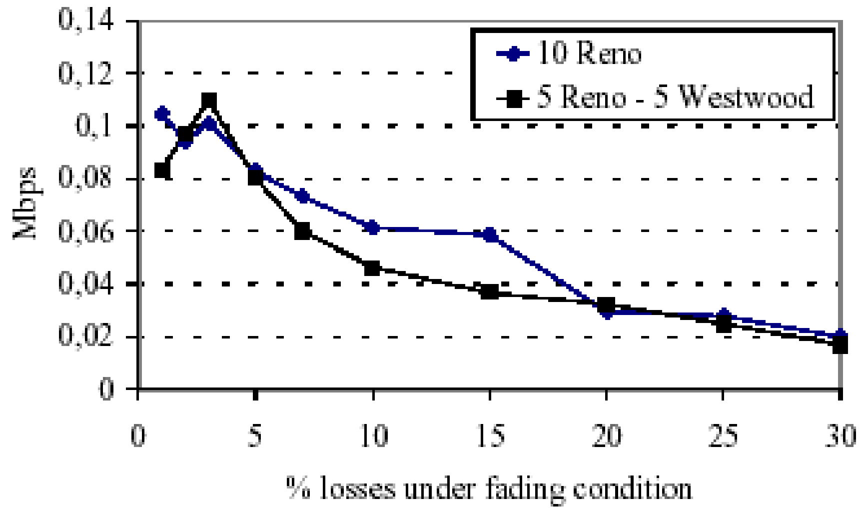




Avg throughput under lossy condition
a)Reno vs Westwood. b)Friendliness evaluation

In frienliness evaluation putting 5 Reno and 5 TCPW connection shows TCPW does not reduce the throughput of Reno connection





Burst error model.
a)TCPW performs better then Reno up to 87%

b)Westwood does not reduce the throughput of Reno
 sources.

Internet Measurements

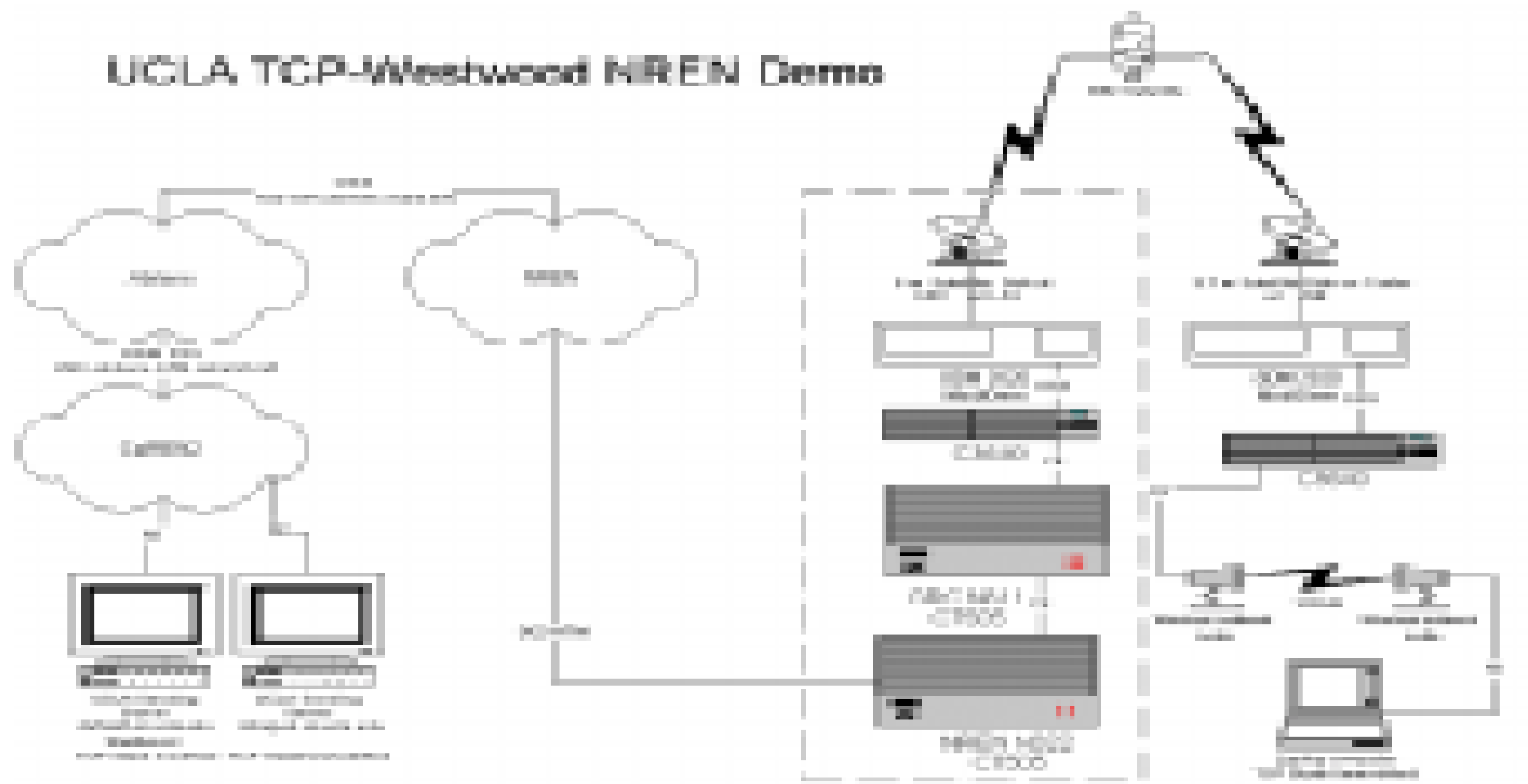


Figure 11: Experiment Scenario

Experiment over the NASA Network

	Min	Max	Avg
RTT	630 ms	960ms	644.3ms
RTO Events	0.00 %	0.48 %	0.22 %
Triple Dup Acks	0.01 %	0.37 %	0.17%
RENO Throughput **bit/s**	264664 bit/s	595488 bit/s	440050 bit/s
Westwood Throughput **bit/s**	752792 bit/s	778040 bit/s	764968 bit/s

Table 1: NASA Experiment Summary

The path has an avg roundtrip time of 650ms and bandwidth at different times on avg is 26.7 Mbps.

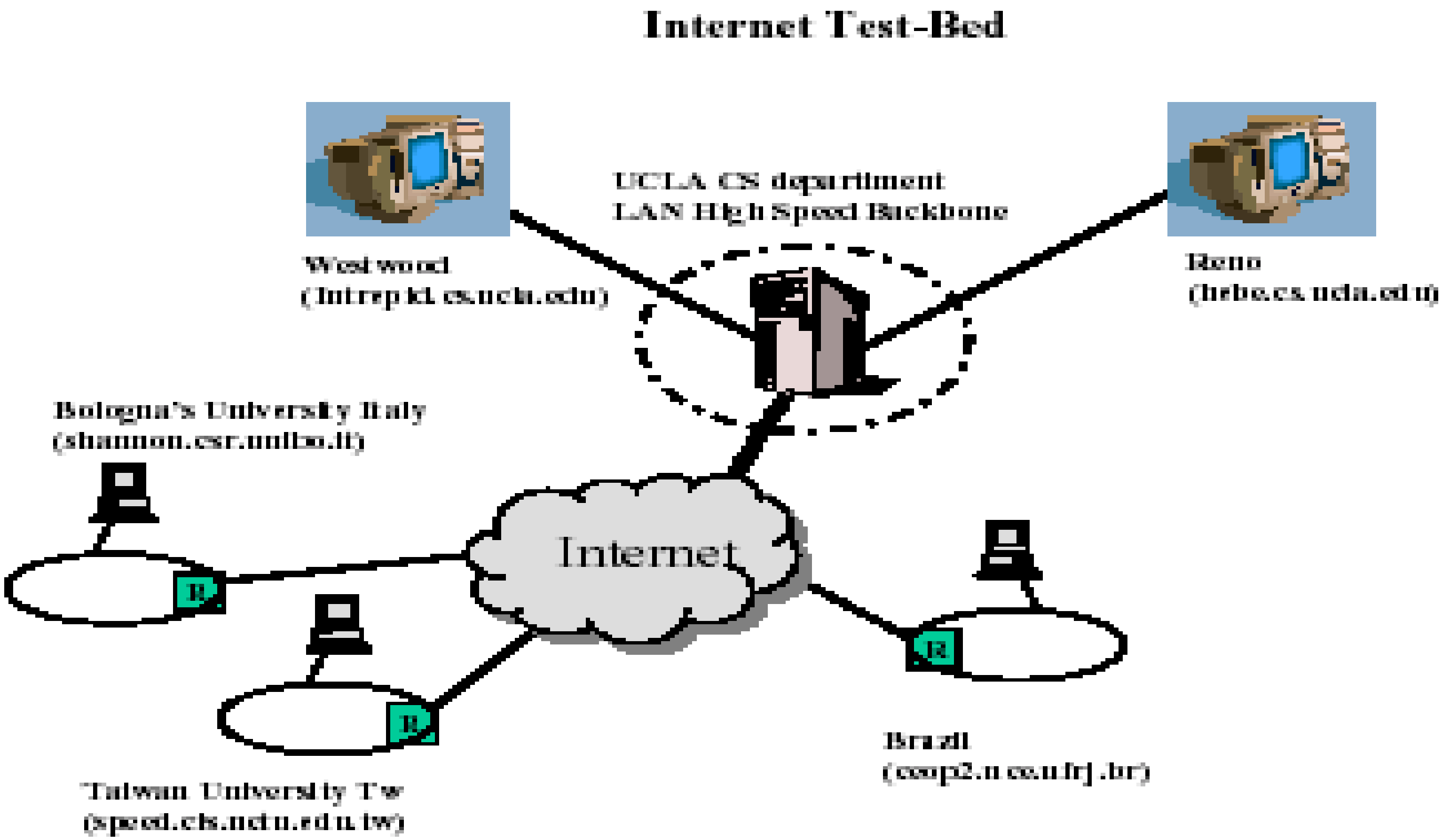
NASA Experiment results

- TCP Westwood achieves on average twice the throughput of Reno

- More efficient setting of *cwnd* and *ssthresh* in TCPW

- TCPW is practically the same over all experiments while Reno throughput shows fluctuations.

Internet Measurement



Destination RTT	Throughput (Kbit/s)	
	TCPW	Reno
Italy 170 ms	629.28	591.44
Taiwan 250 ms	1339.04	1216
Brazil 450 ms	177.28	123.2

Table 2: Internet Experiment Summary

The source is at UCLA while destination is are in 3 different continents and are unaware whether source is Reno or Westwood.

A large file was sent and the receiver were regular Ftp clients

Internet test results

Italy and Taiwan are connected using a wired technology where link errors are minimum , thus TCPW does not introduce much improvement over Reno.

- Brazil which has a lossy satellite link accounts for TCPW improved performance

Conclusion

- TCP Westwood uses wireless links much better then Reno
- Simulation shows improvement up to 578%
- TCP Westwood is friendly to Reno in Wireless scenarios.
- Measurement in NASA shows improvement up to 185% and the internet using a satellite link improvement up till 47%