Wireless Networks for Mobile Applications

Prof. Claudio Palazzi
cpalazzi@math.unipd.it

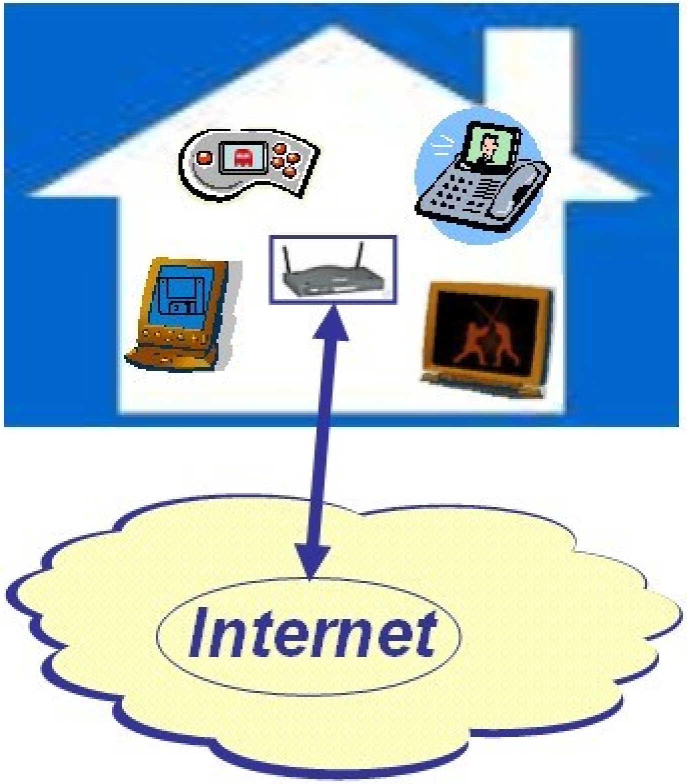
Università degli Studi di Padova

Analysis of the Wireless MAC and Transport Protocols Interference

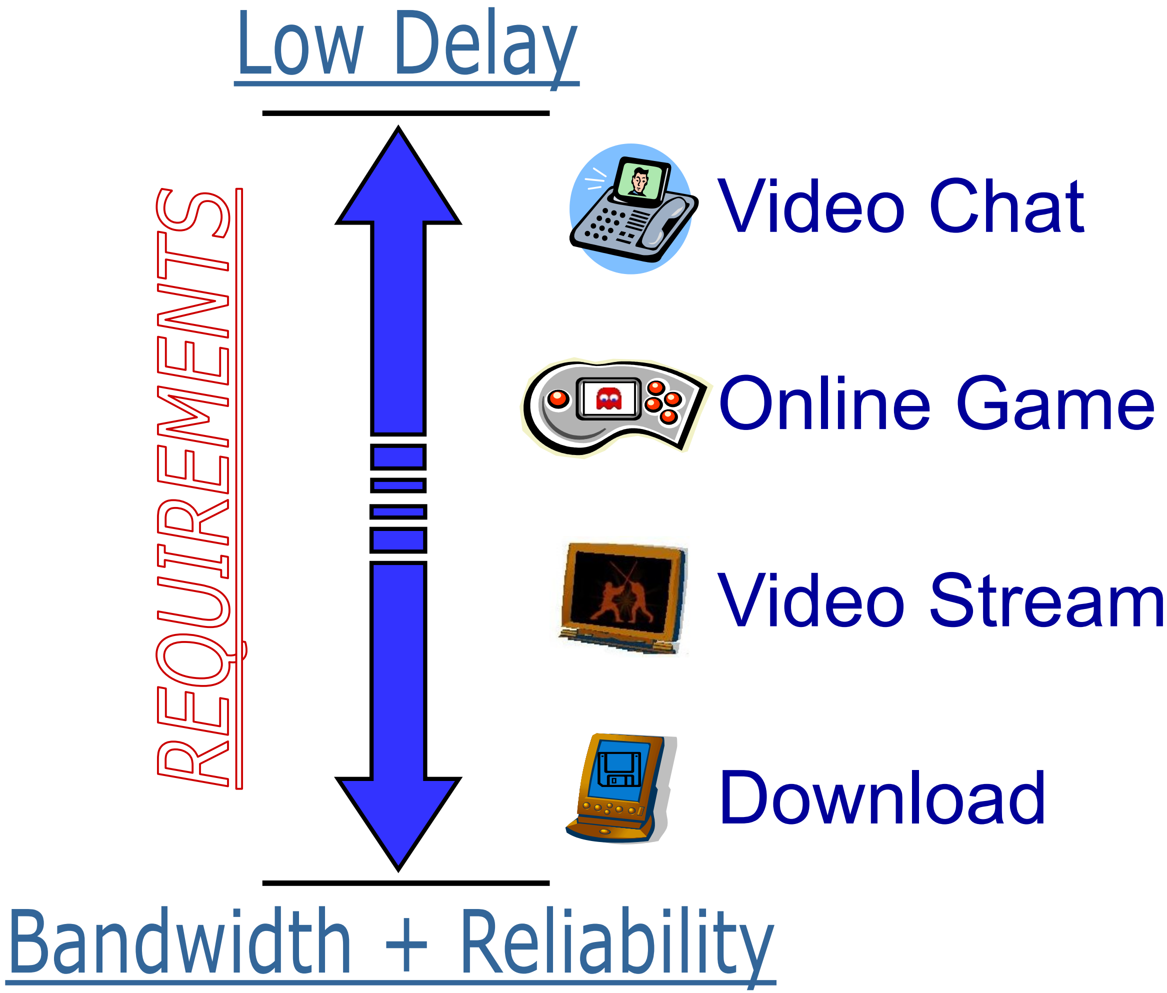
C. E. Palazzi, G. Pau, M. Roccetti, M. Gerla,
"Digital Entertainment Delivery in a Wireless House: Time for a MAC Tuning",
China Communications, CIC, vol.4, no.5 Oct 2006, 94-101.

Background: Wireless Home

- Increasing bandwidth
  - IEEE 802.11g
- Connected appliances
- Online entertainment
  - Media Center



Background: Applications



A Talk with a Friend

“I use IPTV at home

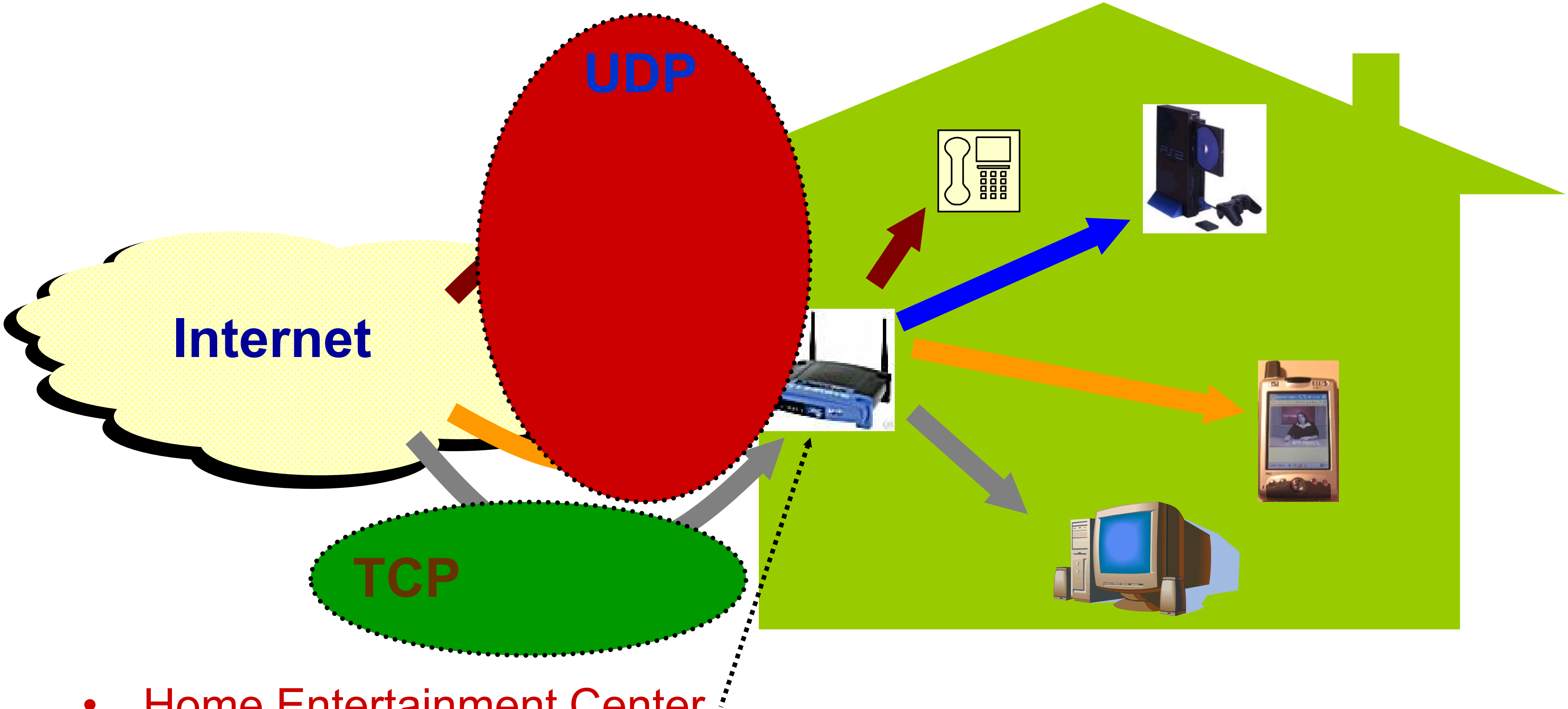
[…]

I had to lower my download/upload limit settings on eMule otherwise the video was scattering

[…]

There was no available bandwidth for the TV stream”

In-Home Wireless Scenario: Last Hop



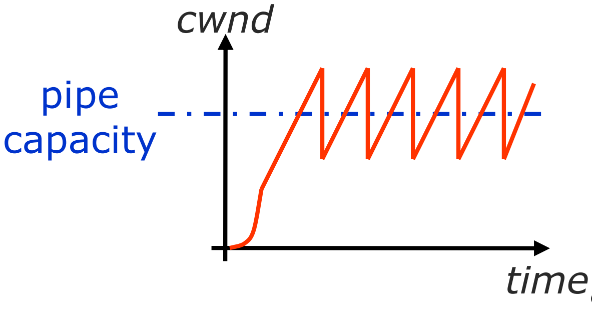
- Home Entertainment Center
  - Gateway between in-home devices and the outside world
  - Endowed with an Access Point to guarantee wireless connectivity
  - Shared channel → two nodes cannot transmit at the same moment
  - Often the bottleneck of the network traffic

Multiple Streams on a Single Wireless Hop

- Study to observe the impact of several streams that share the same wireless hop
- Network protocols developed assuming mostly TCP-based traffics
- This assumption needs a radical reconsideration when (UDP-based) services for entertainment come into the picture
  - Extremely delay sensitive

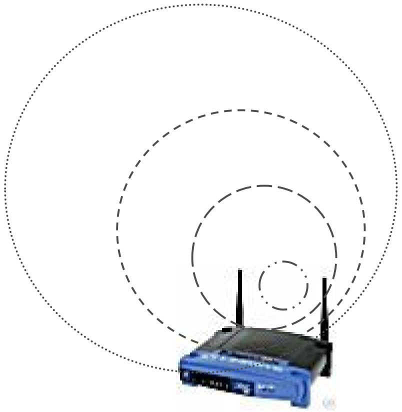
TCP Overview

- Window based flow control mechanism
- Continuously probe the link for more bandwidth
- Can fill links and queues with its packets



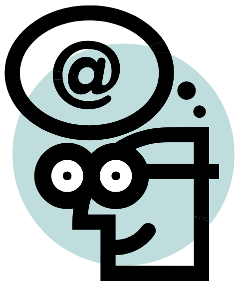
IEEE 802.11g Overview

- High Bandwidth
  - 54Mbps nominal, ~20Mbps effective
- Retransmission mechanism
  - hides wireless losses
  - increases delays

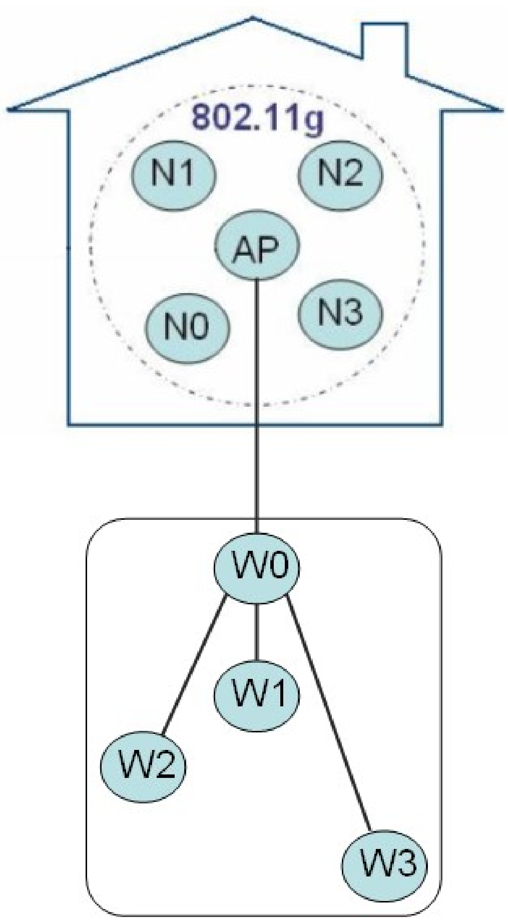


Aim of the Work

- Analyze the coexistence issues among TCP-based and UDP-based flows
  - Impact of TCP's congestion avoidance on (UDP-based) real time flows
- Evaluate the interference among Wireless MAC and Transport Protocols
  - Impact of MAC Layer buffers and retransmissions on…
    - real-time applications (Jitter)
    - Best effort application (Throughput)



Simulation Environment: NS-2



Node 1	Node 2	Delay	Capacity	Queue Size
W1	W0	10ms	100Mbps	140pkts
W2	W0	20ms	100Mbps	140pkts
W3	W0	30ms	100Mbps	140pkts
W0	AP	10ms	100Mbps	140pkts

SIMULATION CONFIGURATION (WIRED LINKS)

From	To	Type	Transport Protocol	Start	End
AP	N0	Movie Stream	UDP	0s	180s
W1	N1	Game Traffic	UDP	45s	180s
N1	W1	Game Traffic	UDP	46s	180s
W2	N2	Video Chat	UDP	90s	180s
N2	W2	Video Chat	UDP	91s	180s
W3	N3	FTP	TCP	135s	180s

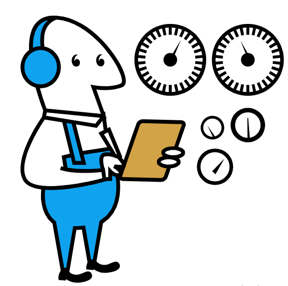
SIMULATED APPLICATION LAYER TRAFFIC FLOWS

Parameters

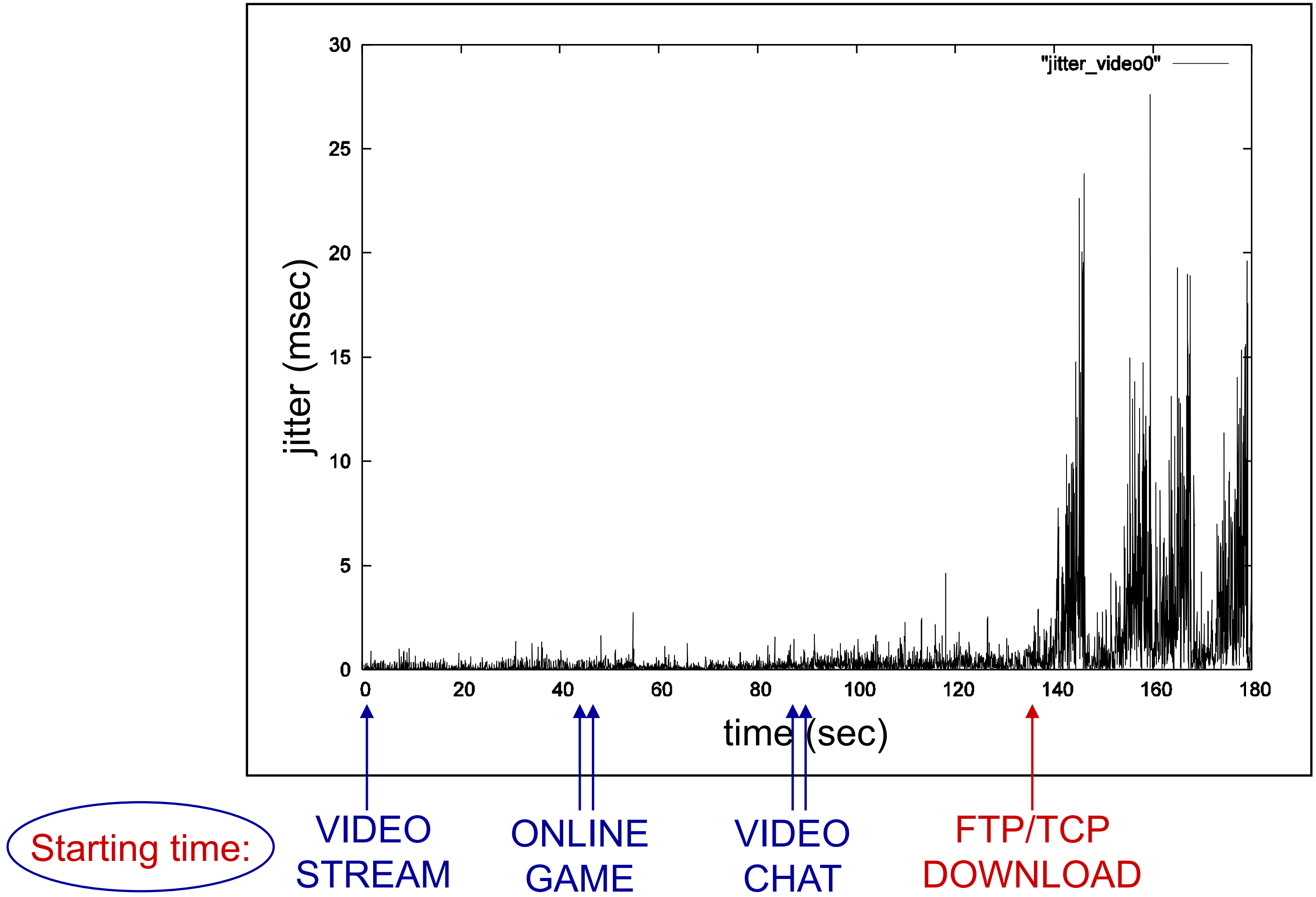
MAC parameters

Parameter	Values	Comments
MAC data retransmissions	1, 2, 3, 4	default value = 4
MAC queue size (pkts)	50, 100	common values
Shadowing deviation	7, 9	medium, high
User-AP distance (m)	5, 10	same or other room

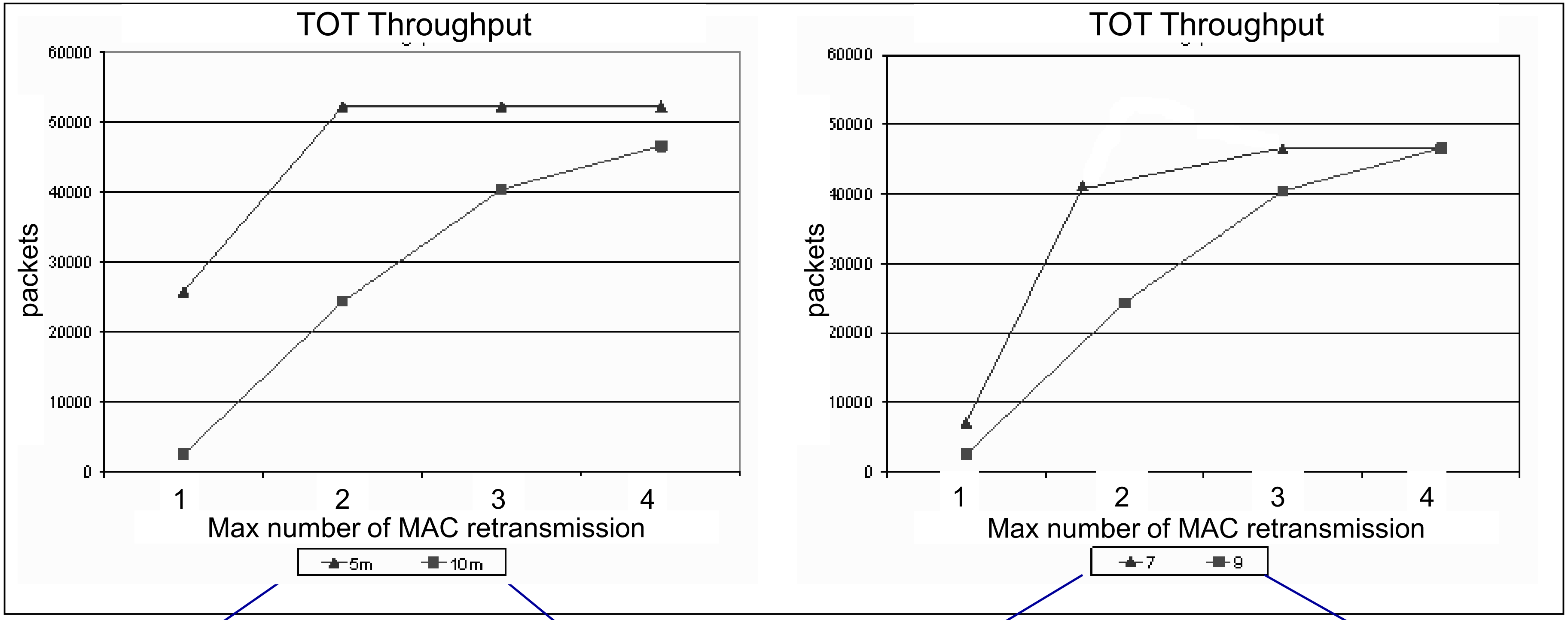
Environment parameters



FTP Impact on Real-Time Applications



Signal Attenuation vs Throughput

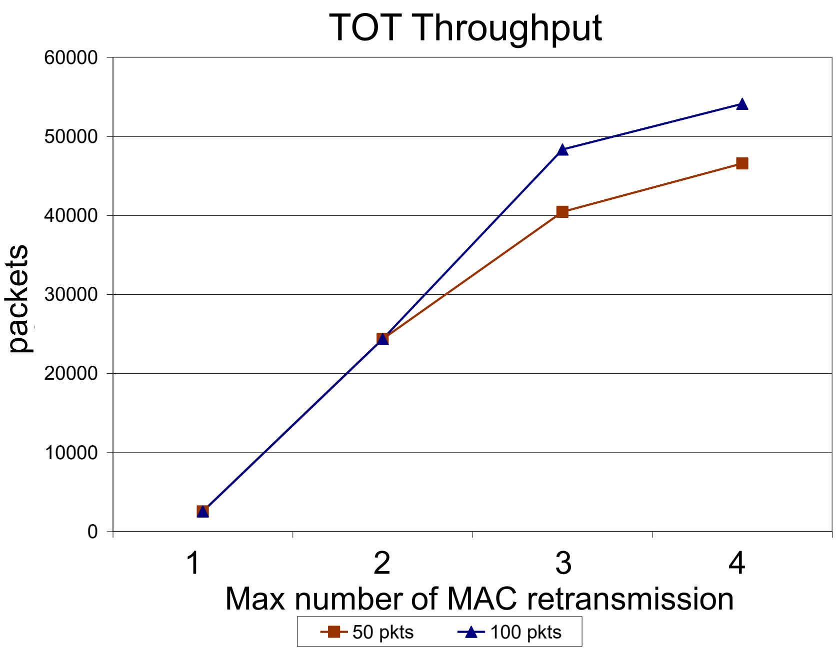


Distance between AP and device (m): 5 vs 10

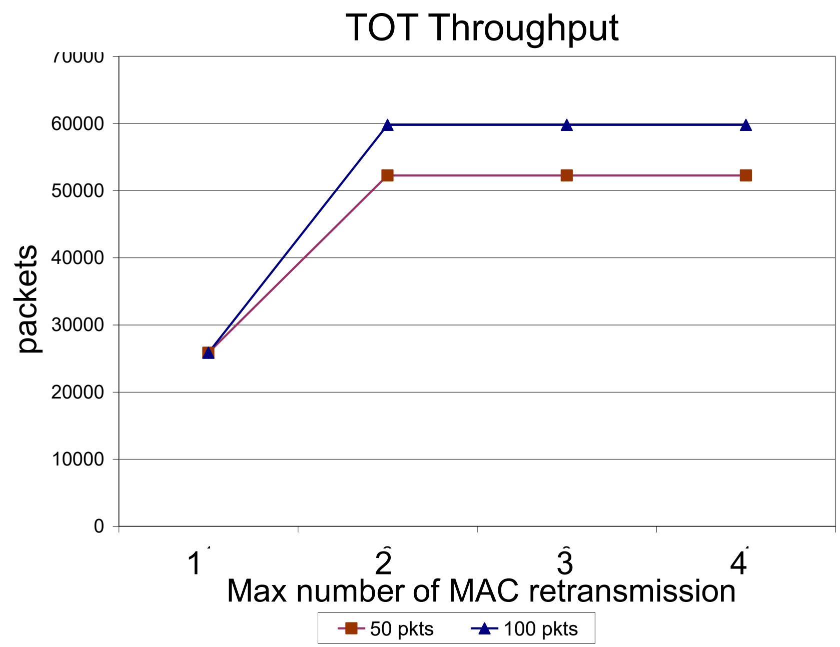
Signal attenuation parameter (shadowing): 7 vs 9

MAC Queue Size vs Throughput

Device-AP distance: 10m
shadowing deviation: 9



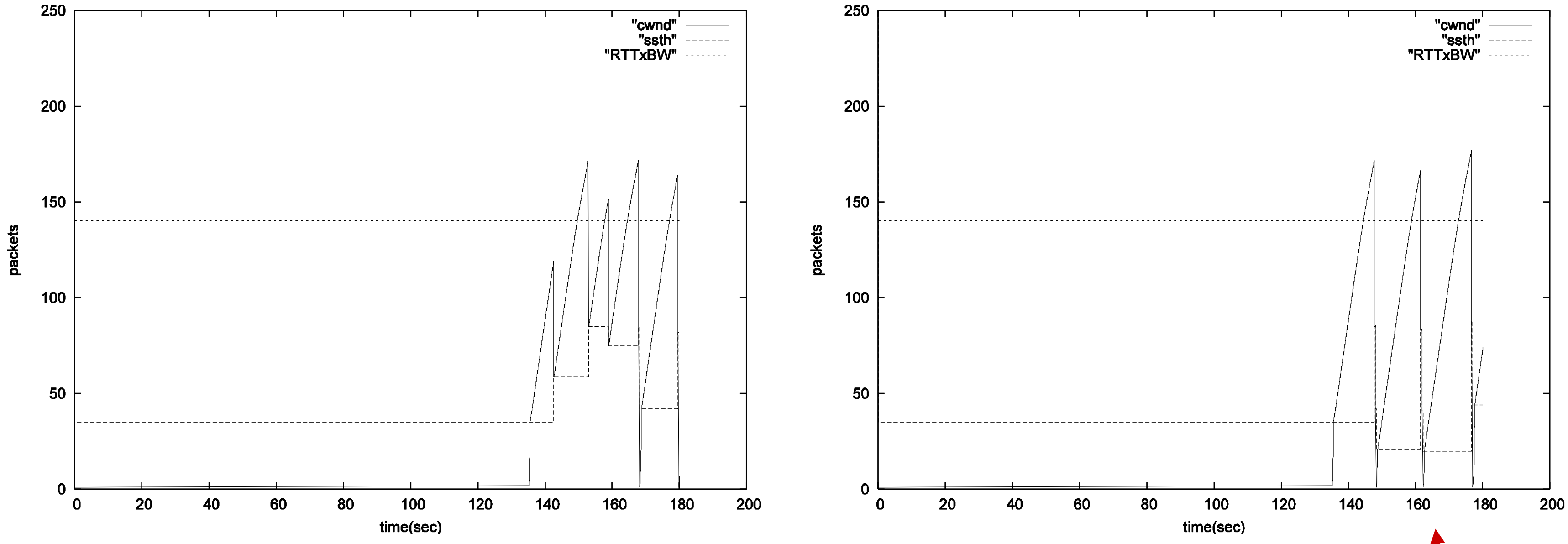
Device-AP distance: 5m
shadowing deviation: 9



MAC queue size (pkts): 50 vs 100

Signal Attenuation vs Throughput

Shadowing Deviation = 9



MAC max retr = 2

MAC max retr = 3

Reverse game and chat flow causes ACK losses: Timeouts!

MAC Queue Size vs Jitter (1/3)

Jitter	50 pkts	100 pkts
maximum (ms)	33.740	108.36
average (ms)	1.306	2.041
variance	7.360	22.079
pkts received	2658	2658

GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [0-180S], MAX MAC RETR = 4, SHADOWING DEVIATION = 9

Jitter	50 pkts	100 pkts
maximum (ms)	33.740	108.36
average (ms)	3.056	5.229
variance	16.665	49.470
pkts received	899	899

GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [135-180S], MAX MAC RETR = 4, SHADOWING DEVIATION = 9

MAC Queue Size vs Jitter (2/3)

Jitter	50 pkts	100 pkts
maximum (ms)	31.091	44.632
average (ms)	1.045	1.566
variance	4.833	11.034
pkts received	2654	2655

Gaming flow jitter: statistics for various MAC layer queue sizes; considered period = [0-180s], max MAC retr = 3, shadowing deviation = 9

Jitter	50 pkts	100 pkts
maximum (ms)	31.091	44.632
average (ms)	2.292	3.835
variance	11.502	24.431
pkts received	896	897

Gaming flow jitter: statistics for various MAC layer queue sizes; considered period = [135-180s], max MAC retr = 3, shadowing deviation = 9

MAC Queue Size vs Jitter (3/3)

Jitter	50 pkts	100 pkts
maximum (ms)	33.740	108.36
average (ms)	3.056	5.229
variance	16.665	49.470
pkts received	899	899

GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [135-180S], MAX MAC RETR = 4, SHADOWING DEVIATION = 9

Jitter	50 pkts	100 pkts
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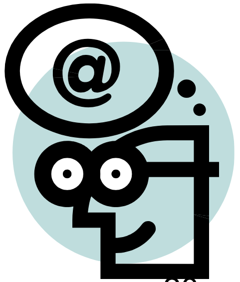
GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [135-180S], MAX MAC RETR = 3, SHADOWING DEVIATION = 9

Huge jitter difference

Summarizing

- Long lasting FTP/TCP flows increase delays
- Need for queuing delay reduction
- Easy solution, appropriately setting MAC layer parameters:
  - Reducing MAC layer retransmissions to 3
  - Smaller MAC queue size (max 50 pkts)

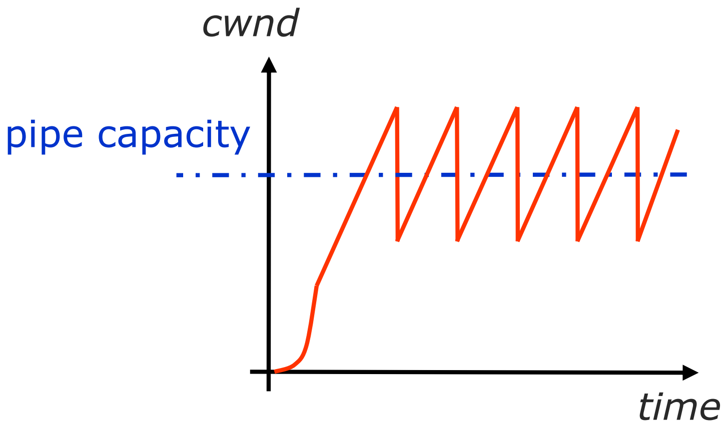


Smart Access Point with Limited Advertisement Window (SAP-LAW)

C. E. Palazzi, S. Ferretti, M. Roccetti, G. Pau, M. Gerla,
"What's in that Magic Box? The Home Entertainment Center's Special Protocol Potion, Revealed",
IEEE Transactions on Consumer Electronics, vol. 52, no. 4, Nov 2006, 1280-1288.

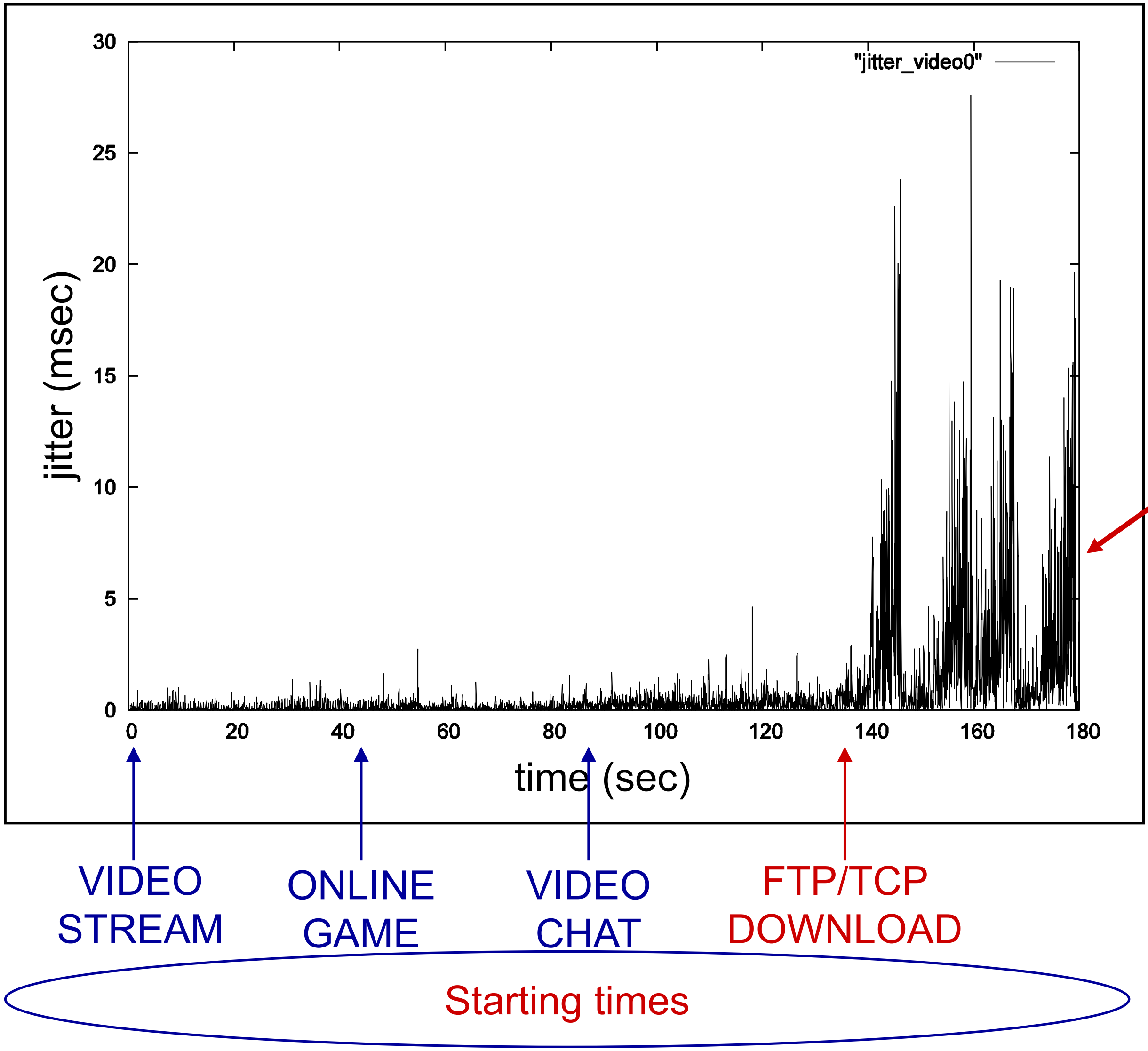
Delays caused by TCP Behavior

- TCP has an aggressive behavior
- Window based flow control mechanism
- Continuously probes the link for more bandwidth
- Can fill up the AP buffer with its packets
  - This may increase delays and deteriorate performances of real-time streams



TCP Impact on Concurrent Real-Time Applications

Jitter of a video stream with other streams activated



Concurrent TCP traffic jeopardizes interactivity for online applications

Reversing the Problem

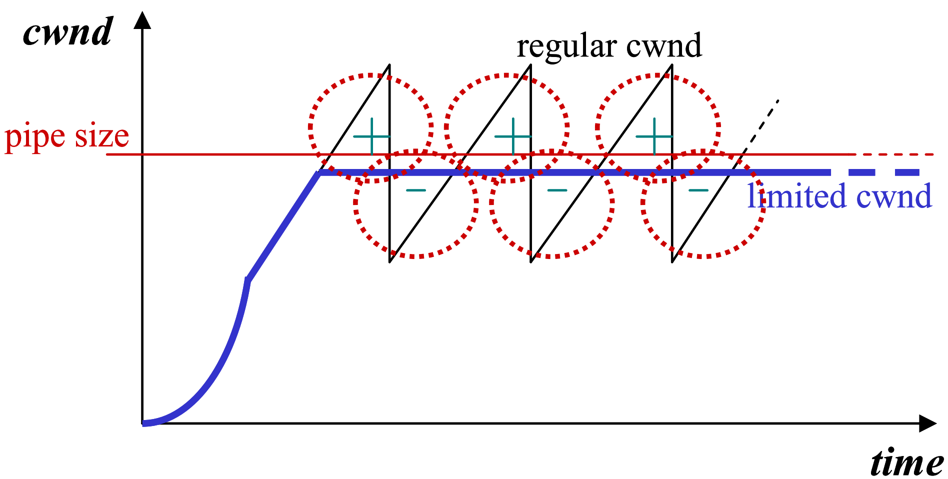
TCP vs **UDP**

- Typically, UDP traffic is seen as a problem for TCP flows
- Here, TCP flows can jeopardize real-time requirements of UDP-based applications
- No improvements on TCP but act on TCP to not upset UDP performances
- Best tradeoff to provide:
  - Low per-packet delays for real time applications
  - High goodputs for downloading applications

"Smart" AP: SAP-LAW

- IDEA: exploit the *advertised window* to limit the bandwidth utilized by TCP flows

Regular cwnd: regular TCP, typical saw tooth shape
Limited cwnd: window regulated by exploiting the advertised window

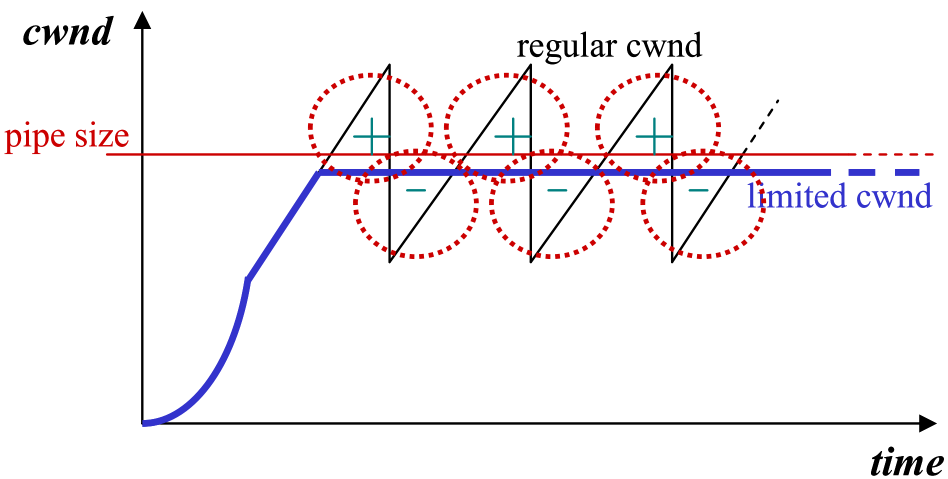


Regular window provides a sending rate that oscillates (+ and – in the picture) around the one ensured by the *limited* window

A balance can be reached on the final throughput

"Smart" AP: SAP-LAW

- IDEA: exploit the *advertised window* to limit the bandwidth utilized by TCP flows
- Avoid buffer utilization at the AP
  - Exploits information available at the AP to determine
    - Amount of bandwidth occupied by UDP-based traffic
    - Number of active TCP flows
  - On-the-fly modification of the *advertised window* of TCP flows ***at the AP***

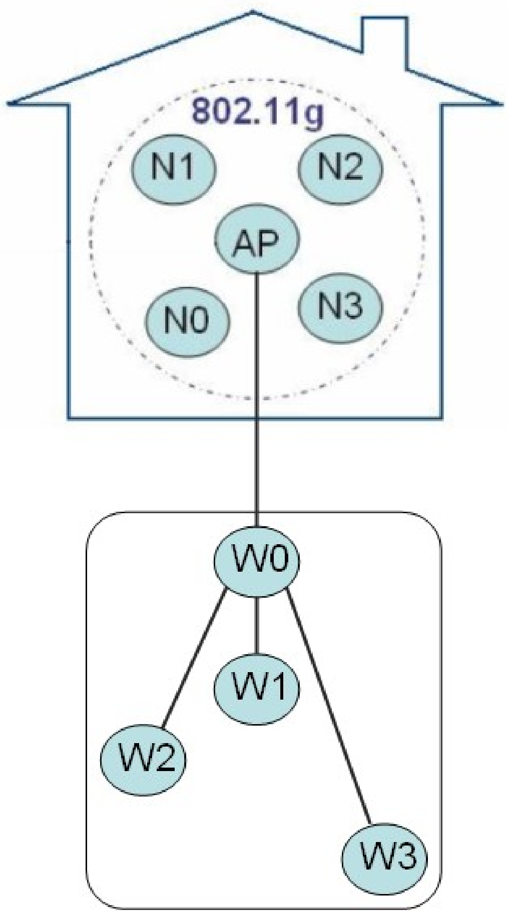


$$maxTCPrate(t) = \frac{(C - UDPtraffic(t))}{\#TCPflows(t)}$$

No queues:

- lower delays (for UDP flows)
- smoother throughput (no losses and reductions of the sending window for TCP flows)

Simulation Environment: NS-2



Node 1	Node 2	Delay	Capacity	Queue Size
W1	W0	10ms	100Mbps	140pkts
W2	W0	20ms	100Mbps	140pkts
W3	W0	30ms	100Mbps	140pkts
W0	AP	10ms	100Mbps	140pkts

SIMULATION CONFIGURATION (WIRED LINKS)

From	To	Type	Transport Protocol	Start	End
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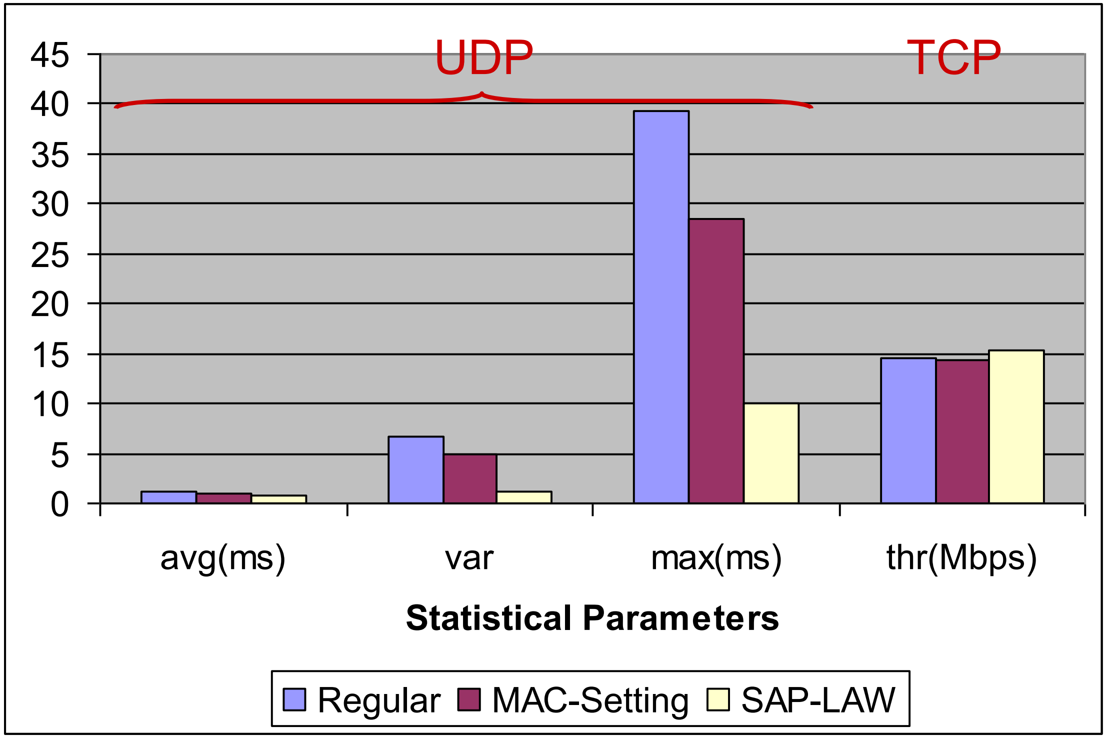
W1	N1	Game Traffic	UDP	45s	180s
N1	W1	Game Traffic	UDP	46s	180s
W2	N2	Video Chat	UDP	90s	180s
N2	W2	Video Chat	UDP	91s	180s
W3	N3	FTP	TCP	135s	180s

SIMULATED APPLICATION LAYER TRAFFIC FLOWS

Summarizing Results

- Regular: classic TCP
- MAC-Setting: classic TCP, reduction of the buffer size at the AP
- SAP-LAW: Our approach



- SAP-LAW has good performances

Real Testbed Assessment

- We have now created a prototype (SLUS: SAP-LAW in User Space), a user space OpenWRT solution on a NETGEAR WGT634U AP and performed real testbed experiments

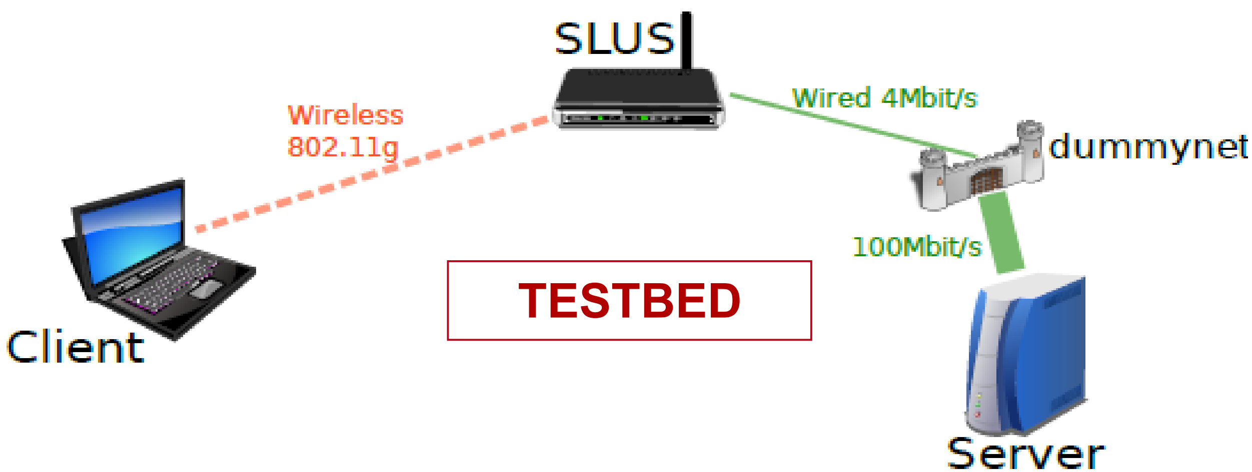
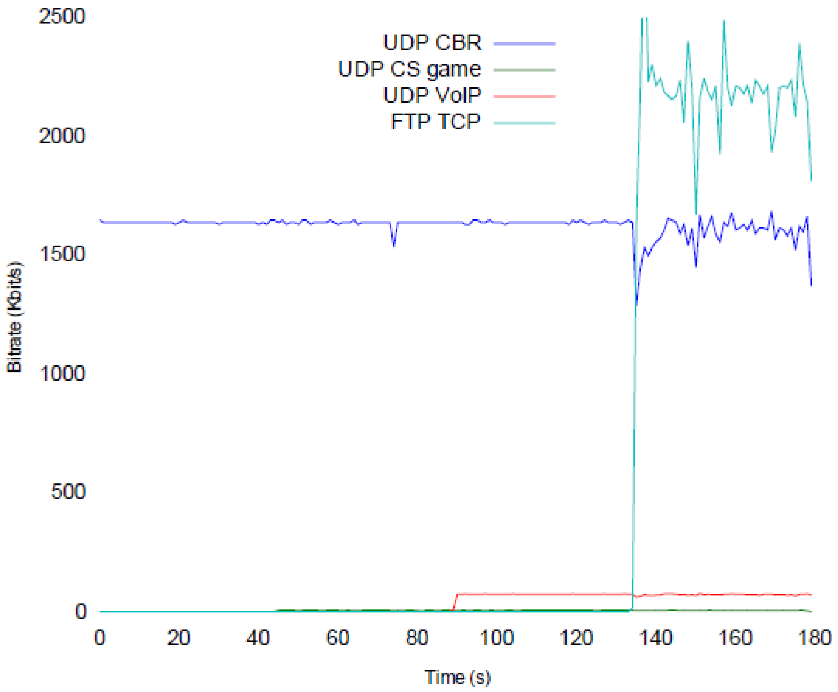


Table 1. Traffic flows generated by ITGSend (D-ITG suite).

Flow type	Protocols	Start time	End time	RTT
CBR flow	UDP	0s	180s	60ms
Online Game	UDP	45s	180s	60ms
VoIP	UDP	90s	180s	60ms
FTP flow	TCP	135s	180s	60ms

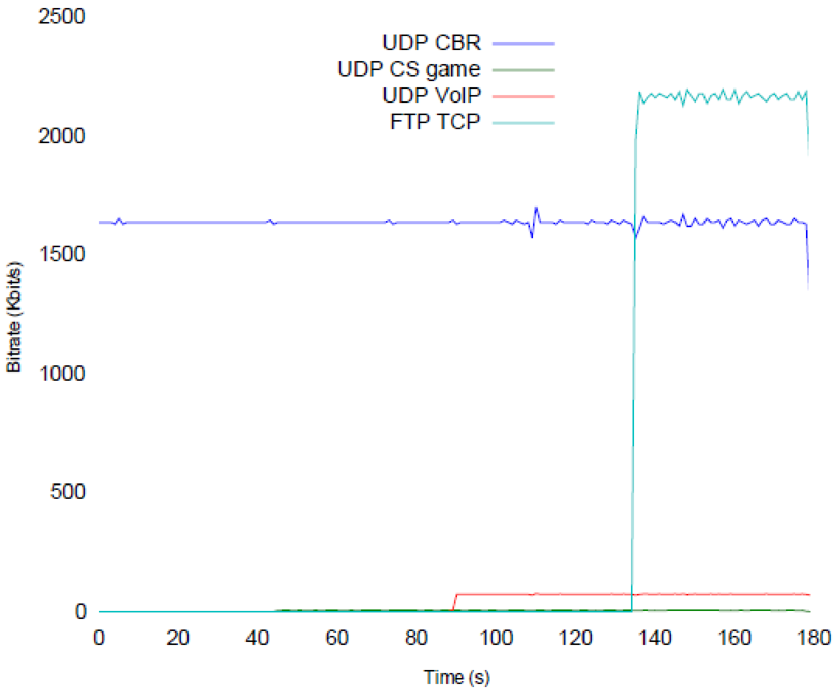
Throughput Evaluation

Regular



High oscillations

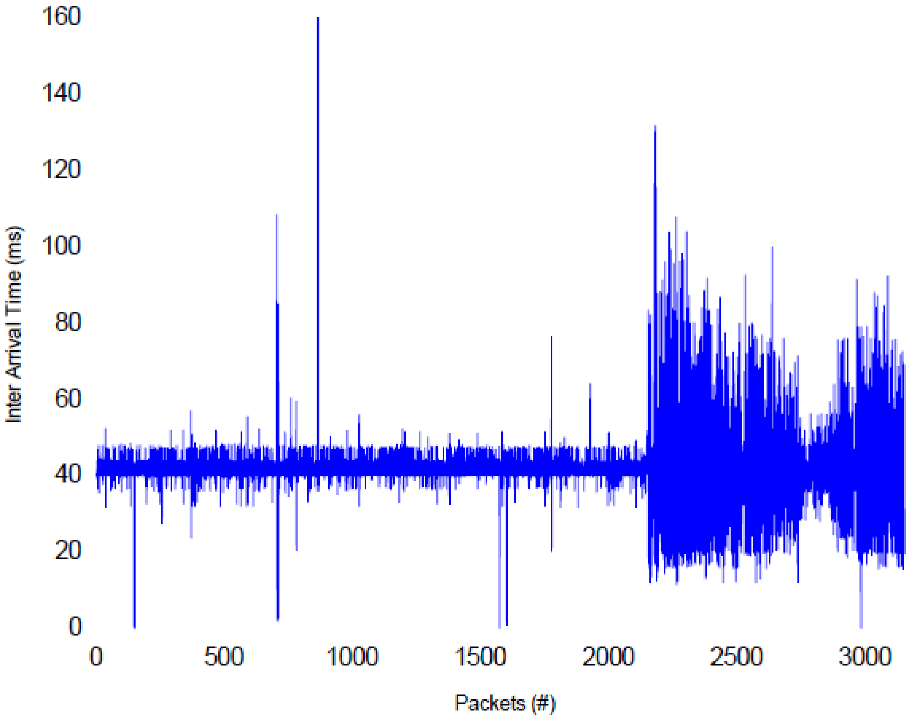
SLUS



Smooth progression (same final throughput)

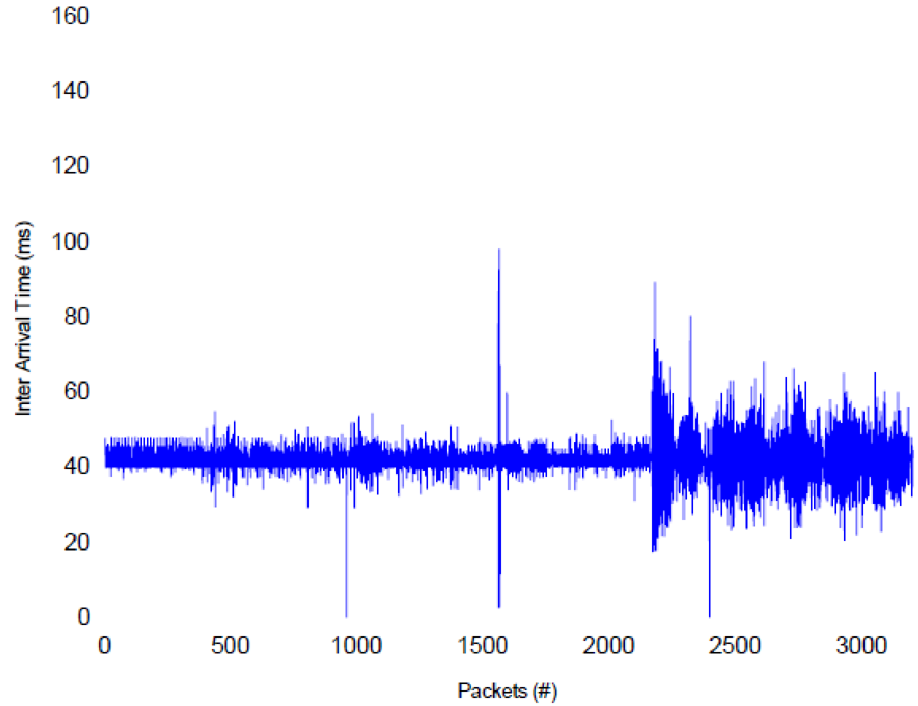
Interarrival Time Evaluation

Regular



packet queuing: high oscillations

SLUS



limited queuing/oscillations (better jitter)

Conclusion

- In in-home wireless scenarios, concurrent long lasting TCP flows increase delays
  - Especially on wireless links
- Real-time online applications need a reduction of the queuing delay
- SAP-LAW: on-the-fly modification of the *advertised window* of TCP flows ***at the AP*** to
  - Augment UDP flows performances
  - Maintain a high goodput for TCP downloads
- SAP-LAW is easily deployable as it requires modifications *only* at the AP

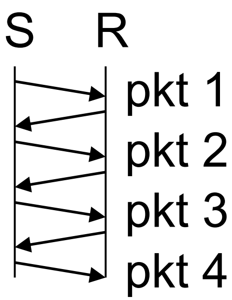
Enhancing SAP-LAW for RTT-fairness

C. E. Palazzi, N. Stievano, M. Roccetti,
"A Smart Access Point Solution for Heterogeneous Flows",
in Proc. of the IEEE International Workshop on Ubiquitous Multimedia Systems and Applications (UMSA'09)- International Conference on Ultramodern Telecommunications (ICUMT 2009),
St. Petersburg, Russia, Oct 2009

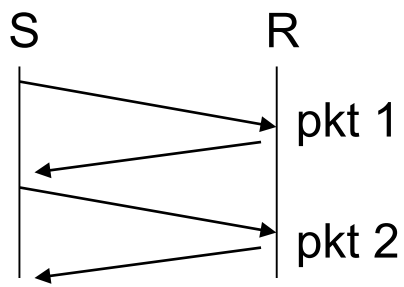
TCP’s RTT-unfairness

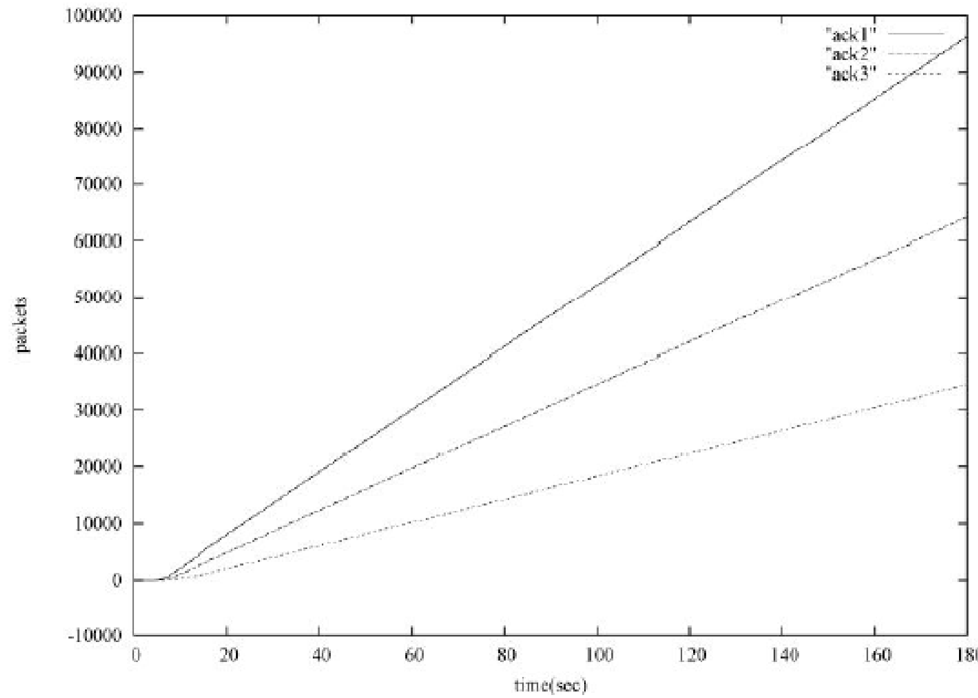
- The throughput of a connection is inversely proportional to the RTT length
  - Short RTT flows capture the channel
  - Long RTT flows starve

Short RTT



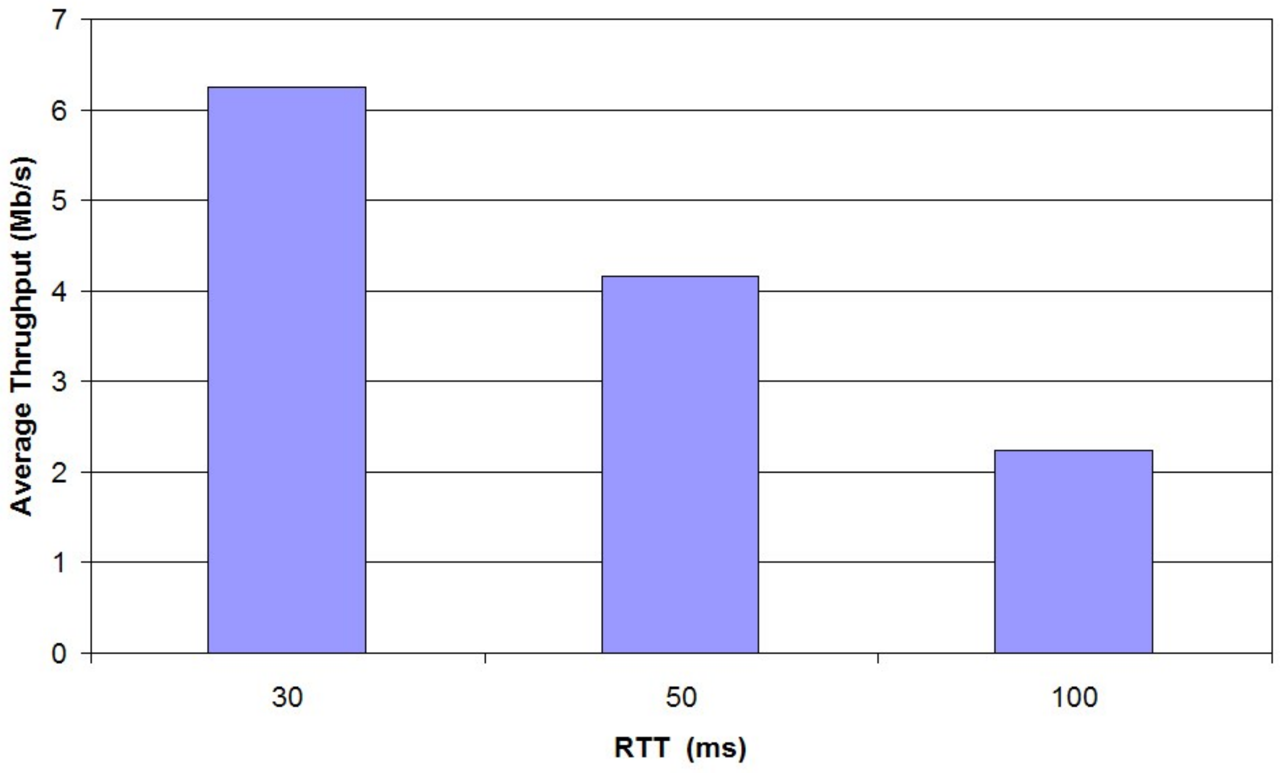
Long RTT





TCP's RTT-unfairness

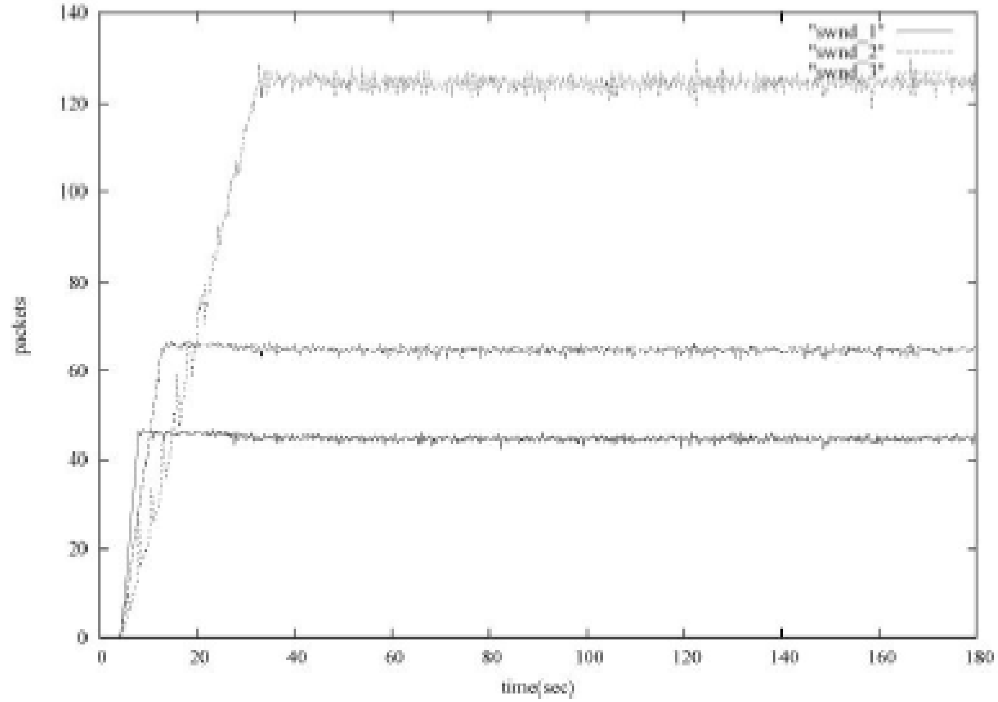
- Even SAP-LAW does not solve it:
  - Same windows results in different throughput (if different RTTs)



Advertised Window Computation

$$maxTCPrate_i(t) = \frac{(C - UDPtraffic(t)) * RTT_i}{\sum \frac{RTT_i}{avg\_RTT_{min}}}$$

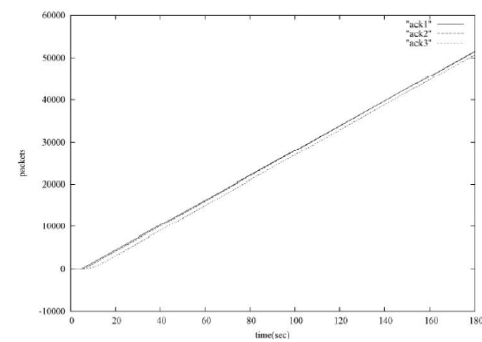
Sending window



Three TCP flows with

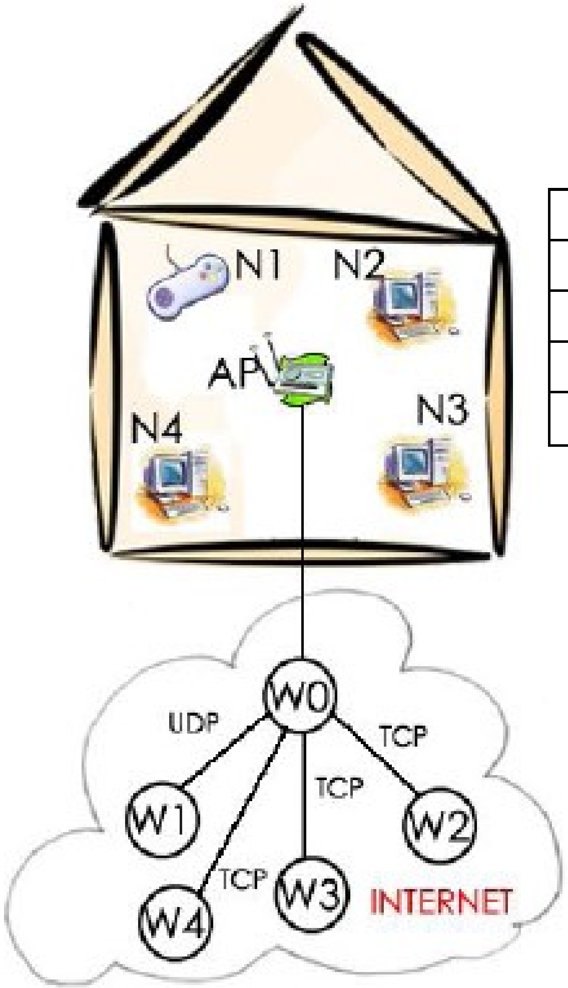
30, 50, 100 ms of RTT

Throughput



Different sending windows
produces same throughput

Simulation Assessment



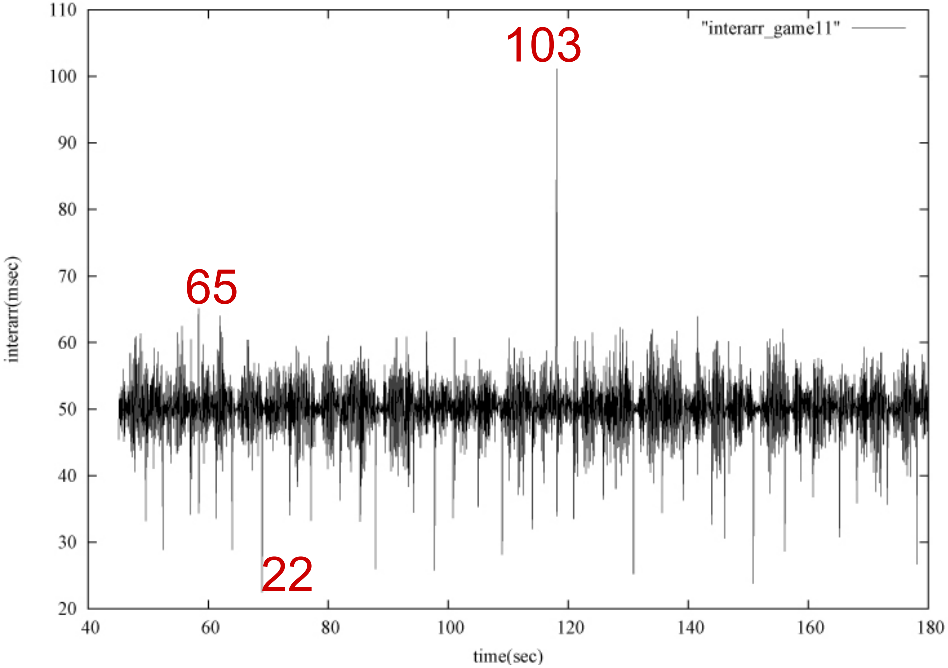
Flow Type	Protocol	From	To	Start	End	RTT
FTP 1	TCP	N2	W2	1 s	180 s	30 ms
FTP 2	TCP	N3	W3	1 s	180 s	50 ms
FTP 3	TCP	N4	W4	1 s	180 s	100 ms
Online Game	UDP	N1	W1	45 s	180 s	20 ms

- NS-2 simulator
- Wireless bottleneck (802.11g)
- Various configurations

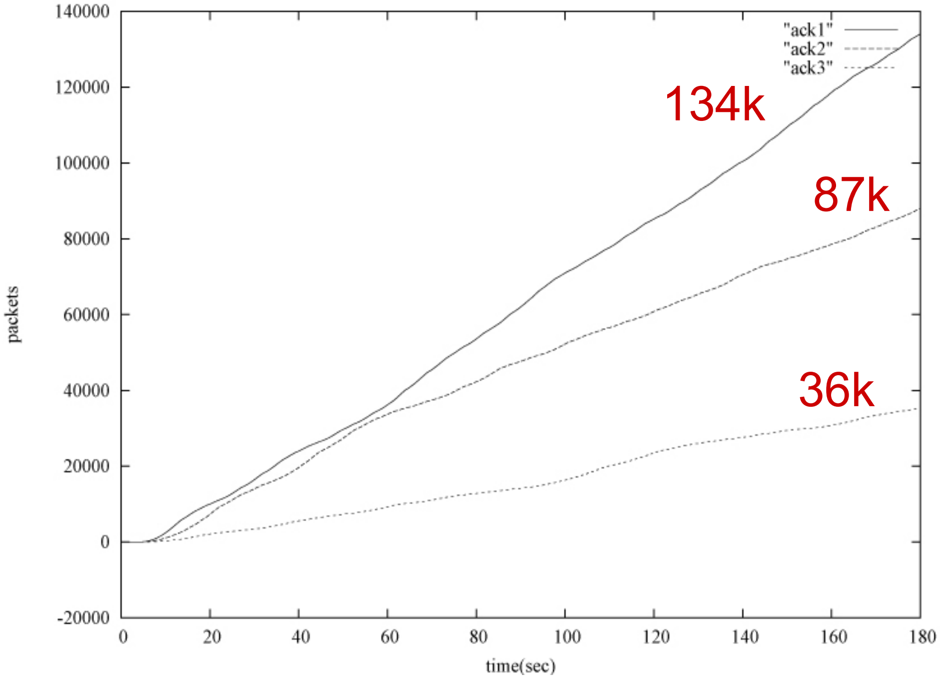
Main contribution of this work is the comparison of our SAP-LAW with other protocols/solutions.

Comparison Among Transport Protocols: TCP SACK

Interarr time of game events



ACK transmission of three TCP flows

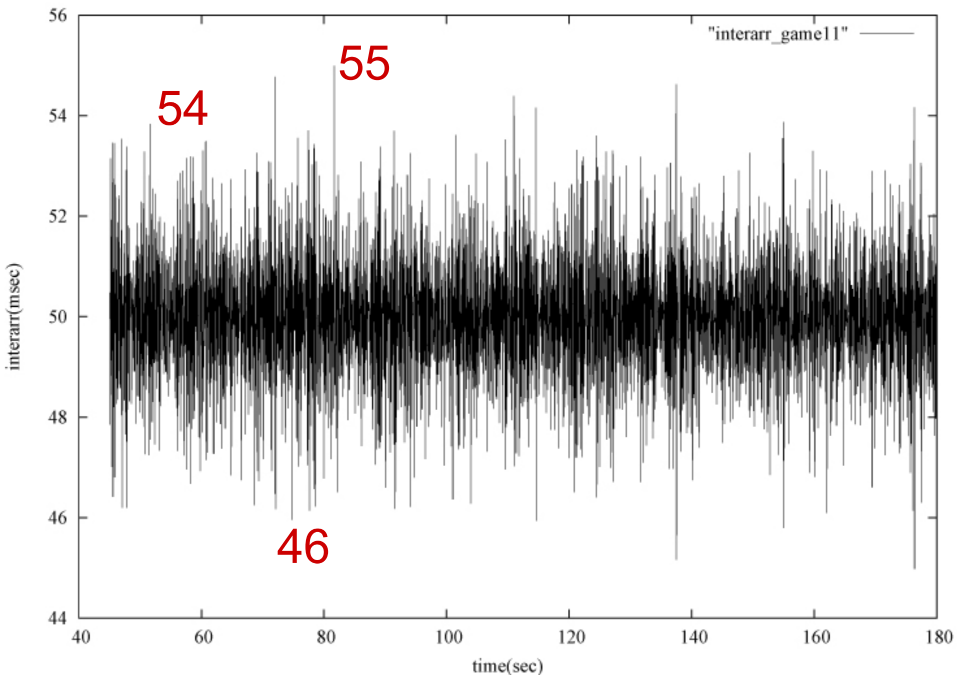


High oscillations due to queuing

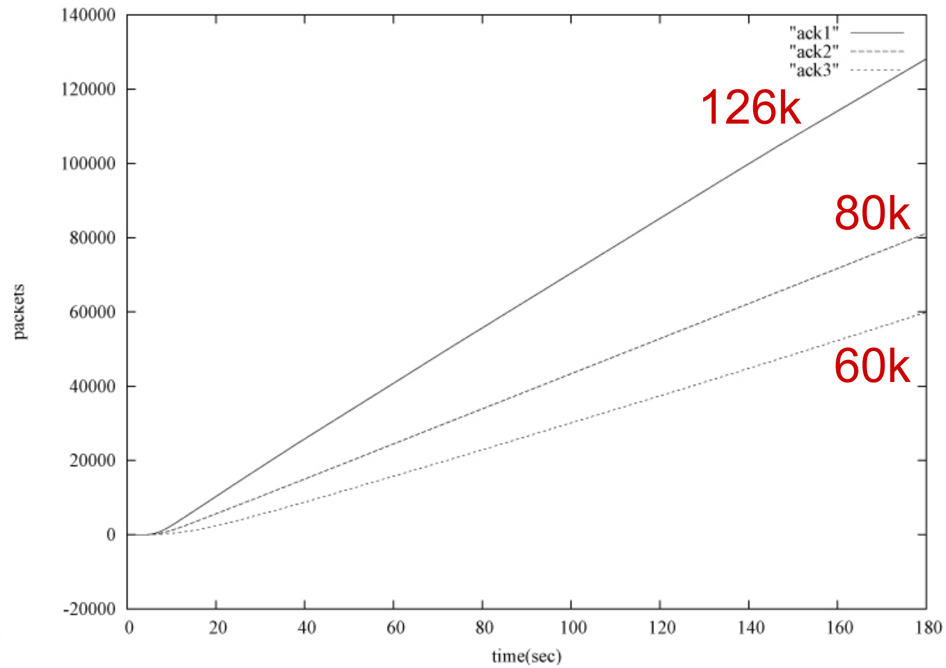
Unfair bandwidth usage

Comparison Among Transport Protocols: TCP Vegas

Interarr time of game events



ACK transmission of three TCP flows



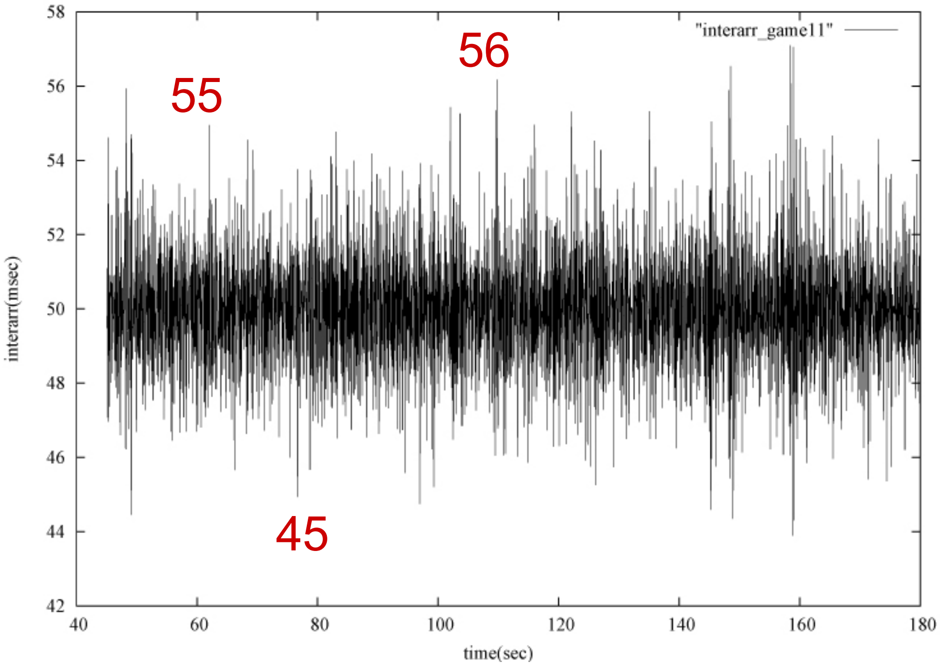
No queuing: low oscillations

Still unfair bandwidth usage

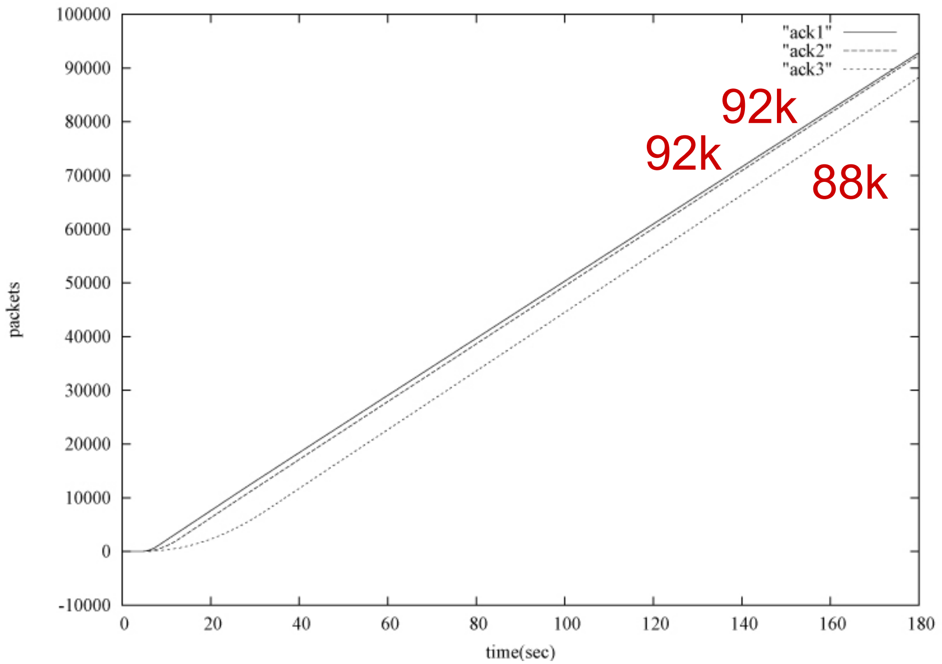
Plus, TCP Vegas cannot coexist with legacy TCP

Comparison Among Transport Protocols: SAP-LAW

Interarr time of game events



ACK transmission of three TCP flows

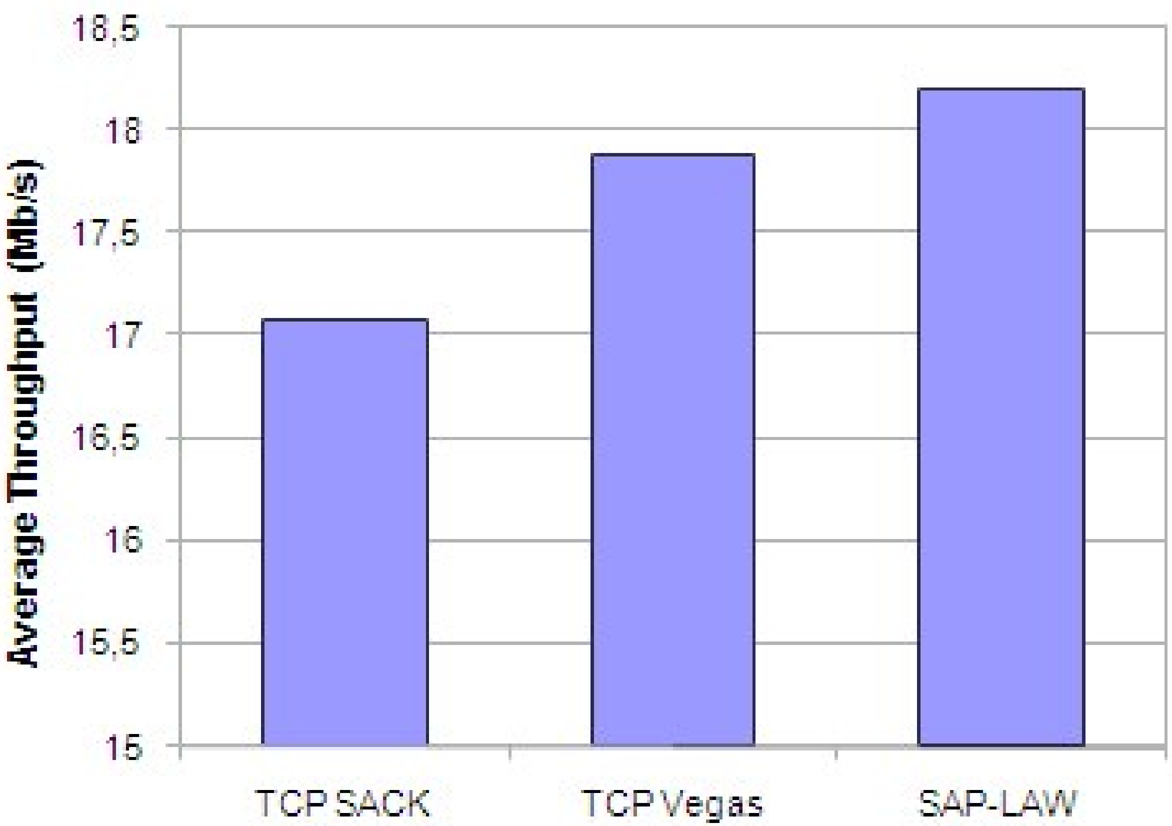


No queuing: low oscillations!

Fair bandwidth usage!

Plus, regular TCP used under SAP-LAW to preserve compatibility versus legacy TCP

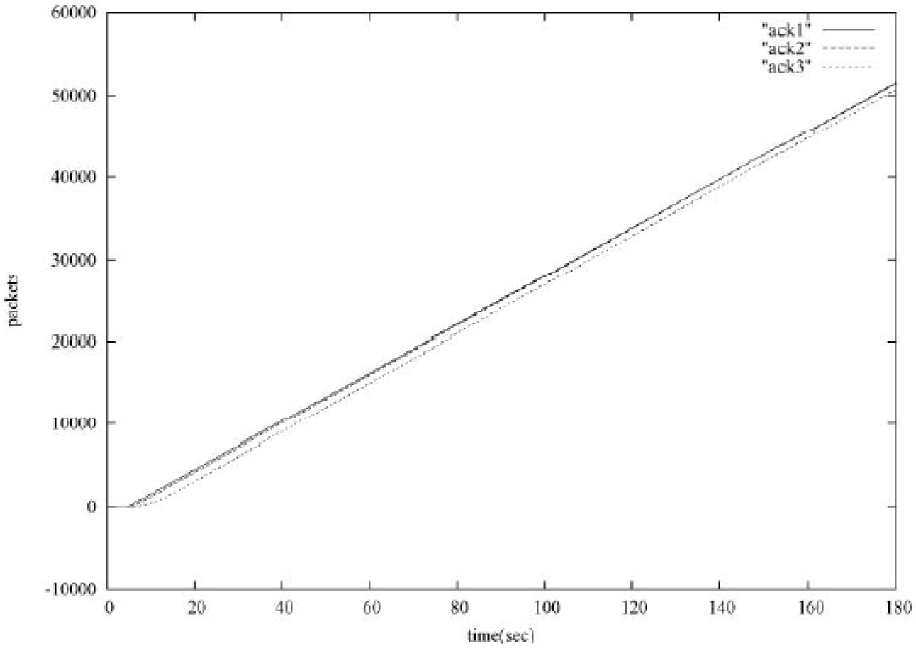
Comparison Among Transport Protocols: Efficiency



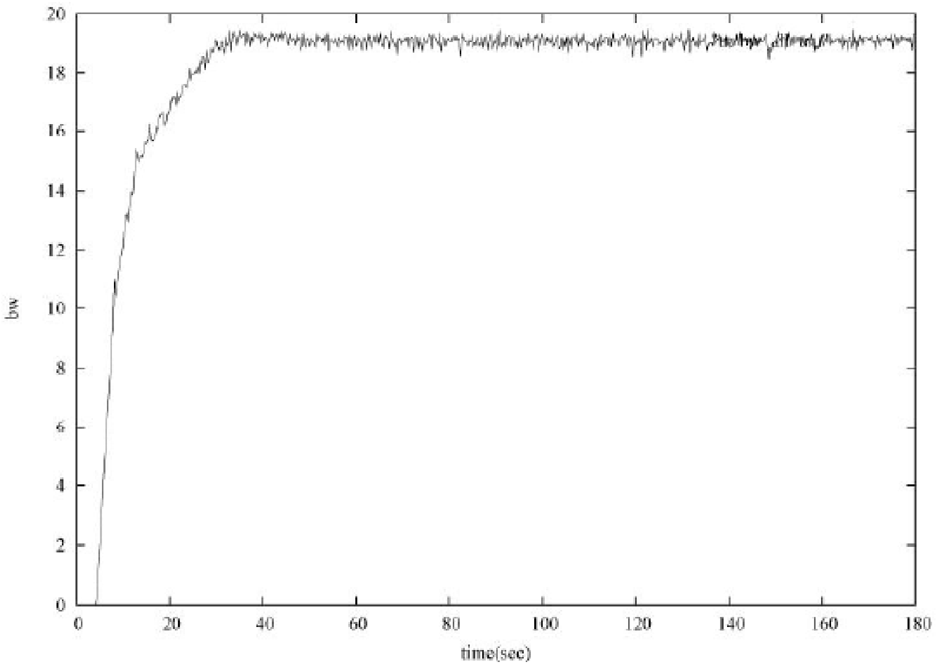
No losses also means higher efficiency in terms of throughput

Results: High and Fair TCP's Throughputs

Single throughputs



Aggregate throughput



The three TCP flows have the same throughput regardless of different RTTs

The aggregate throughput consumes all the available bandwidth

Conclusion

- Two problems:
  1. Long lasting TCP flows increase delays
     - Real-time applications need a reduction of the queuing delay
  2. TCP's throughput depends on RTT

- SAP-LAW solution: on-the-fly modification of the *advertised window* of TCP flows *at the AP*

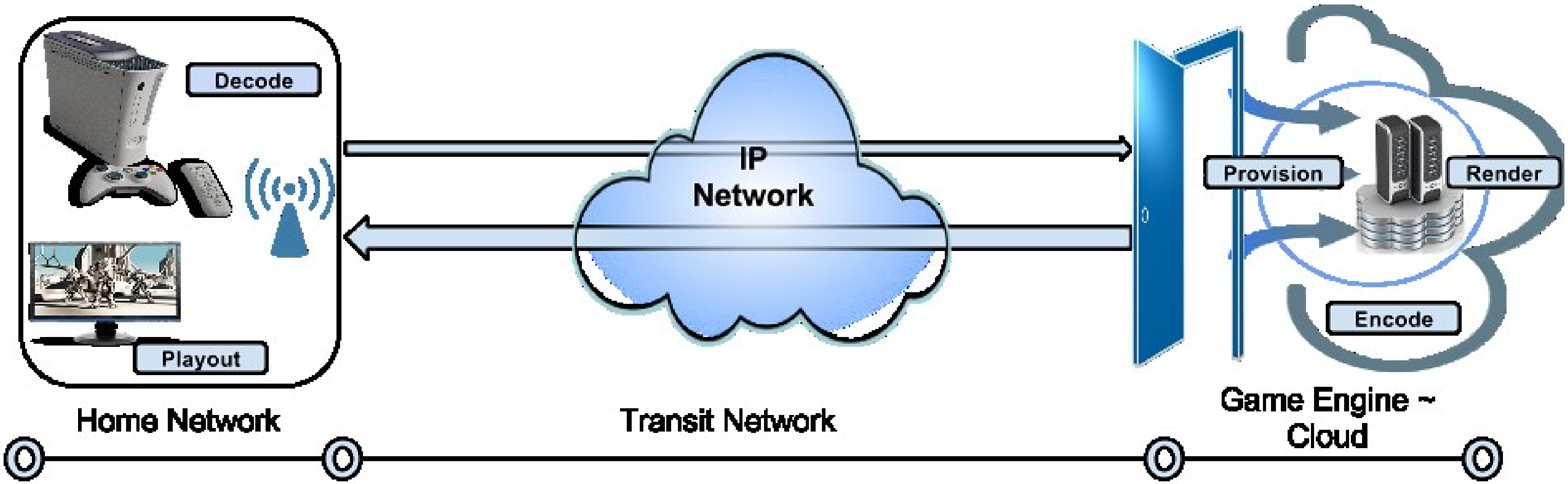
- SAP-LAW is easily deployable as it requires modifications *only* at the AP
  – Utilized on top of legacy transport protocols

Vegas over Access Point (VoAP)

Making Room for Thin Client Game Systems in a Wireless Home

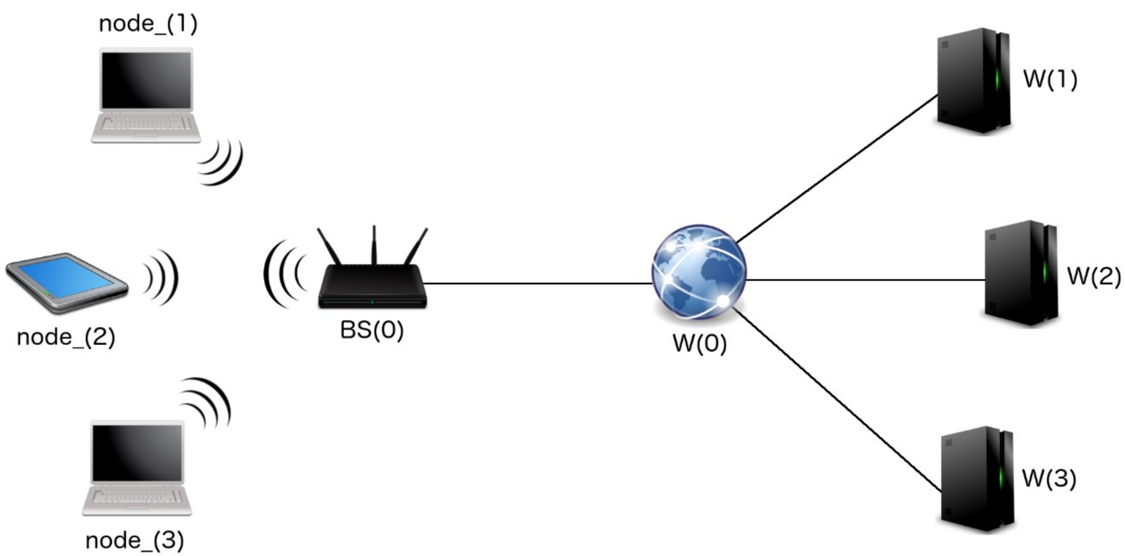
A. Bujari, M. Massaro, C. E. Palazzi,
"Vegas over Access Point: Making Room for Thin Client Game Systems in a Wireless Home",
IEEE Transactions on Circuits and Systems for Video Technology, 99, Jun 2015.

Thin Client Game Systems



- Classic Online Games
  - 10-200 Kbps of traffic between client and server
  - Messages contains actions and game arena updates
  - Each message has to be delivered within 100-150 ms
- <u>Thin Client Game (Cloud based games???)</u>
  - About 10 Kbps from each client to server (user's actions)
  - Tens of Mbps from server to each client (high quality video stream)

Thin Client Game Systems



- Coexisting TCP flows and thin client game flows
- The tested solution acts on the advertised window of TCP based flow
  - The difference from SAP-LAW is the algorithm used to set the advertised window
  - Inspired by the TCP Vegas algorithm
    - The AP can enforce it on all TCP flows in the bottleneck (so no friendliness issue)

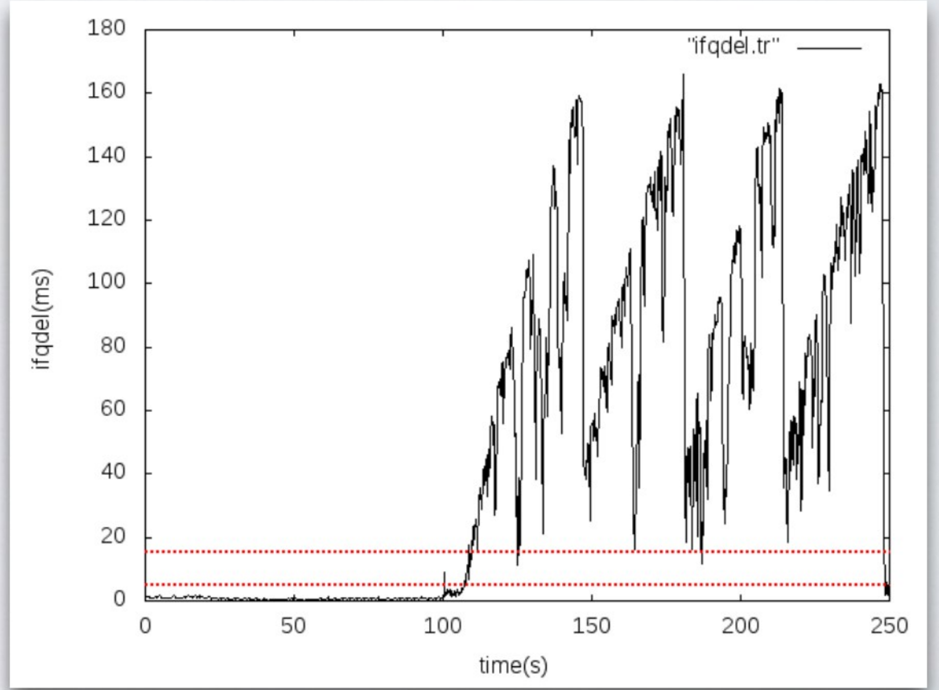
VoAP: Vegas over Access Point

Two thresholds, α and β (ms) α < β

- If delay < α
  - the channel is free
  - the advertised window is increased

- If α < delay < β
  - the channel is well exploited
  - the advertised window is left unchanged

- If delay > β
  - the channel is saturating
  - the advertised window is decreased

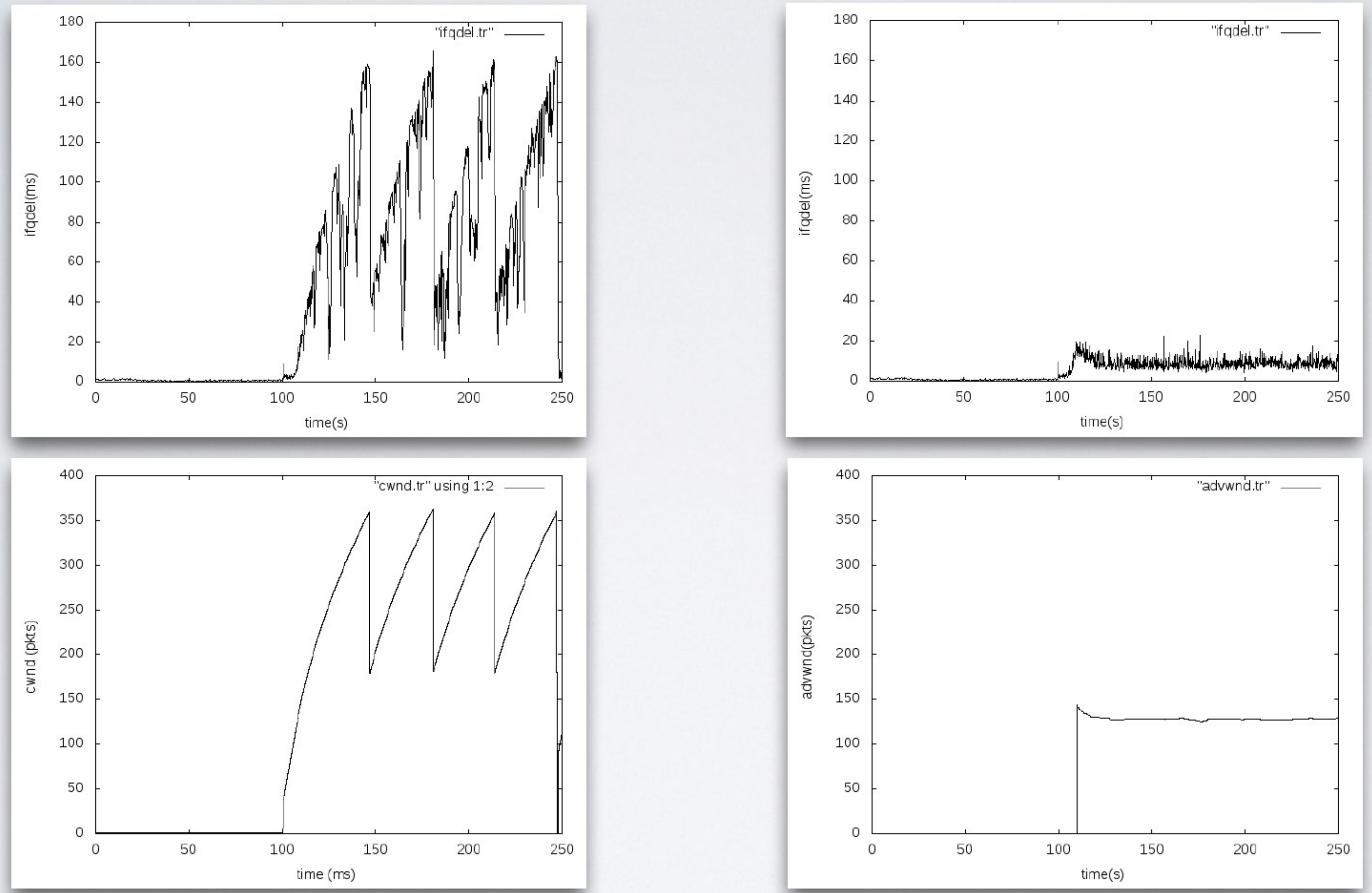


Interactivity: Queuing Delay

Standard TCP | VoAP

Queue* delay

Sending window

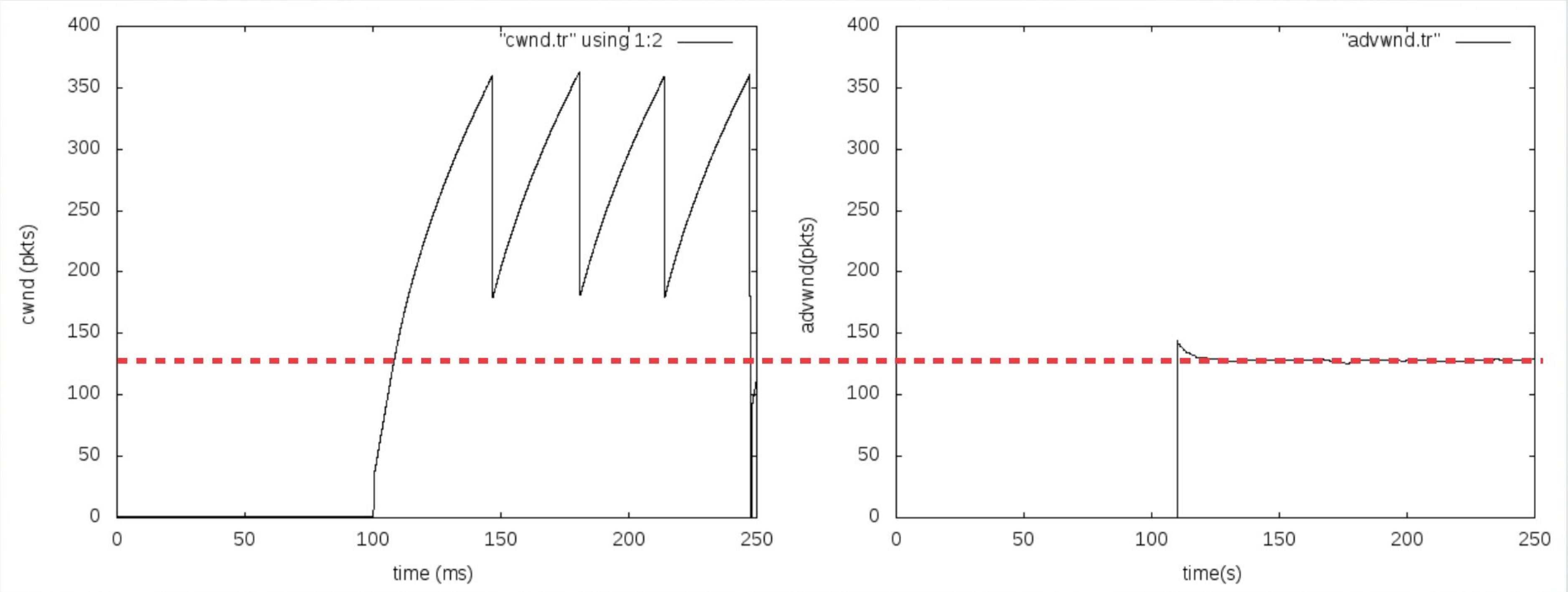


* to simulate some real implementation, the Access Point queue length has been set to **250 packets**

Efficiency: Throughput (1/2)

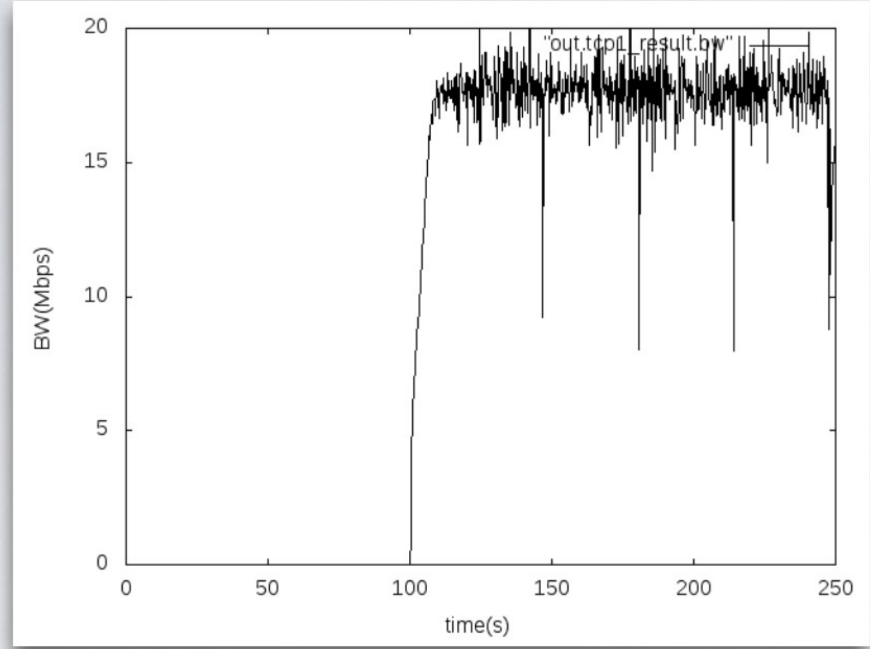
Packets in excess do not increase TCP throughput, they just increase the queue length

VoAP uses delays to detect the bottleneck limit (red line) and keeps the number of outgoing packets below it

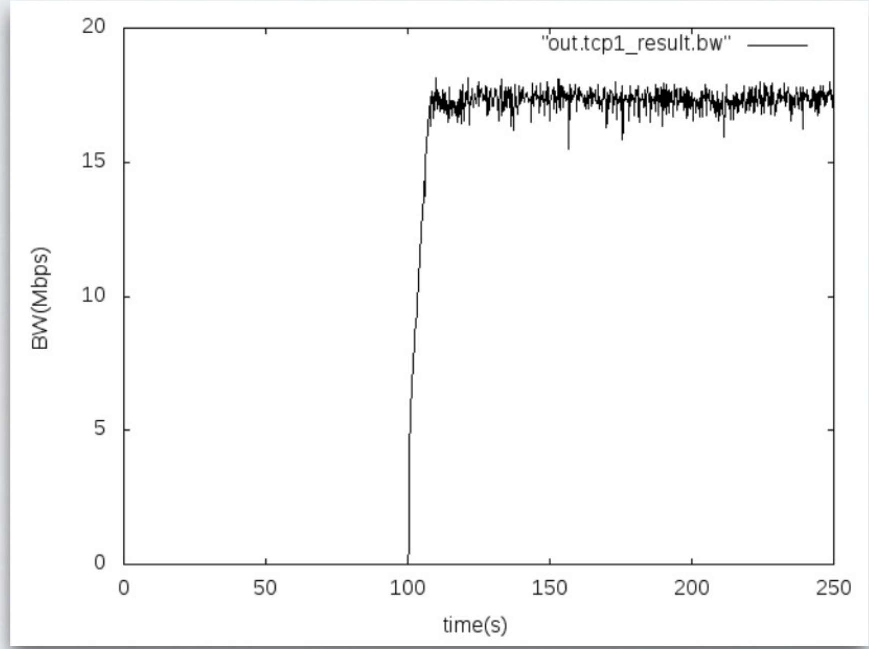


Efficiency: Throughput (2/2)

TCP Standard



VoAP

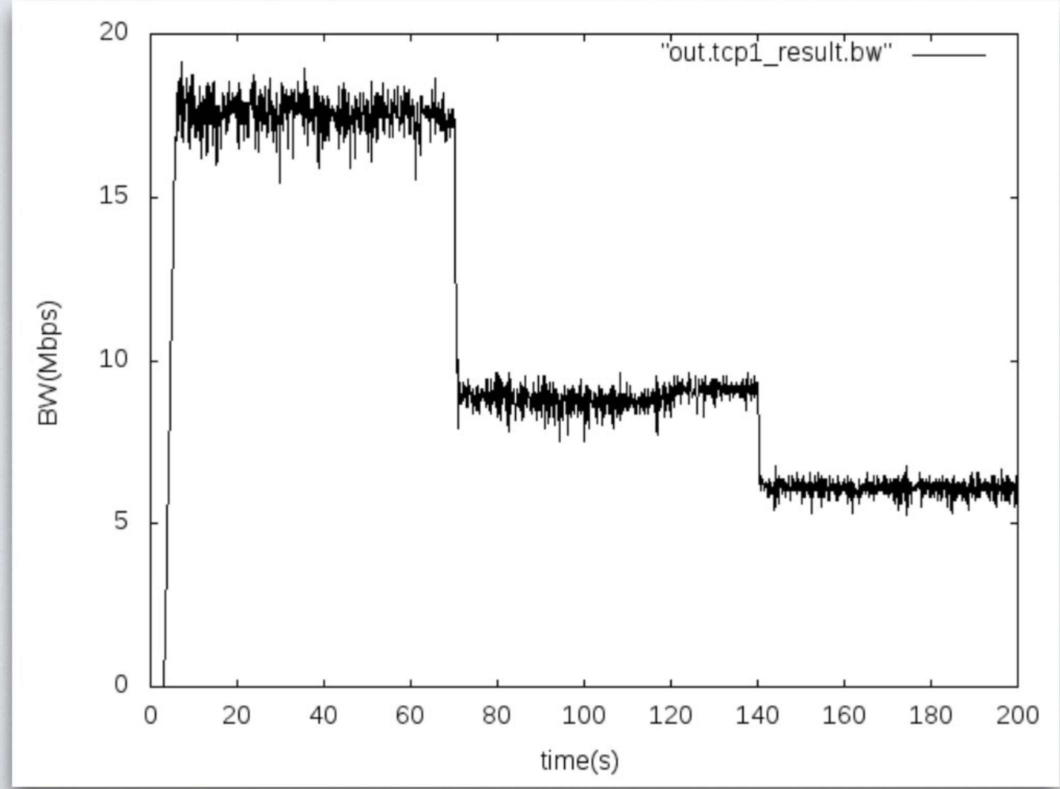


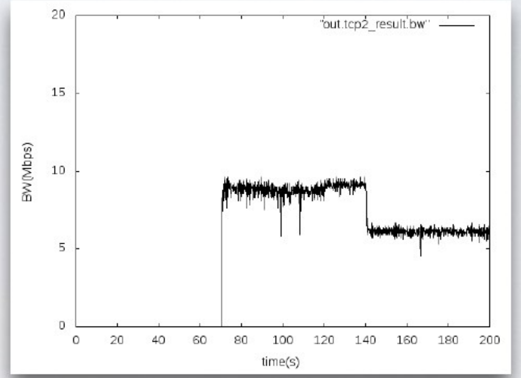
The difference between the two throughputs is about 1%

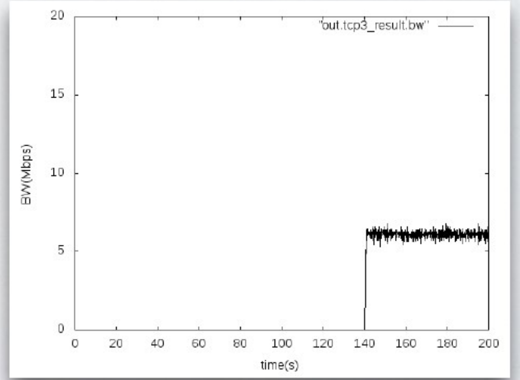
Fairness: Fair Share of Bandwidth

The total number of outgoing packets is fairly divided between the active flows

Three TCP flows starting respectively at 0 s, 70 s and 140 s







Experiments with Real Game Traffic

Unreal Tournament

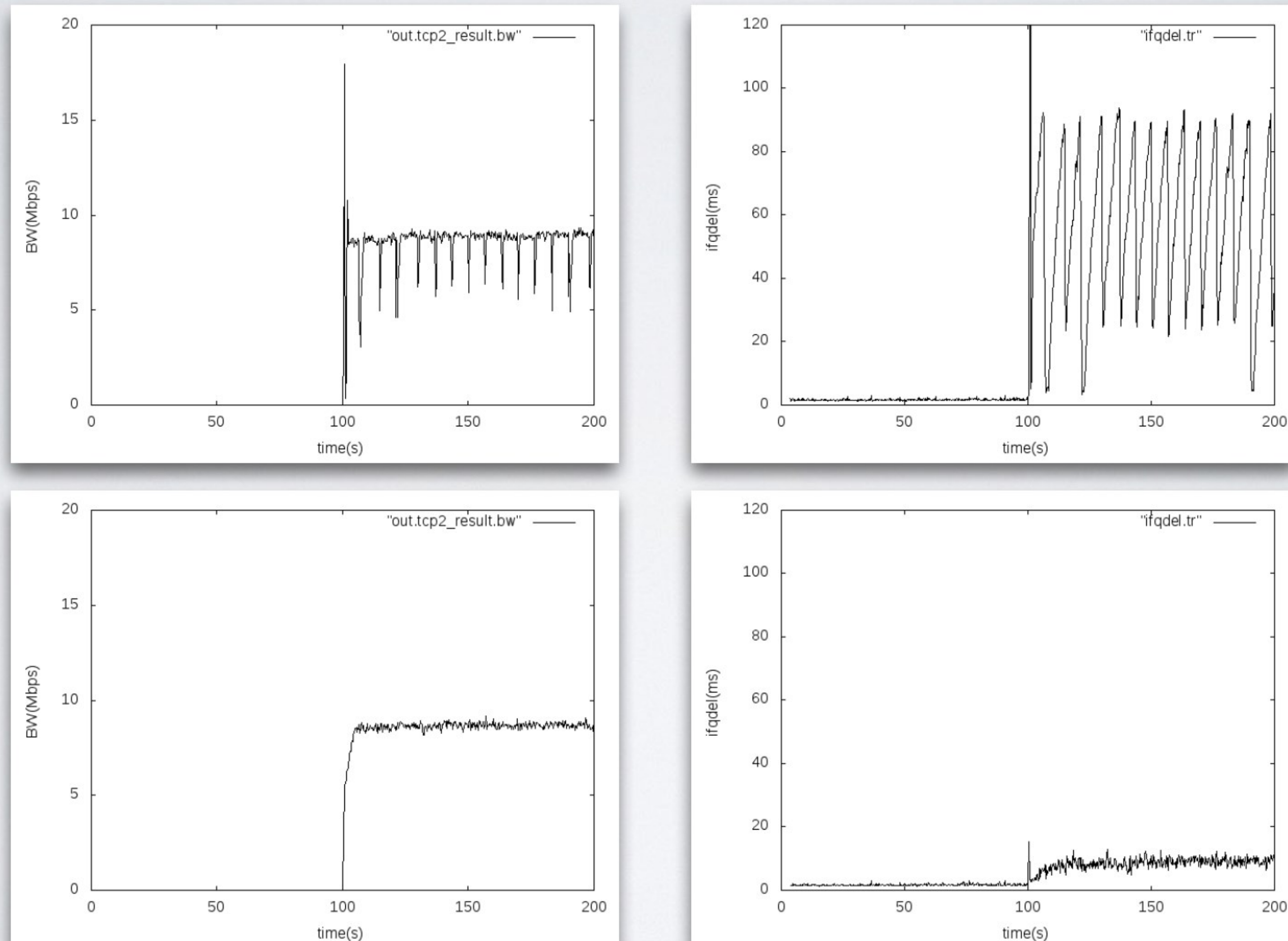
Grand Ages: Rome

Game	Packet size	Interarrival	Bandwidth
Unreal Tournament	947 B	1.2 ms	6247 Kbps
Rome	914 B	1.6 ms	3817 Kbps

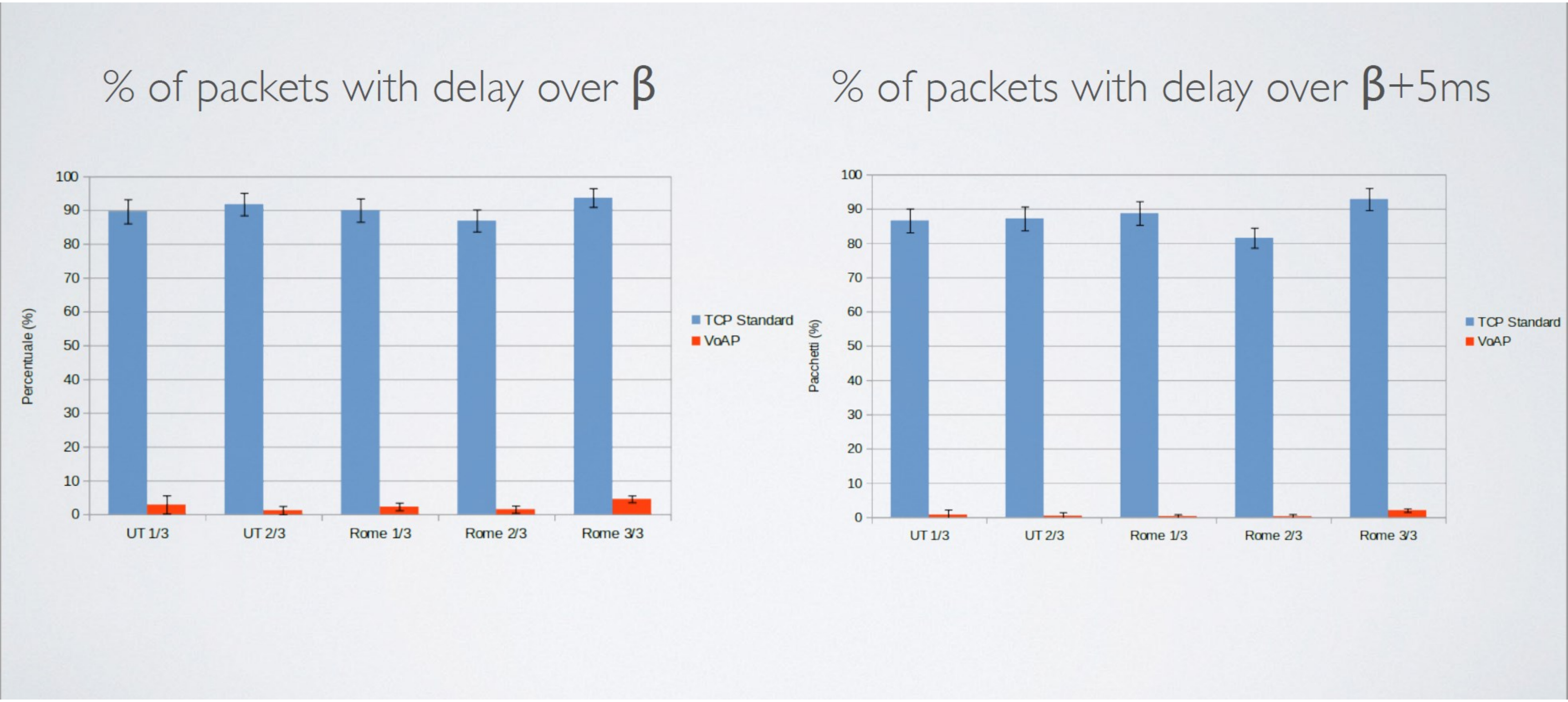
Experiments with Real Game Traffic

Bandwidth | Queue delay

Standard / VoAP



Experiments with Real Game Traffic



β set as 10 ms

Conclusion

- Keep a low per packet delay (interactivity)
- The throughput is preserved (efficiency)
  - Important for TCP based flows (downloaded files but also for some high quality videos
- TCP flows can fairly share the bandwidth (fairness)
- VoAP is easily employable in real scenarios
  - Requires modifications only at the AP
    - buy new or update old