Transport Layer Caching Mechanisms and Optimization

ICCRG meeting @ IETF-85, Atlanta, GA, USA

Nestor Tiglao
INESC-ID/IST
nestor.tiglao@inesc-id.pt

inesc id lisboa

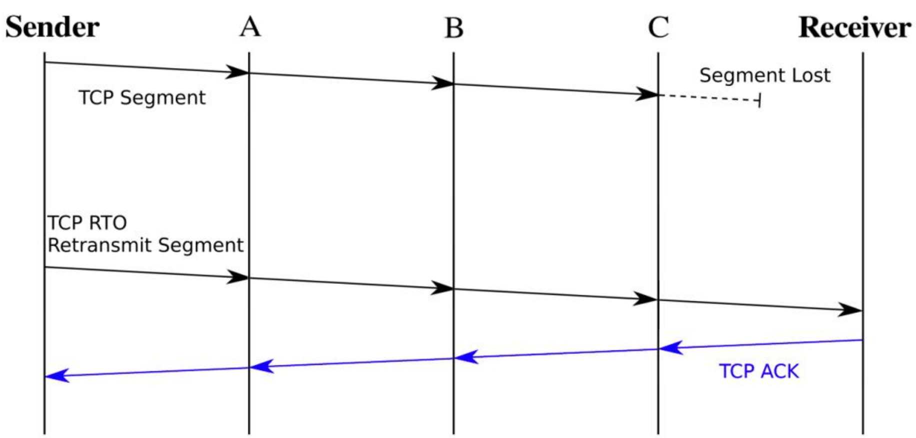
INSTITUTO SUPERIOR TÉCNICO

Outline

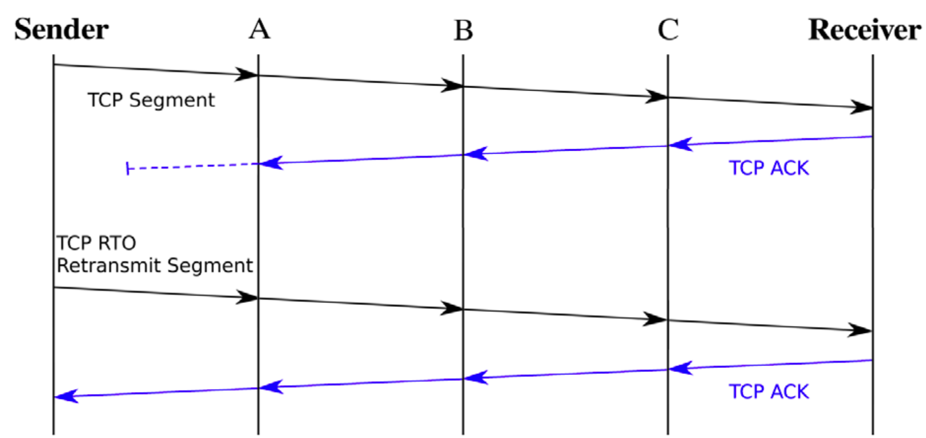
- Background
- Transport layer caching model
- Main results
- Related IETF work
- Congestion Control
- Summary

Poor TCP Performance in Wireless Multi-hop Networks

- Higher bit error rates and packet loss
- Underlying MAC protocols (exponential back-off, hidden/exposed nodes)
- TCP end-to-end error and congestion control mechanisms



TCP Segment loss

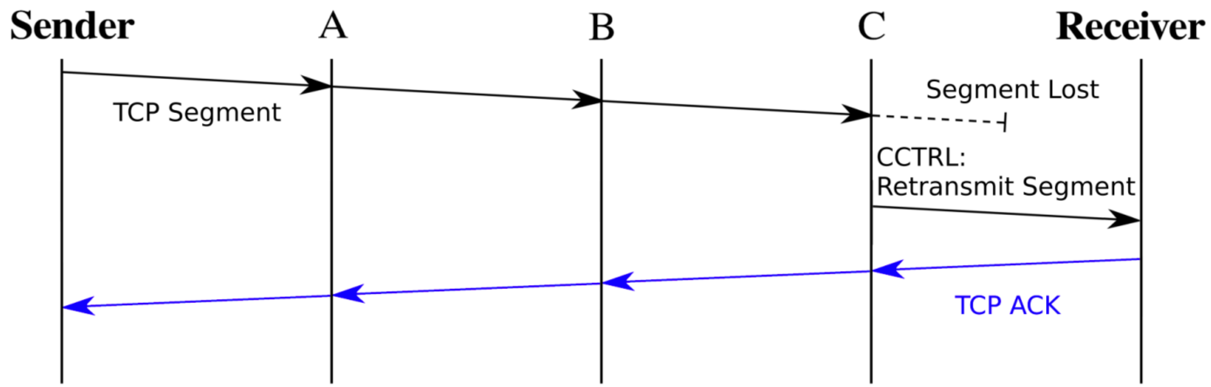


TCP ACK loss

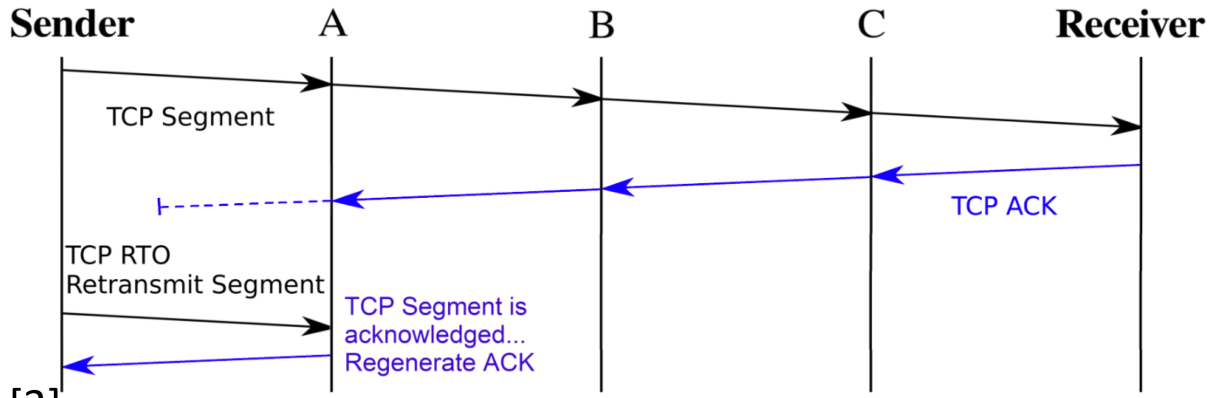
Reference: [3]

Proposed Solutions

- Distributed TCP Caching (Dunkels et al., 2004)



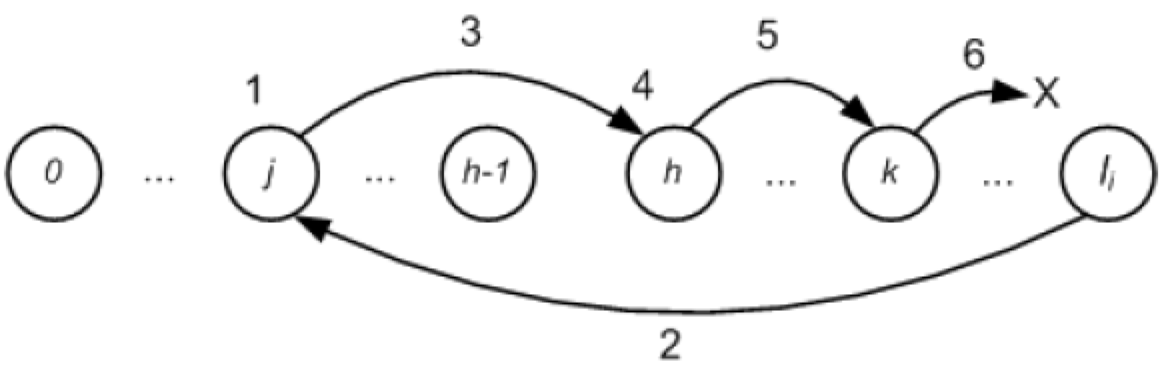
- TCP Support for Sensor Networks (Braun et al., 2007)



Reference: [3]

Transport Layer Caching Model

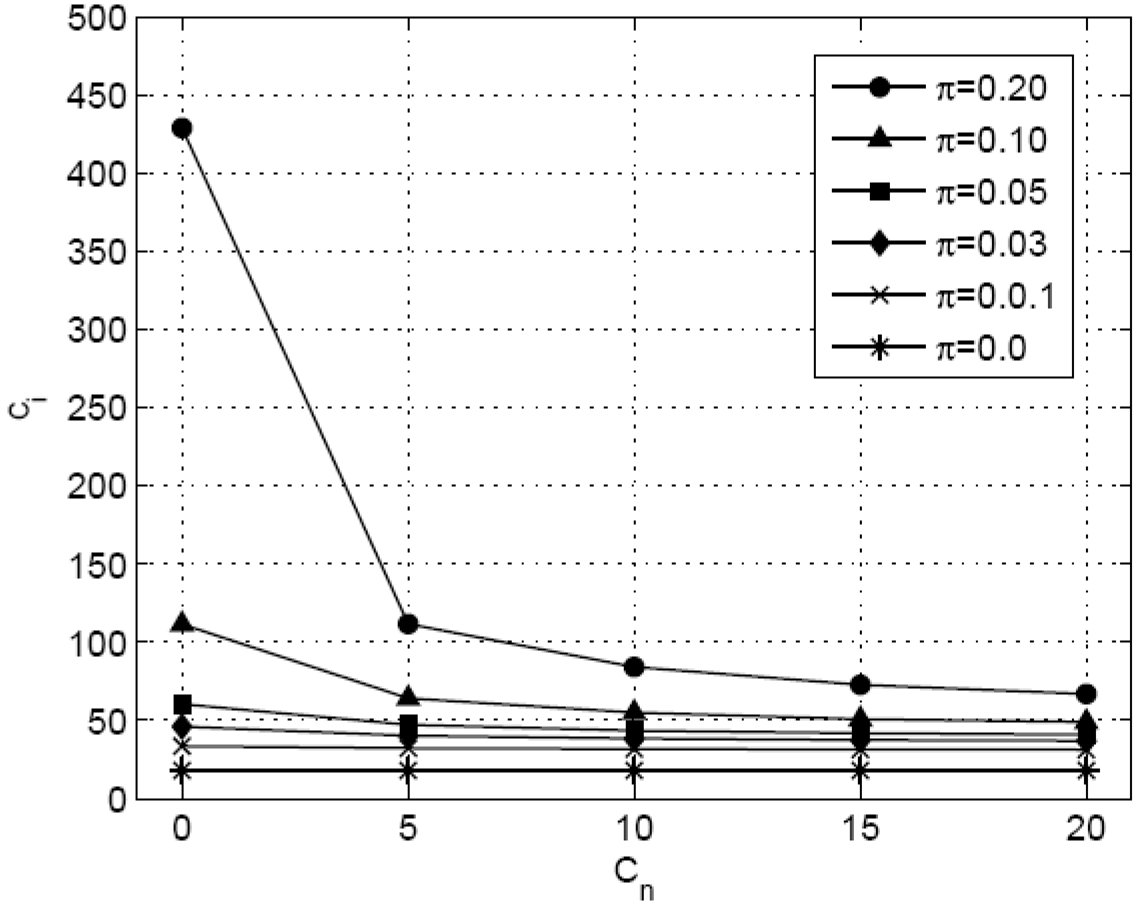
- Analyze benefit of intermediate caching in lossy networks, e.g., wireless sensor networks
- Probabilistic model
  - Link-layer component
  - Transport-layer component
- Define: Probability of Effective Progress of the packet, $PEP_i(t,h)$



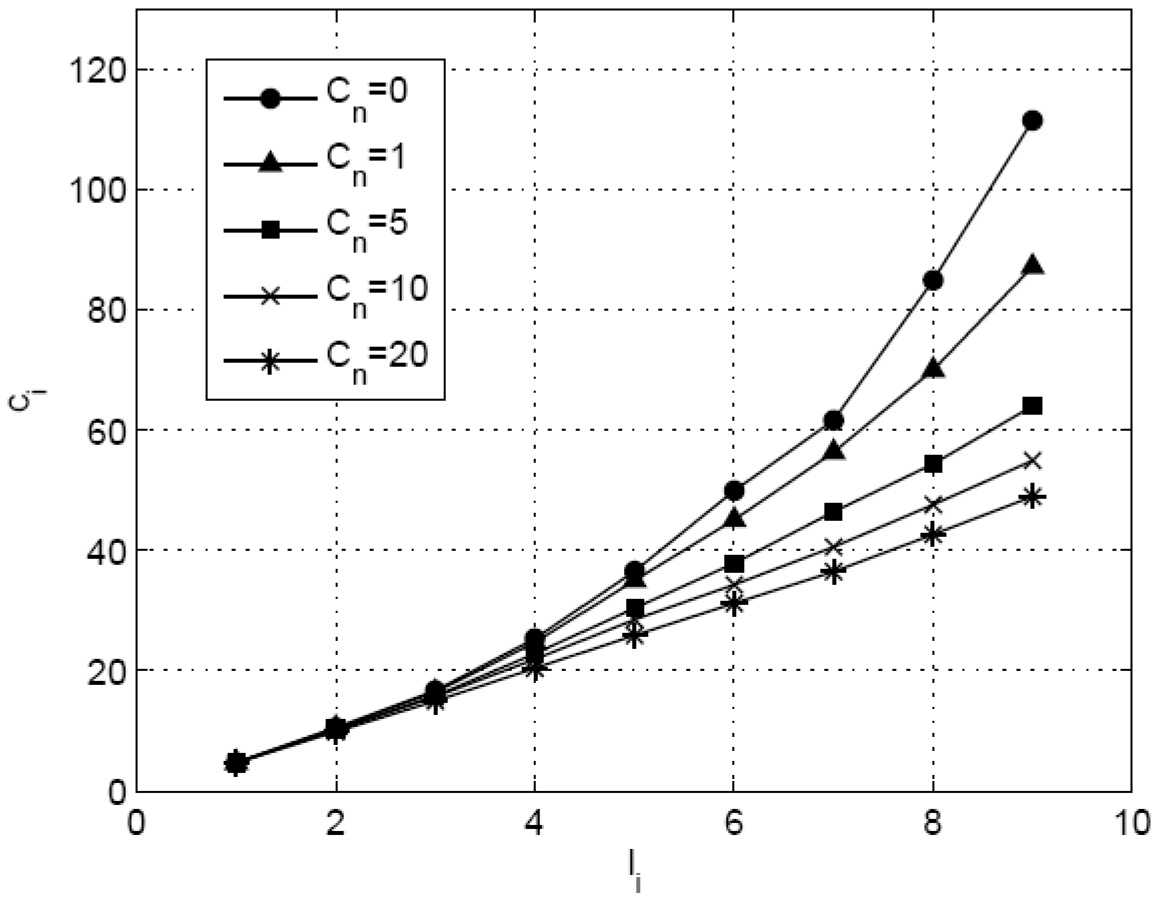
Analytical Results

- Reliable delivery
- Based on DTSN semantic – DATA, NACK, MACK (MAC –layer ACK)
- RTS/CTS disabled
- Performance metric: Transmission cost, c_i
- Function of cache size, C_n
- Effective error probability associated with the transmission of a packet taking into account the maximum number of MAC retries, π

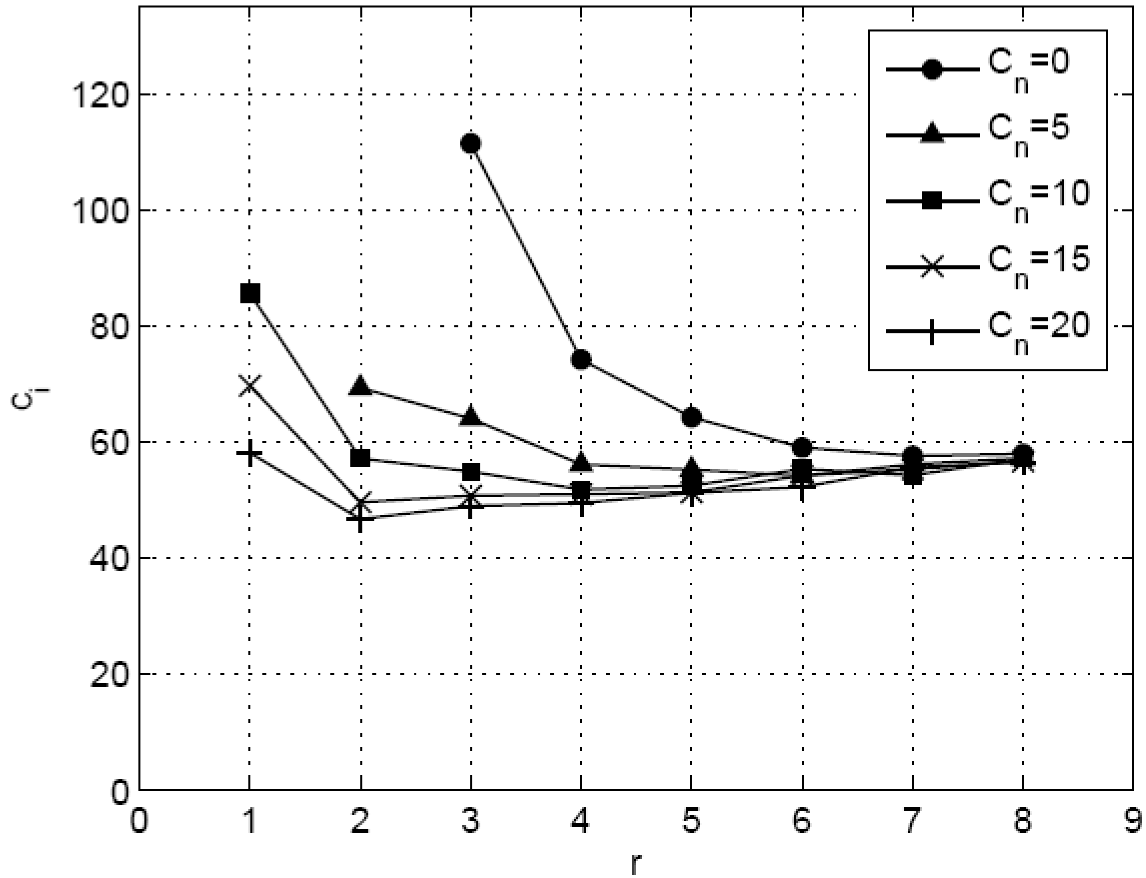
Analytical Results
Single flow: Cost vs. Cache Size



Analytical Results
Single flow: Cost vs. Hop Length



Analytical Results
Single flow: Cost vs. Retry Limit



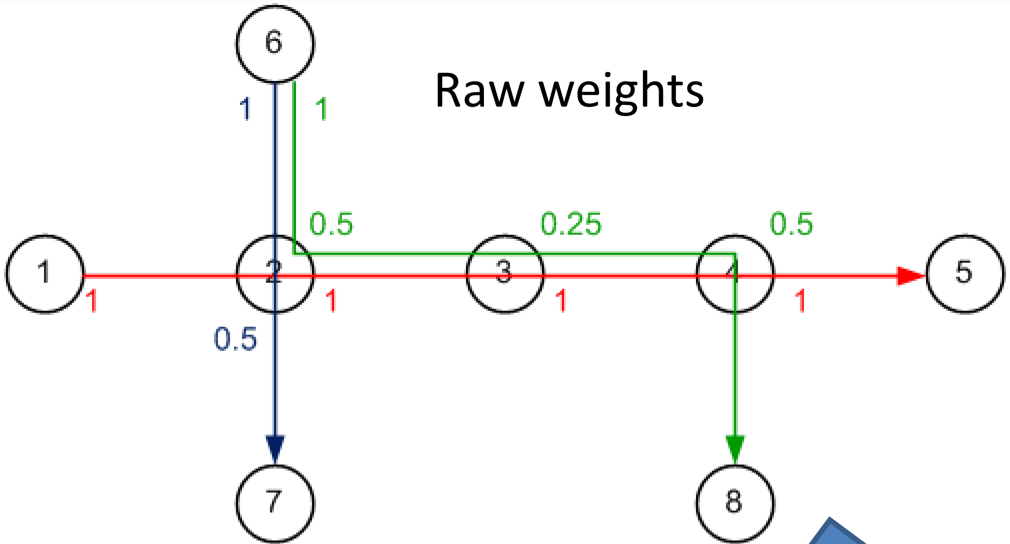
Analytical Results
Concurrent flows: Cache Partitioning

- Caching weight assigned to flow *i* at node *n*, ω_i^n
- At each node, fraction of cache memory allocated to each flow *i* that crosses the node *n*

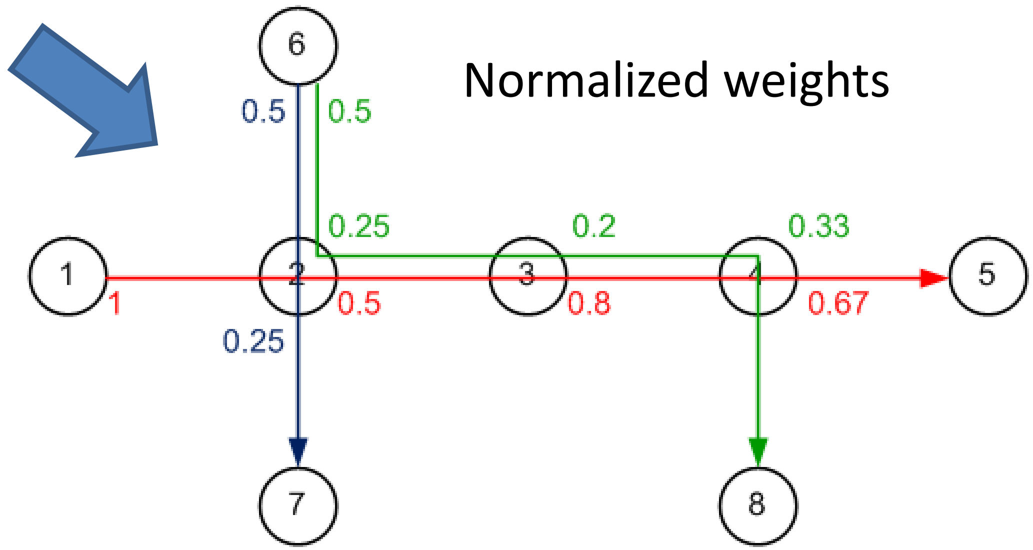
$$\rho_i^n = \frac{\omega_i^n}{\sum_{j=1}^{F_n} \omega_j^n}$$

- Cache Partitioning Policies
  - Uniform
  - Increasing
  - Decreasing
  - U Shape
  - Inverted U Shape

Cache Partitioning Example



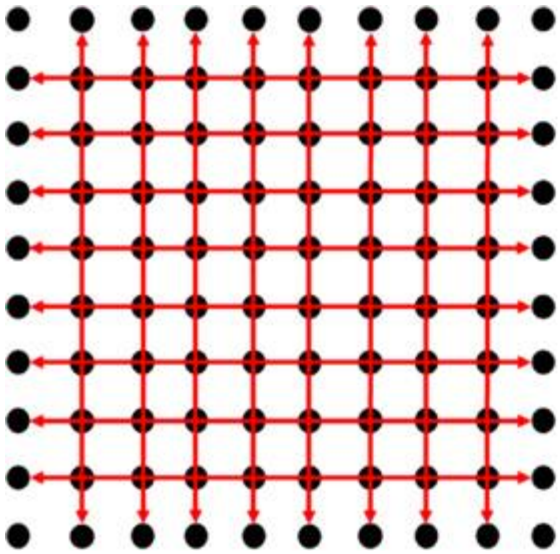
Raw weights



Normalized weights

Red flow – Uniform
Blue flow – Decreasing
Green flow – U Shape

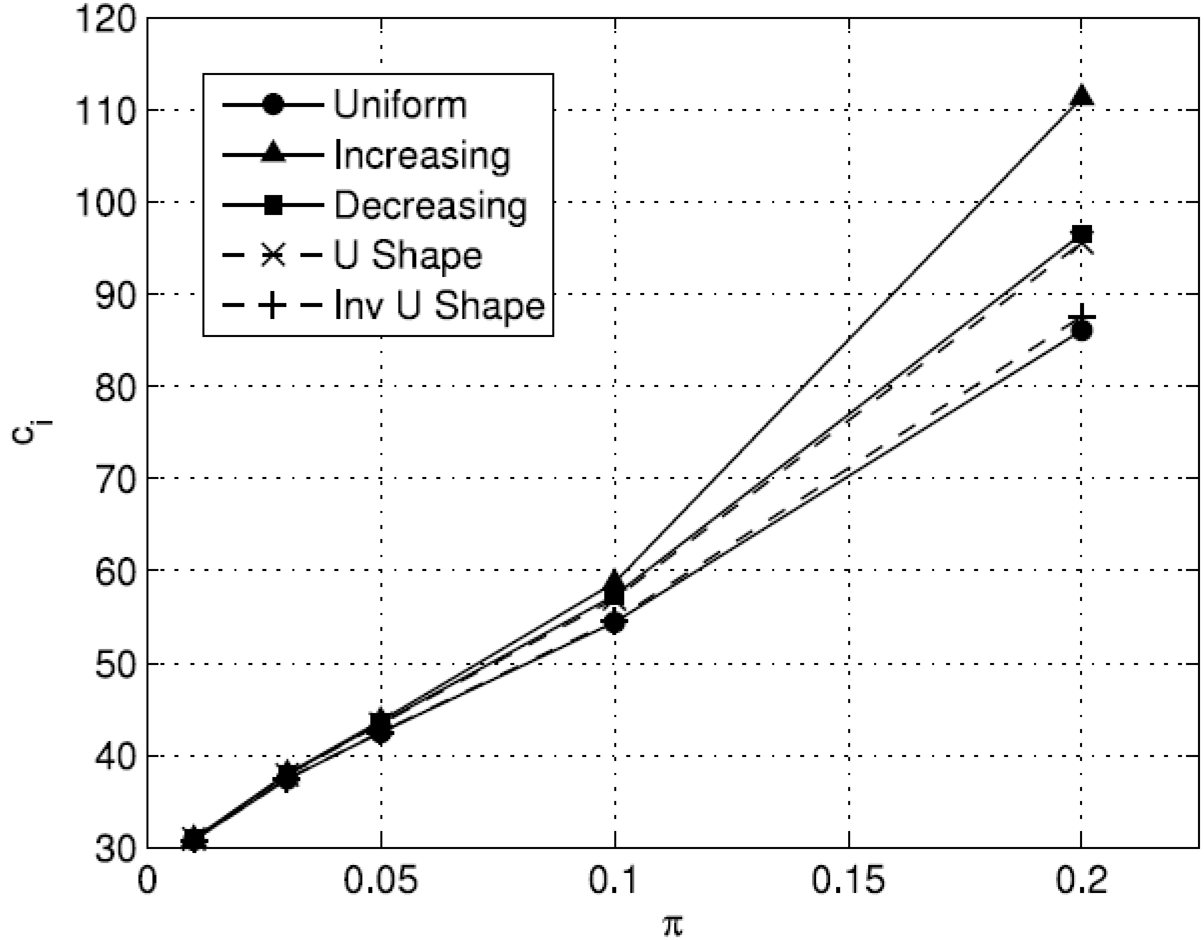
Concurrent Flows
Grid Topology



Concurrent flows: 10x10 Grid Network Uniform Error Rates

$C_n = 20$

$l_i = 9$



Concurrent Flows
Non-uniform Error Rates

- Heuristic: assign higher weight to flows experiencing higher error rates and with greater hop length

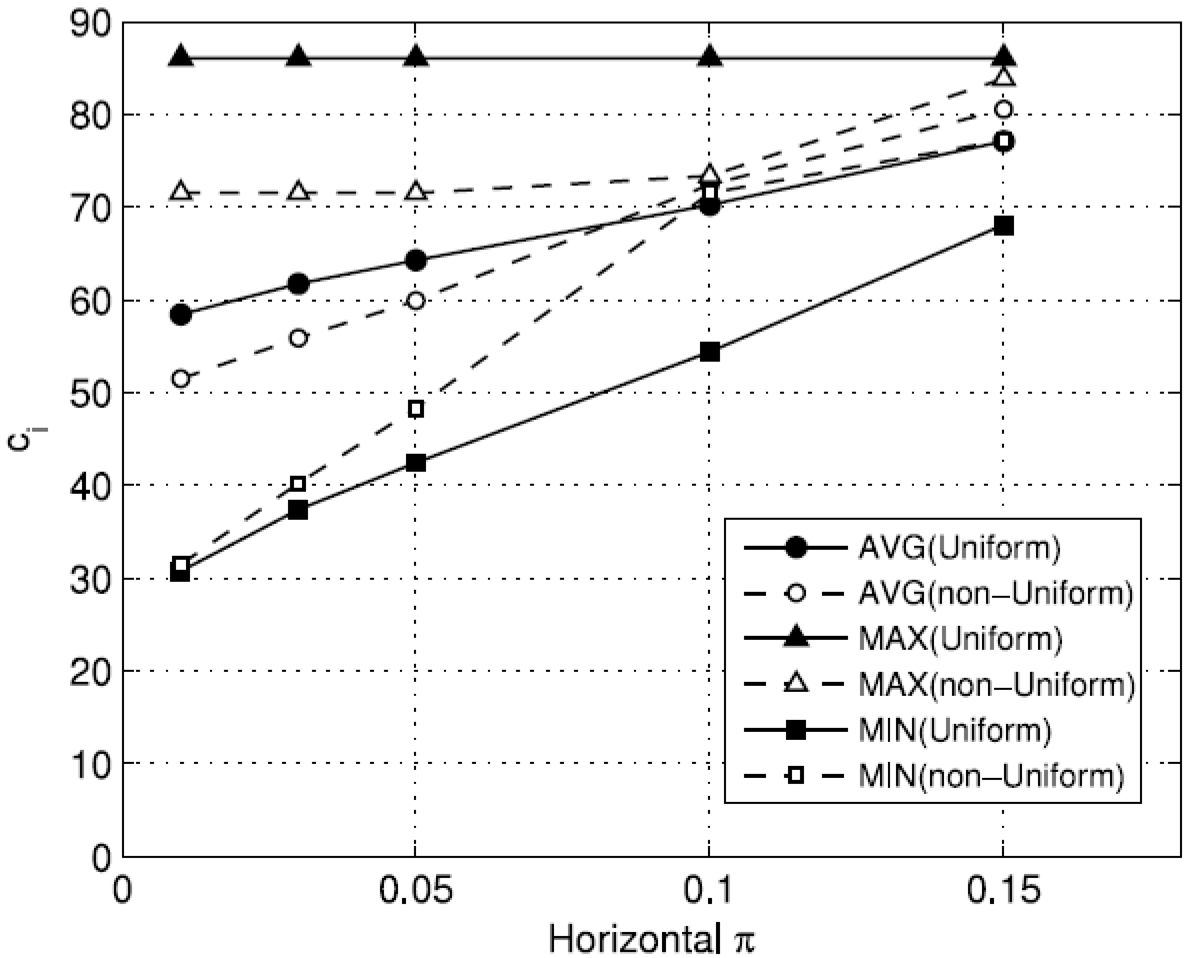
$$\omega_i^{\varphi_i(k)} = (\pi_{\varphi_i(k),\varphi_i(k+1)}^{DATA} \cdot \pi_{\varphi_i(k+1),\varphi_i(k)}^{NACK})^{\alpha} (l_i)^{\beta}$$

Concurrent Flows : 10x10 Square Network Non-uniform Error Rates

vertical $\pi = 0.2$

$C_n = 20$

$l_i = 9$

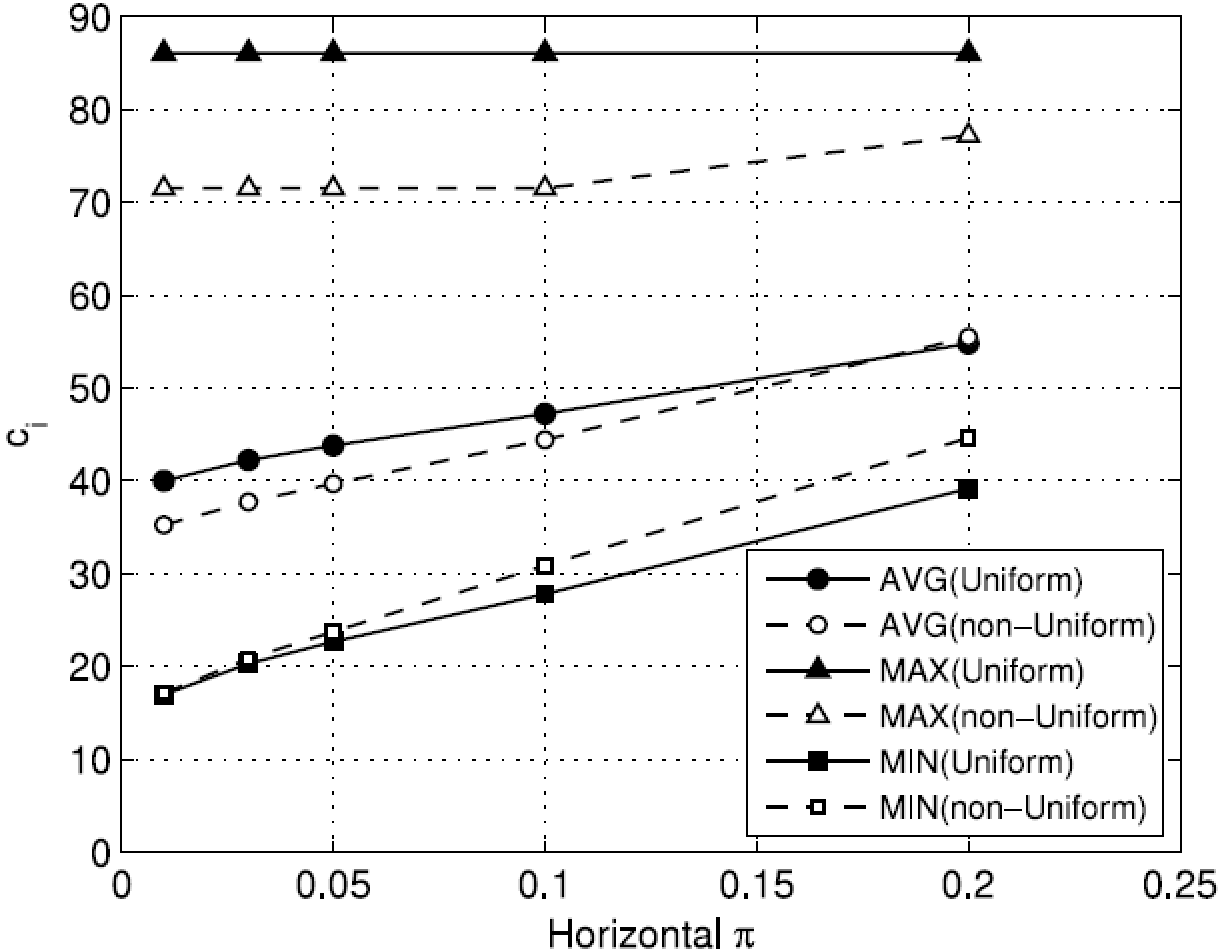


Concurrent Flows : 9x5 Rectangular Non-uniform Error Rates

vertical $\pi = 0.2$

$C_n = 20$

$l_i = 9$

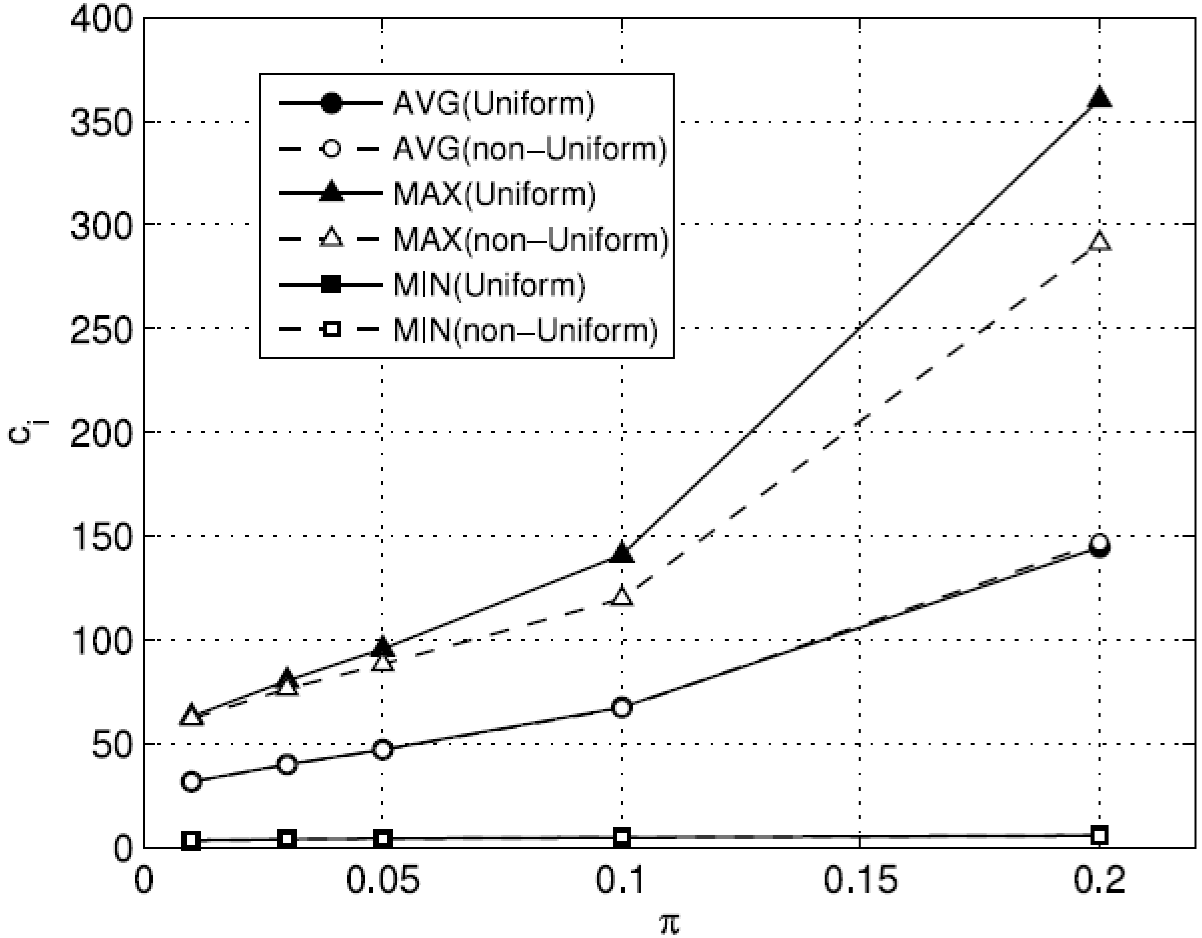


Concurrent Flows : 10x10 Grid Convergecast Pattern

1 sink node

99 source nodes

$C_n = 20$



Simulation Results

- ns-2 simulator
- Performance evaluation
  - Better energy efficiency
  - Improve goodput
  - Better delay performance
  - Can improve fairness (Jain's fairness index)
- Refer to [7]

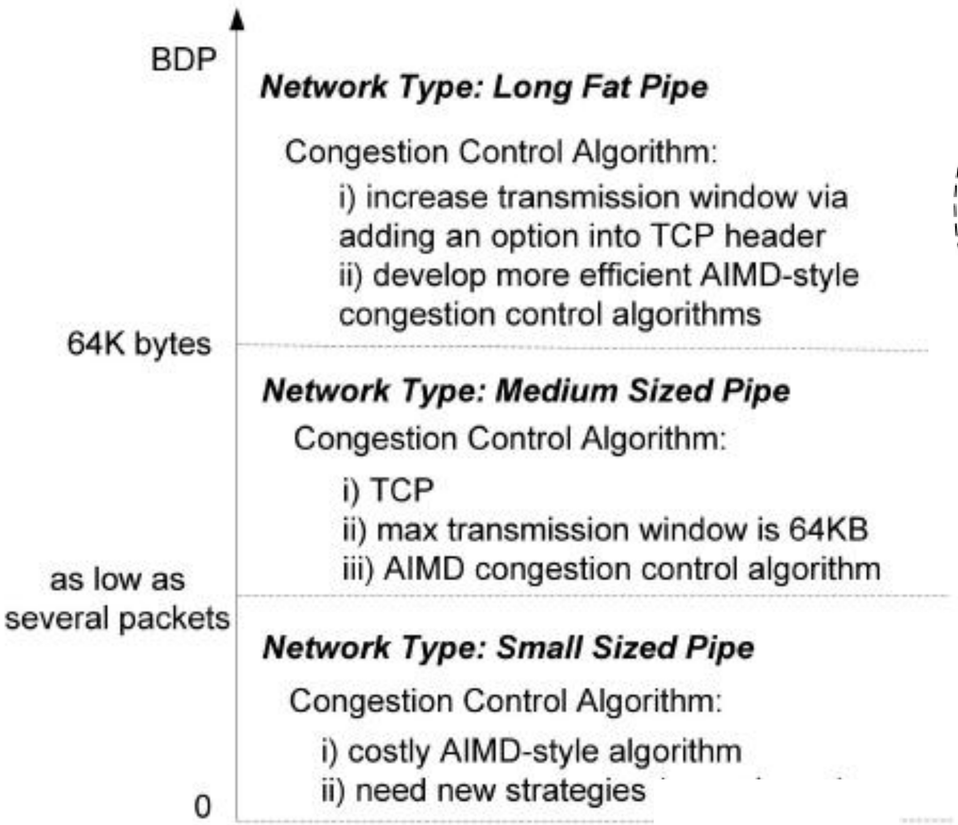
CA-TCP (draft-sarolahti-irtf-catcp-00)

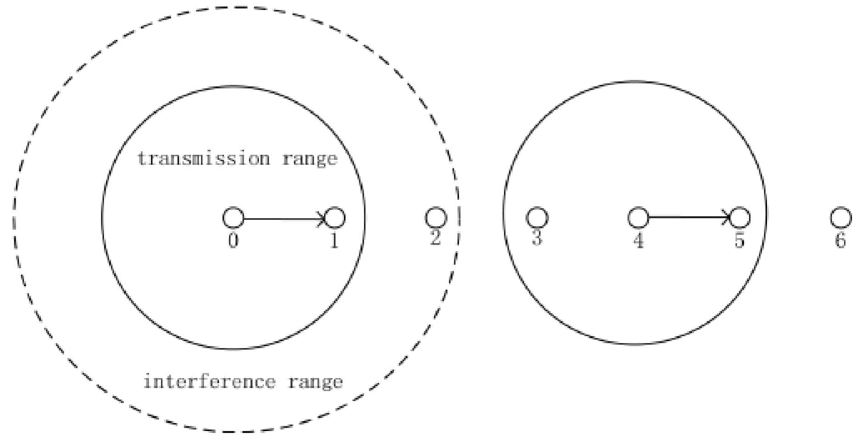
- TCP options
  - Cachable segments are supplied with a “Content Label”
  - TCP ACKs contain “Content Request”
- Cache can send segments on behalf of the sender
- Perhaps cache partitioning can be explored
  - Example: CDNs

Congestion Control

- Window-based/Rate-based
  - AIMD approach
- Bandwidth Delay Product (BDP-based)
  - BDPs represent the maximum amount of unacknowledged data that are allowed in flight at any moment
  - Multi-hop wireless networks based on spatial reuse, e.g. 802.11 MAC, BDP = 1/4 x path length

Congestion Control Dependency on BDP





BDP of an n-Hop Linear Chain

Number of Hops	BDP
1, 2, 3	1
4, 5, 6	2
7, 8, 9	3
10	4

Reference: [6]

Summary

- Transport layer caching can significantly improve performance in loss recovery
- Cache partitioning is crucial
- New approaches to congestion control
- Possible applications
  - Enhancements to CA-TCP
  - Caching-enabled transport protocol for LLNs
  - Caching in 6LoWPAN fragmentation recovery, http://tools.ietf.org/html/draft-thubert-6lowpan-simple-fragment-recovery-07

Thank you!

References

1. Nestor Michael C. Tiglao, António M. Grilo, An analytical model for transport layer caching in wireless sensor networks, Performance Evaluation, Volume 69, Issue 5, May 2012, Pages 227-245, ISSN 0166-5316.
2. Marchi, Bruno, António Grilo, and Mário Nunes. DTSN: distributed transport for sensor networks. *Computers and Communications, 2007. ISCC 2007. 12th IEEE Symposium on*. IEEE, 2007.
3. Philipp Hurni, Ulrich Bürgi, Markus Anwander, and Torsten Braun. 2012. TCP performance optimizations for wireless sensor networks. In Proceedings of the 9th European conference on Wireless Sensor Networks (EWSN'12), Gian Pietro Picco and Wendi Heinzelman (Eds.). Springer-Verlag, Berlin, Heidelberg, 17-32.
4. Dunkels, Adam, et al. Distributed TCP Caching for Wireless Sensor Networks. *Proceedings of the 3 rd Annual Mediterranean Ad-Hoc Networks Workshop*. 2004.
5. Braun, Torsten, Thiemo Voigt, and Adam Dunkels. TCP support for sensor networks. *Wireless on Demand Network Systems and Services, 2007. WONS'07. Fourth Annual Conference on*. IEEE, 2007.
6. Xia Li; Peng-Yong Kong; Kee-Chaing Chua; , DTPA: A Reliable Datagram Transport Protocol over Ad Hoc Networks, *Mobile Computing, IEEE Transactions on* , vol.7, no.10, pp.1285-1294, Oct. 2008
7. Tiglao, N; Grilo, A., Optimal Cache Partitioning in Reliable Data Transport for Wireless Sensor Networks, Proceedings of the 4th Workshop on Network Control and Optimization – NETCOOP'10, Ghent, Belgium, pp. 90-96, Nov. 29-Dec. 1, 2010.