ATL : An Adaptive Transport Layer Protocol Suite for Next Generation Wireless Internet

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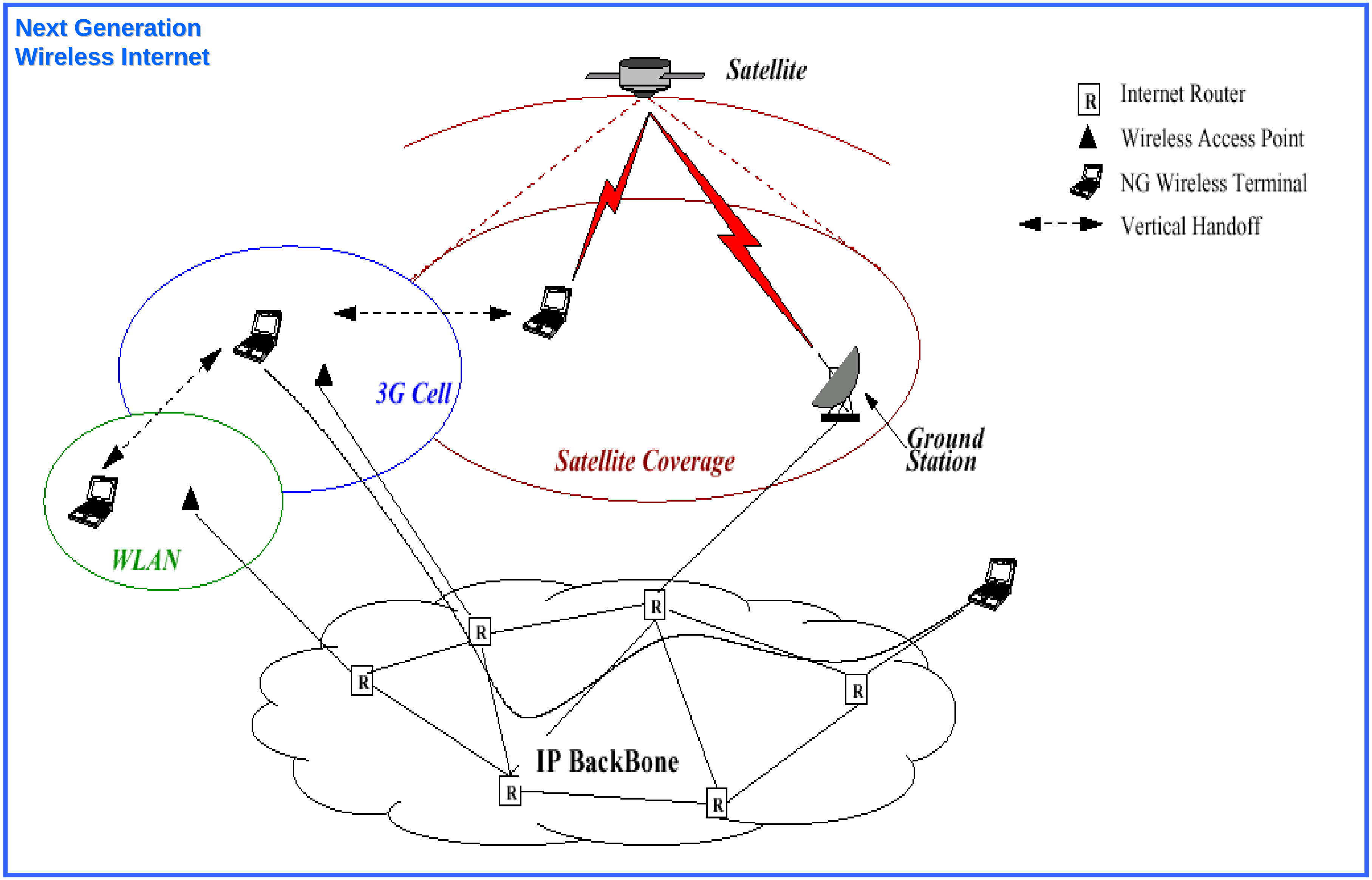
First paper deals with unified transport protocol for 4G wireless networks

Background

- 4G wireless networks
  - Convergence of wireless systems and Internet è NGWI
  - *Provide anywhere, anytime seamless service to mobile users*
  - *Challenges*
    - *Heterogeneous architectures*
      - *Various access delay*
      - *Various link error rates*
      - *Various mobility pattern*
    - *Heterogeneous service demands*
      - High Data Rate with reliable transport
      - Real Time Multimedia with timely delivery
    - Need a unified, efficient, and seamless adaptive transport layer to couple with these heterogeneities

Proposed NGWI architecture including WLAN, 3 G, and Satellite networks converged with next generation internet backbone

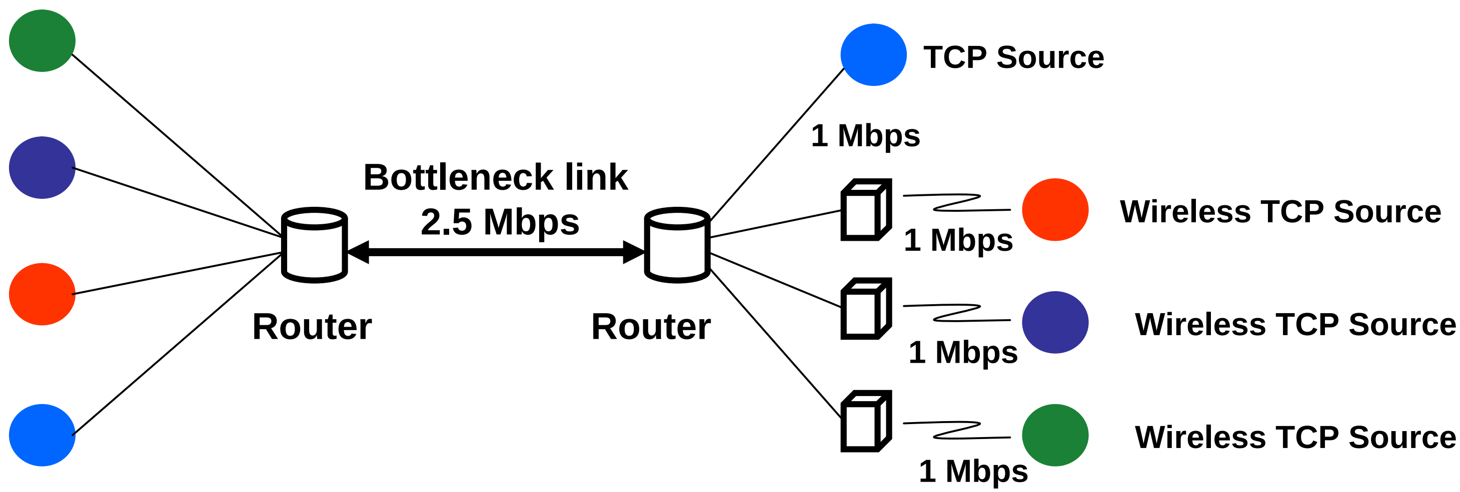


Effects of Architectural Heterogeneity in NGWI

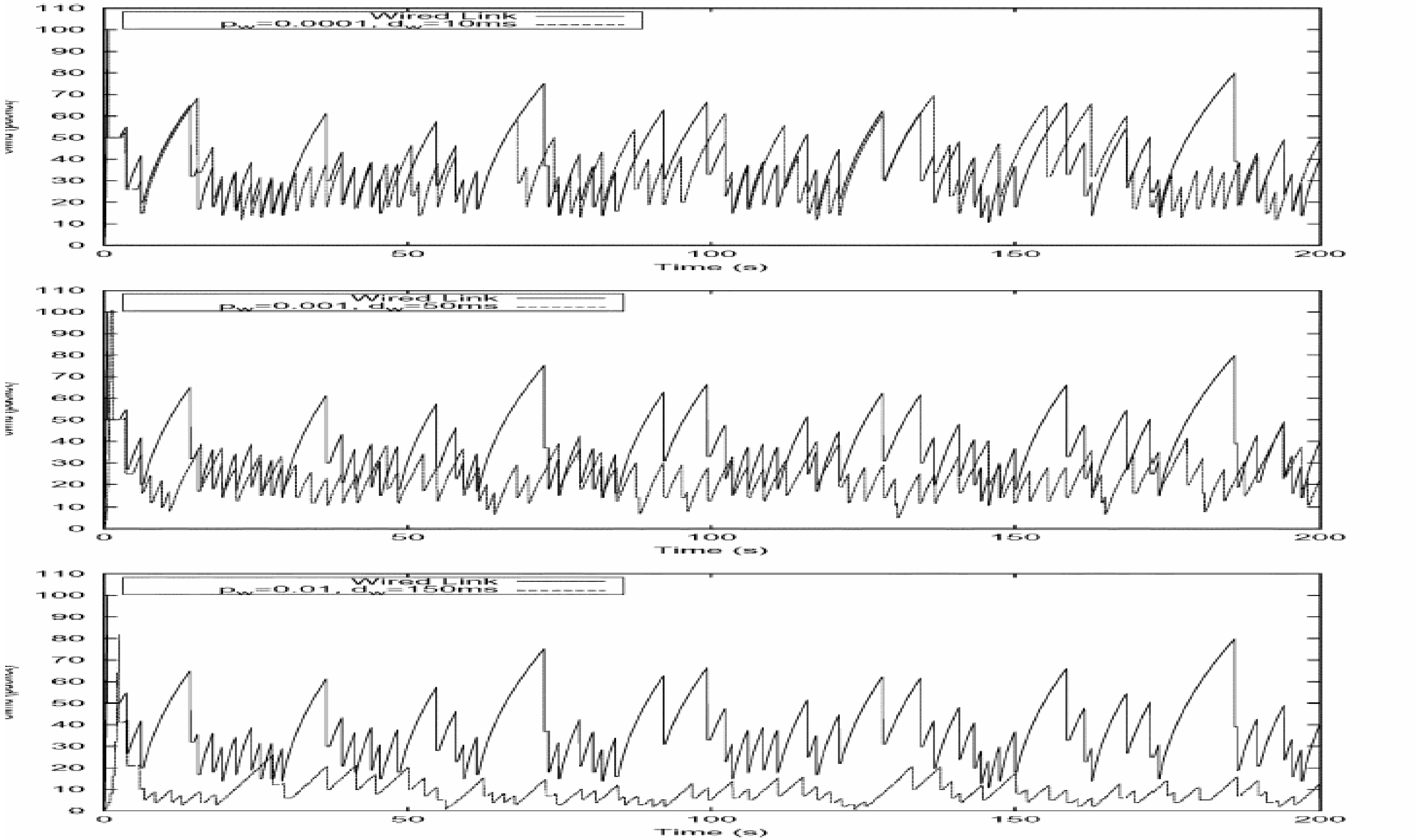
- Performance of TCP protocols affected by
  - Probability of Packet loss (p_w) due transmission error
  - Round Trip Time (RTT)
- Case Study

TABLE I
SIMULATION PARAMETERS AND RESULTS

Wireless System	d_w (ms)	p_w	*B/W (Mb/s)*	*Tput (Mb/s)*	*Gput (Mb/s)*
Wired	10	0	1	0.7286	0.86555
WLAN	10	10^{-4}	1	0.7271	0.84686
3G Cellular	50	10^{-3}	1	0.4899	0.57977
Satellite	150	10^{-2}	1	0.1549	0.12417



Congestion window change with time for different wireless link conditions.



Related Work for Wireless TCP

- Existing transport protocols for wireless networks only for a specific wireless system i.e. independent solutions exist for WLANs, WMANs, and satellite networks

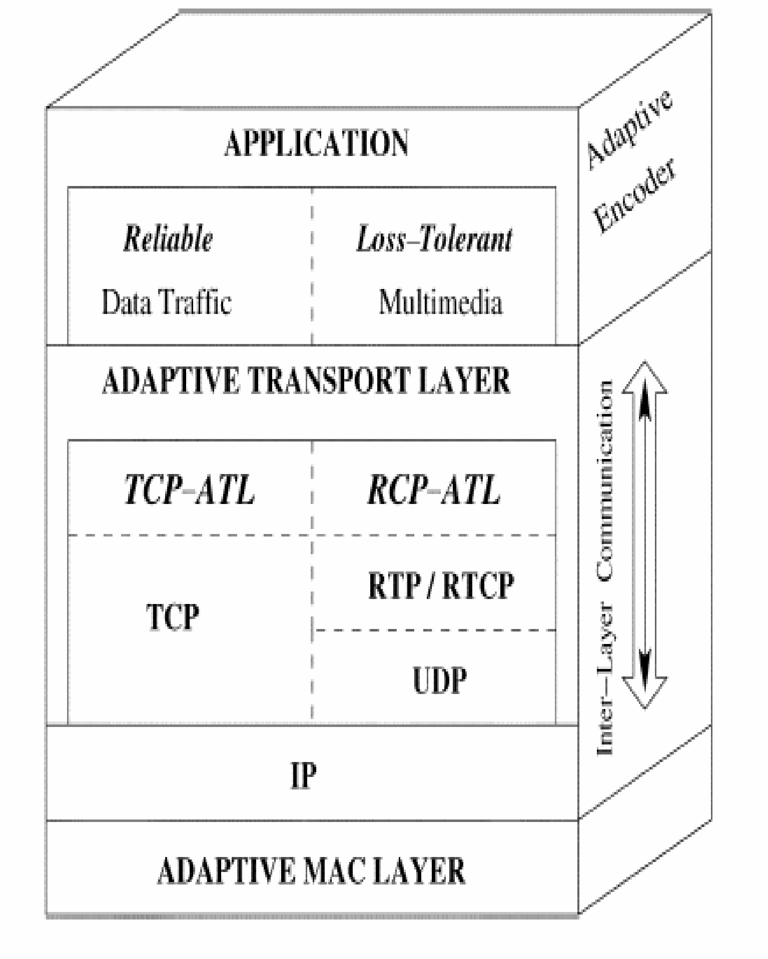
Protocol	Suited For	Disadvantage
Snoop Protocol	WLAN	Insignificant wireless link delays compared to end to end delays.
WTCP	WWAN	Relies on interpacket separation as a congestion control metric. So, it is not valid for WLAN and picocell.
TCP Peach & TCP Peach+	Satellite Networks	Congestion control algorithm may not be applicable to WLAN and picocell environments, since they address links with high bandwidth delay product
TCP Westwood	Hybrid Wireless Network	Performance degrades for links with high delays, due to decrease in estimation accuracy for late arriving feedback (it uses ACK to calculate congestion window size)

Remark:

No single Solution to address all the heterogeneity pertaining to NGWI. Need a unified transport layer to handle both architectural diversity and heterogeneous application requirements of NGWI

Motivation

- This paper try to propose ATL
  - Unified Adaptive Transport Layer that dynamically adjusts its protocol configurations to adapt to heterogeneous wireless environments and support reliable data and multimedia delivery
    - Adaptive Congestion Control for reliable traffic
    - Adaptive Rate Control for multimedia traffic
    - Fairness
    - Low Complexity and Backward Compatibility



Relationship Between Throughput of TCP Connection and System Parameters

Throughput of conventional TCP connection can be expressed as :

$$\mathcal{T}_{\alpha,\beta}(p, R, T_0, b) = \frac{1}{R\sqrt{\frac{2b(1-\beta)p}{\alpha(1+\beta)}} + T_0\left(3\sqrt{\frac{(1-\beta^2)bp}{2\alpha}}\right)p(1+32p^2)}$$

(α, β) : AIMD parameters

p : Total probability of packet loss due to both wireless link and congestion control

R : End to end RTT

T_0 : Initial retransmission timeout (RTO)

p_c : Probability of packet loss experienced due to congestion

R_c : End to end RTT of the connection in wired networks

T_{oc} : Initial retransmission timeout for wired networks

b : Number of packets acknowledged with a single ACK

Wired TCP throughput = $\mathcal{T}_{1,1/2}(p_c, R_c, T_{0c}, b)$

$$\mathcal{T}_{1,\frac{1}{2}}(p, R, T_0, b) < \mathcal{T}_{1,\frac{1}{2}}(p_c, R_c, T_{0c}, b)$$

Main Idea for Adaptive Congestion Control for Reliable Data Transport

- Goal:
  - To achieve throughput $T_{1,1/2}(p_c, R_c, T_{0c}, b)$ regardless of the underlying architecture and link conditions
- Idea:
  - Select (α, β) such that

$$T_{\alpha,\beta}(p, R, T_0, b) \approx T_{1,\frac{1}{2}}(p_c, R_c, T_{0c}, b)$$

Key Formulas for Adaptive Congestion Control for Reliable Data Transport

$p=1-(1-p_w)(1-p_c)$
$R= R_C + 2\, d_w$

p_w : probability of wireless link related packet loss
p_c : probability of packet loss due to congestion
R_c : end to end RTT of the connection without any additional wireless link delay
d_w : one way wireless link delay

$p_c = (p-p_w)/(1-p_w)$
$R_c = R-2d_w$

$$\hat{T} = T_{1,1/2}(p_c, R_c, T_{oc}, b)$$

$$R\sqrt{\frac{2b(1-\beta)p}{\alpha(1+\beta)}} + T_0\left(3\sqrt{\frac{(1-\beta^2)bp}{2\alpha}}\right)p(1+32p^2) = \frac{1}{\hat{T}}.$$

$$\alpha = \frac{bp(1-\beta)}{2(1+\beta)}\left[\hat{T}\left(2R+3T_0p(1+32p^2)(1+\beta)\right)\right]^2 \quad \forall\beta \in [0.5, 1)$$

TCP-ATL Adaptive Data Transport Protocol Operation

- Uses SACK-TCP
- Continuously measure RTT & packet loss rate p within a sliding time of window of τ
- d_w and p_w are assumed to be obtained from the underlying adaptive medium access control layer via simple cross layer interaction
- Calculate p_c & R_c
- Calculate $\hat{T} = T_{1,1/2}(p_c, R_c, T_{oc}, b)$
- β can safely selected from [0.5,1]
- AIMD parameter α calculated according to varying link conditions using:

$$\alpha = \frac{bp(1-\beta)}{2(1+\beta)}\left[\hat{T}\left(2R + 3T_0 p(1+32p^2)(1+\beta)\right)\right]^2$$

Relationship Between Throughput of Multimedia Traffic Flow under Adaptive Rate Control (AIMD) and System Parameters

General rate-based AIMD control scheme:

- Without any retransmission
- Receiver sends back an ACK for every received packet

p : Total probability of packet loss due to both wireless link and congestion
R : End to end RTT

S : transmission rate
S = S + α if no packet loss is detected (additive increase) during each RTT
S = β*S if a packet loss is detected (multiplicative decrease) during each RTT

Throughput for a rate based AIMD scheme is expressed as:

$$T^{T}_{\alpha,\beta}(p,R) = \frac{\alpha}{4(1-\beta)}\left[1+\beta+\sqrt{(3-\beta)^2+\frac{8(1-\beta^2)}{\alpha R p}}\right]$$

Main Idea for Adaptive Rate Control

- Goal:
  - To achieve throughput $T_{1,1/2}(p_c, R_c, T_{0c}, b)$ regardless of the underlying architecture and link conditions
- Idea:
  - Select (α, β) such that

$$T_{\alpha,\beta}^{r}(p, R) \approx T_{1,\frac{1}{2}}(p_c, R_c, T_{0c}, b)$$

Key Formulas for Adaptive Rate Control

$p = 1-(1-p_w)(1-p_c)$
$R = R_C + 2\, d_w$

p_w : probability of wireless link related packet loss
p_c : probability of packet loss due to congestion
R_c : end to end RTT of the connection without any additional wireless link delay
d_w : one way wireless link delay

$p_c = (p-p_w)/(1-p_w)$
$R_c = R-2d_w$

$$\frac{\alpha}{4(1-\beta)}\left[1+\beta+\sqrt{(3-\beta)^2+\frac{8(1-\beta^2)}{\alpha R p}}\right] = \hat{T}.$$

$$\hat{T} = T_{1,1/2}(p_c, R_c, T_{oc}, b)$$

$$\alpha = \frac{(1+\beta)}{2}\left(\hat{T}+\frac{1}{R\cdot p}\right)\left[\sqrt{1+\frac{8\hat{T}^2(1-\beta)}{\left(\hat{T}+\frac{1}{R\cdot p}\right)^2(1+\beta)^2}}-1\right]. \qquad \forall\beta \in [0.5,1)$$

RCP- ATL : Adaptive rate control protocol for multimedia traffic operation

- Run on top of RTP or RTCP/UDP/IP
- No any retransmission
- Obtains p and R from receiver by ACK
- Follows AIMD rate control behavior
- $S=\beta * S$ (in case of packet loss)
- $S=S+\alpha$ (without any packet loss)
- P_W and d_W are assumed form underlying MAC layer

$$\alpha = \frac{(1+\beta)}{2}\left(\widehat{T} + \frac{1}{R\cdot p}\right)\left[\sqrt{1+\frac{8\widehat{T}^2(1-\beta)}{\left(\widehat{T}+\frac{1}{R\cdot p}\right)^2(1+\beta)^2}}-1\right].$$

Operation of the protocol for each source/receiver combination

- Wireless Source/ Wired Receiver: no modifications required
- Wired Source/ Wireless Receiver: p_w and d_w are supplied to the source
- Wireless Source/ Wireless Receiver: Calculate p_{ws} d_{ws} p_{wr} d_{wr}

$$p = 1 - (1 - p_w^s)(1 - p_c)(1 - p_w^r)$$
$$R = R_c + 2(d_w^s + d_w^r).$$

$$p_c = 1 - \frac{1 - p}{(1 - p_w^s)(1 - p_w^r)}$$
$$R_c = R - 2(d_w^s + d_w^r).$$

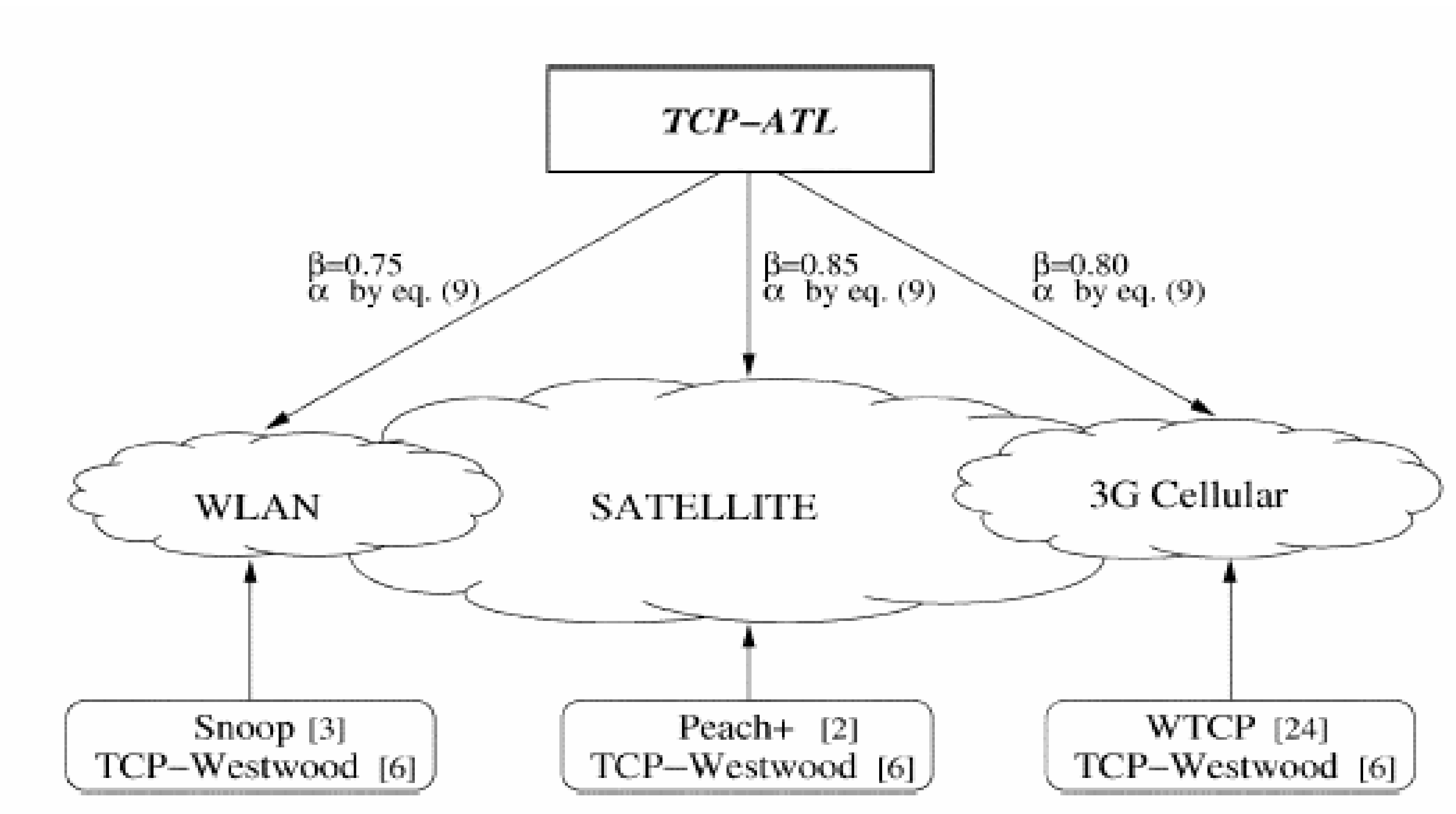
- Wired Source/ Wired Receiver:

  $p_w = 0$ $d_w = 0$

Pseudo algorithm for the operation of adaptive congestion and rate control scheme used by TCP ATL and TCP RTL protocols

```
Configure_AIMD()
  /* Case 1 */
  if (Wireless Source / Wired Receiver)
    Obtain $p_w$ and $d_w$ from MAC layer;
    $p_c = \frac{p - p_w}{1 - p_w}$;
    $R_c = R - 2d_w$;
  end;
  /* Case 2 */
  if (Wired Source / Wireless Receiver)
    Obtain $p_w$ and $d_w$ from RECEIVER;
    $p_c = \frac{p - p_w}{1 - p_w}$;
    $R_c = R - 2d_w$;
  end;
  /* Case 3 */
  if (Wireless Source / Receiver)
    Obtain $p_w^s$ and $d_w^s$ from MAC layer;
    Obtain $p_w^r$ and $d_w^r$ from RECEIVER;
    $d_w = d_w^s + d_w^r$;
    $p_c = 1 - \frac{1-p}{(1-p_w^s)(1-p_w^r)}$;
    $R_c = R - 2(d_w^s + d_w^r)$;
  end;
  Calculate $\widehat{T} = T_{1,\frac{1}{2}}(p_c, R_c, T_{0c}, b)$ with (7);
  if (0 ms $< d_w <$ 50 ms)
    Set $\beta = 0.75$;
  if (50 ms $\le d_w <$ 150 ms)
    Set $\beta = 0.80$;
  if ($d_w \ge$ 150 ms)
    Set $\beta = 0.85$;
  if (TCP_ATL)
    Set $\alpha$ with (9);
  else if (RCP_ATL)
    Set $\alpha$ with (13);
  end;
end;
```

Performance Evaluation



TCP – ATL Performance

Simulation Parameters

p_w : 10^{-1} and 10^{-6}

d_w (one way wireless link delays) :

10ms (WLAN) b - 0.75

50ms (3G Cellular) b - 0.80

150ms (Satellite Networks) b- 0.85

Link capacity : 2 Mbps

Data packet size : 1 KB

one way delay for the wired bottleneck : 10 ms

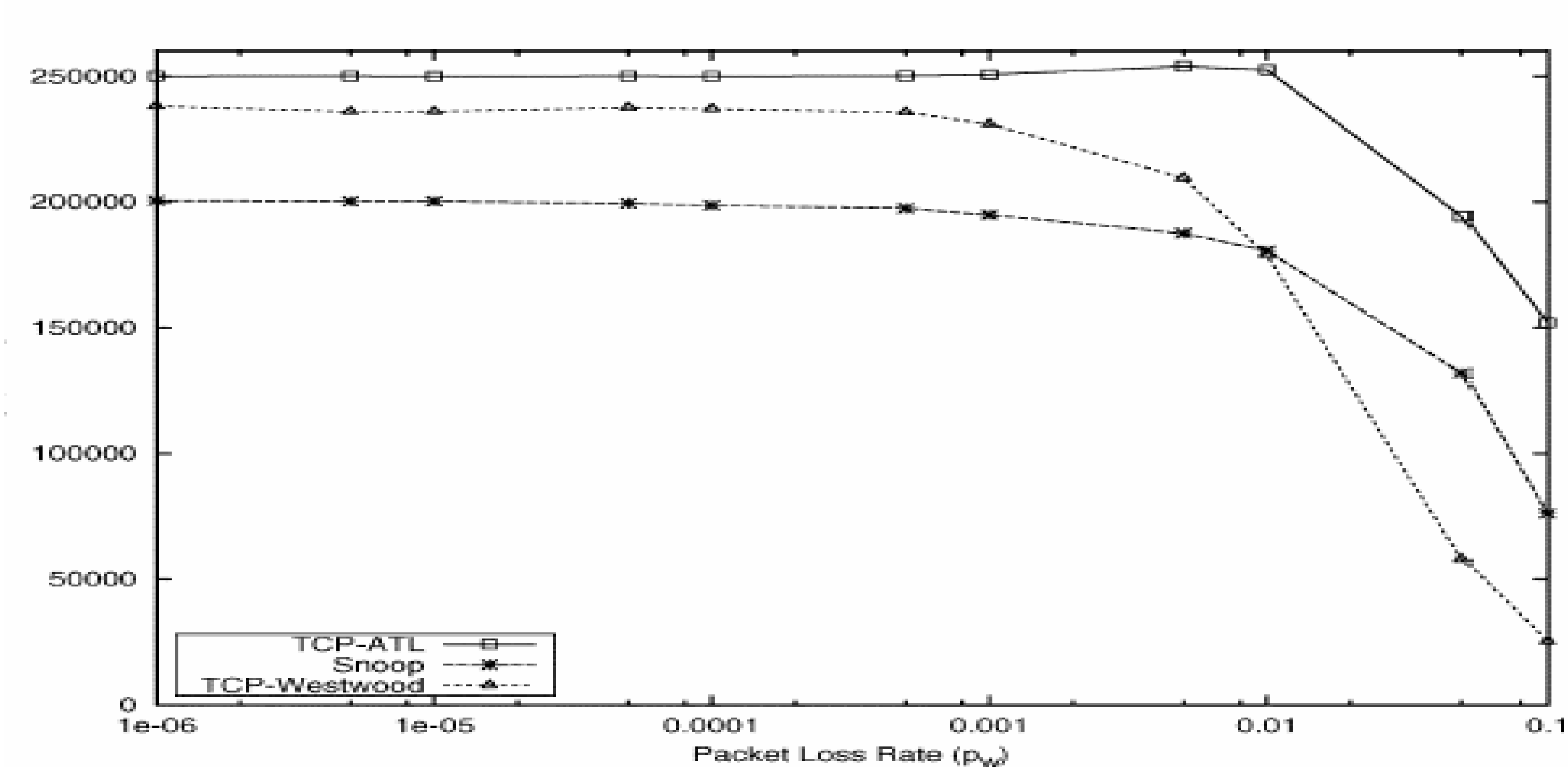
each data packet acknowledged by a single ACK

Simulation is performed for a duration of 600 sec

Evaluation Metrics:

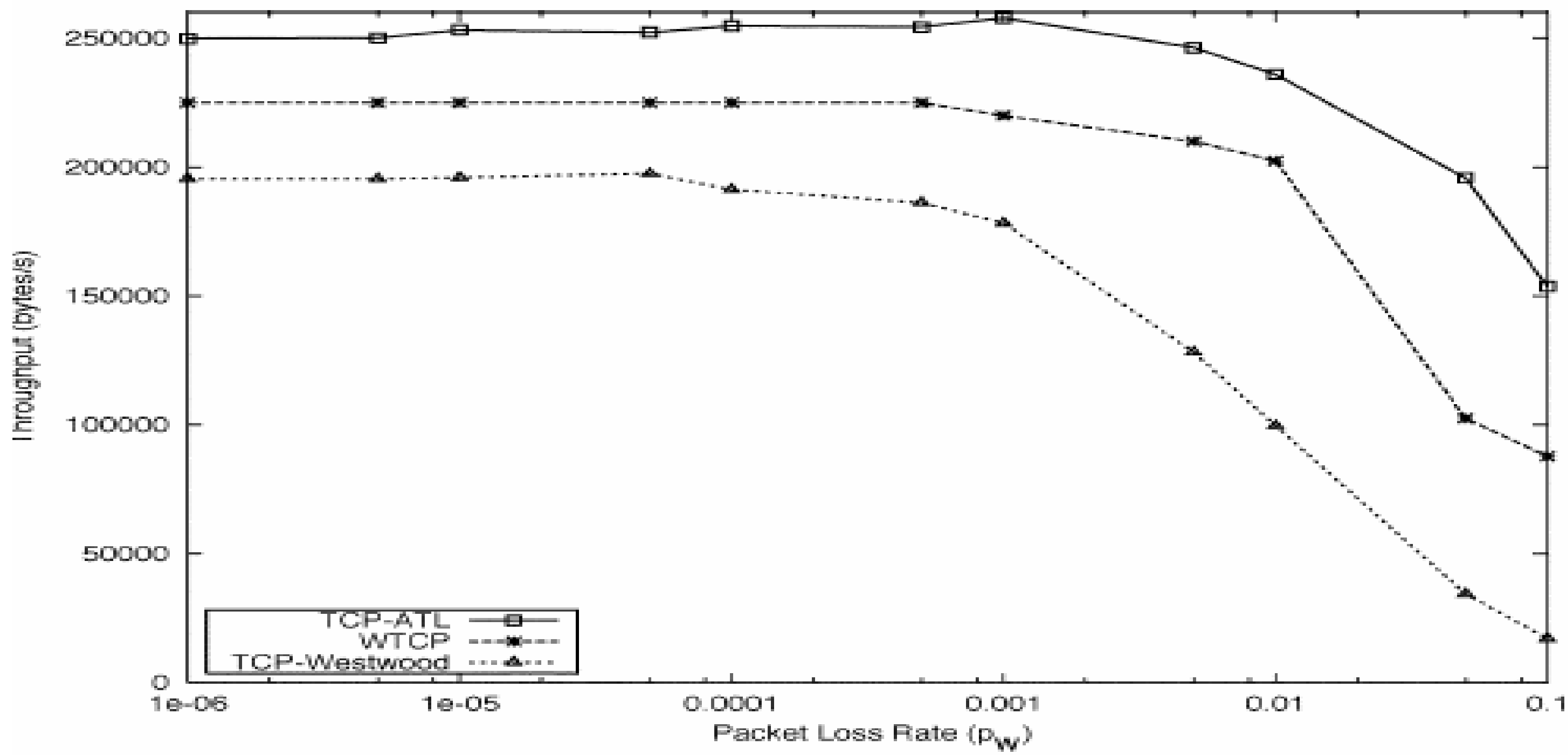
- Throughput
- Blackout
- Fairness

WLAN



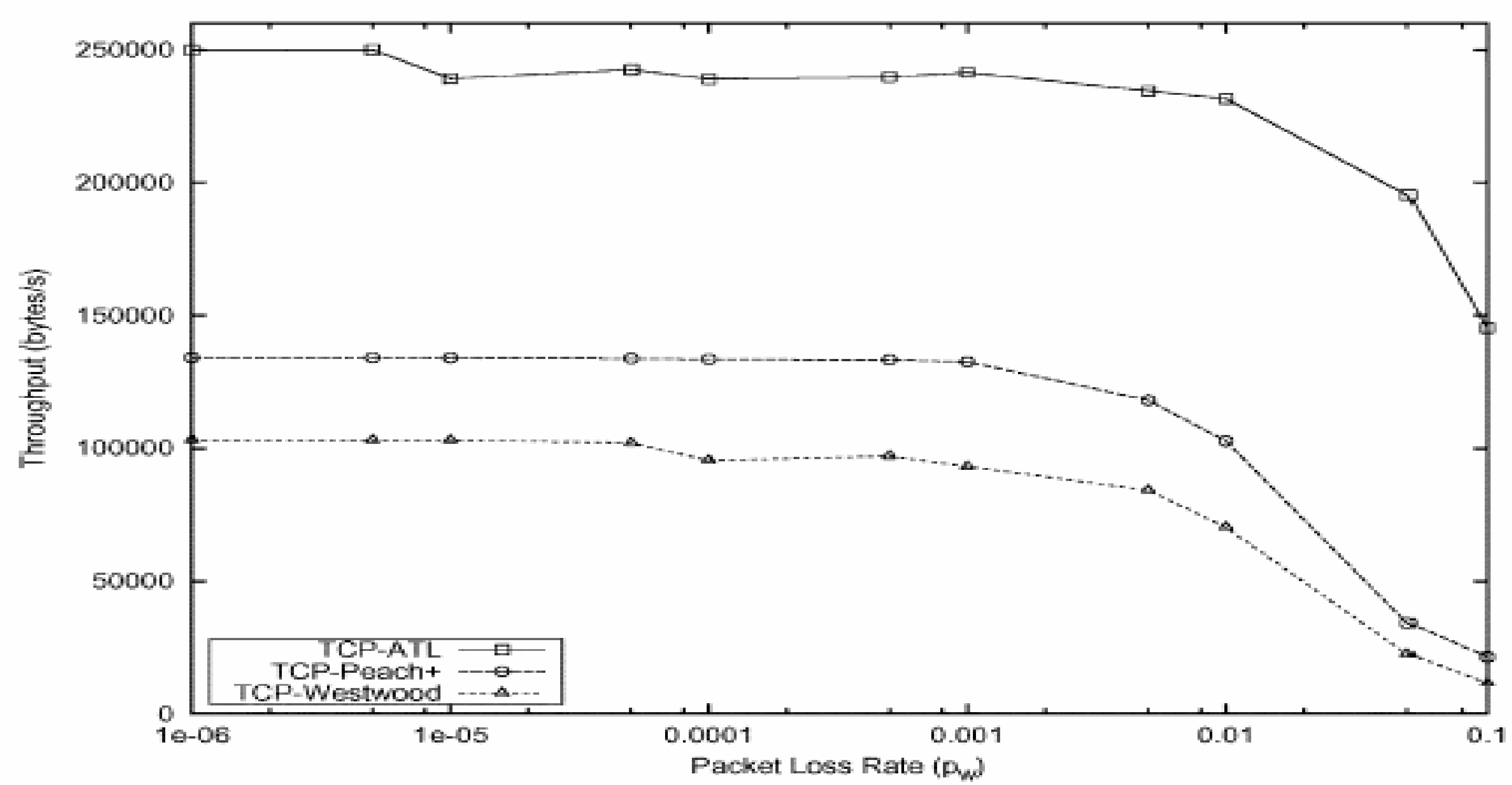
Throughput comparison of TCP-ATL, SNOOP and TCP Westwood for d_w=10ms and varying p_w

3 G Cellular



Throughput comparison of TCP-ATL, WTCP, and TCp – Westwood for d_w=50 ms and varying p_w

Satellite



Throughput comparison of TCP-ATL, TCP Westwood and TCP Peach+ for d_w = 150 ms and varying p_w

Roaming Between Heterogeneous Architectures

TABLE II
THROUGHPUT ACHIEVED WHILE (WIRELESS SOURCE) ROAMING BETWEEN HETEROGENEOUS WIRELESS ARCHITECTURES

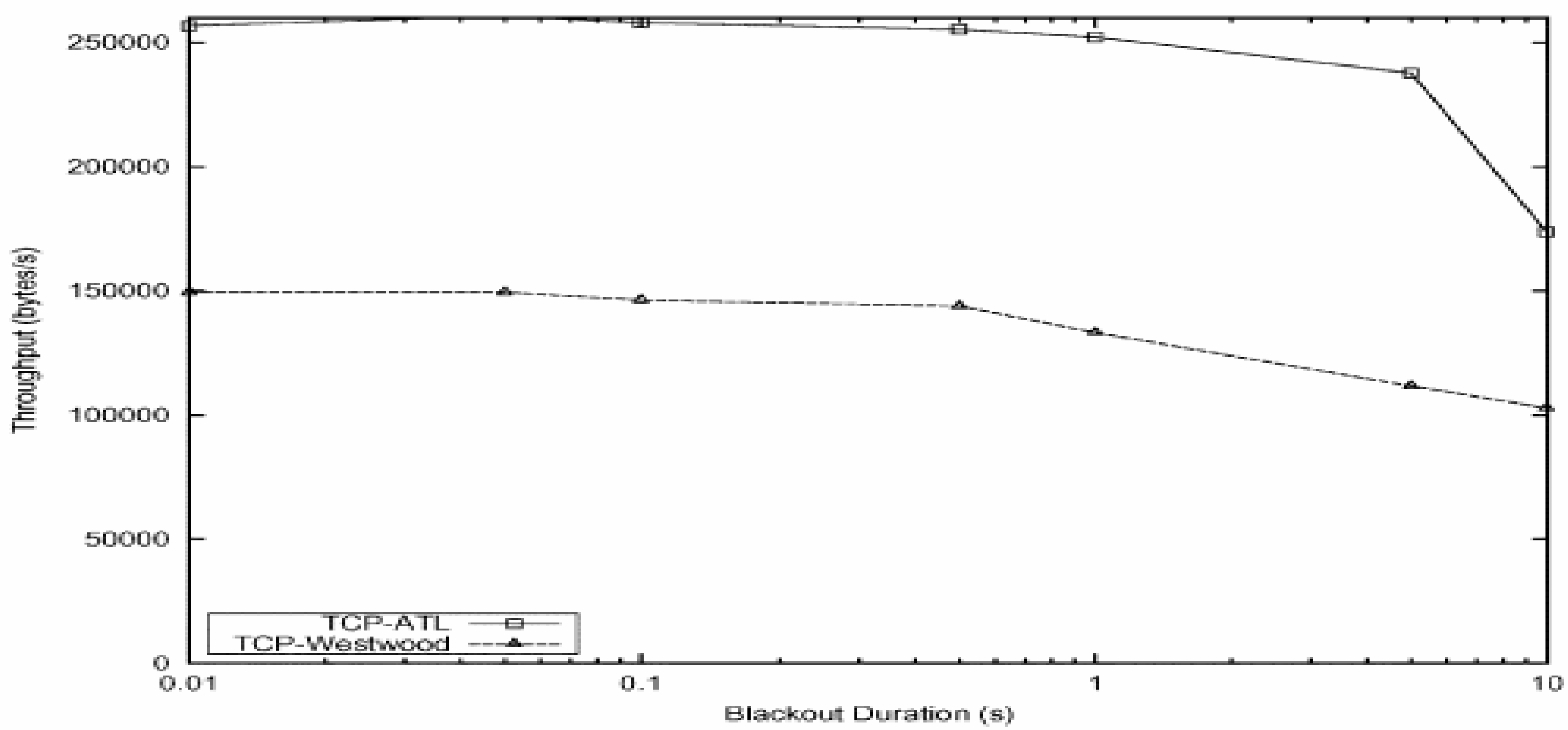
Exp. #	$(t_1;t_2)$	$(N_1;N_2;N_3)$	*Tput (Mb/s)*
1	(100,300)	(WLAN,3G,Sat)	1.8870
2	(200,300)	(WLAN,Sat,3G)	1.9149
3	(200,500)	(Sat,WLAN,3G)	1.8919
4	(200,400)	(Sat,3G,WLAN)	1.8979
5	(100,200)	(3G,WLAN,Sat)	1.8701
6	(400,500)	(3G,Sat,WLAN)	1.9210

TABLE III
THROUGHPUT ACHIEVED WHILE (WIRELESS RECEIVER) ROAMING BETWEEN HETEROGENEOUS WIRELESS ARCHITECTURES

Exp. #	$(t_1;t_2)$	$(N_1;N_2;N_3)$	*Tput (Mb/s)*
1	(100,300)	(WLAN,3G,Sat)	1.8521
2	(200,300)	(WLAN,Sat,3G)	1.8943
3	(200,500)	(Sat,WLAN,3G)	1.8755
4	(200,400)	(Sat,3G,WLAN)	1.8771
5	(100,200)	(3G,WLAN,Sat)	1.8561
6	(400,500)	(3G,Sat,WLAN)	1.9093

High throughput is maintained regardless network heterogeneity

Blackouts

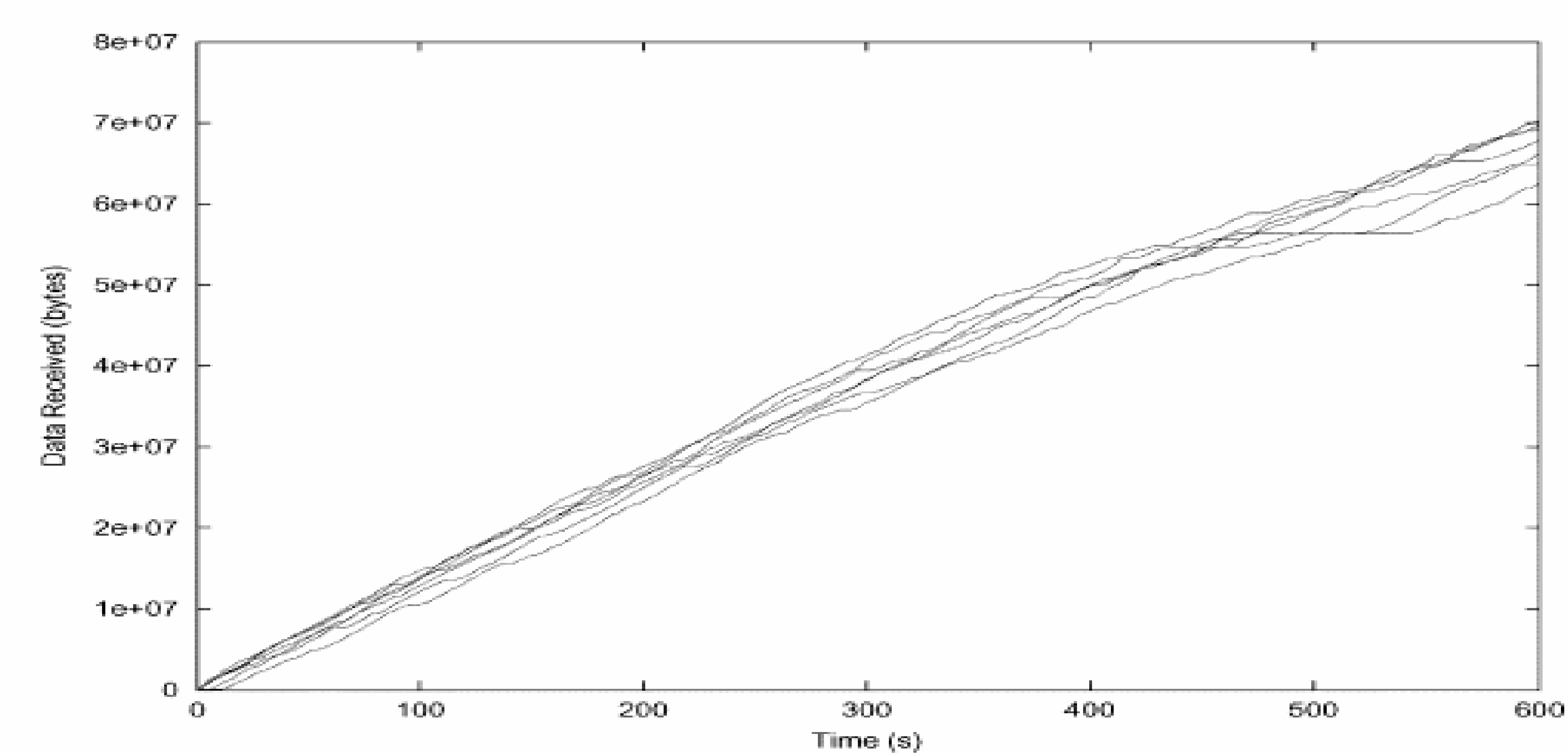


Throughput comparison of TCP – ATL and TCP westwood for varying blackout duration for d_w=50 ms and p_w = 10^{-3}

Blackout occurs at 300 sec and simulation duration is 600 sec

Fairness

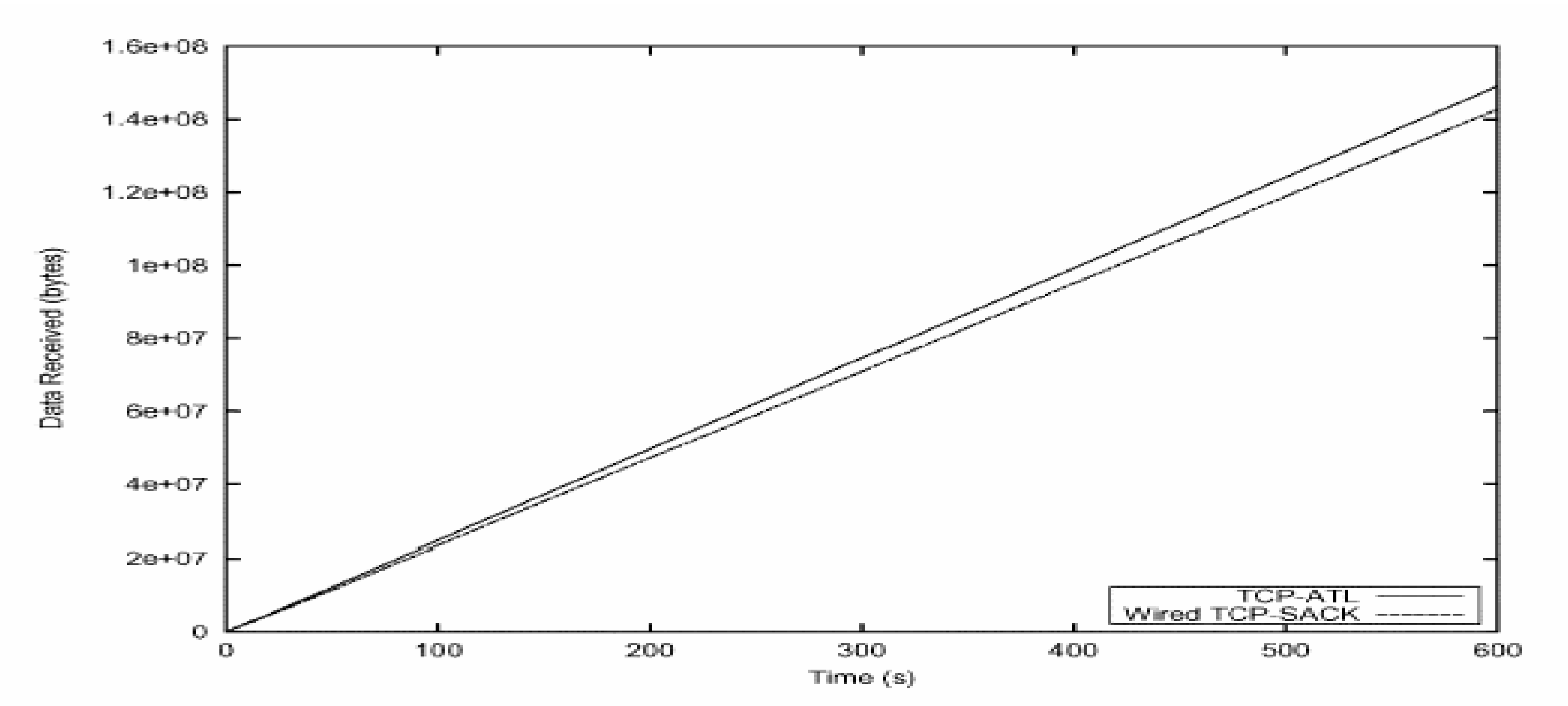
Intraprotocol fairness: Fairness among 6 TCP – ATL flows sharing the same bottleneck



Intraprotocol Fairness: Total bytes received by each of the TCP-ATL sinks with time for d_w=10 ms and p_w = 10^{-3}

Fairness

Fairness to wired TCP flows : Fairness of TCP – ATL to wired TCP sources
5 TCP-ATL flows with a wireless link and 5 SACK-TCP flows without wireless link



Fairness to wired TCP flows :Total bytes received by the TCP – ATL and wired TCP sinks with time for d_w = 10 ms and p_w =10^{-3}

RCP ATL performance

Simulation Parameters:

p_w – 10^{-1} to 10^{-6}

(One way wireless link delay) d_w-10 ms (WLAN) , 50 ms (3G) , 150 ms (Satellite)

RAP – which is best for wired environments

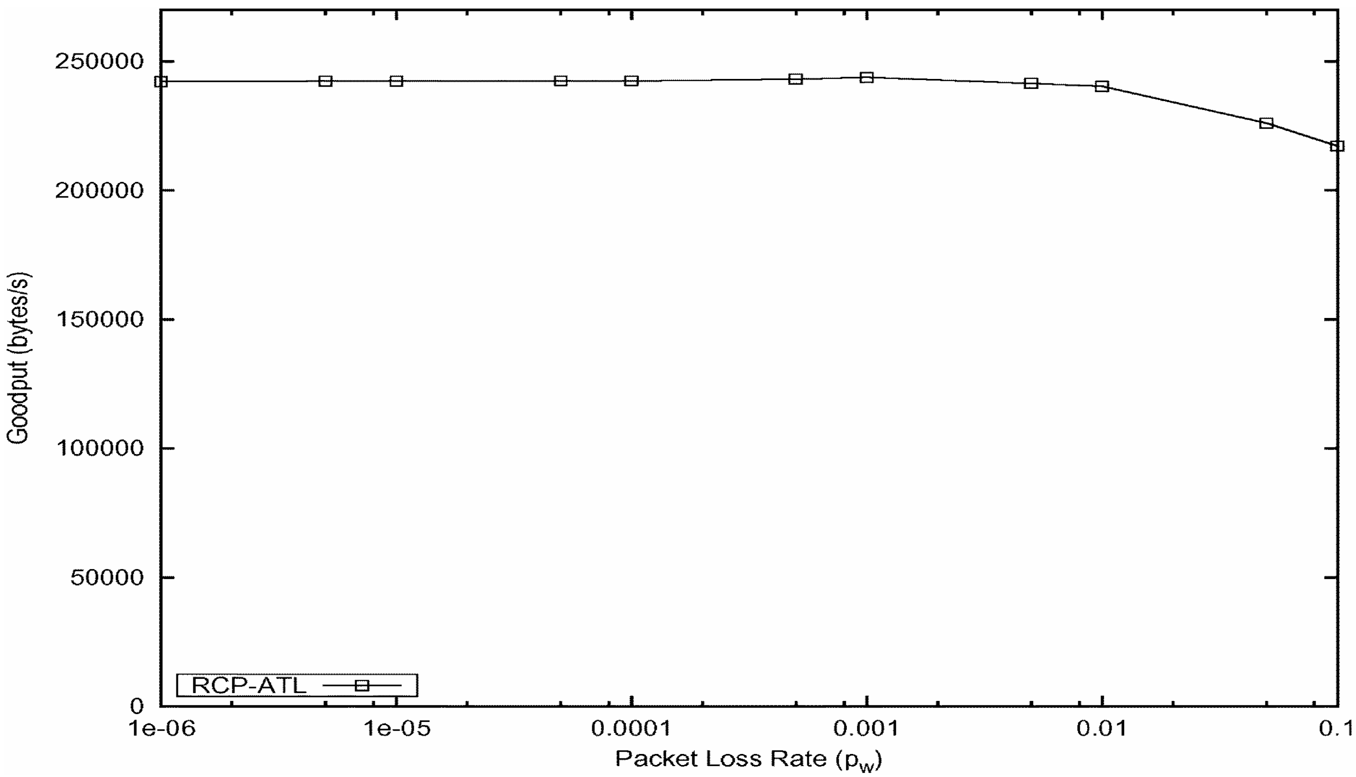
No rate control scheme for WLAN and 3G cellular networks

RCS – which is best for satellite networks

Evaluation metrics:

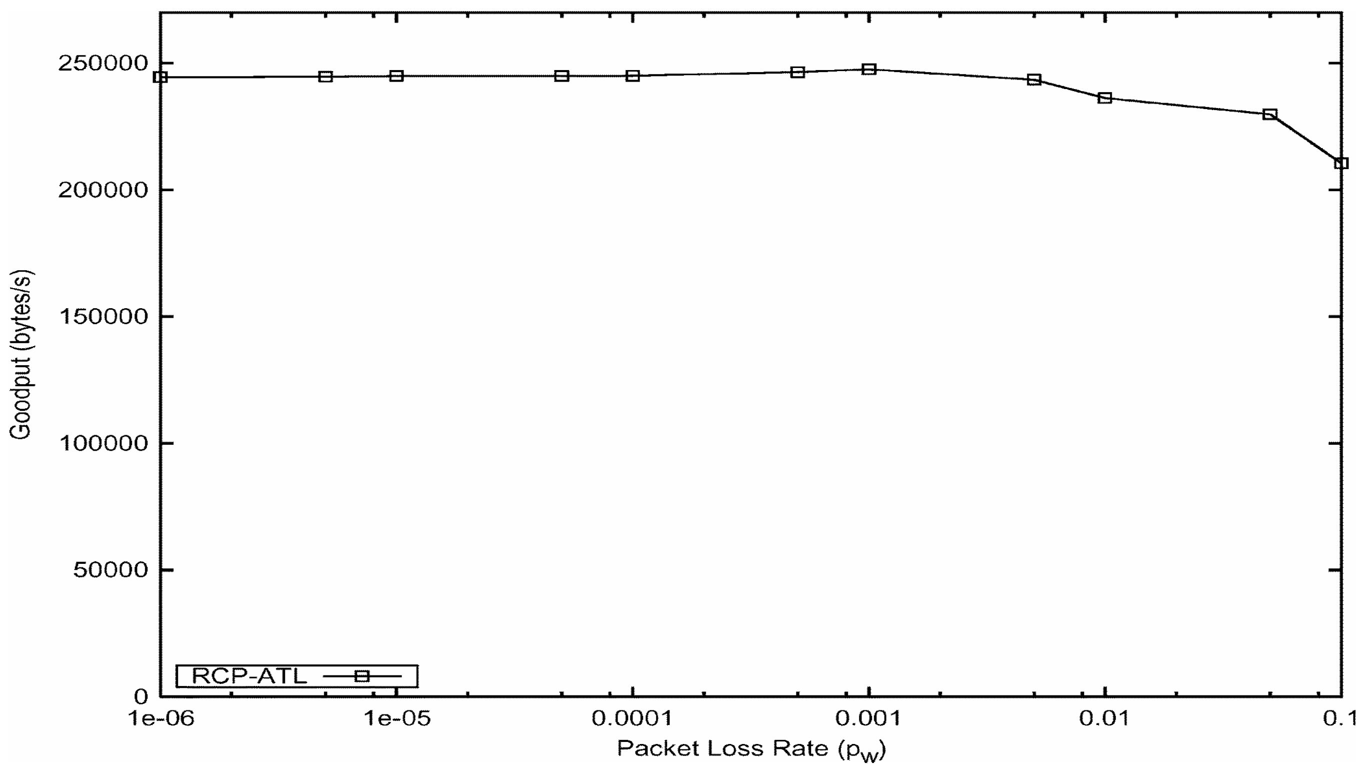
- Goodput performance
- Fairness
- Jitter Issues

Goodput (WLAN)



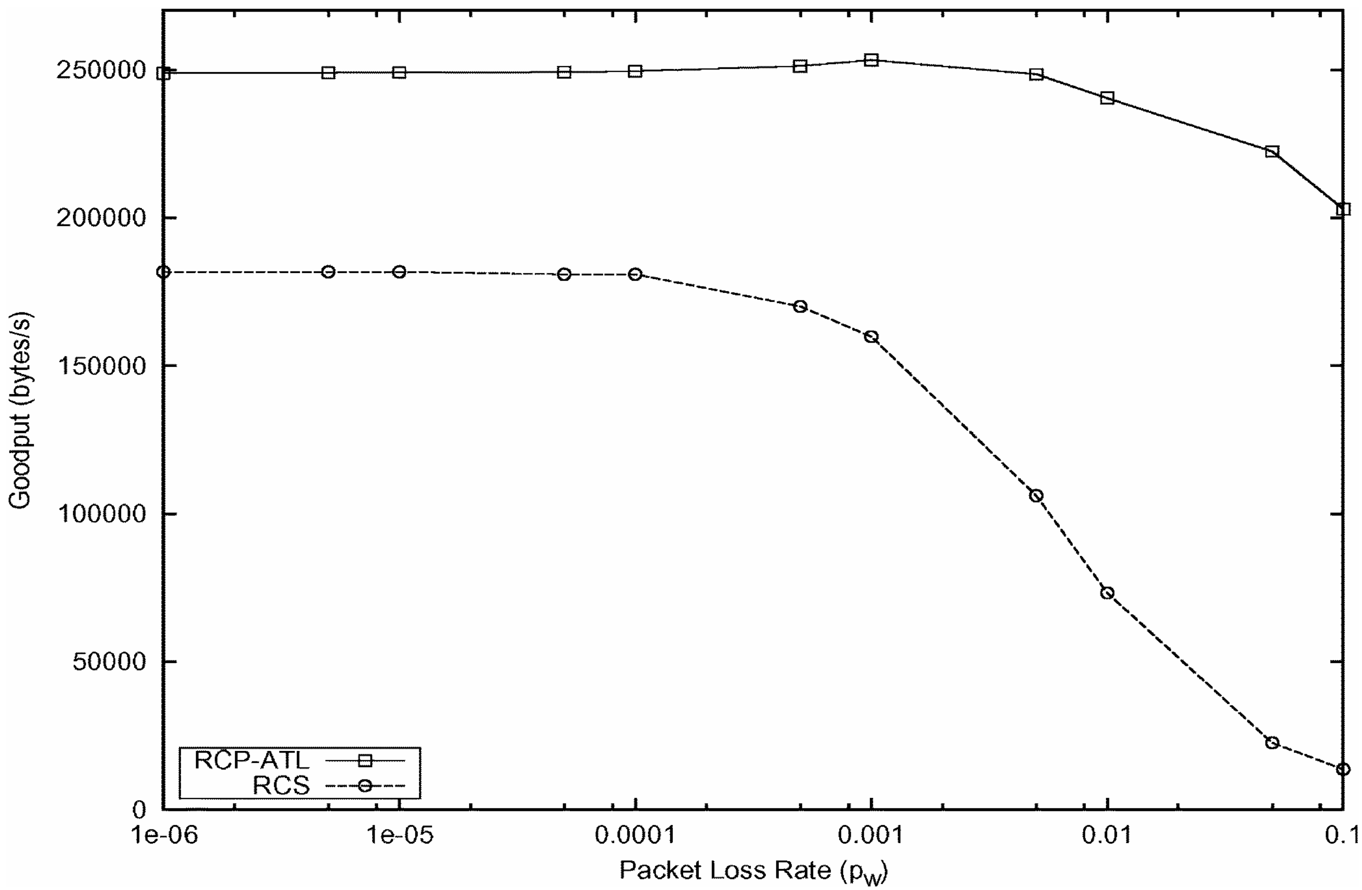
Goodput achieved by RCP-ATL for d_w = 10 ms and varying p_w

Goodput (3 G cellular)



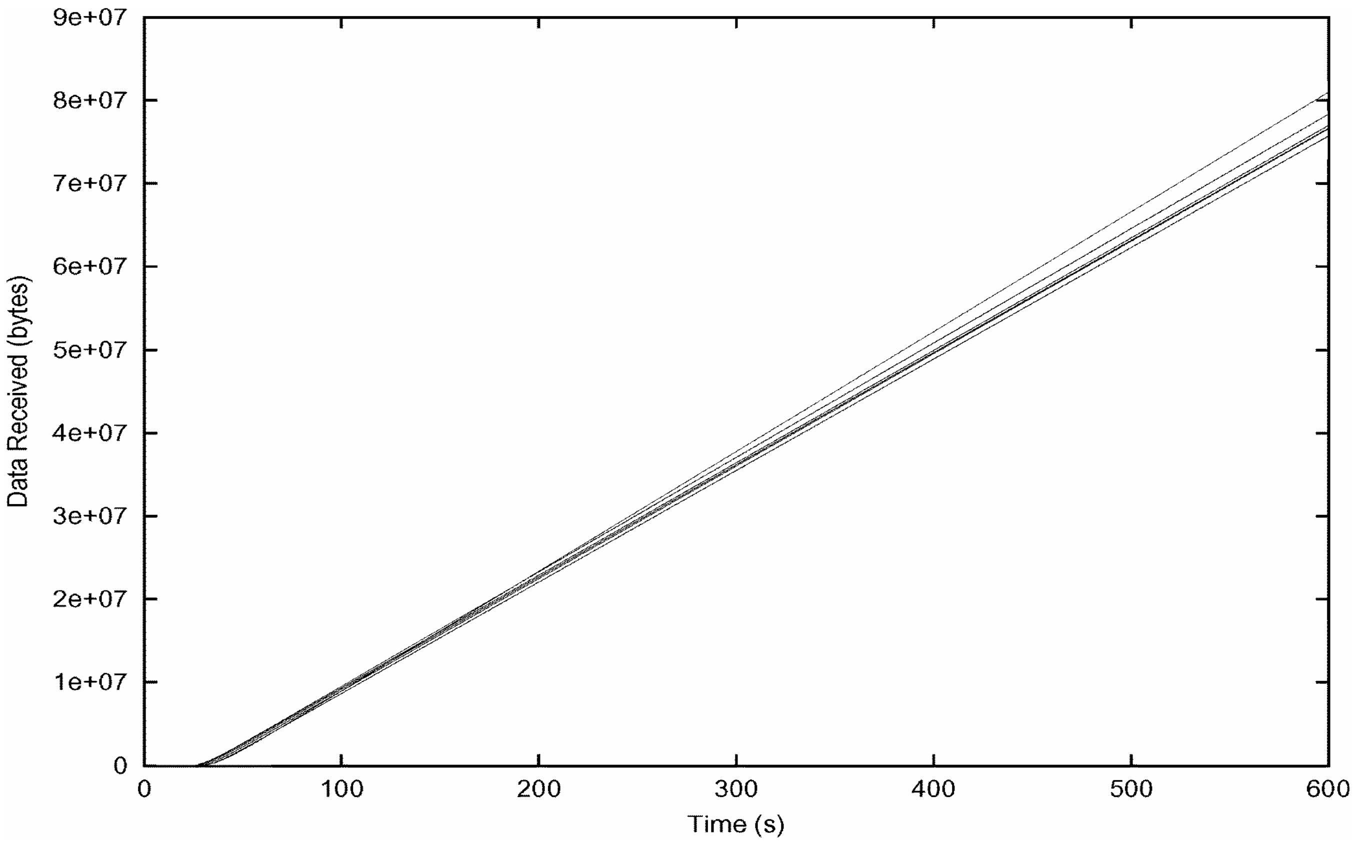
Goodput achieved by RCP–ATL for d_w= 50ms and varying p_w

Goodput (Satellite)



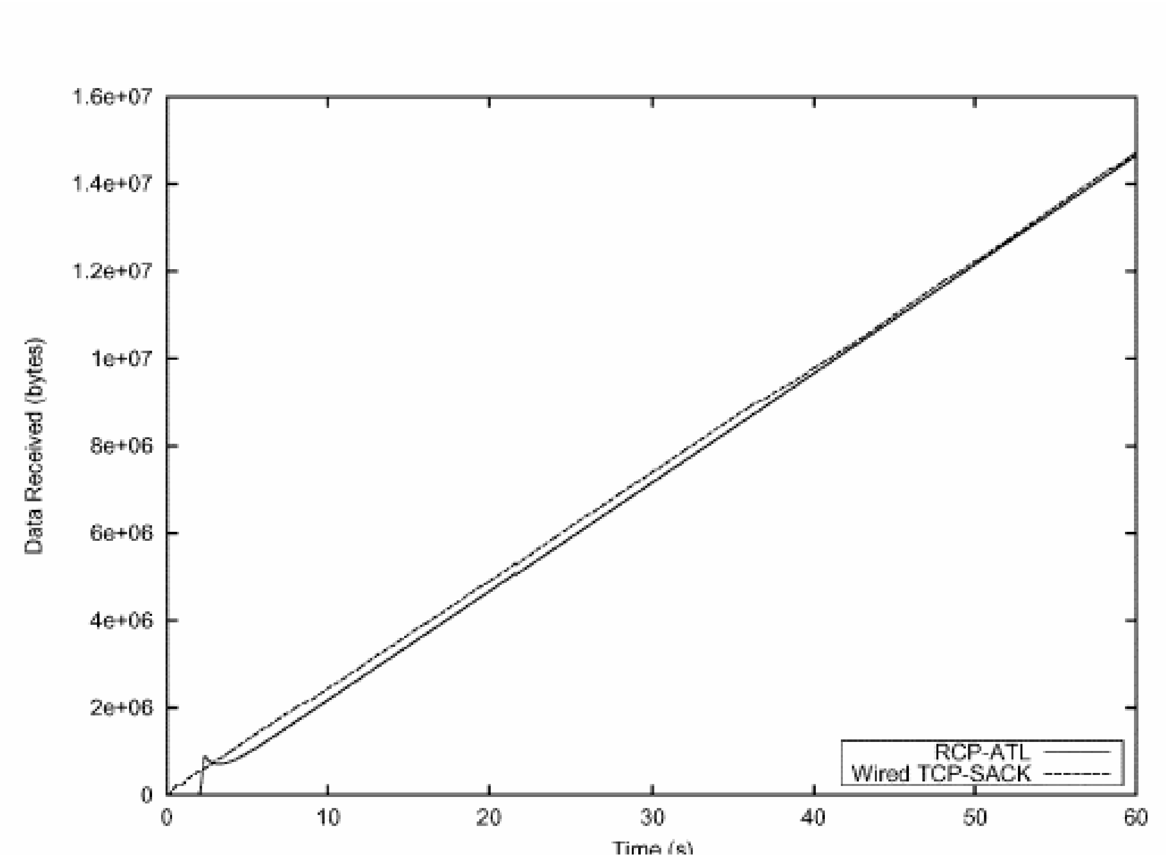
Goodput comparison of RCP-ATL and RCS for d_w =150 ms and varying p_w

Fairness



Intraprotocol fairness : Total bytes received by each of the RCP-ATL sinks with time for d_w= 10 ms and p_w =10^{-3} (6 RCP-ATL flows)

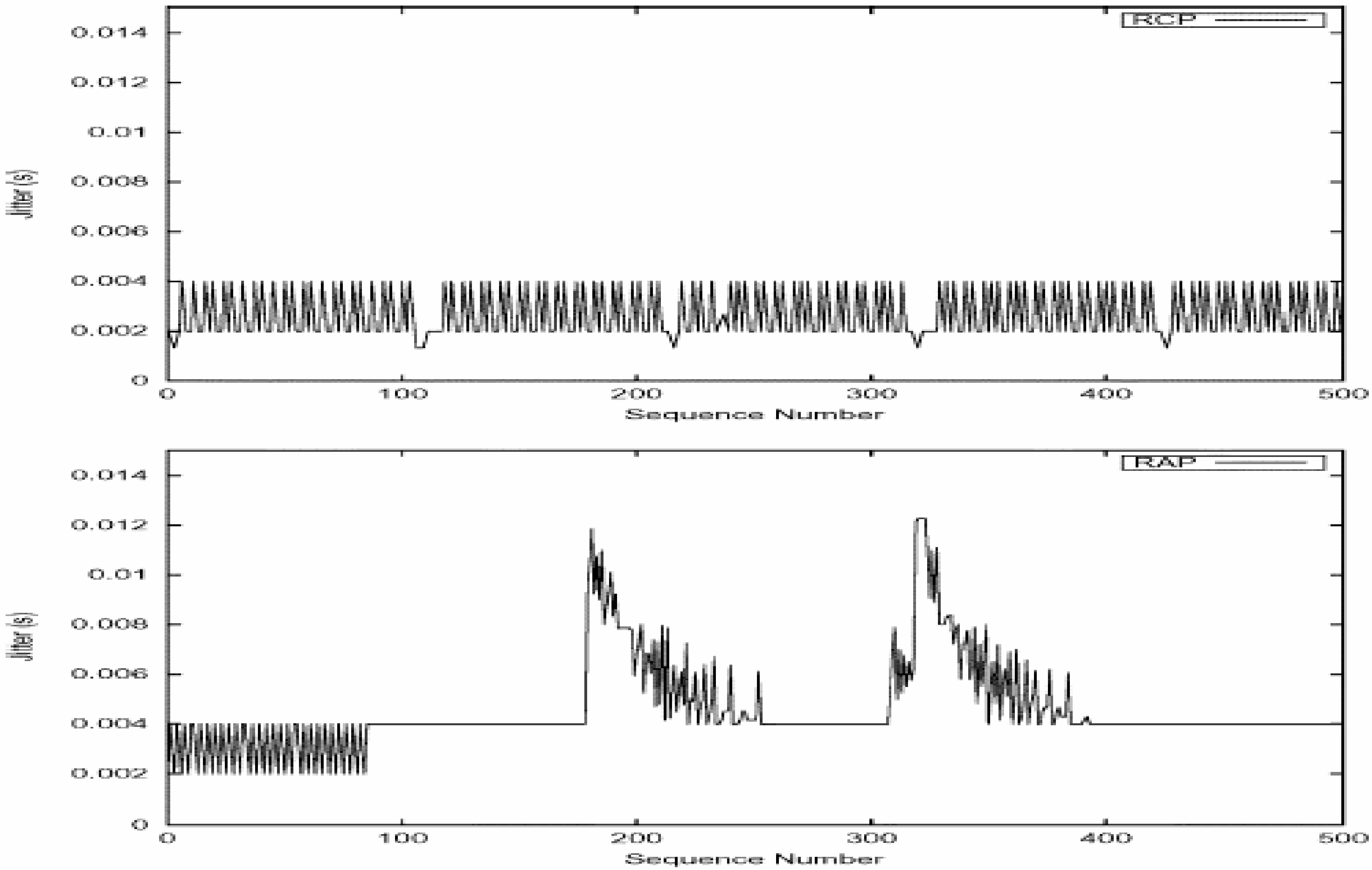
Fairness



Fairness to wired TCP flows: Total bytes received by RCP-ATL and wired TCP sinks with time for d_w=10 ms and $p_w = 10^{-3}$

5 TCP-ATL flows with a wireless link and 5 SACK-TCP flows without wireless link

Jitter Issues



Jitter experienced by the RCP-ATL and RAP packets for d_w=10 ms and p_w =10^{-4}

Conclusions

Unified ATL incorporates:

TCP – ATL : for reliable data transfer
RCP – ATL : for multimedia delivery in NGWI

- ATL protocols maintain high performance throughout different wireless architectures
- Provides Fairness
- No additional overhead
- Addresses Blackout solutions
- RCP-ATL improves jitter performance

Suited for reliable data and multimedia transport in NGWI

Limitations:

- Only considers single wireless link
- RCP-ATL depends on the formula (10) that may not be correct

Homework for Bonus Credit

- Find two bugs in the proof of Equation (10) provided in Appendix