Balancing Loss-Tolerance between Link and Transport Layers in Multi-Hop Wireless Networks

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We gratefully acknowledge support from Air Force/ESC Hanscom and MIT Lincoln Laboratory, Letter No. 14-S-06-0206

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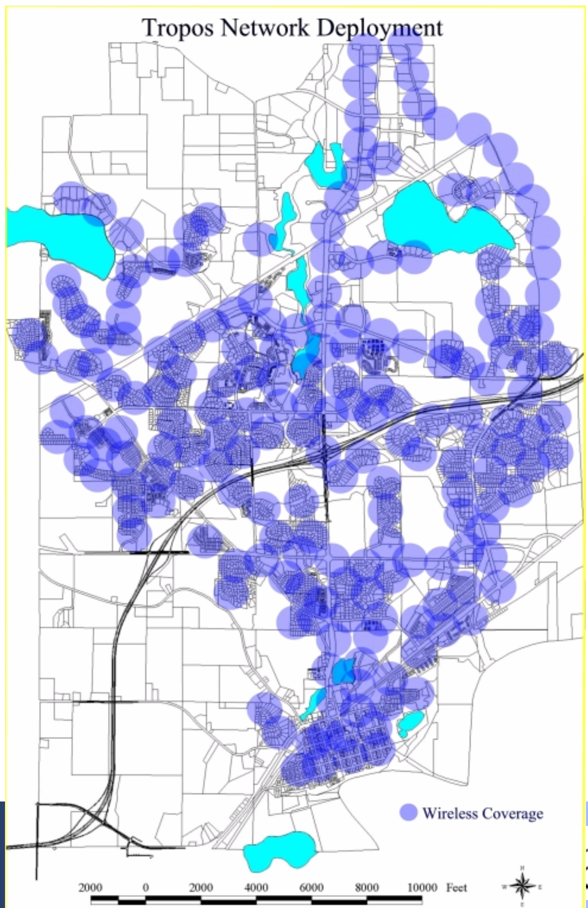
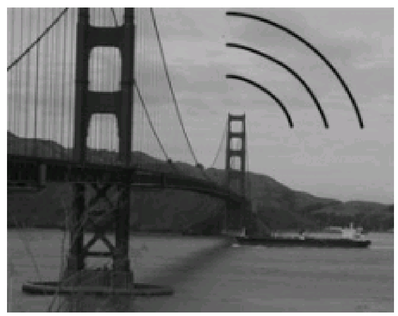
Multi-Tier NLOS MANETs & Meshes: Challenging Conditions for TCP/Link Layers

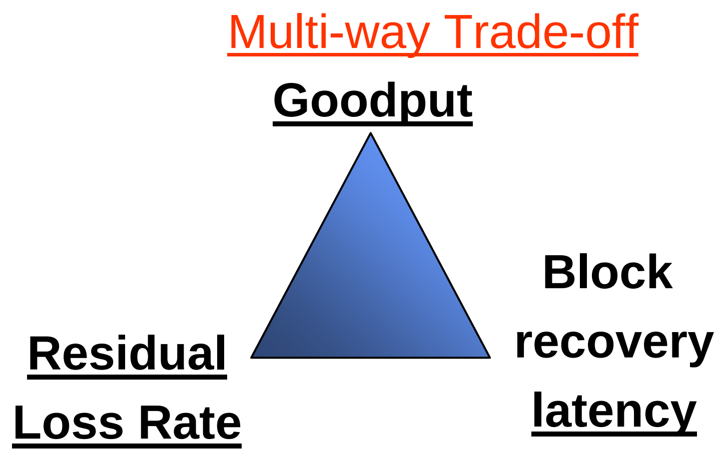




- Municipal Wireless Deployments / Community wireless networks / mesh networks will lead to poor performance caused by **low SNR and high interference**.
  - Tropos , Google Wifi
- Dense wireless deployments in urban areas/ high rises will cause disruptions/ burst errors due to interference.
- Preliminary studies such as Roofnet have reported high packet losses.
- Protocols need to be loss tolerant and provide reliability

Protocol Objectives

- **Dividing the burden of reliability between link and transport layers**
  - And also between proactive and reactive phases
- **Good performance over *multiple hops even at high loss rates*.**
- **Delay Control**
  - Link-latency should be as small as possible
- **Small Residual Loss Rate**
  - Transport layer should be exposed to a negligible residual loss rate
- **High Link-level Goodput**
  - Link-goodput determines user goodput and should be high
  - Translates to high Transport Layer Goodput



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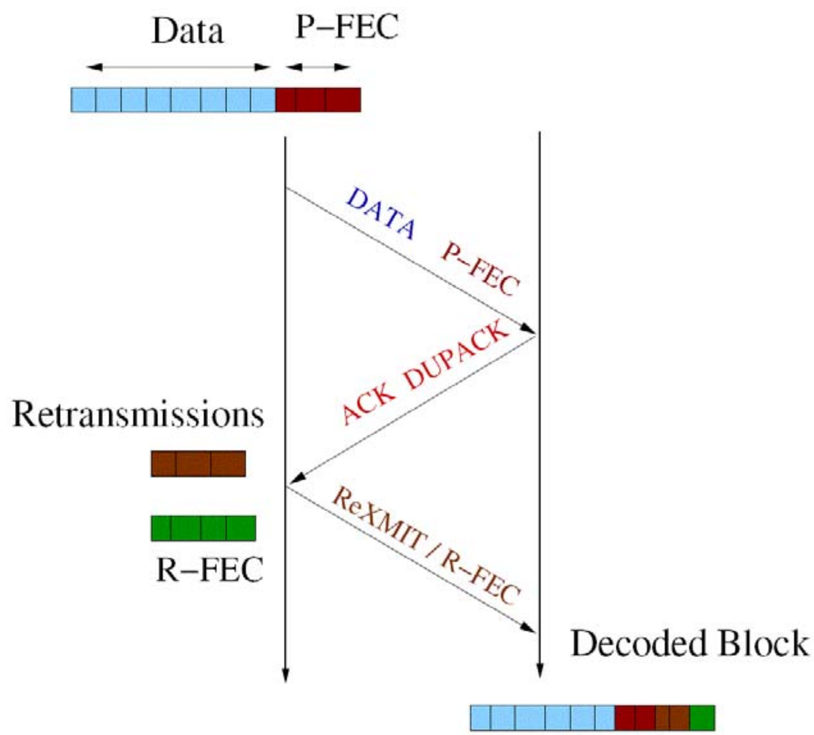
Building Blocks

- **Tools Available:**
  - Forward Error Correction (FEC)
    - » minimize wastage
  - Retransmissions (ARQ)
  - Loss Estimation
    - » dynamically tune the FEC
  - Adaptive Granulation
    - » How does varying the packet/fragment size at transport/ link layer help us?

What is the right mix of mechanisms to achieve loss tolerance and robustness?

LT-TCP, LL-HARQ Scheme Features

- **Loss Estimation using EWMA to estimate channel loss rate.**
- **Data granulation and block construction**
  - Block = Data + PFEC
  - RFEC stored for future use
- **Initial transmission consists of data + PFEC packets.**
- **Feedback from the receiver indicates the number of units still needed for recovery.**
- **RFEC packets are sent in response to the feedback.**
- **If k out of n units reach the receiver, the data packets can be recovered.**
- **LT-TCP at the transport layer and LL-HARQ at the link layer.**
- **LL-HARQ operates with a strict limit of 1 ARQ attempt to bound latency.**



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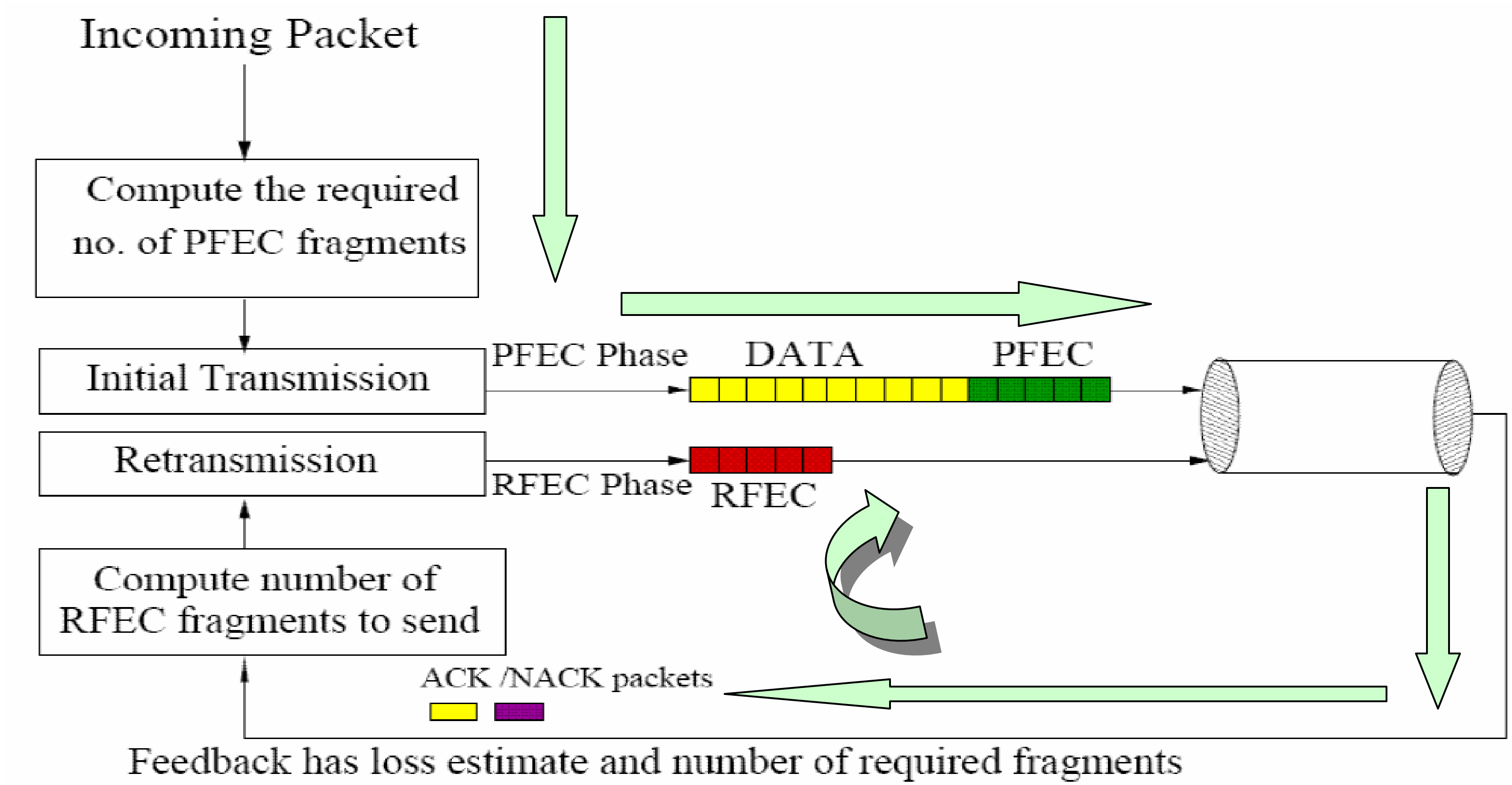
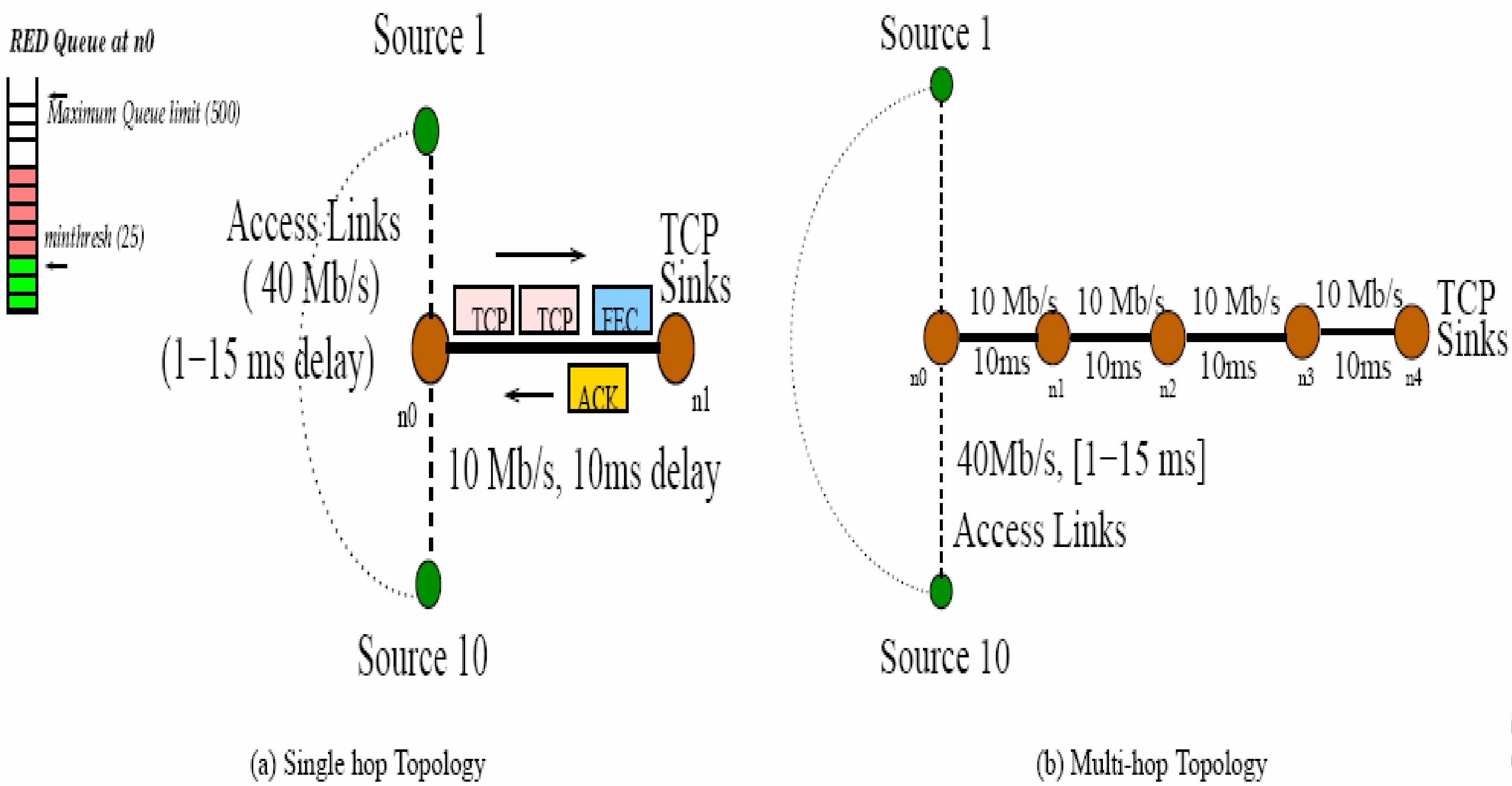
Protocol Framework



Achieving Balance Between Transport and Link Layers

- **We seek to achieve a division of labor between the transport and link layers.**
- **We want the link layer to do as much as possible.**
  - But current link approaches work too hard trading off
    - » Latency, due to high ARQ
    - » Goodput, with non-adaptive and *ad hoc* FEC.
- **With LT-TCP + LL-HARQ**
  - LL-HARQ works to minimize link residual loss rate but does not provide zero loss rate to TCP.
  - Over a single hop, residual loss rate is low enough for TCP-SACK to handle.
  - Over multiple hops, residual loss rate is too large for TCP-SACK.
  - LT-TCP, designed to be robust to loss can handle such scenarios.
  - LT-TCP + LL-HARQ give good performance even under worst case conditions.

Simulation Setup: 1-hop and 4 hops



Test Configurations: 1-Lossy Link Case and Multi-Hop Path Case. Each link is affected by the disruption error process as described.

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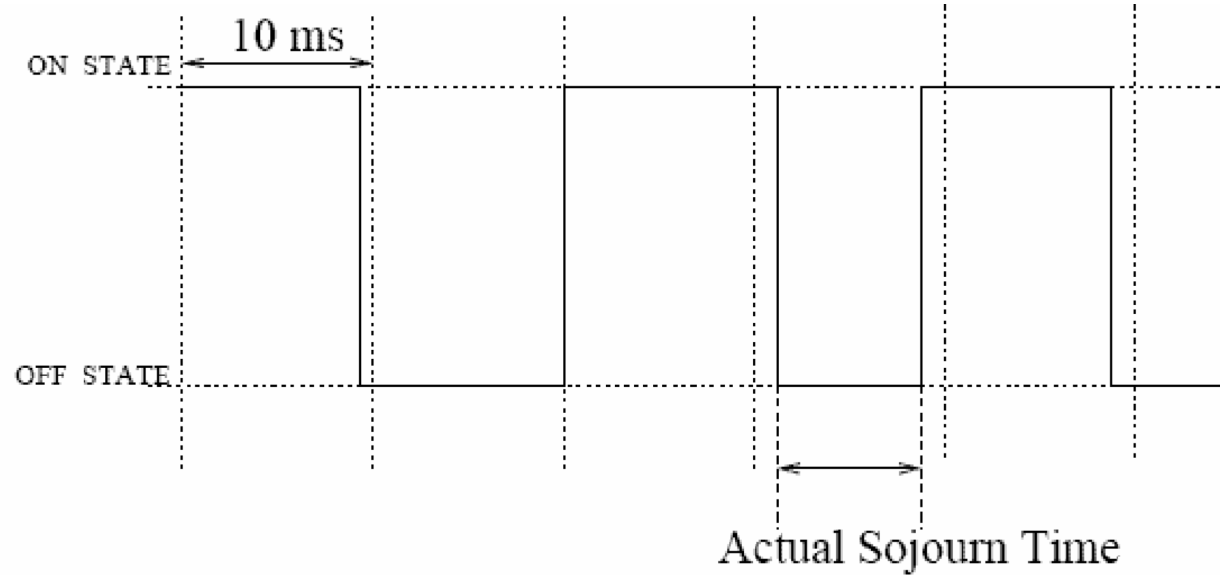
Simulation Parameters

- **LL-ARQ is the baseline protocol and it differs from LL-HARQ in the following:**
  - Number of ARQ attempts
  - FEC protection
- **Bursty Error Process:**
  - ON-OFF loss model
  - Error Rate in ON state = 1.5 times error rate in OFF state
  - Example: 50% PER = 25% PER in OFF and 75% PER in ON states.



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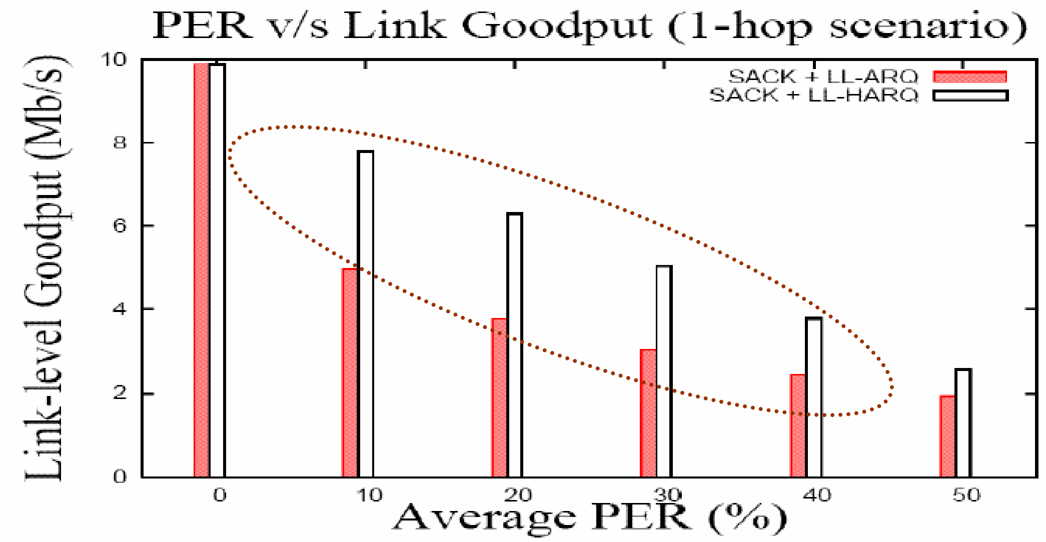
Link Level Goodput



Link-level goodput for the single hop topology.

- **Compare the performance at the link layer for the baseline transport protocol (TCP-SACK)**
- **We see that LL-HARQ is able to significantly outperform LL-ARQ**
- **Per hop link latency is much better with LL-HARQ than with LL-ARQ.**

10 Flows, 4 hops	AVERAGE PACKET ERROR RATE					
Average Link Latency (ms)	0 %	10 %	20 %	30 %	40 %	50 %
LL-ARQ	10.83	32.18	45.63	59.64	80.19	98.80
LL-HARQ	10.83	14.21	15.15	17.04	18.47	19.01

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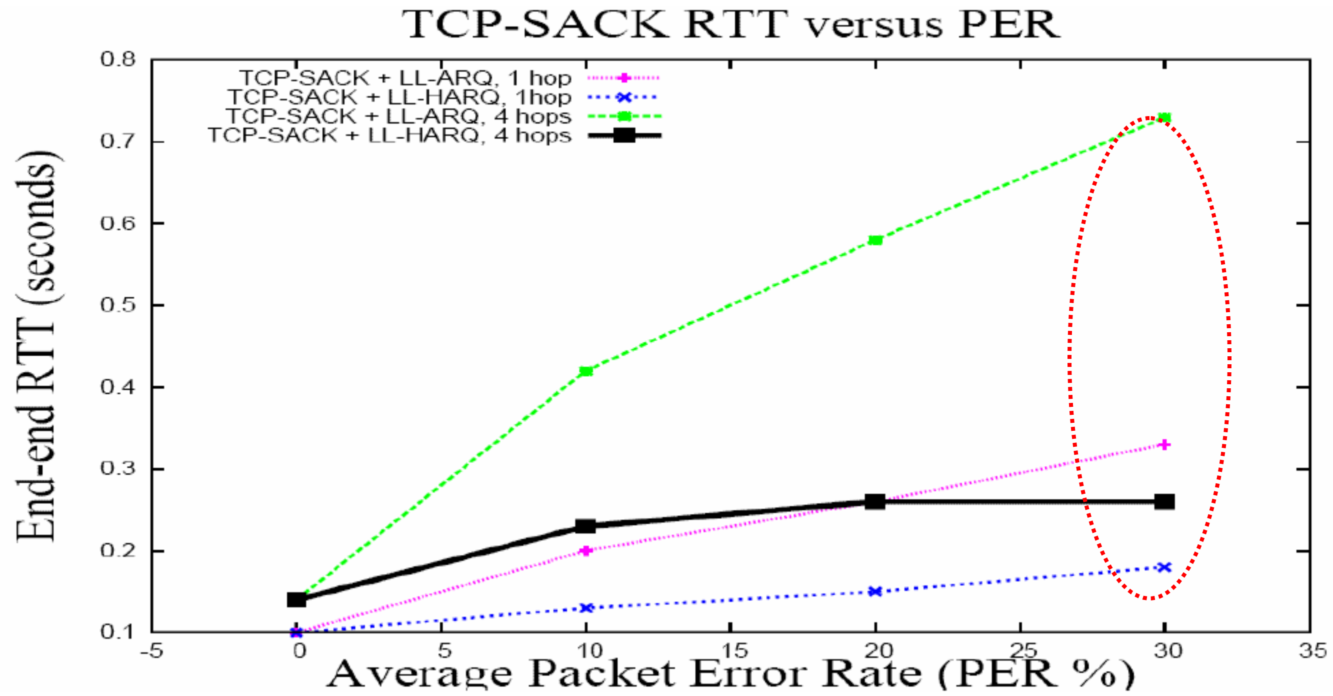
End-End Delay

- **We study the effect on the link protocol on the end-end RTT.**
- **As seen, with LL-ARQ, per hop latency is high.**
- **Over multiple hops, this translates to unacceptably high end-end delay.**
- **The high service time of LL-ARQ translates to low transport goodput.**

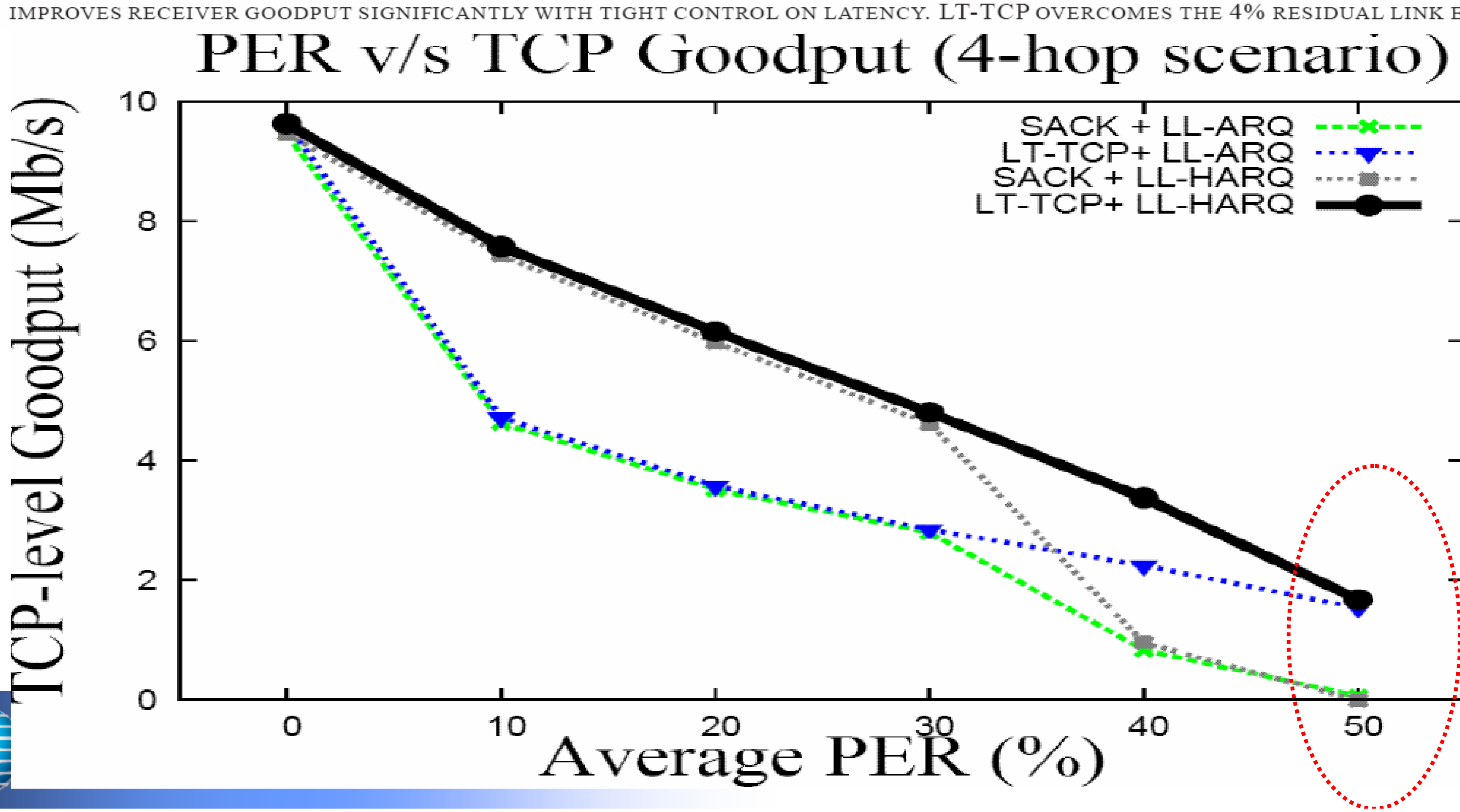


Transport Layer Goodput

10 Flows, 4 hops	AVERAGE PACKET ERROR RATE					
PARAMETER	0 %	10 %	20 %	30 %	40 %	50 %
Receiver Goodput(Mb/s)	**9.63**	**7.58**	**6.16**	**4.81**	**3.38**	**1.68**
CI Bounds (Goodput)	[9.62,9.64]	[7.56,7.61]	[6.12,6.19]	[4.78,4.85]	[3.38,3.38]	[1.62,1.74]
Link level Residual Loss Rate	**0.00**	**0.00**	**0.01**	**0.08**	**0.61**	**3.99**
Link level Goodput	**9.93**	**7.81**	**6.35**	**5.02**	**3.77**	**2.41**
Average Link Latency (ms)	**11.08**	**14.69**	**15.65**	**17.73**	**19.36**	**20.08**

TABLE I

10 FLOWS, 4 HOP TOPOLOGY, ON-OFF ERROR MODEL: **LT-TCP+LL-HARQ** PERFORMANCE FOR DIFFERENT LOSS RATES. THE COMBINATION IMPROVES RECEIVER GOODPUT SIGNIFICANTLY WITH TIGHT CONTROL ON LATENCY. LT-TCP OVERCOMES THE 4% RESIDUAL LINK ERROR RATE.



Summary

- **Higher data rates/ smaller cells / dense deployments will lead to high packet loss rates on wireless networks.**
- **We look at independent yet similarly designed protocols at the transport and link layers.**
- **Key Goals:**
  - High Link goodput → high transport performance
  - Low latency on link layer to keep end-end delay low on multihop paths.
  - Low residual loss rate desired
- **Key building blocks are**
  - Loss Estimation
  - Data Granulation into Blocks
  - Adaptive FEC (provisioned as proactive and reactive)
    - » No FEC provisioned if there is no loss
  - Tight Delay control at the link layer
- **Results show that LT-TCP and LL-HARQ complement each other to yield synergistic benefits.**
  - Performance is better compared to TCP-SACK / LL-ARQ combinations.