Enhancing TCP Fairness in Ad Hoc Wireless Networks Using Neighborhood RED

Kaixin Xu, Mario Gerla
University of California, Los Angeles
{xkx, gerla}@cs.ucla.edu

Lantao Qi, Yantai Shu
Tianjin University, Tianjin, China
{ltqi, ytshu}@tju.edu.cn

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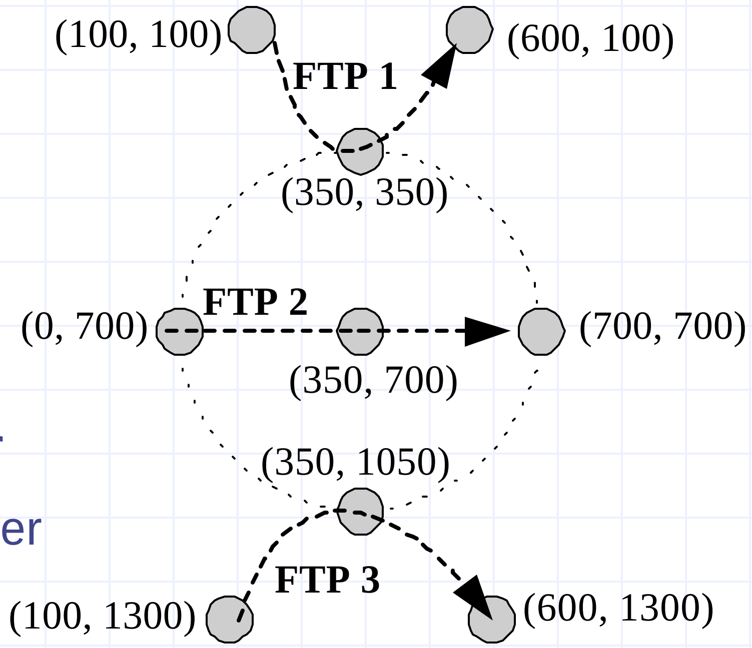
Motivation

- TCP is important in ad hoc network applications
  - Reliable transfer of data/image files and multimedia streaming
  - Congestion protection
  - Efficient utilization and fair share of the resources
- However, TCP has shown unfair behavior in ad hoc nets

TCP Unfairness in Ad Hoc Networks

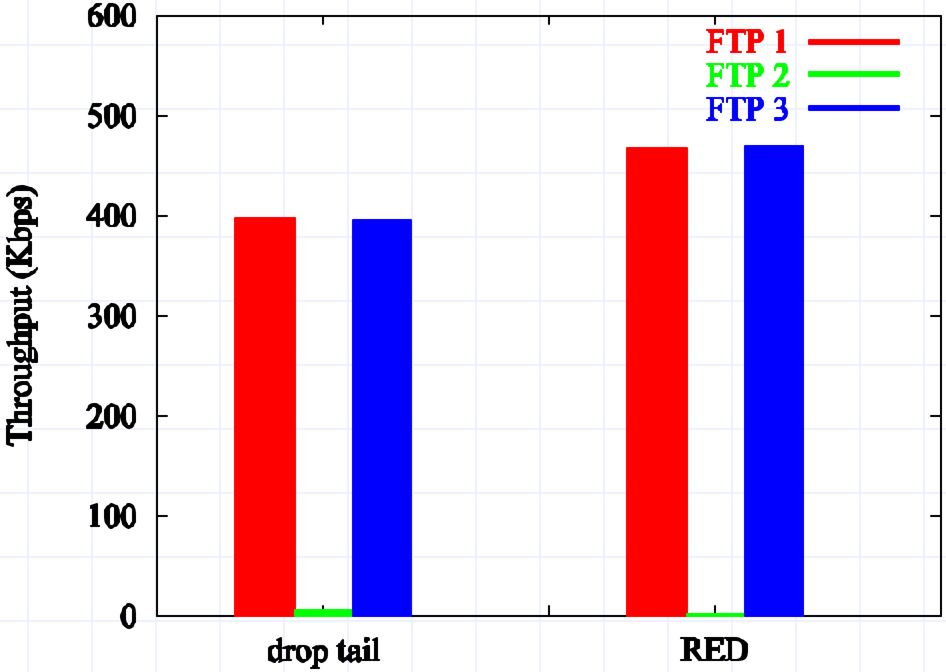
- Fairness index in wireless networks
  - Weighted MaxMin Fairness Index
    - Weight(i) = # of flows that compete with flow i (including itself)
    - $$F(X,t)=\frac{\left[\sum_{i=1}^{n} w_i(t)X_i(t)\right]^2}{n\left[\sum_{i=1}^{n} \left(W_i(t)X_i(t)\right)^2\right]}$$



- Simulation in QualNet simulator
  - 3 TCP flows contending with each other
  - Weight of 3 flows, 2:3:2

Significant TCP Unfairness

- Three flow example
- Flow 2 is nearly starved
- Original RED fails to improve the fairness
- Weighted Fairness Index = 0.67

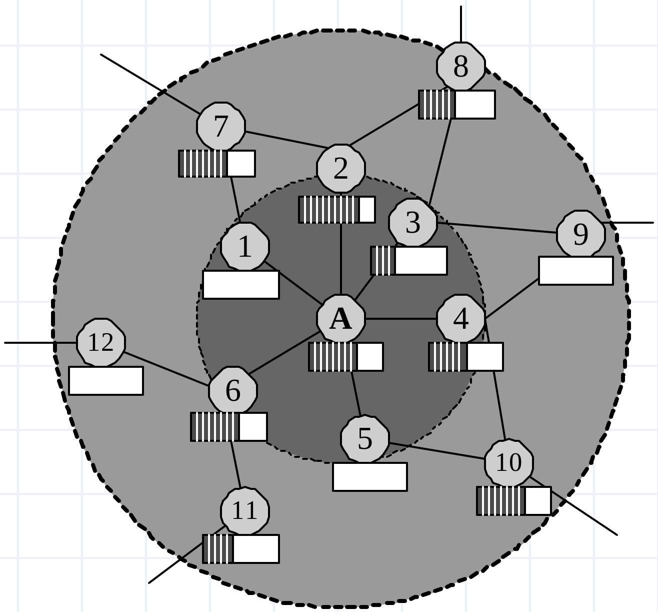


Why RED Does Not Work?

- Random Early Detection (RED)
  - Active queue management scheme
  - Average queue size: $avg = (1 - w_q) * avg + w_q * q$
  - Drop probability: $p_b = \frac{\max_p (avg - \min_{th})}{\max_{th} - \min_{th}}$, proportional to buffer occupancy
- Why RED does not work in ad hoc networks?
  - Congestion simultaneously affects multiple queues
  - Queue at a single node cannot completely reflect the state
- Extend RED to the entire congested area – Neighborhood of the node

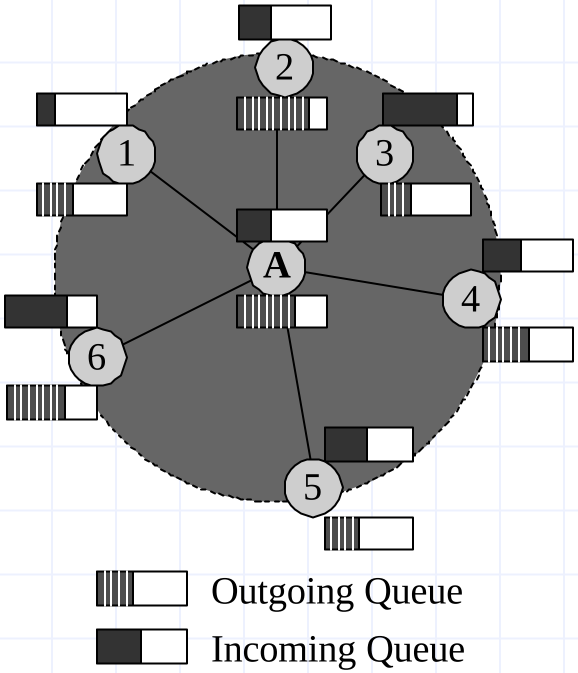
Neighborhood and Its Distributed Queue

- A node's neighborhood consists of the node itself and the nodes which can interfere with this node's signal
  - 1-hop neighbors directly interfere
  - 2-hop neighbors may interfere
- Queue size of the neighborhood reflects the degree of local network congestion



Simplified Neighborhood Queue Model

- 2-hop neighborhood queue model is not easy to operate
  - Too much overhead to propagate queue values 2 hops away
- Simplified model
  - Only include 1-hop neighbors
  - Two queues at each neighbor:
    - Outgoing queue
    - "Incoming queue"= # CTS packets overheard by A
- Distributed neighborhood queue – the aggregate of these local queues



Characteristics of Neighborhood Queue

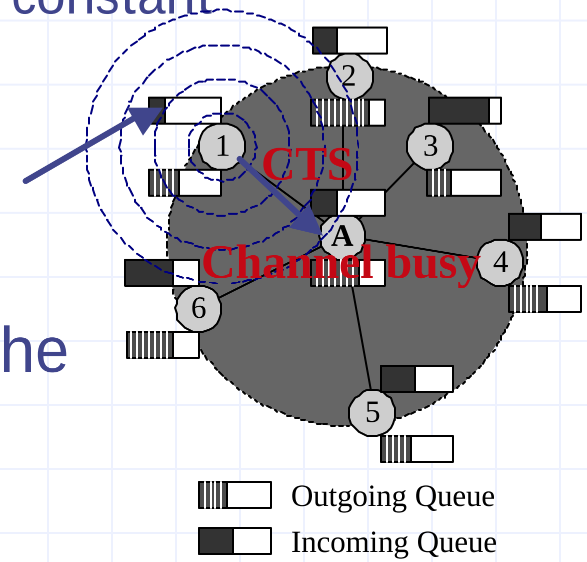
- Consists of multiple queues located at the neighboring nodes
- Not a FIFO queue due to location dependency
- Transmission order of sub-queues may change dynamically due to
  - Topology changes
  - Traffic pattern changes
- TCP flows sharing the same neighborhood may get different feedbacks in terms of packet delay and loss rate

Neighborhood Random Early Detection (NRED)

- Extending RED to the distributed neighborhood queue
- Key Problems
  - Counting the size of the distributed neighborhood queue
  - Calculating proper packet drop probability at each node
- Components of Neighborhood RED
  - Neighborhood Congestion Detection (NCD)
  - Neighborhood Congestion Notification (NCN)
  - Distributed Neighborhood Packet Drop (DNPD)

Neighborhood Congestion Detection

- Direct way: Announce queue size upon changes
  - Too much overhead, exacerbates congestion
- Our method: Indirectly estimate an index of instant queue size by monitoring wireless channel
  - Channel utilization ratio $U_{busy} = \frac{channel-busy-time}{sampling-interval}$
  - Queue size index $q = K * U_{busy}$, K is a constant
- Average queue size is calculated using RED's alg.
- Congestion: queue size exceeds the minimal threshold

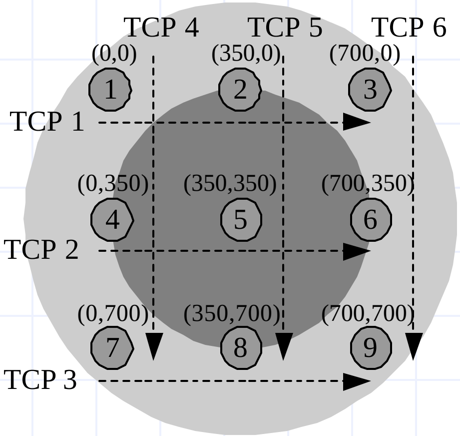


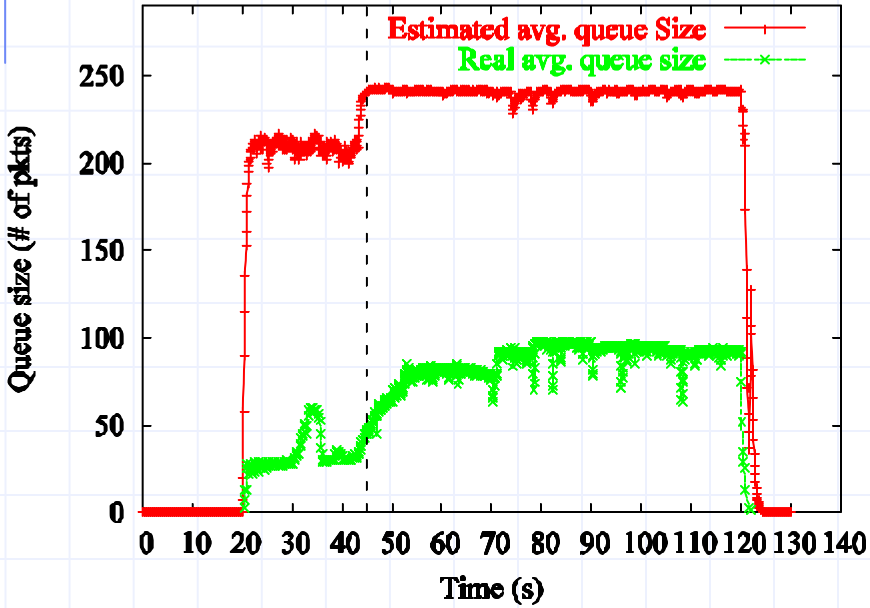
Neighborhood Congestion Notification & Distributed Neighborhood Packet Drop

- Neighborhood Congestion Notification
  - Congested node computes drop probability following RED's alg.
  - It broadcasts the drop probability to all neighbors
- Distributed Neighborhood Packet Drop
  - Neighborhood Drop Prob = Max of all drop probabilities heard from neighbors

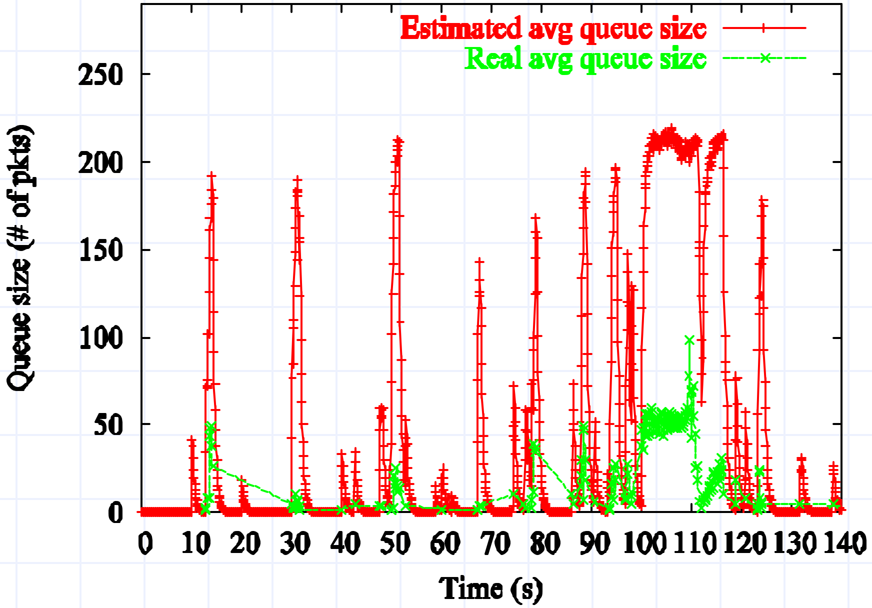
Verification of Queue Size Estimation

- Estimating Node5's neighborhood queue size index
- Get real queue size by recording queue size at all nodes





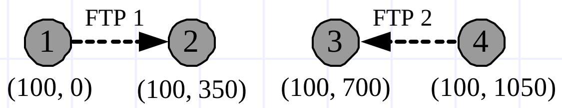
FTP Traffic



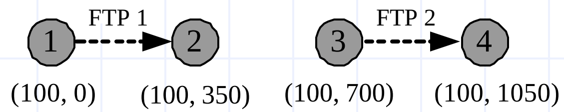
HTTP Traffic

Parameter Tuning: Scenarios

- QualNet simulator
- Basic but typical scenarios
  - Hidden terminal situations
  - Exposed terminal situations
- Configuration parameters
  - Minimum threshold & Maximum threshold
    - Set to 100 and 240 based on previous experiment
  - Vary the maximum packet drop probability (max_p)



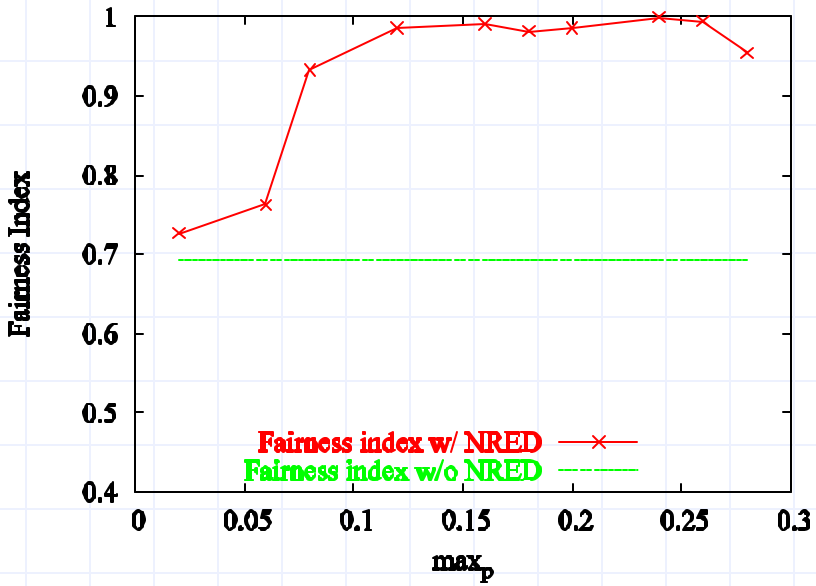
Hidden Terminal



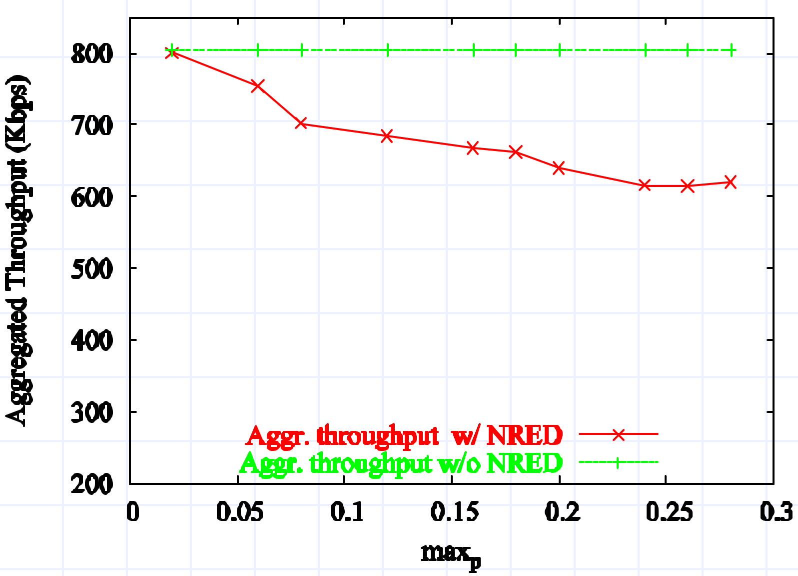
Exposed Terminal

Parameter Tuning: Hidden Terminal Scenario

- Weighted fairness index
- Instantaneous throughput: $X(t) = \frac{D_t}{\Delta_t}$, here Δ_t denotes the data successfully received during time period $[t \rightarrow t + \Delta_t]$

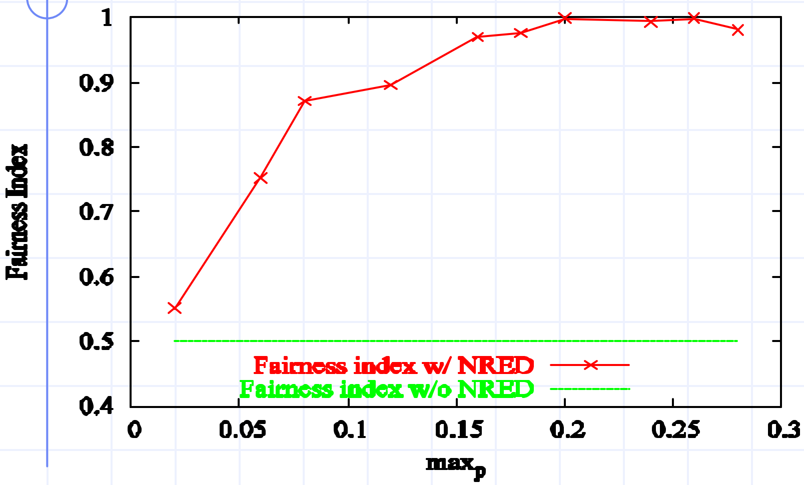


Fairness index

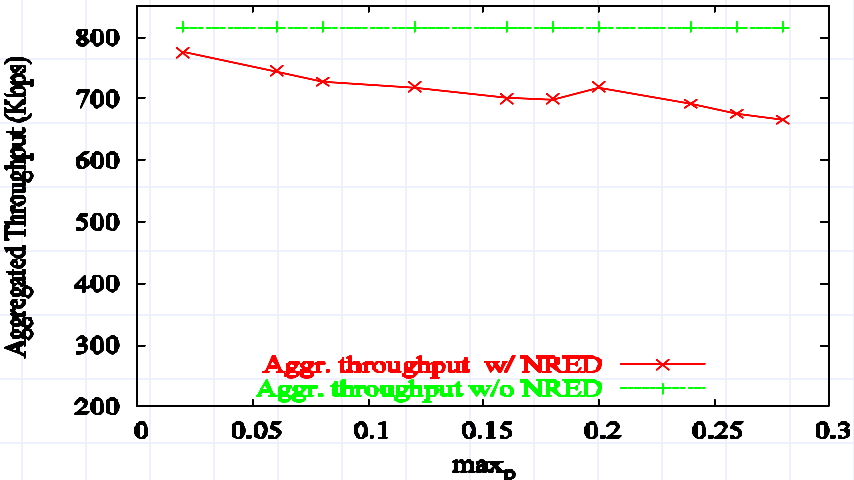


Aggregated throughput

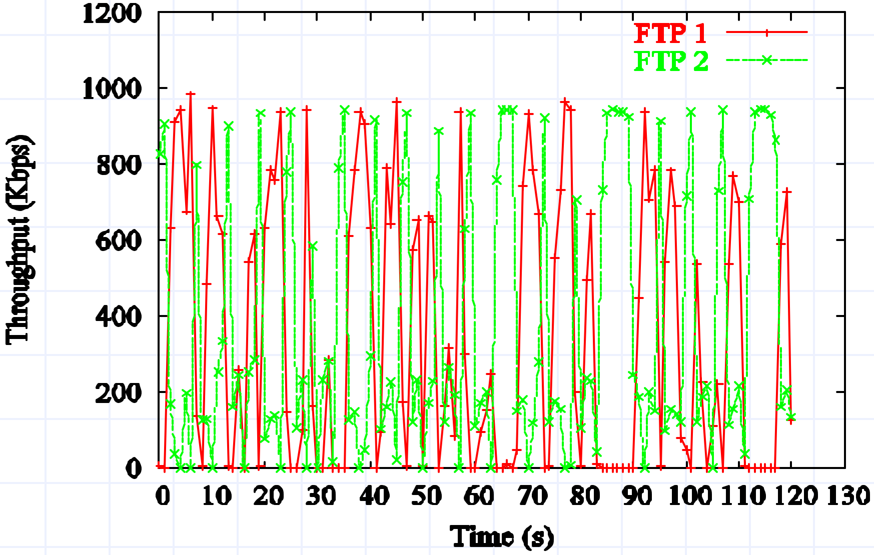
Parameter Tuning: Exposed Terminal Scenario



Fairness index



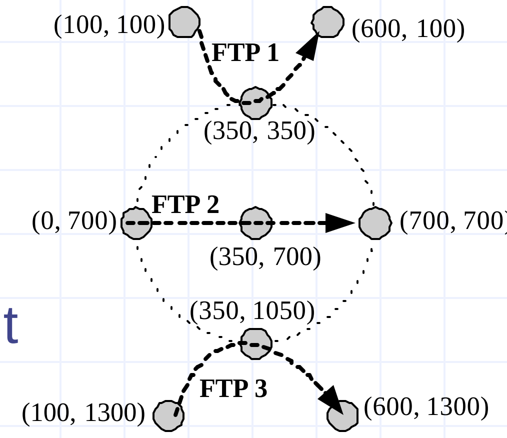
Aggregated throughput

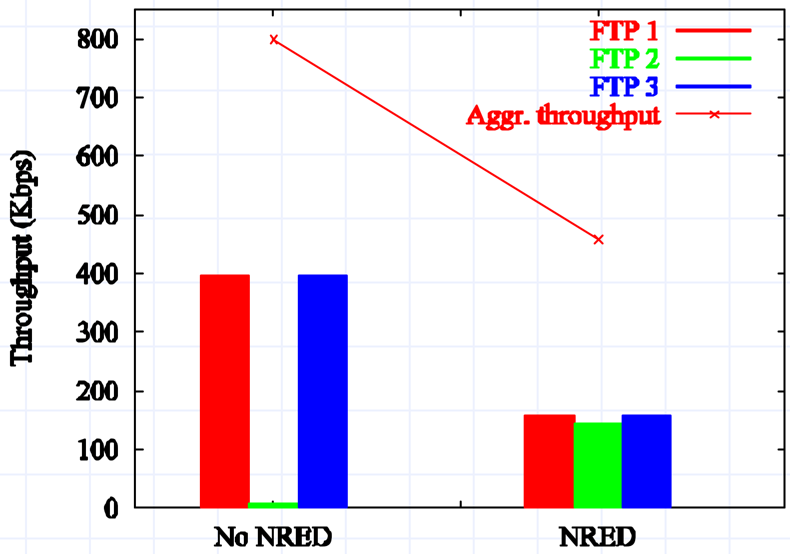


Instant throughput W/ max_p = 0.14

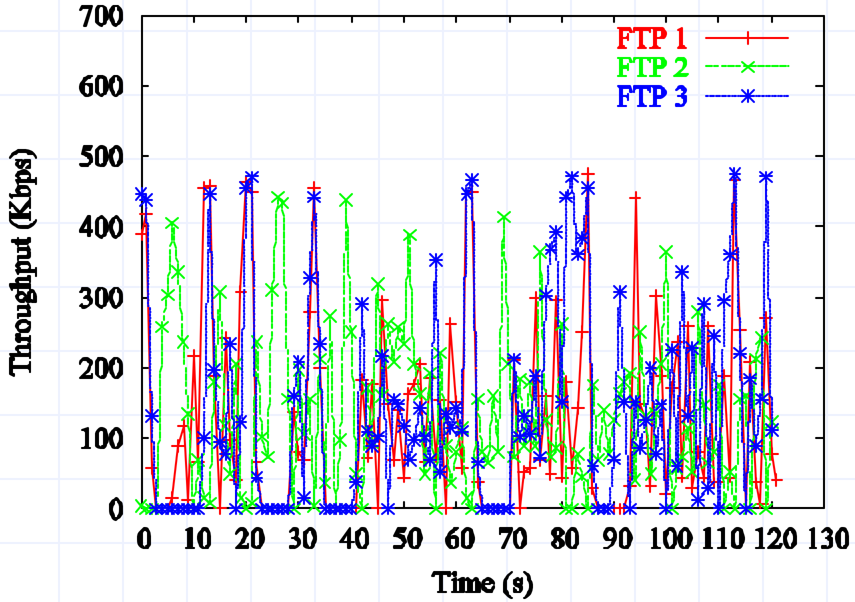
Performance Evaluation: Simple Scenario

- Both long-term and short-term fairness is achieved
- Loss of aggregated throughput
  - Tradeoff between fairness and throughput
  - Channel is not fully utilized





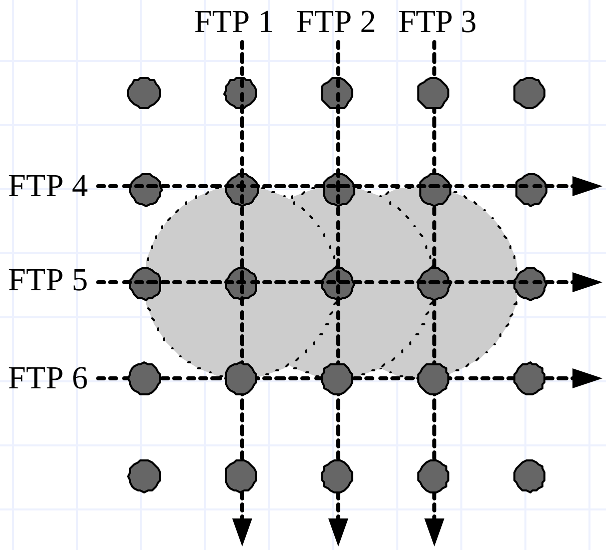
Overall Throughput

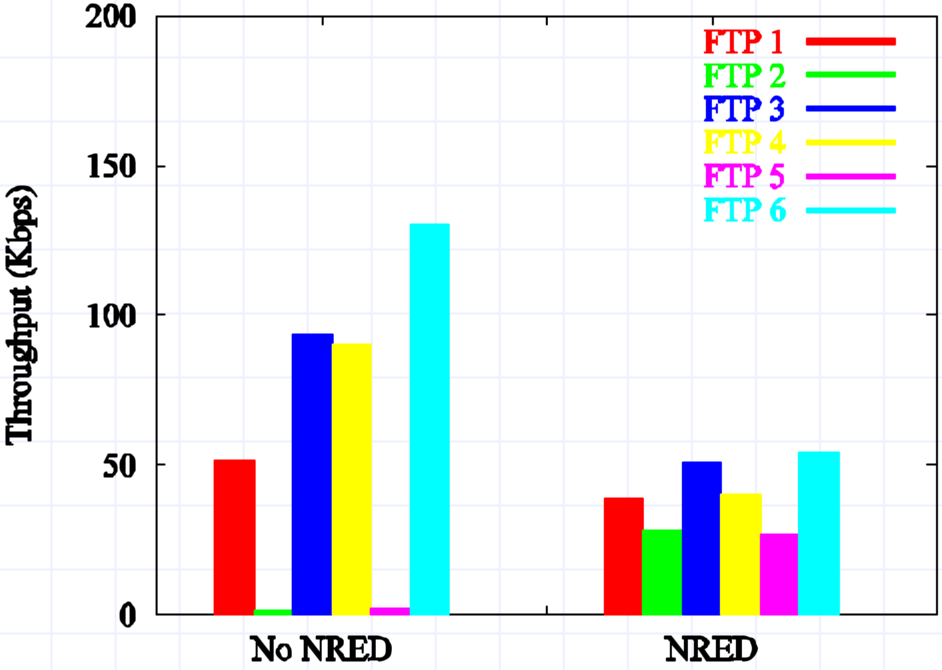


Instantaneous Throughput

Performance Evaluation: Multiple Congested Neighborhood

- Multiple congested neighborhoods
- FTP2 & FTP 5 have more competing flows, are more likely to be starved

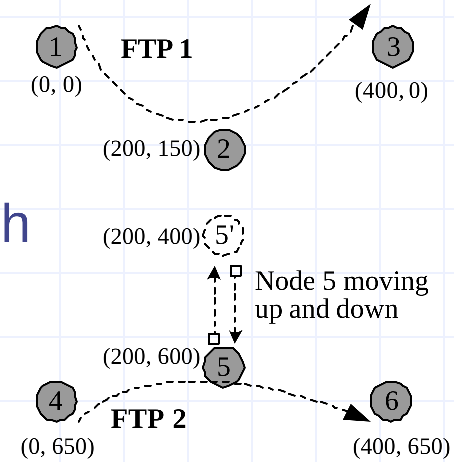


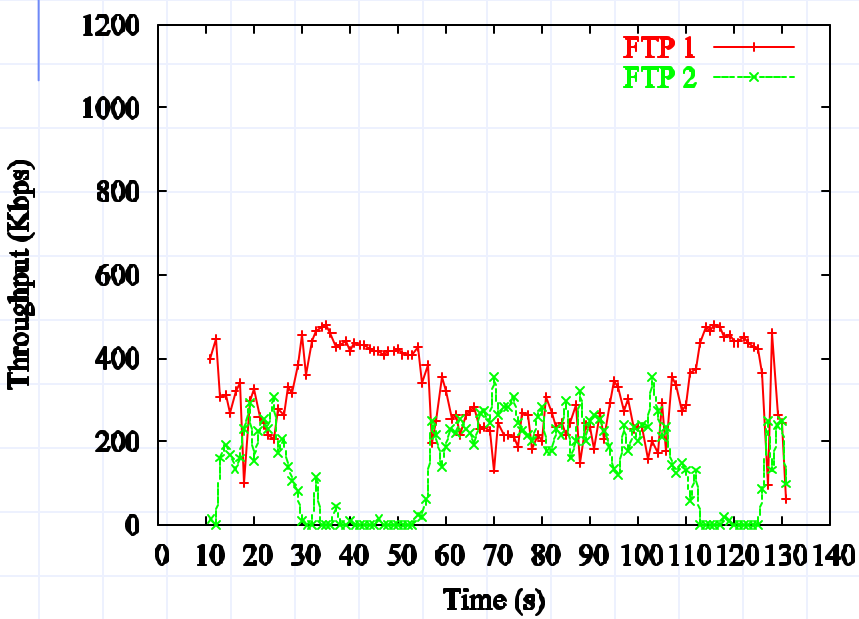


Overall Throughput

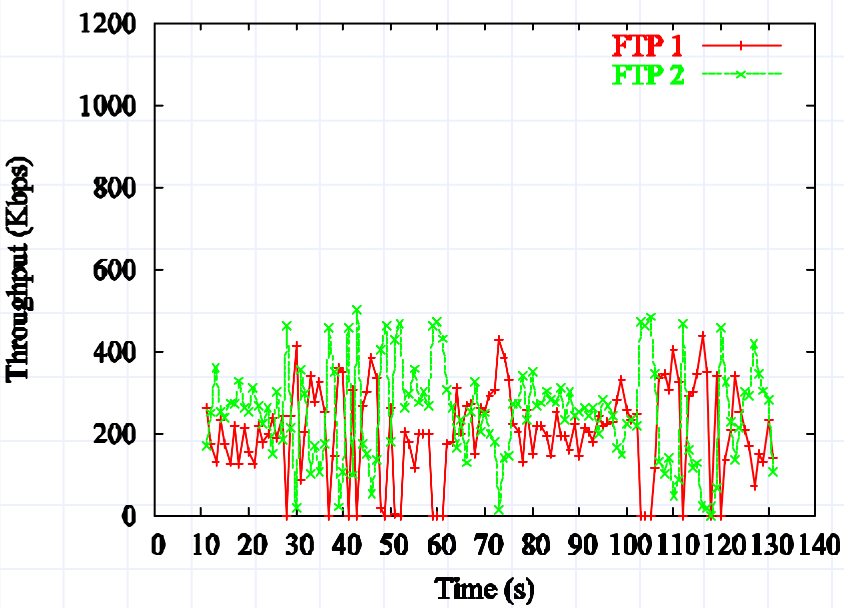
Performance Evaluation: Mobility

- Node 5 moves up and down
  - Moving Up: two flow interfere with each
  - Moving down: No much interference
- NRED can adapt to mobility





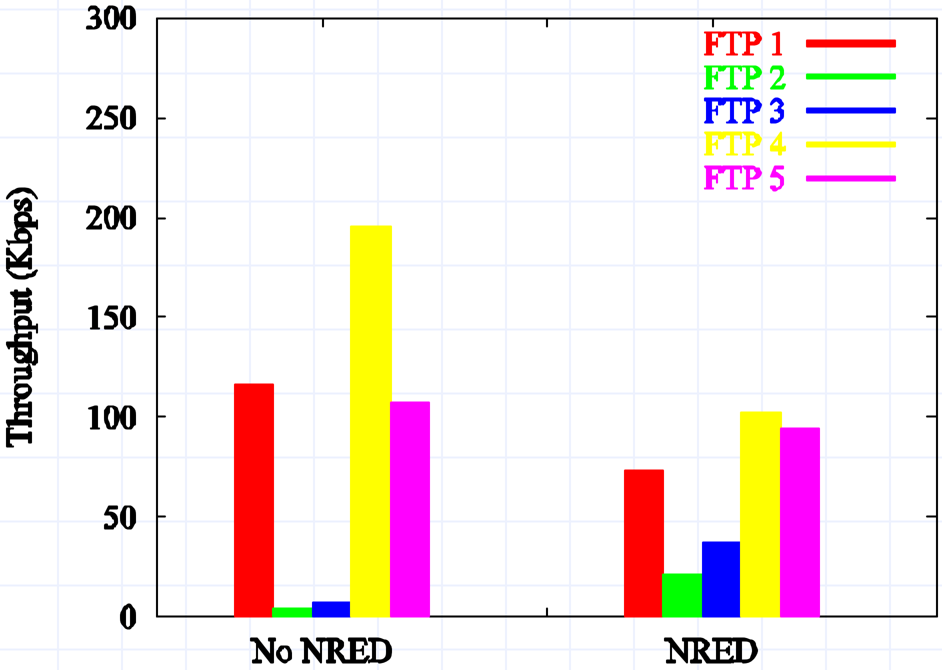
Without NRED



With NRED

Performance Evaluation: Realistic Scenario

- 50 nodes randomly deployed in 1000mX1000m field
- 5 FTP/TCP connections are randomly selected
- AODV routing
- No mobility



Conclusions

- Significant TCP unfairness has been found and reported in ad hoc networks
- NRED is a network layer solution
  - Easy to implement
  - Incremental deployment
- Major Contributions
  - Model of neighborhood queue
    - Distributed neighborhood queue
    - Not FIFO, different and dynamic priorities
  - Network layer solution for enhancing TCP fairness in ad hoc networks

Thanks!