Measurement and Modeling of the Origins of Starvation in Congestion Controlled Mesh Networks

Jingpu Shi, Omer Gurewitz, ***Vincenzo Mancuso***, Joseph Camp, and Edward W. Knightly

vincenzo.mancuso@ieee.org

Rice Networks Group

Università degli Studi di Palermo

Objectives

Origins of starvation

- Demonstrate analytically as well as experimentally that the basic scenario of any CSMA-based Mesh Networks is sufficient to induce starvation

Counter-Starvation Policy

- Suggest a simple solution which is supported by standard 802.11 protocols

Overview

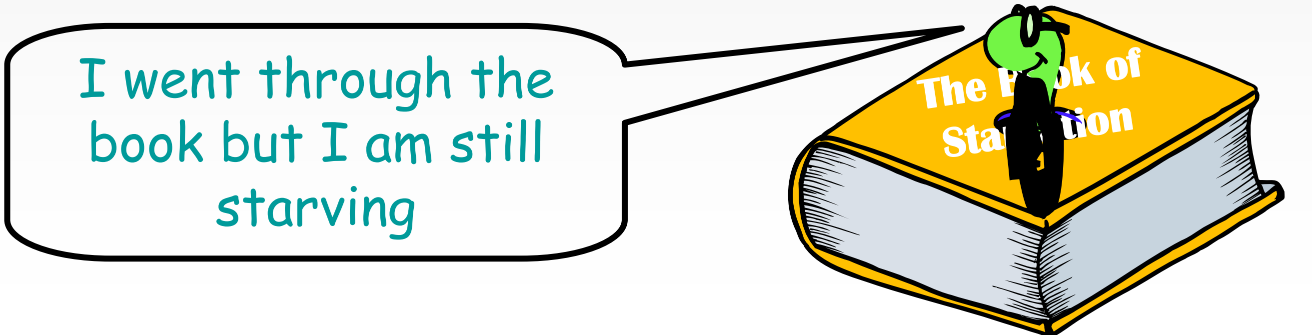
- Previous work showed that severe unfairness can occur in multihop wireless networks due to MAC behavior
  - e.g., M. Garetto, J. Shi, and E. Knightly, "*Modeling Media Access in Embedded Two-Flow Topologies of Multi-hop Wireless Networks*". ACM MobiCom 2005.
- It has been shown that TCP magnifies MAC unfair contention
  - e.g., S. Lee K. Xu, S. Bae and M. Gerla, "*Tcp behavior across multihop wireless networks and the wired internet*", WOWMOM 2002.
- Solutions were suggested
  - ***Z. Fu, P. Zerfos, H. Luo, S. Lu, L. Zhang, and M. Gerla, INFOCOM'03 – LRED, Fixed window based on the hop count***
  - ***K. Sundaresan, V. Anantharaman, H. Hsieh, and R. Sivakumar, MobiHoc'03 – ATP***
  - ***T. Jimenez and E. Altman, PWC'03 – delayed TCP ack***

However...

Our prior understanding of “why starvation occurs” is incorrect and has yielded solutions that are not effective

e.g.,

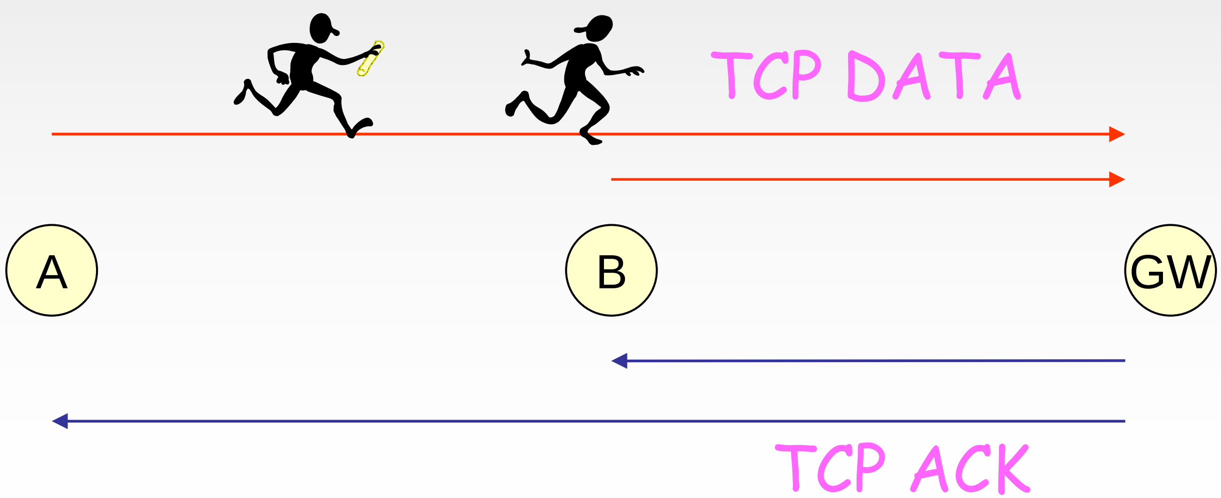
- it is believed that TCP pacing/smart dropping with the optimal pacing rate solves this but
  - we will show that any rate yields starvation
- it is also believed that limiting or fixing TCP window to a small value is sufficient to induce fairness and
  - we will show that even a fixed TCP window of one packet can be enough for severe throughput imbalance



Basic Scenario of Mesh Network

- At least one Mesh Point for packet relay
  - Three node network
    - Node GW - Wired gateway
    - Node A and Node B – Mesh Points

- At least two TCP flows

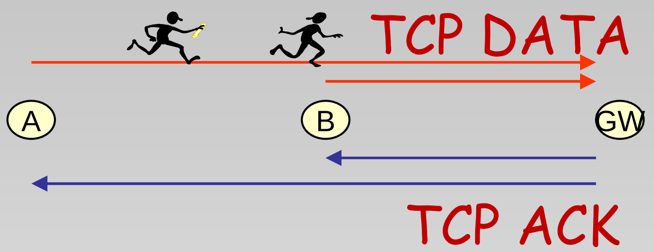


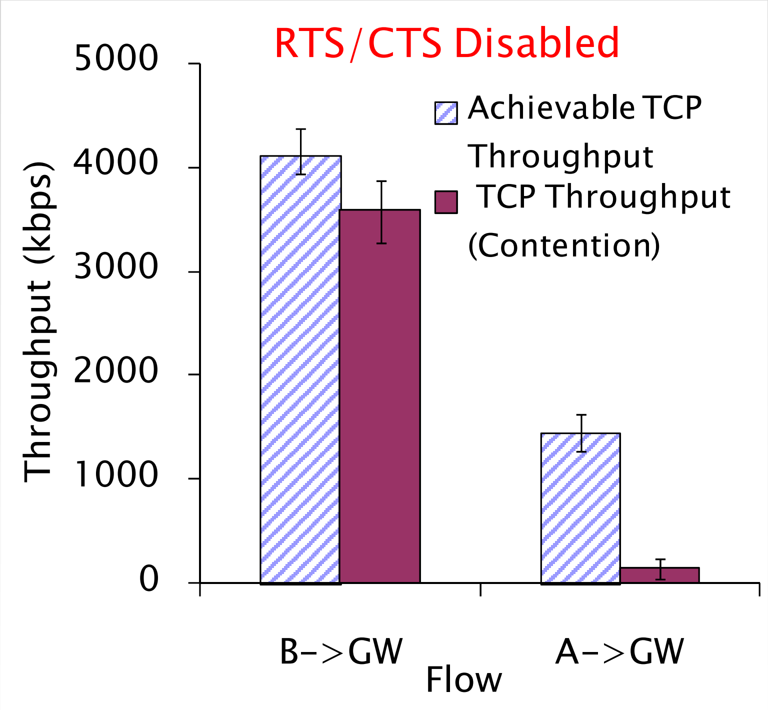
Severe Throughput Imbalance

Measurements in an operational 802.11 Mesh Network (TFA, Houston TX)

Potential for ***starvation*** in operational mesh networks

- ***under saturation conditions***
- i.e., artificial traffic is injected to A and B



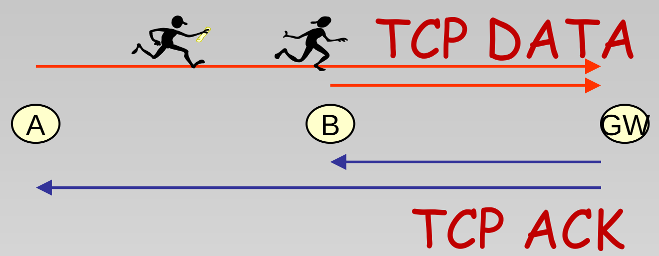


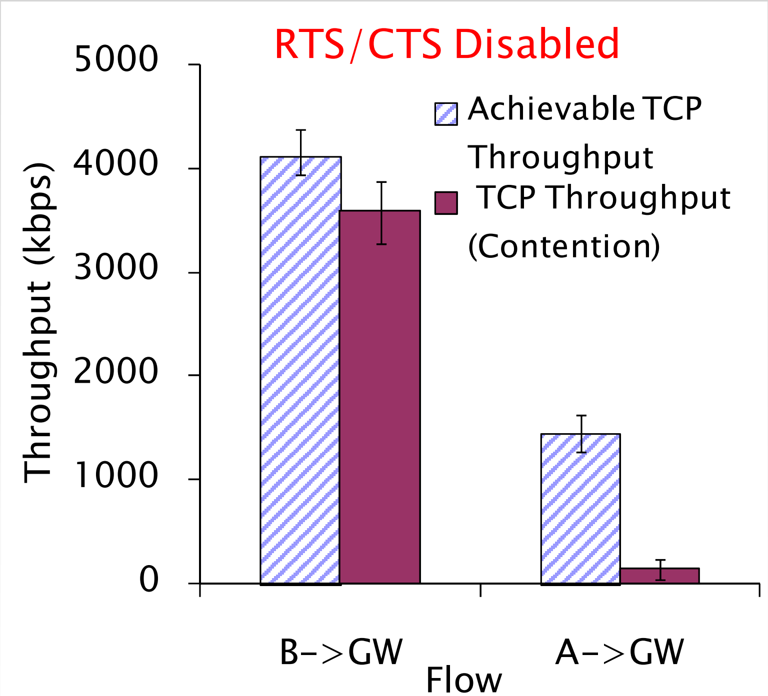
Severe Throughput Imbalance

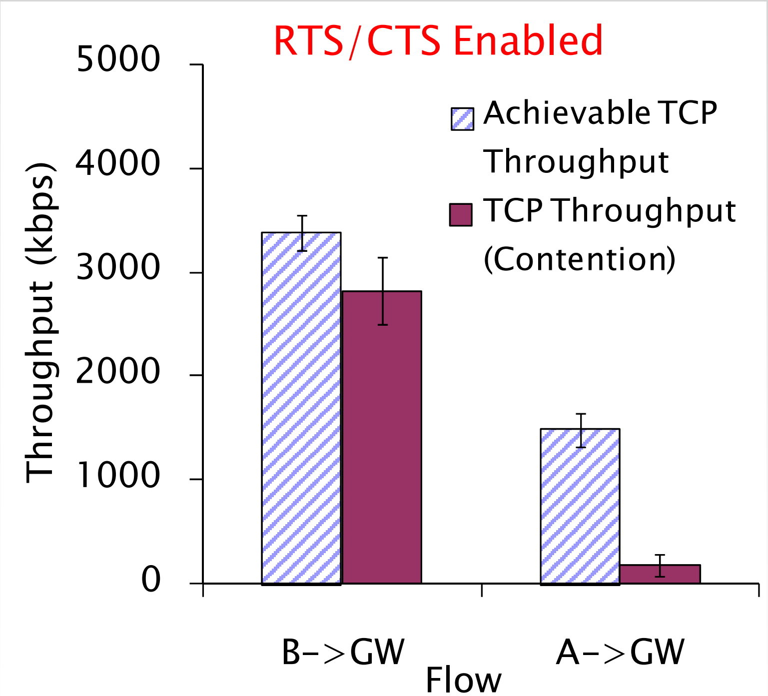
Measurements in an operational 802.11 Mesh Network (TFA, Houston TX)

Potential for ***starvation*** in operational mesh networks

- ***under saturation conditions***
- i.e., artificial traffic is injected to A and B







The two-hop node "starves" when contending with the one-hop node

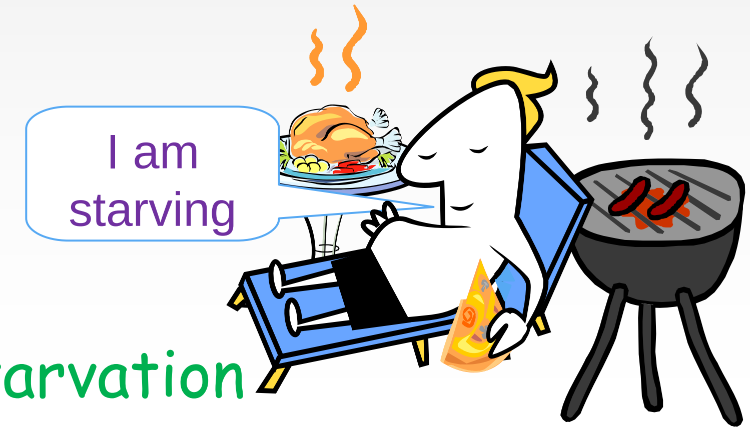
Origins of starvation

Compounding effect of three factors:

(i) The *collision avoidance* in medium access protocol induces bi-stability in which pairs of nodes *symmetrically* alternate in capturing system resources

(ii) The *congestion control* in transport protocol induces *asymmetry* in the time spent in each state and favors the one-hop flow

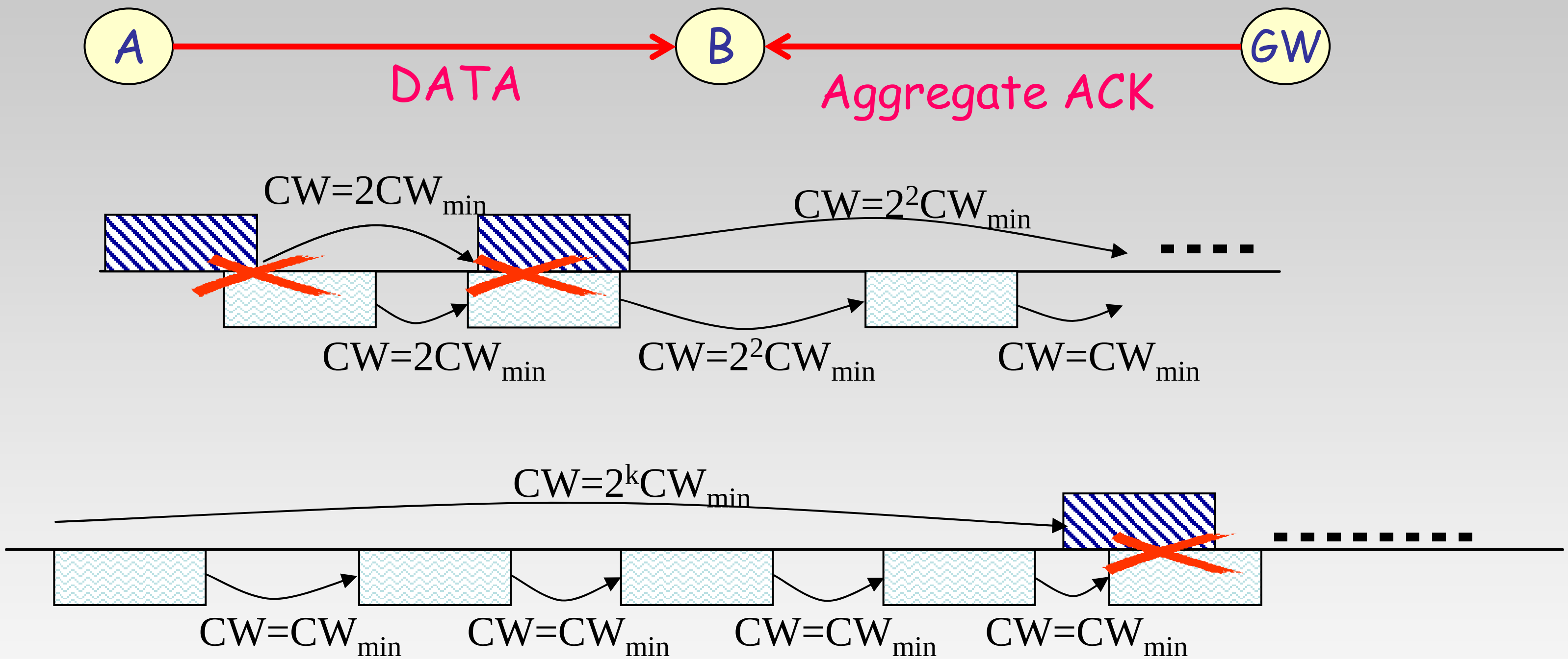
(iii) High penalty due to cross-layer effects in terms of loss, delay, and consequently, throughput, in order to re-capture system resources



Texas-size Starvation

Origins of starvation

I) Medium Access and MAC Bi-stability



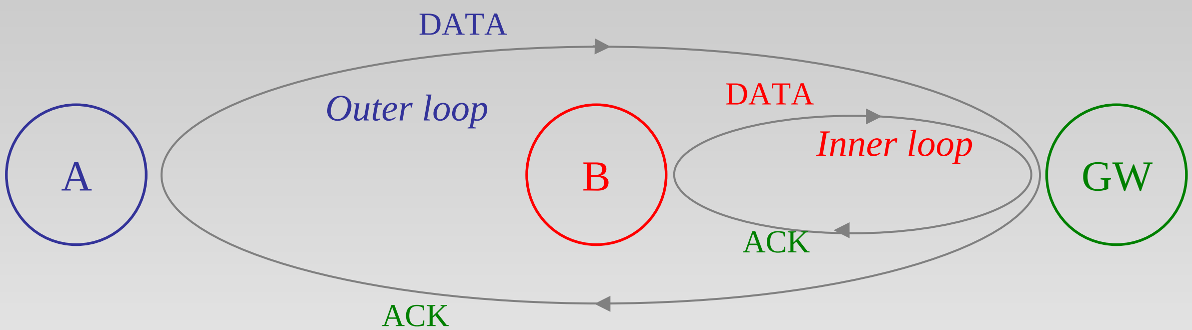
Due to lack of coordination:

- Bi-stable state: either A transmits and GW is in high backoff, or GW transmits and A is in high backoff
- *Success* state and *fail* state alternate
- *Symmetric behavior*

Origins of starvation

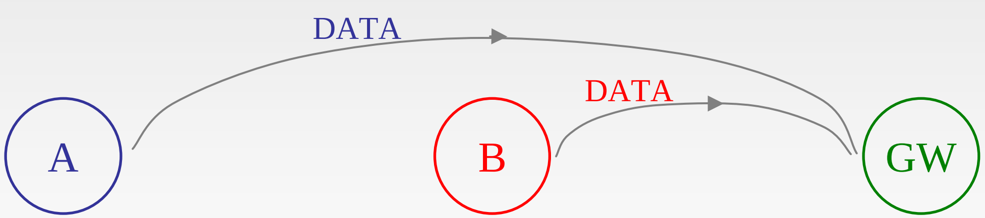
II) Asymmetry Induced by TCP

- Two nested transport loops and sliding windows

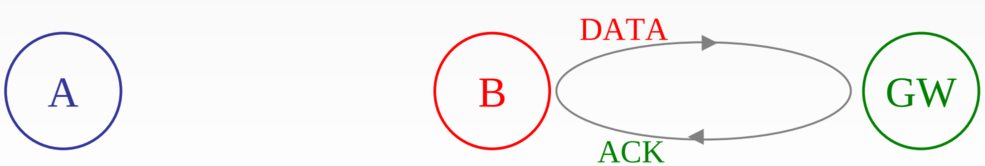


- *Asymmetric impact* of multipacket capture

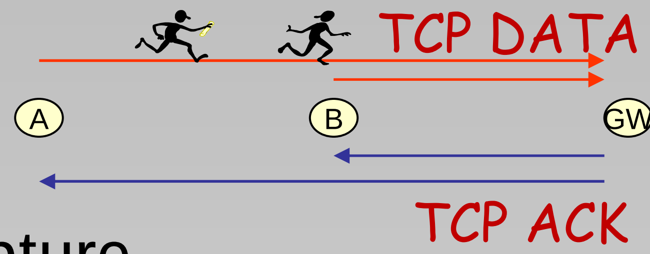
- (A, B) burst:
  the burst size is limited by:
  - TCP window size



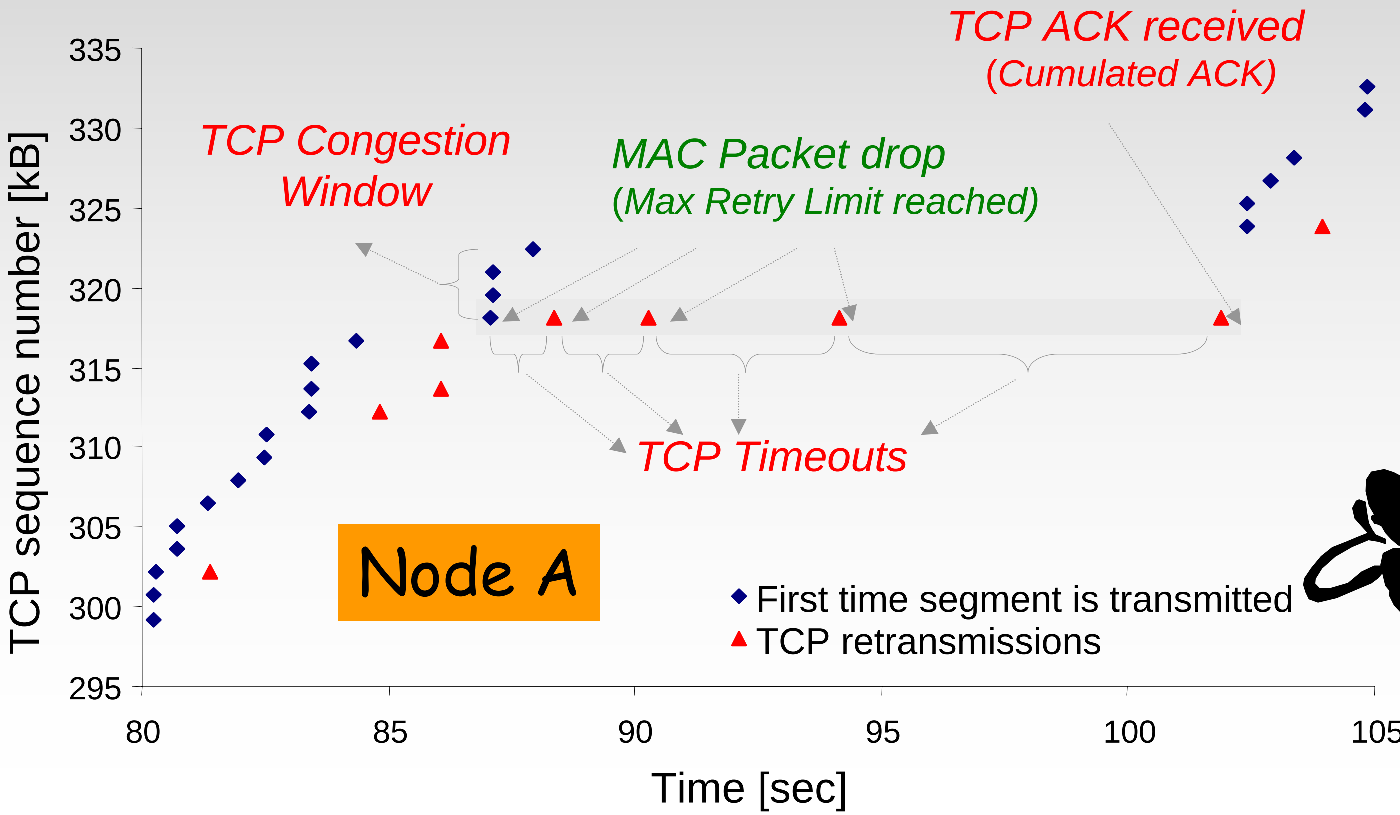
- (GW, B) burst:
  self-sustaining loop:
  - TCP ACK are generated

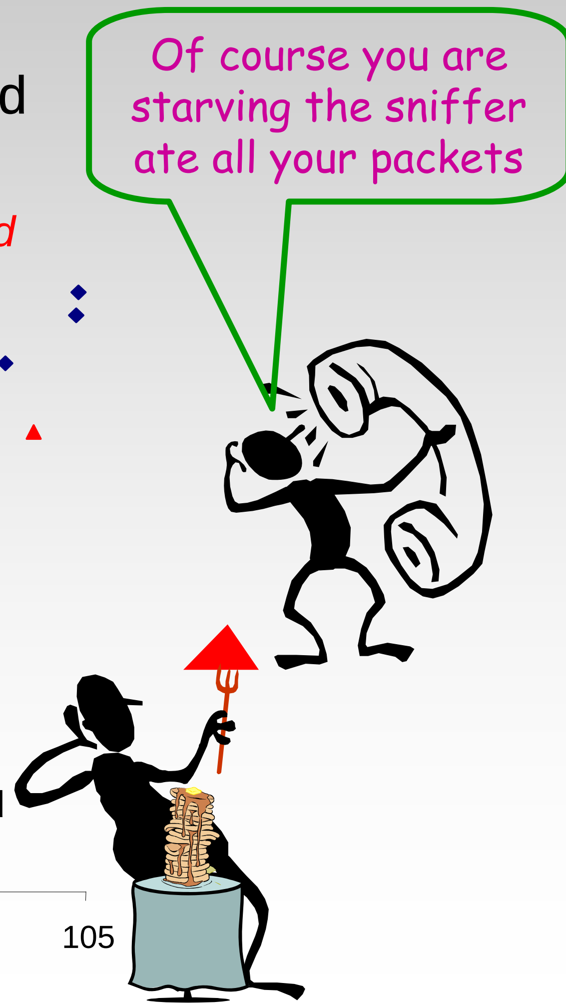


Origins of starvation
III) Severe Penalties



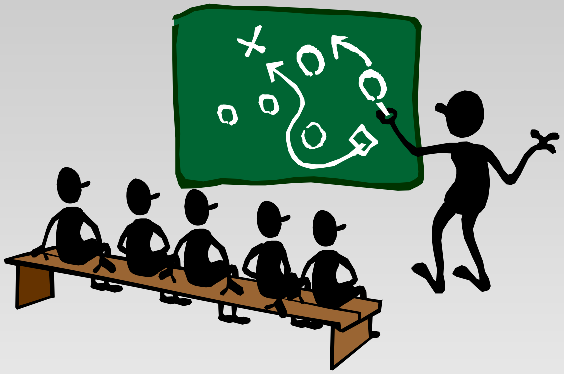
- Asymmetric impact of multipacket capture
  - Node GW incurs small penalty:
    short duration of fail state *but* long packet bursts
  - Node A incurs high penalty:
    long duration of fail state *and* low offered load
    high backoff & multiple TCP timeouts

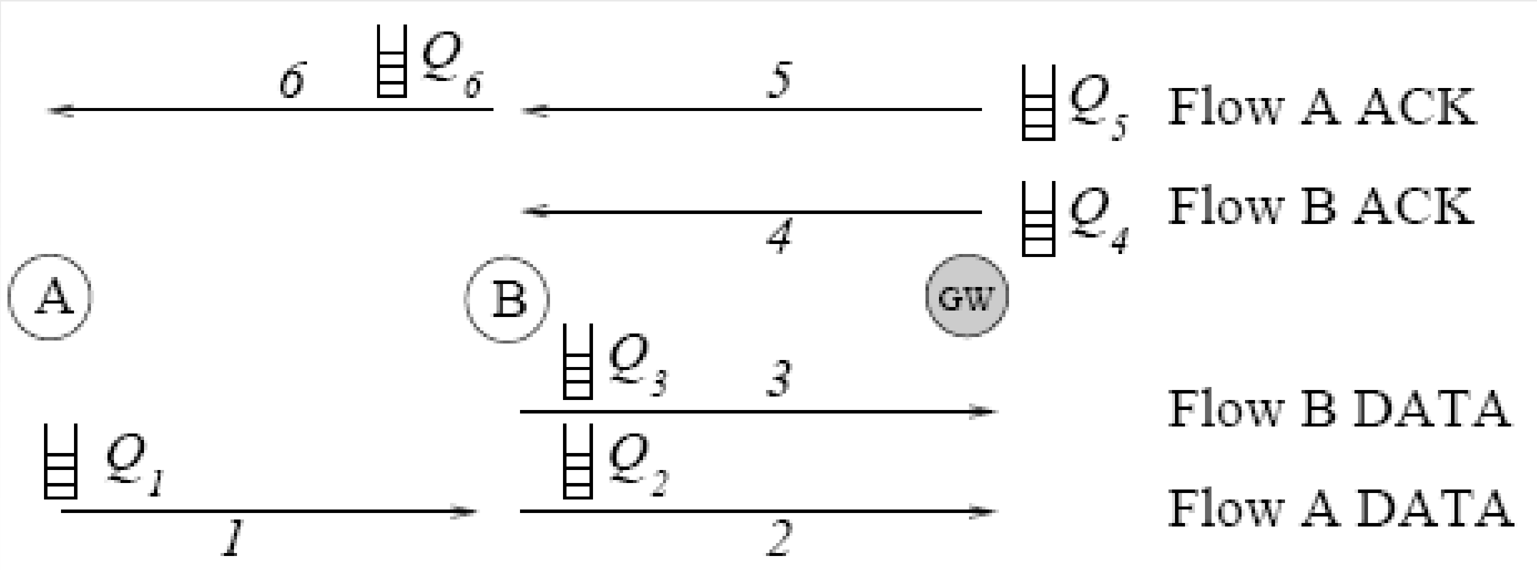




Analytical Model

- Objectives
  - Isolate and capture the root cause of starvation
  - Only model one aspect of congestion control
    - sliding window
- Technique
  - Embedded Markov chain model





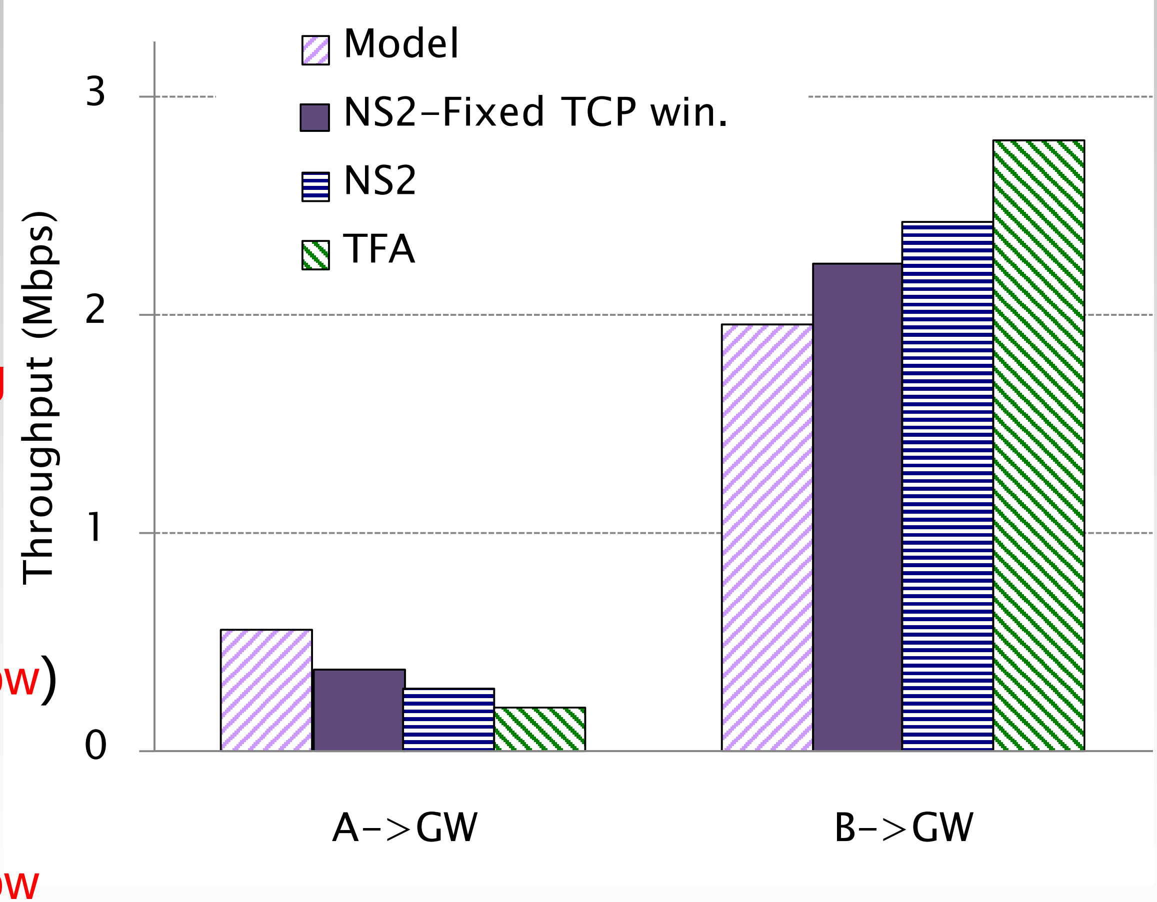
Evaluation

- Model
  - static sliding window congestion control mechanism
- NS2
  - fixed TCP congestion window

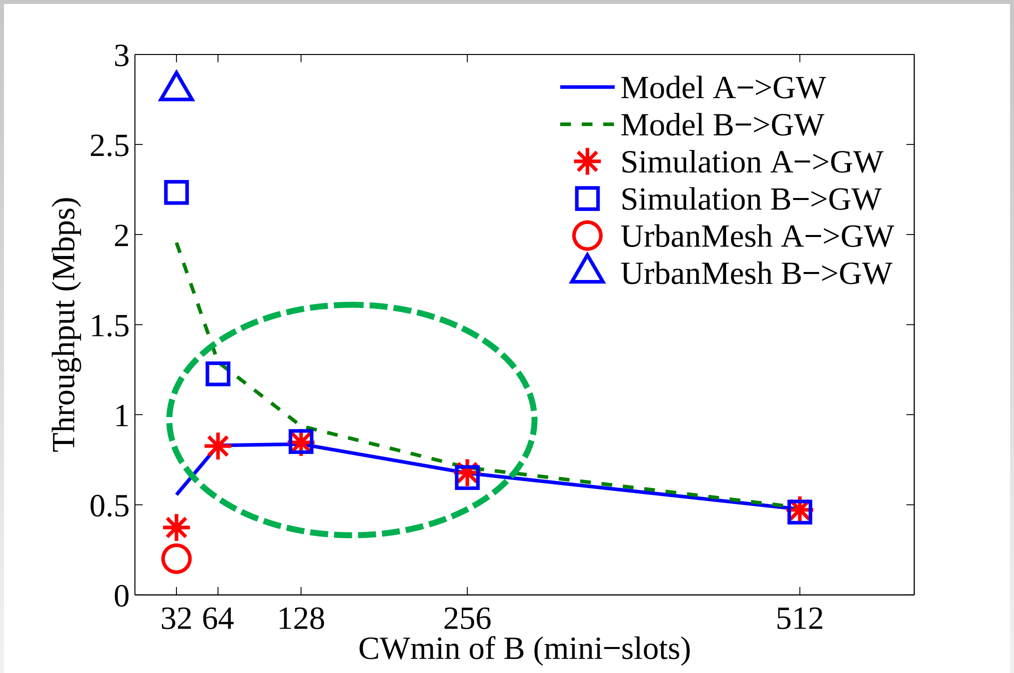
    (TCP mechanisms including timeouts and cumulative ACKs)
- NS2
  - legacy TCP New Reno

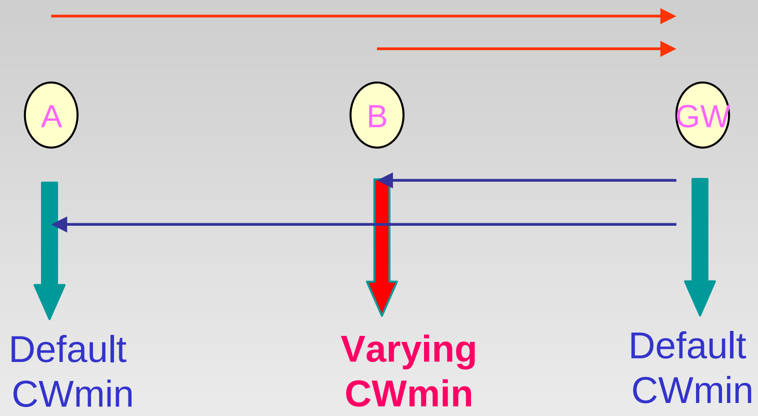
    (dynamic congestion window)
- TFA
  - legacy TCP New Reno

    (dynamic congestion window +MAC and PHY influences)



Counter-Starvation Policy





When CW_{min} increases, fairness is improved/achieved

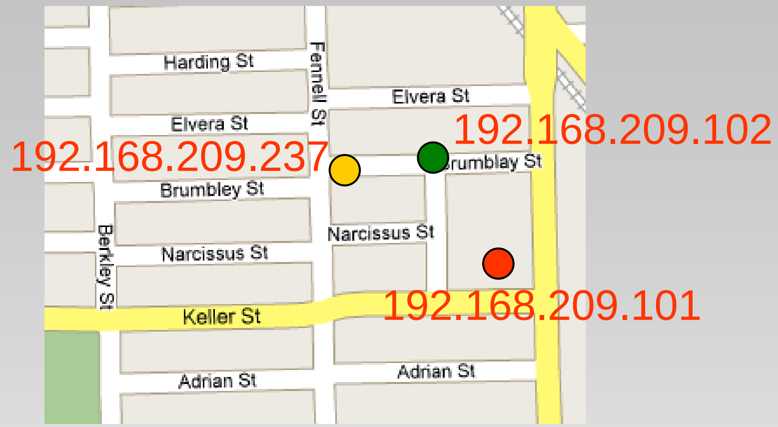
Solution: increase first hop contention window

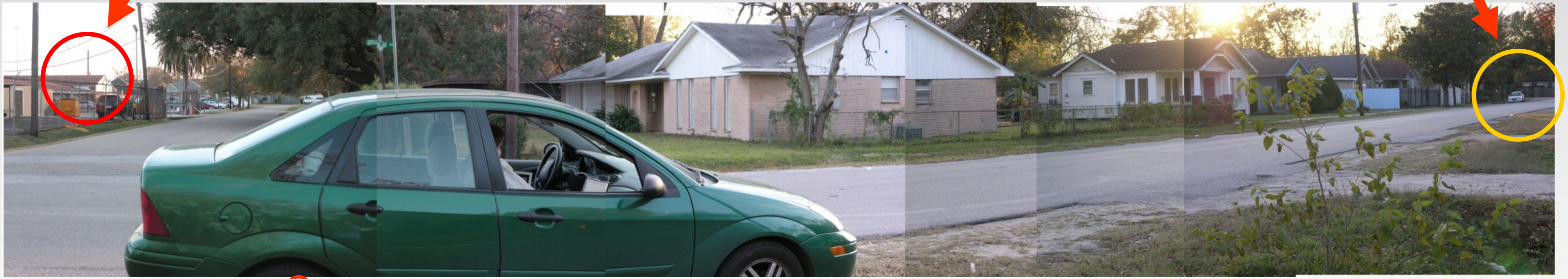
Counter-Starvation Policy

All nodes that are directly connected to the gateway should increase their minimum contention window to a value significantly greater than that of all other nodes

- Simple to implement- no overhead or message exchange between nodes
- Compliant with IEEE 802.11e EDCA

Policy Validation on Mirror Mesh





Linux Operating System (kernel 2.6)

Atheros wireless card (Madwifi v.0.9.2 driver)

MAC IEEE 802.11b

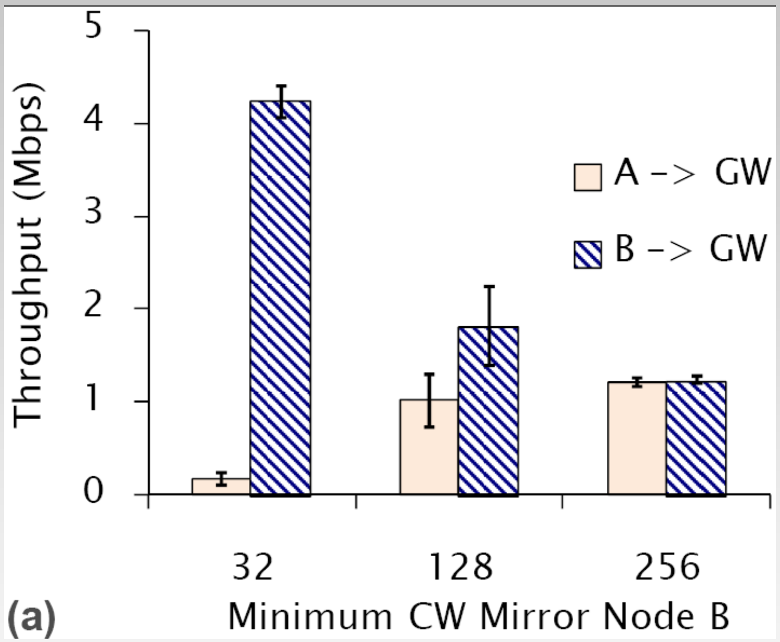
Data rate fixed to 11Mbps

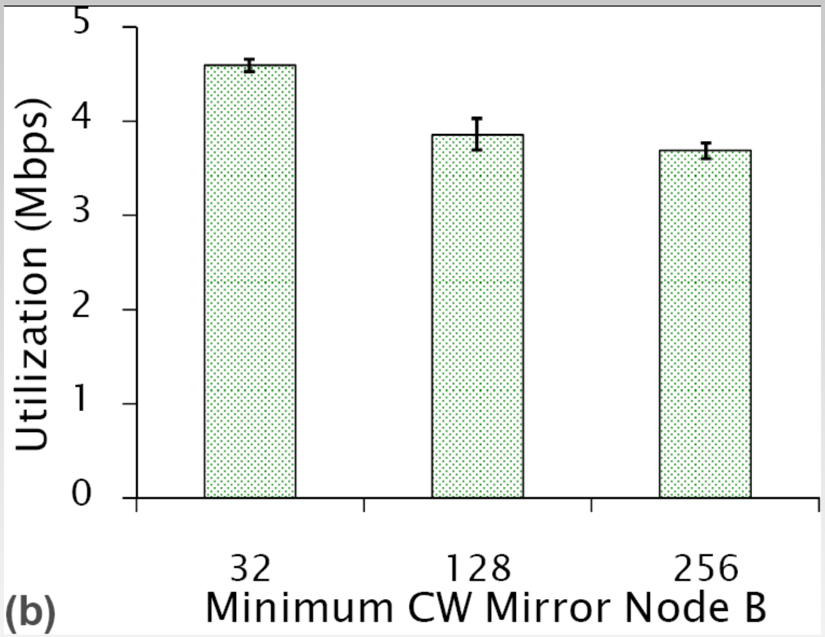
Default CWmin = 16

Data packet size = 1500 Bytes

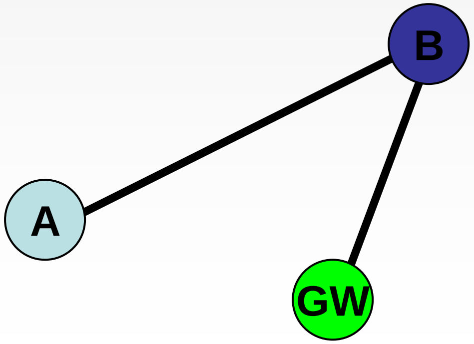
Experimental Validation

RTS/CTS Enabled





Fairness can be achieved (under different definitions)



Broader Scenarios

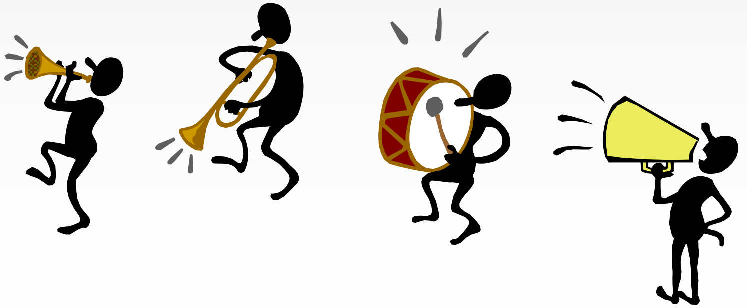
Validate and evaluate the effect of the solution on more general scenarios:

- RTS/CTS disabled
- Different packet size
- Downstream
- UDP traffic
- Parking lot topology (longer chain topologies)
- Multi-branch topologies
- Multiple TCP flows

- Confirms that the starvation phenomenon exists in much broader scenarios
- Proposed solution is effective in more general topologies

Summary

- Analytically show that one-hop TCP flows interacting with multi-hop TCP flows is sufficient to induce starvation
- Demonstrate potential starvation in an operational multi-tier urban mesh network
- Analyze the joint effect of MAC and transport layer's congestion control on unfairness
- Suggest a simple Counter-Starvation Policy
- Implement and empirically validate the solution on MirrorMesh, a network re-deployment within the same urban environment




Questions