TCP and IEEE 802.11b Protocol Performance in Indoor Wireless Channels

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OUTLINE

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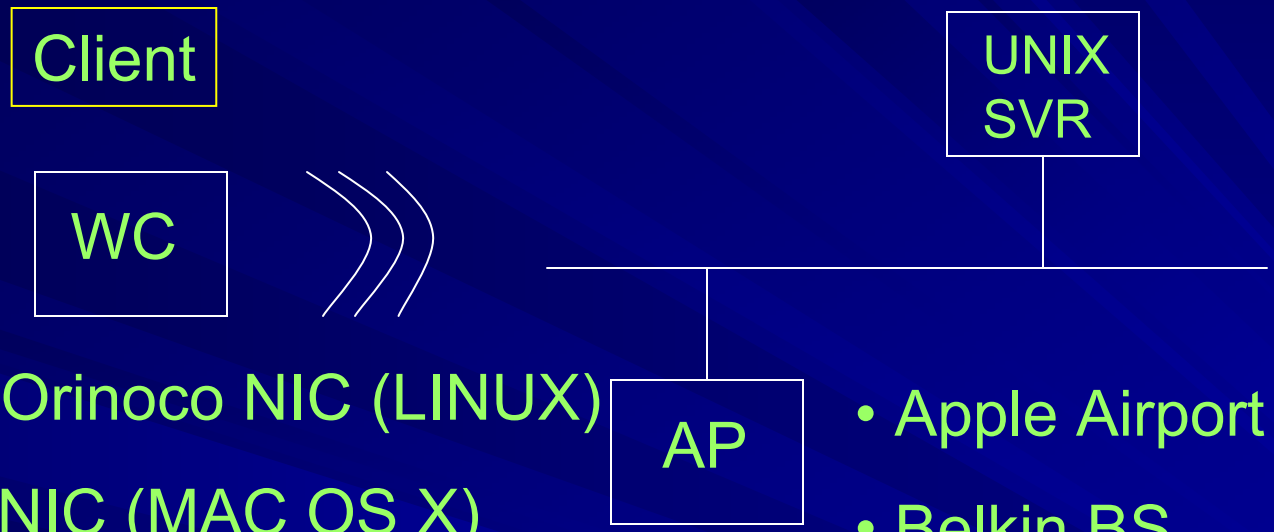
Problem Statement

- Analyze experimentally performance of data transfers in indoor wireless channels
  - Impact of Channel Interference
    - Path Loss
    - Non Line of Sight (NLOS)
    - Fading
  - Impact of MAC/PHY layer protocols
    - Channel sensing and Access Mechanism
    - Retransmissions
    - Protocol Overhead
  - Impact of Transport Layer (TCP)
    - Retransmission Mechanism
    - Round Trip Time (RTT) variations

Experimental Setup



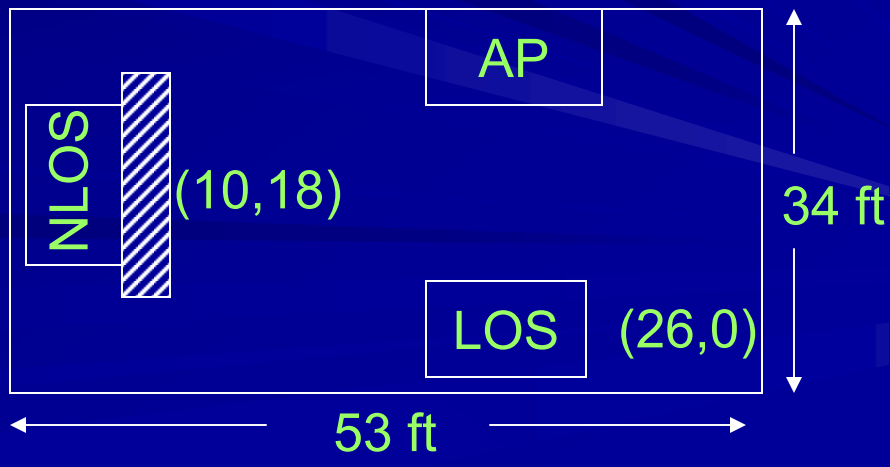
- Lucent Orinoco NIC (LINUX)
- Airport NIC (MAC OS X)

- Apple Airport
- Belkin BS

Experiment

Block transfer : 10^5 IP packets
Monitor Packet Headers at AP & server
WC: *tcpdump*

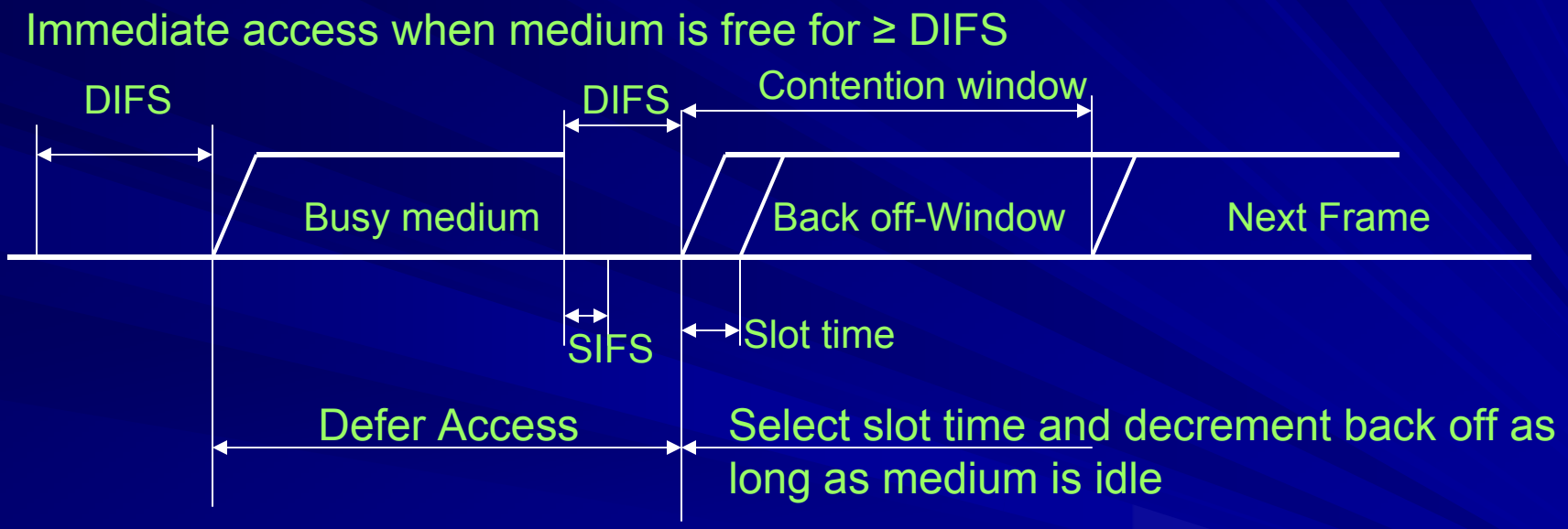
Channel



IEEE 802.11b Specifics

- PHY layer
  - Direct Sequence Spread Spectrum (DSSS)
- MAC layer
  - Channel Sensing & Access (CSMA/CA)
- Mode of operation
  - Infrastructure Mode
  - Distributed Coordination function (DCF)
- Overhead
  - PHY/MAC/TCP/IP layers : 90 bytes
- Maximum Throughput : 11 Mbps
- Achievable Throughput : 5 - 6 Mbps

Access Mechanism



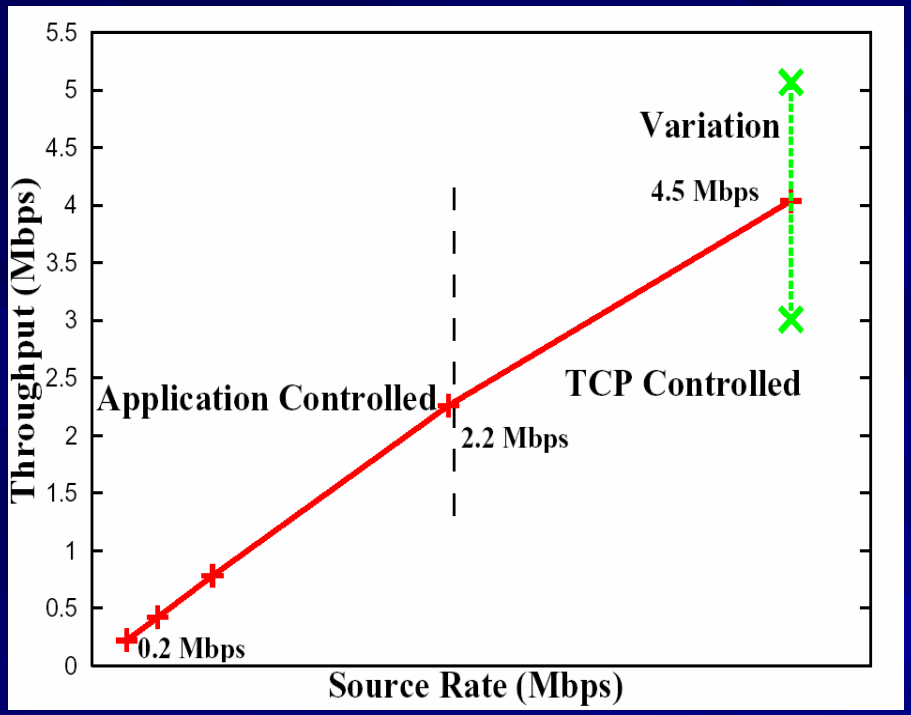
Slot time : 20 ms
Short Inter Frame Space (SIFS) = 10 ms
Distributed Inter Frame Space (DIFS) = 50 ms

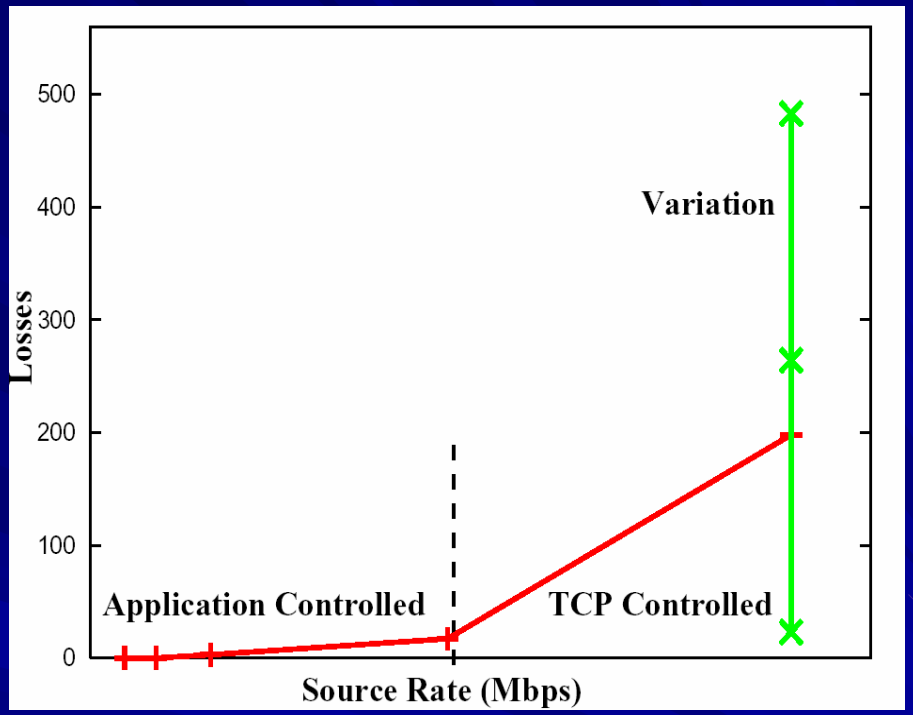
TCP Dynamics

- TCP version : Reno
- Window size W_t : min[CWND,RWND]
  - CWND : congestion window, RWND : receiver window
  - W_t < ssthresh : Slow start : $W_t = W_t + 1$
  - $W_t \geq$ ssthresh : Congestion avoidance:
    - $W_t = W_t + 1/W_t$
- Acknowledgements
  - expected within a timeout value calculated adaptively from round trip times.
- Retransmissions:
  - Fast Retransmit after 3 duplicate Acks.
  - Retransmission Time out (RTO) :
    - If Acks Lost ; Exponential back off in RTO

TCP Average Statistics

Throughput & Packet Loss

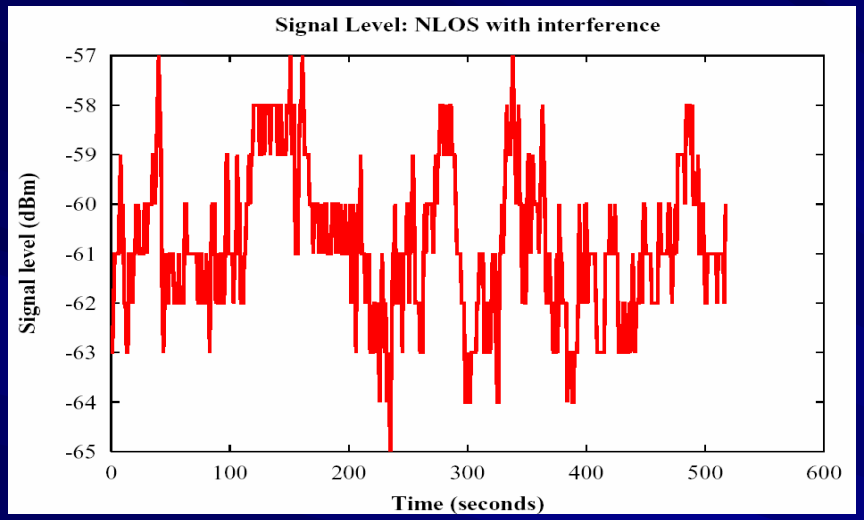




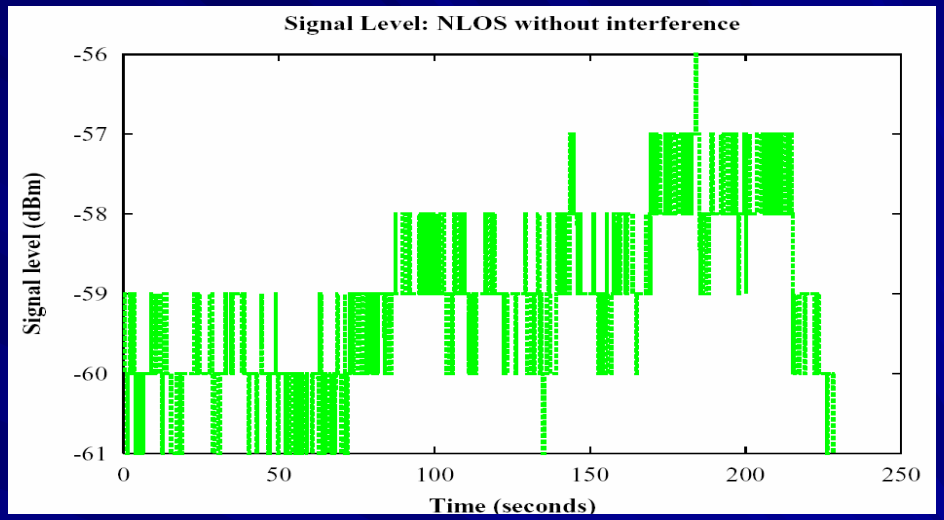
- Channel Capacity : 4-6 Mbps
- Application rate < Channel capacity : 100% throughput achieved
- Application rate > 4 Mbps
  - Throughput & Packet Loss highly variable
  - Function of channel & TCP dynamics

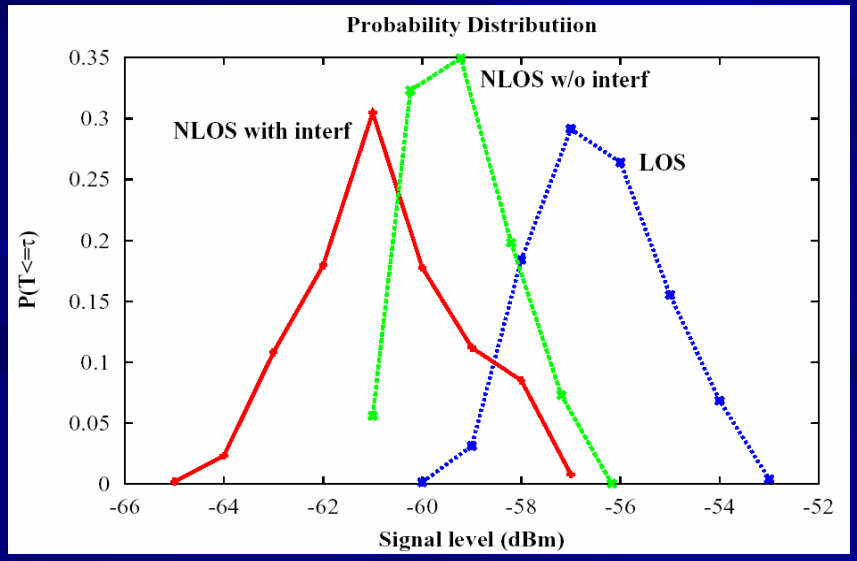
Signal measurements at client

NLOS with channel variations



NLOS: Invariant Channel





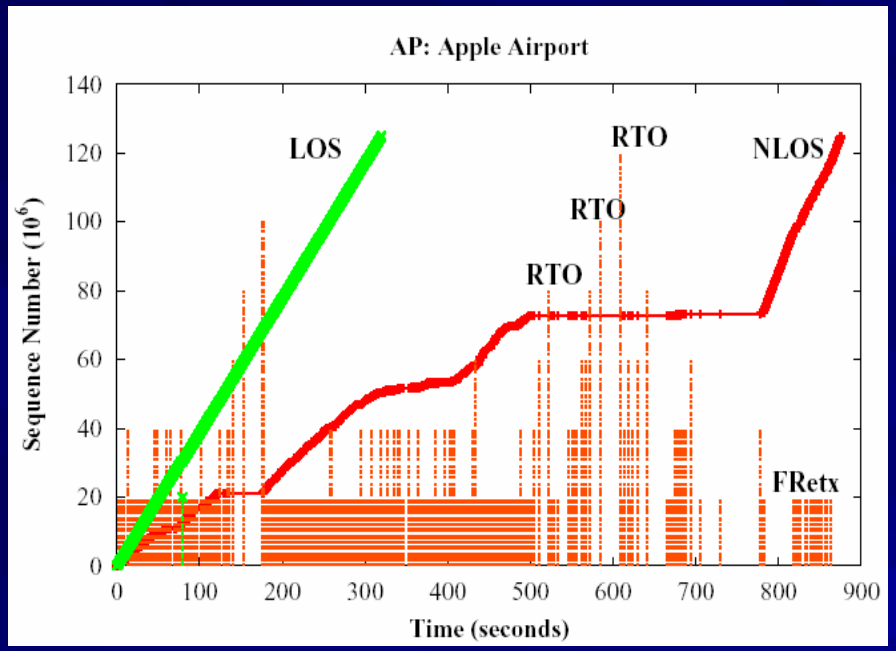
Monitor: iwconfig

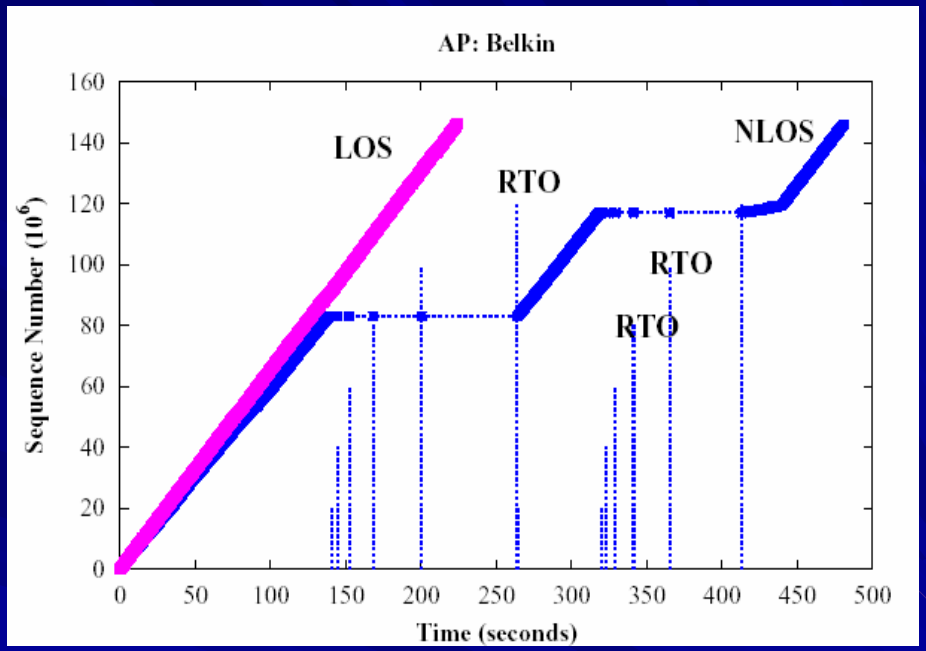
Channel Interference is caused by:

- Movement of people in room
- Usage of microwave oven

TCP Performance Analysis

Comparison of Apple & Belkin Access Points





Apple Airport:

- Higher Loss Rate
- Periodic Losses (2 seconds)
  - Data Frames Lost at AP due to interference with polling/beacon frames
- Loss Recovery: TCP Fast Retransmit

Belkin

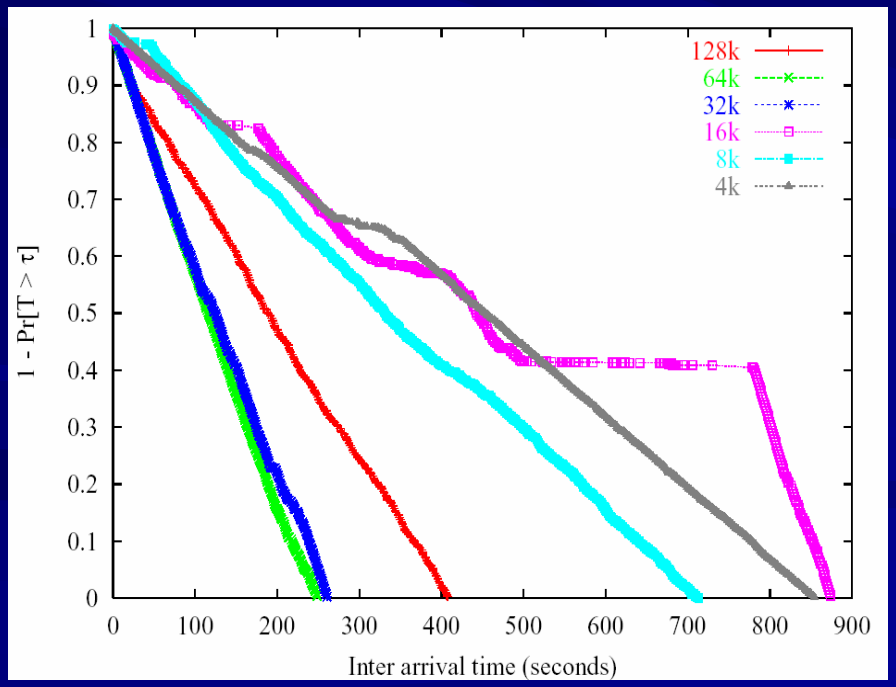
- Low Loss Rate
- Loss of signal level
  - Multiple TCP Retransmission of the same segment
  - ACK frames lost at client due to channel fading
- Loss Recovery: RTO expiry

Effect of signal level variation

1. LOS performs better than NLOS as the signal undergoes more fading in the latter case
2. The Belkin Base station performs better than Airport due to the absence of Beacon signals

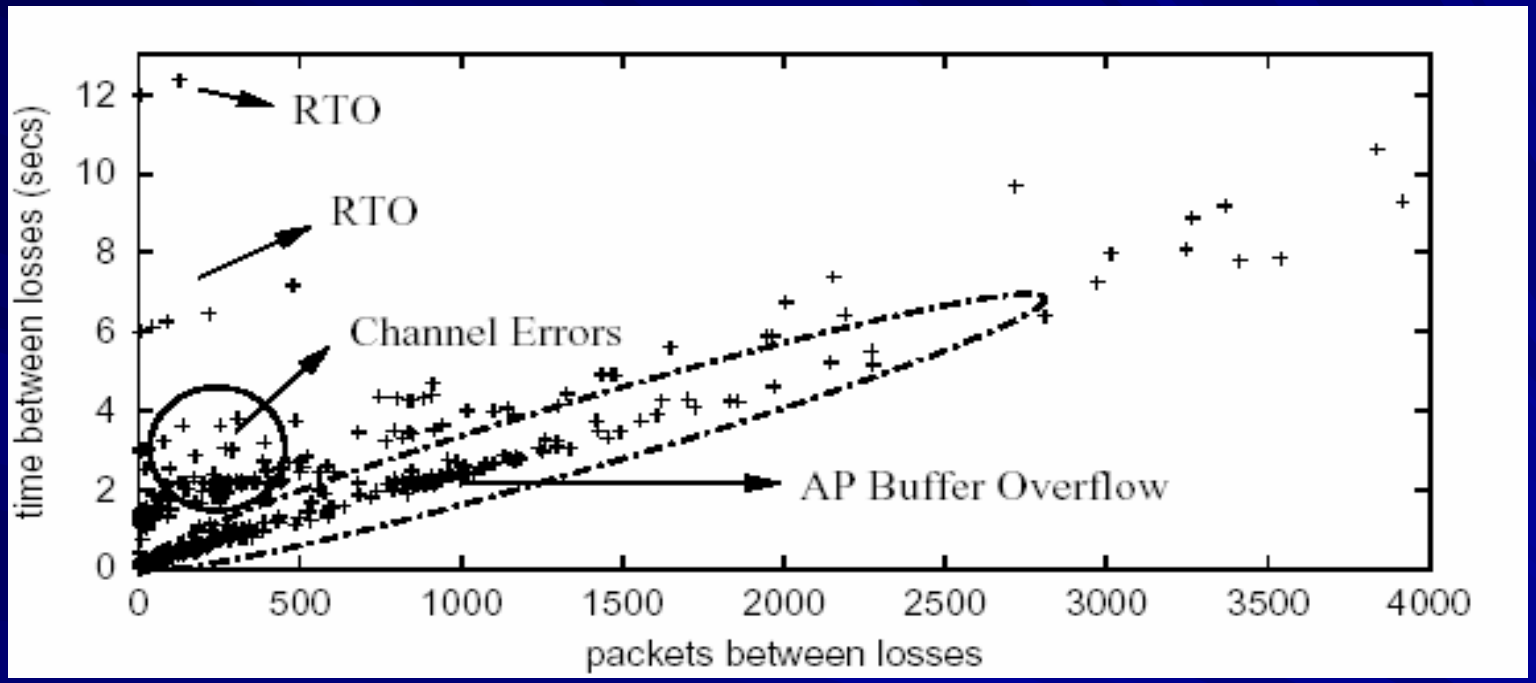
		LOS	NLOS
Throughput (Mbps)	Apple	5	1.44
	Belkin	5.22	2.43
Losses(%)	Apple	2.5×10^{-5}	0.6
	Belkin	0	18×10^{-5}

Effect of window size variation



wsize (Bytes)	offered (Bytes)	RTT (ms)	Losses (%)	Obs.tput (Mbps)
128k	62780	45	0.039	3.21
64k (stable)	46720	37	0.011	3.84
32k (stable)	21900	26	0.010	4.09
16k	10220	10	0.069	3.2
8k	4380	5	0.062	1.4
4k	2920	2.5	0.045	1.2

Dependence between time between losses and packets transmitted between losses



- Strong clusters show a dependence between the inter-loss time and number of packets transmitted between losses
- When TCP transmission rate reaches over 5 Mbps, AP Buffers overflow
- Clusters around 2 second inter-loss time caused by packet drops due to interference with polling frames and channel fading effects

Conclusions

- Experimental analysis of TCP data transfer in indoor wireless channels shows a number of performance degrading features caused by the interaction of system and channel features.
  - TCP throughputs of 5-6 Mbps observed in LOS and NLOS - Channel Invariant Conditions
  - Throughput reduction induced when Channel is Time-Varying
    - Due to Channel Fades and Loss of Signal Level at Client
  - Throughput reduction also induced by specific AP functions
    - Apple Airport: Interference of Polling Frames with Data Frames in AP Buffer
    - Belkin AP : Due to inability to capture signal at receiver during fades
  - TCP Error Recovery
    - Fast Retransmit predominant for Airport induced errors
    - RTO Expiry and Backoff predominant for Belkin induced errors.
- Experimental analysis of TCP Performance in Interference Prone Environments must be careful in identifying channel and system related effects
  - Better Monitoring Tools must be developed and supported by wireless system manufacturers to improve indoor wireless performance.