

Scalable Simulation of Large-Scale Wireless Networks with Bounded Inaccuracies

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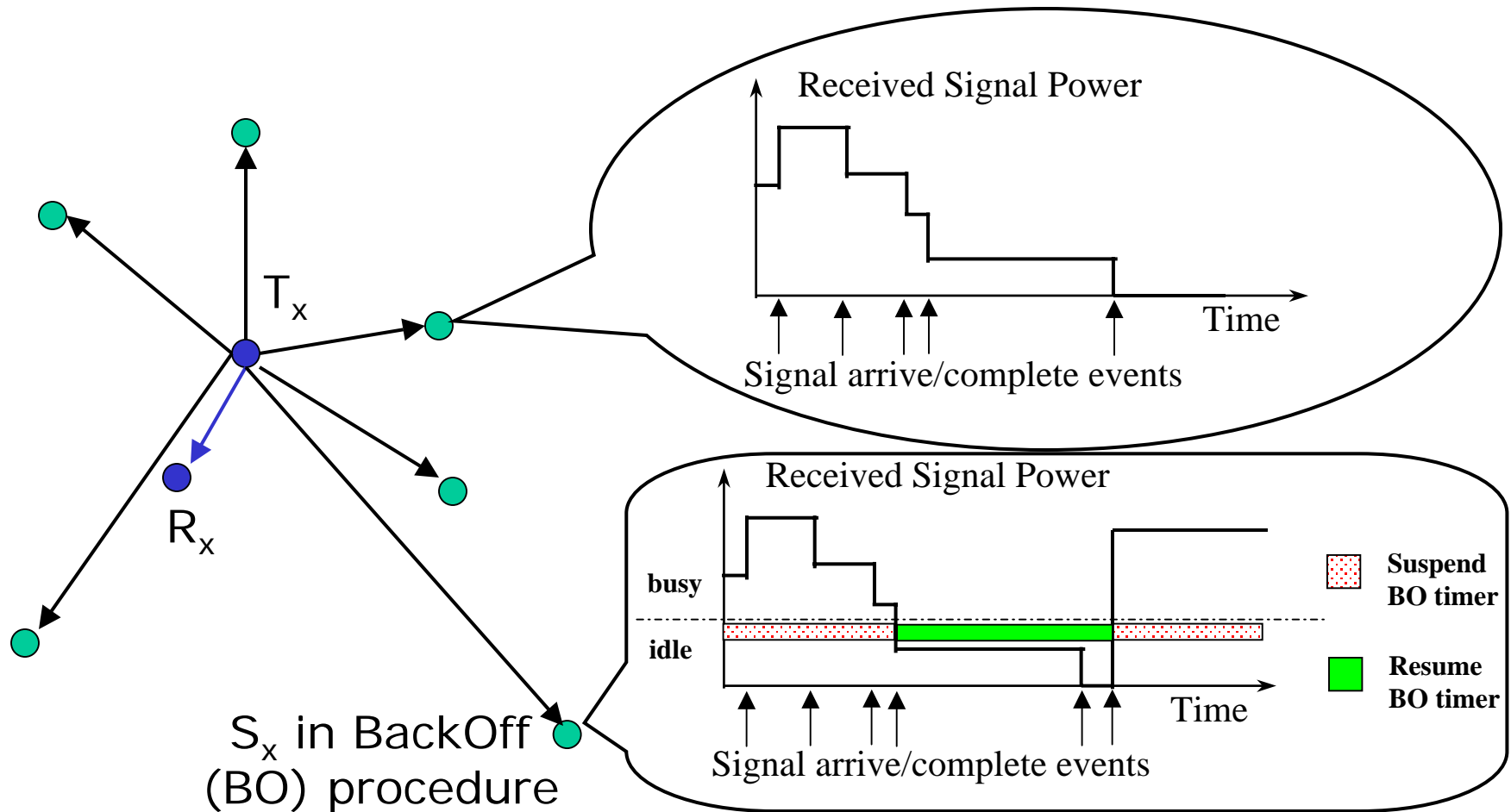
Problem Statement

- Simulation
 - most common tool for wireless network research
- Wireless Network Simulation Dilemma
 - Pros
 - Low cost replacement to physical testbeds
 - Controllable and Repeatable experimentation
 - Capable of modeling physical layer details
 - Better accuracy than analytical models
 - Cons
 - Simulation speed is slow
 - Limited scalability
- Can we further improve large-scale wireless network simulation without losing its competitive edge?

Our Approach

- Better understanding of wireless network simulation overhead
- Identification of weakness of commonly used propagation limit
- Derivation of more appropriate distance limit, with better tradeoff between performance and accuracy
- Reduction of physical layer simulation events without losing accuracy at all

Implementation of Signal Propagation in Existing Wireless Network Simulator

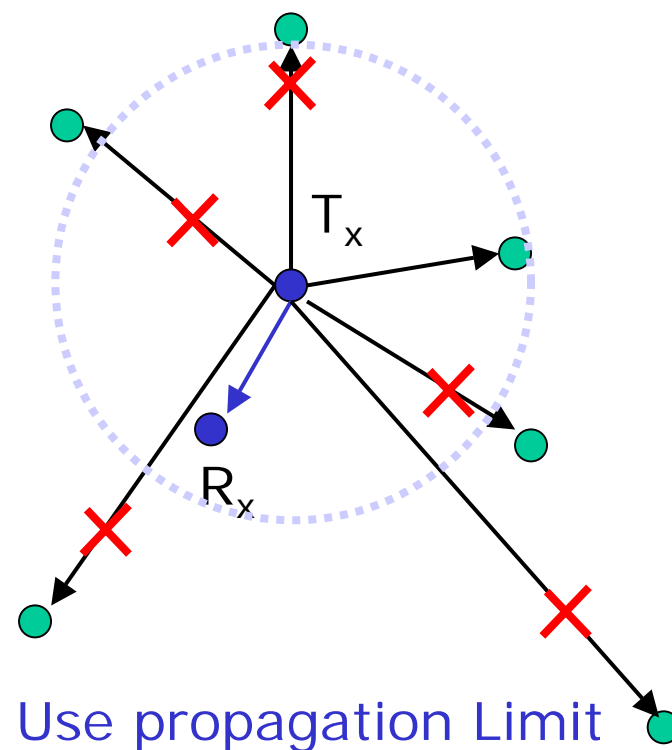


Overhead in Wireless Network Simulation

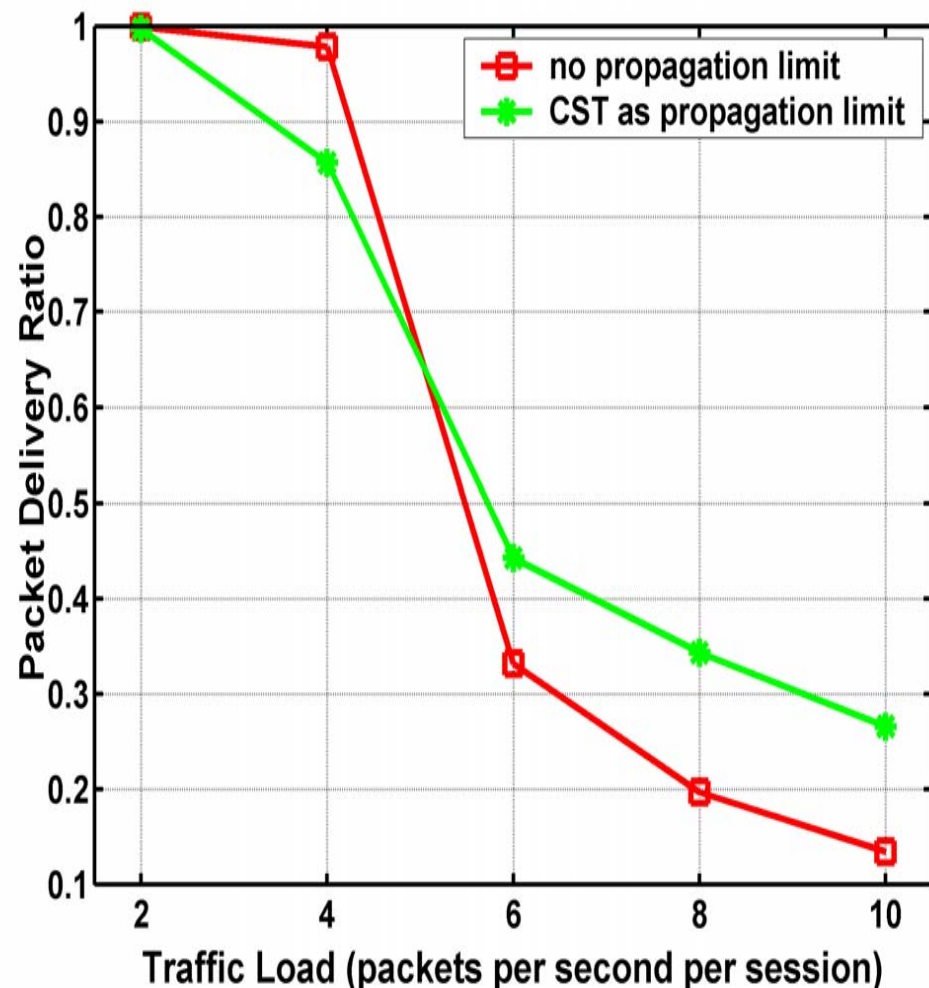
- $O(N)$ events per transmission for network of size N !!!

Need to reduce events

- **Common approach** to drop signals weaker than carrier sensing threshold (CST), i.e. to limit signal's reachability



Misleading Results of Common Approach



Experiment setup:

100 nodes
2000x2000m²
AODV
30 random CBR sessions
512 bytes/pkt; 2~10 pkts/sec
Same traffic load for all sessions

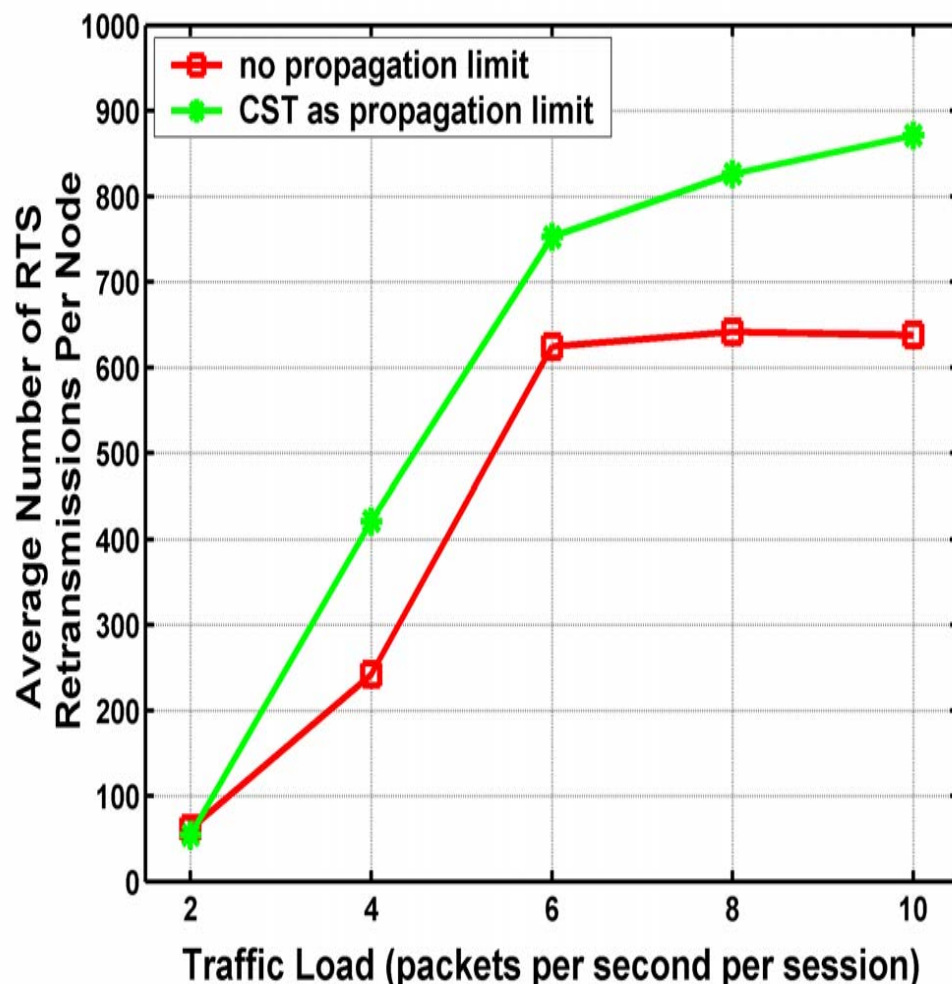
Measurement:

Packet Delivery Ratio

Observation:

CST results deviate from the original significantly

Interpretation of the Misleading Results



Observation:

1. More nodes fail to sense channel busy, which increases nodes' probability of transmission and causes more RTS collisions
2. Ignoring weak signals cause better SINR, which increases successful reception

Observation to Interference Power

- Upper bound on aggregated power \hat{P} of interferences outside distance D :

$$\hat{P} = \sum_{s: d_s > D} \frac{P_s}{PL(d_s)} = \sum_{s: d_s > D} \frac{P_s}{PL(d_0)} \left(\frac{d_0}{d_s} \right)^\alpha \leq \frac{P_{\max} d_0^\alpha}{PL(d_0)} \sum_{s: d_s > D} \frac{1}{d_s^\alpha}$$

- Approximate with continuous function

$$\hat{P} \leq \frac{P_{\max} d_0^\alpha}{PL(d_0)} \int_D^\xi \frac{2\pi\lambda x}{x^\alpha} dx = \begin{cases} \frac{2\pi\lambda P_{\max} d_0^\alpha}{PL(d_0)} (\ln \xi - \ln D) & \alpha = 2 \\ \frac{2\pi\lambda P_{\max} d_0^\alpha}{(2-\alpha) PL(d_0)} (\xi^{2-\alpha} - D^{2-\alpha}) & \alpha \neq 2 \end{cases}$$

s : transmitter PL : path loss d_s : distance from s to receiver
 P_s : tx power d_0 : reference distance P_{\max} : max tx power
 α : exponent λ : max density of concurrently tx nodes
 ξ : network radius

Applying Better Distance Limit

- Derivation of better distance limit - D
 - Limiting ignored interference power under a threshold σ_n^2

$$\hat{P} \leq \sigma_n^2 \Rightarrow D \geq \left(\xi^{2-\alpha} - \frac{(2-\alpha)\sigma_n^2 \overline{PL}(d_0)}{2\pi\lambda P_{\max} d_0^\alpha} \right)^{\frac{1}{2-\alpha}} \quad D \approx 2500\text{m with following parameters}$$

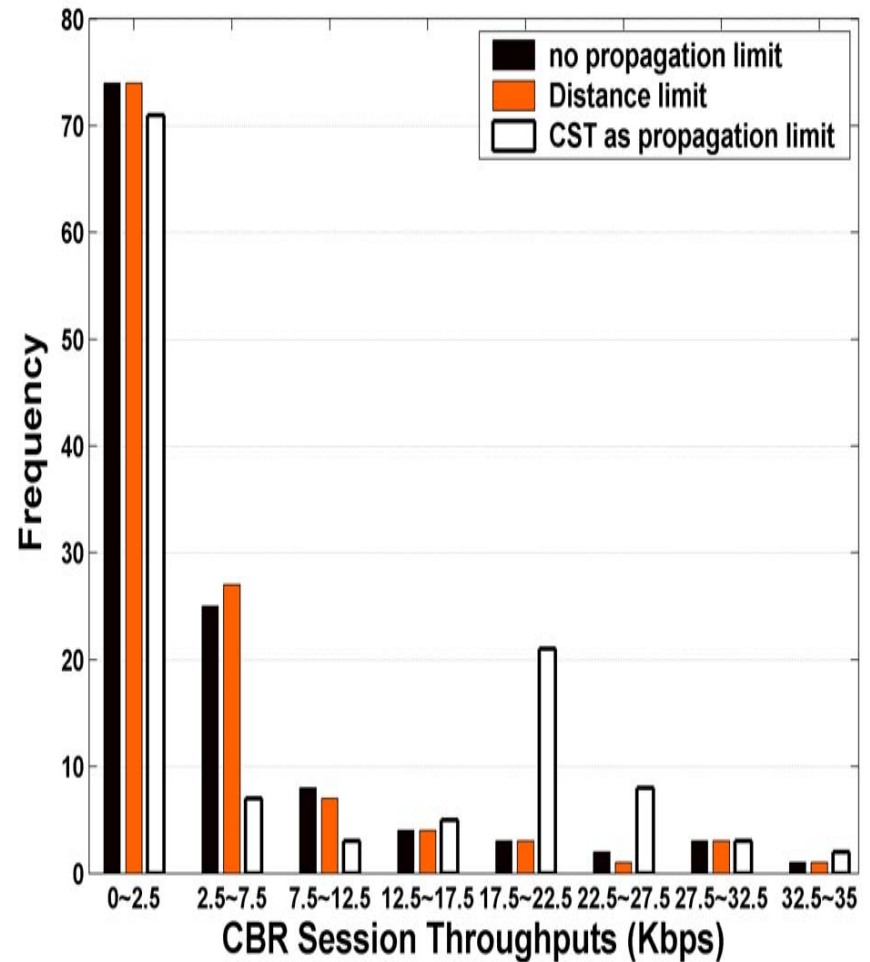
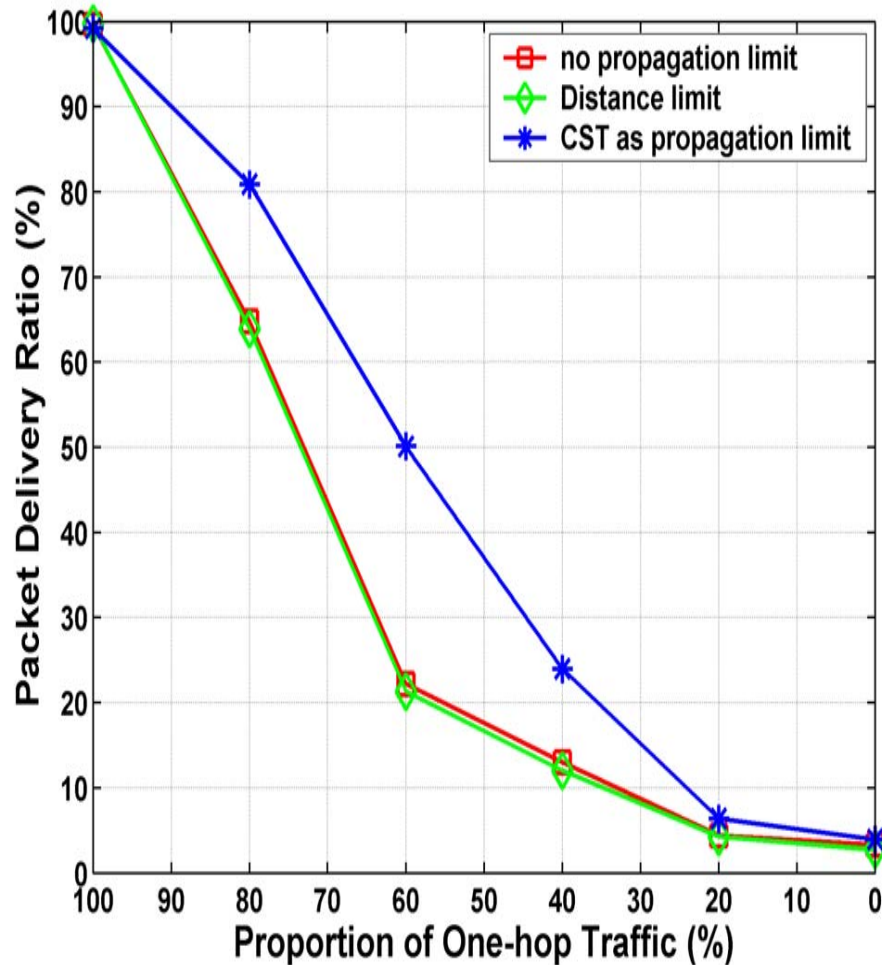
Table. Common experiment parameters

Propagation Model	TWO-RAY	Physical Data Rate	2Mbps
Channel Frequency	2.4GHz	Antenna Height	1.5m
Physical Model	802.11b DSSS	Transmission Power	15dBm
Modulation Scheme	DPSK	Receiving Threshold	-81dBm
MAC Model	802.11 DCF	Receiver Sensitivity	-91dBm

Validation of Distance Limit, D

- Experiment setup
 - 400 nodes uniformly distributed
 - 4000x4000m² terrain
 - AODV Routing
 - 120 CBR sessions between random pair of nodes and 8 pkts/sec each
 - 512 bytes/packet
 - Portion (%) of sessions are one hop traffic
- Measurement
 - Packet Delivery Ratio
 - Throughput Histogram of all sessions

Validation of D (cont')

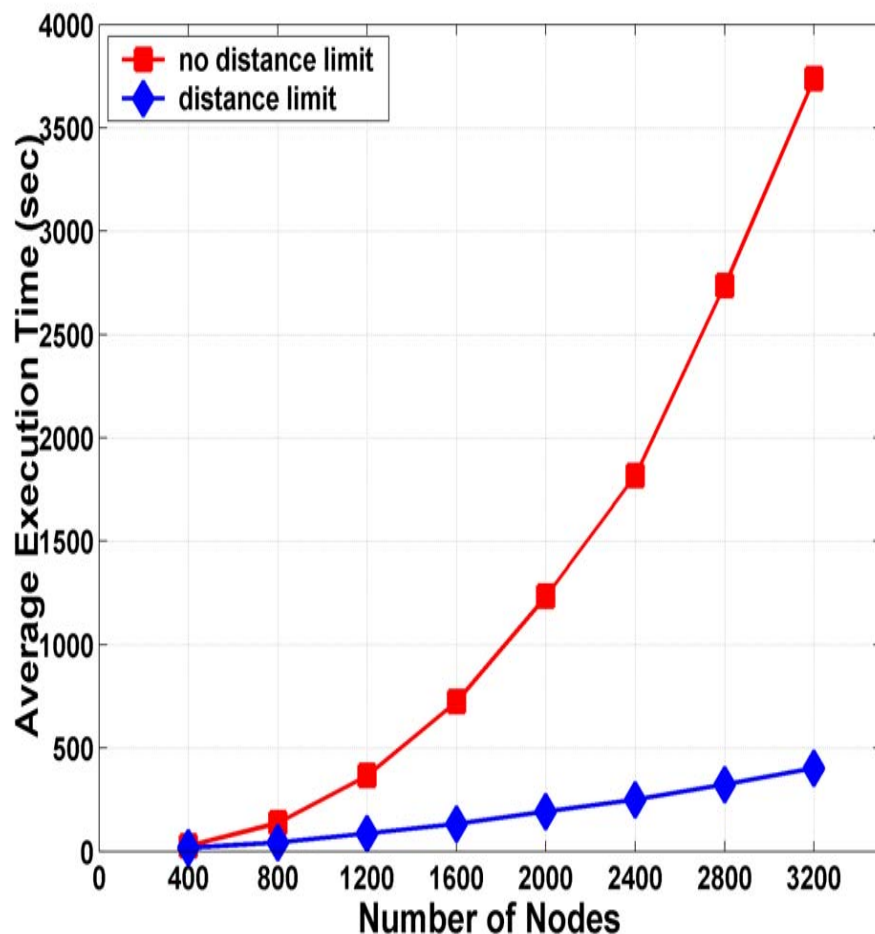


Performance Evaluation

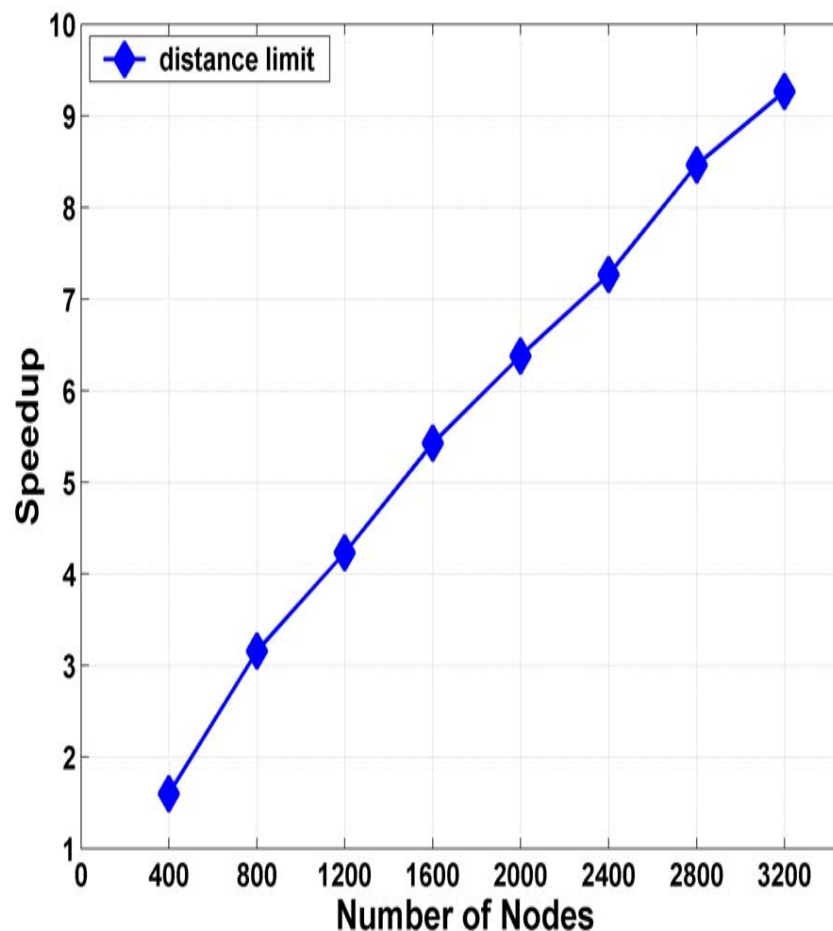
- Experiment setup
 - QualNet Network Simulator
 - Nodes are uniformly distributed
 - 30% of nodes have a CBR session to another node within two hop distance
 - 10 pkts/sec; 512 bytes/pkt
 - Varying network size
 - Varying node density
 - Varying traffic load

Performance with D - Varying Network Size

Execution Time

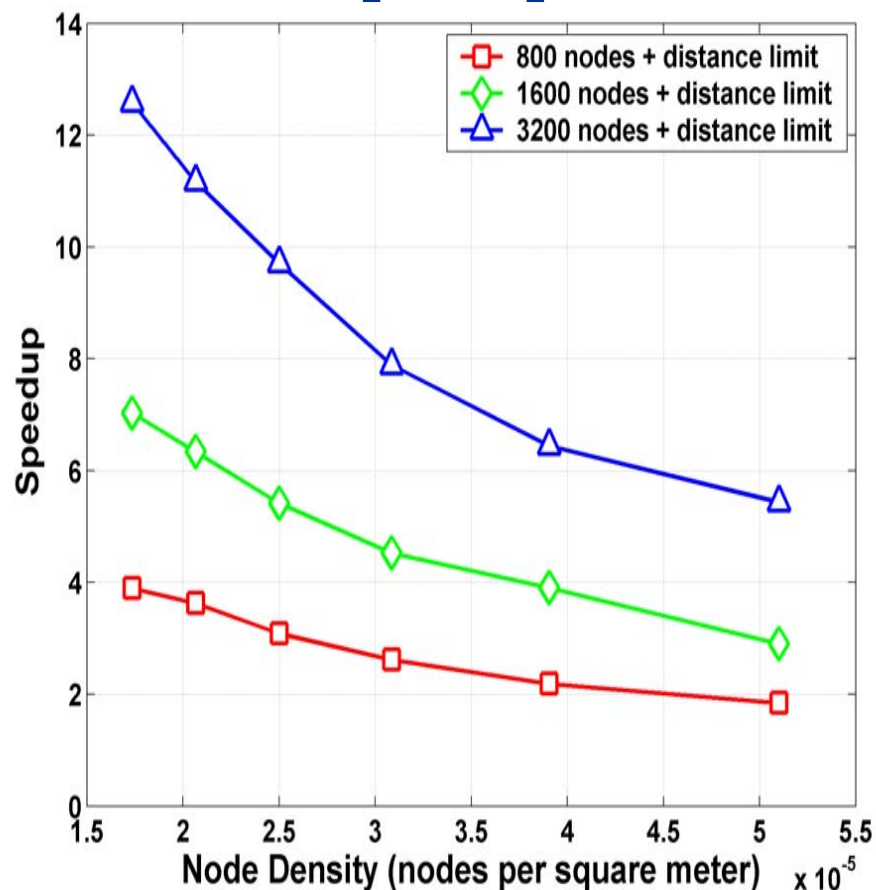


Speedup



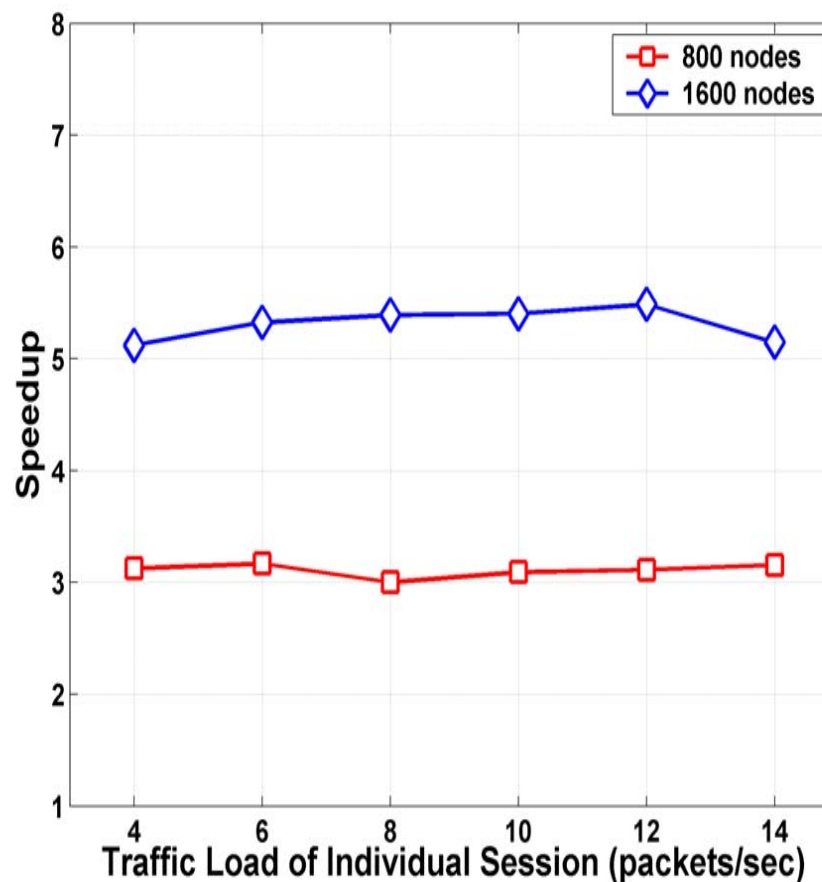
Performance with D - Varying Other Parameters

Speedup



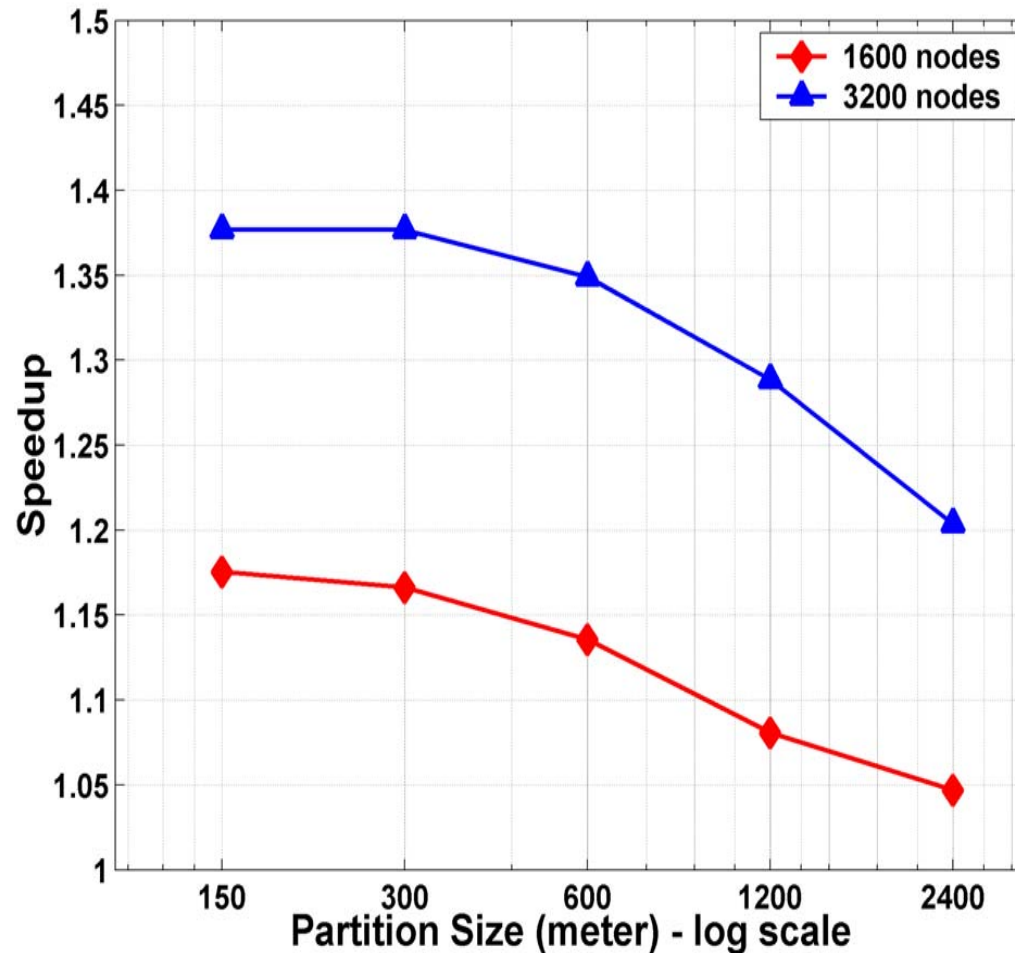
Varying node density

Speedup



Varying Traffic Load

Improvement by Partitioning



Observation

Partitioning can improve Performance, but...

Very limited improvement
Speedup < 1.4 in this scenario

Lesson's Learned

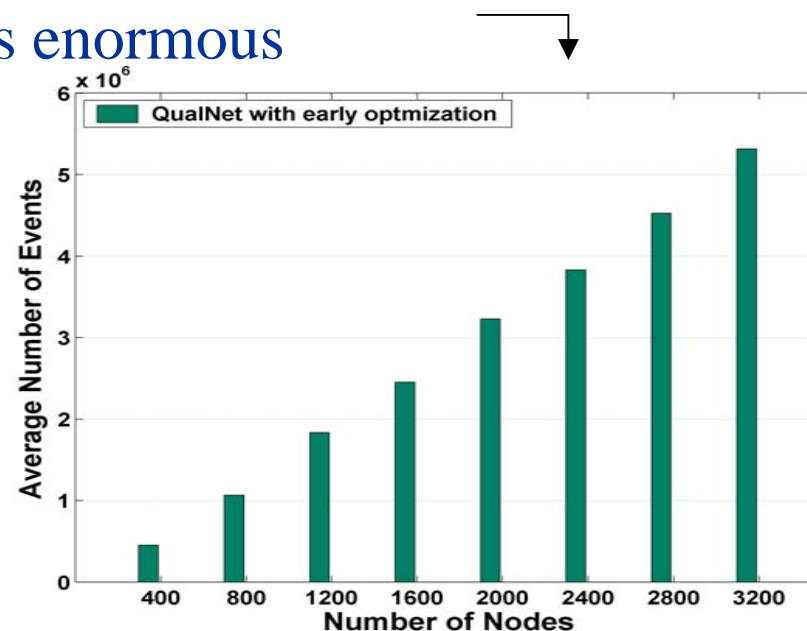
Improvement depends on inefficiency in simulator implementation

(e.g. "Simulation of Large Ad Hoc Networks" in MSWiM'03 claims huge performance gain of partitioning on *ns-2*. But such results cannot be found with QualNet – which runs much faster than *ns-2* without partitioning)

Solution: Reduction of PHY layer events

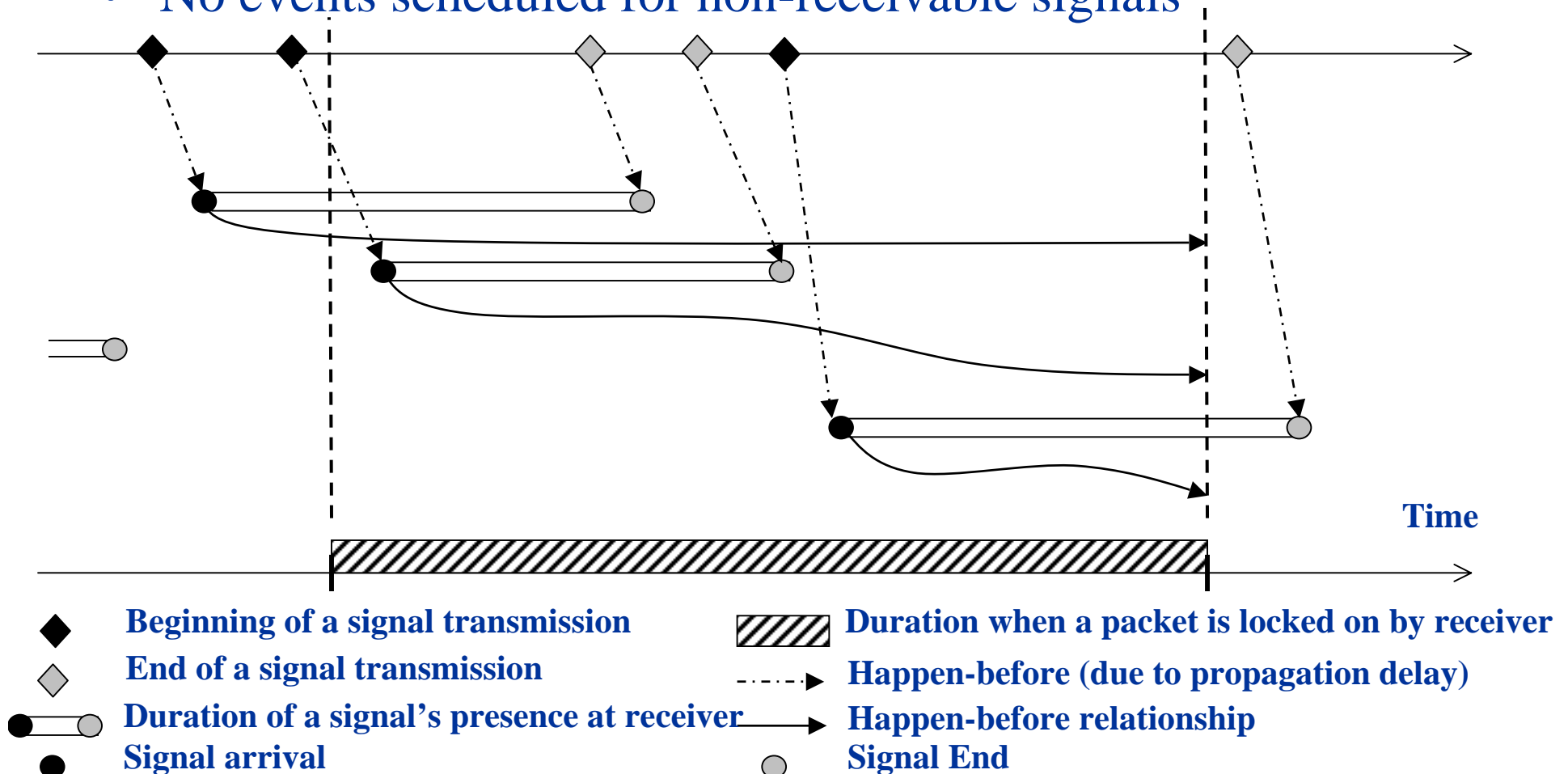
- In common network simulators
 - A packet transmission by PHY will generate a signal arrival & signal end event
 - Needed to update SINR & CCA
 - Event scheduling overhead is enormous

- Solution:
 - Lazy Event Scheduling
With Corrective Retrospection
(LSCR)



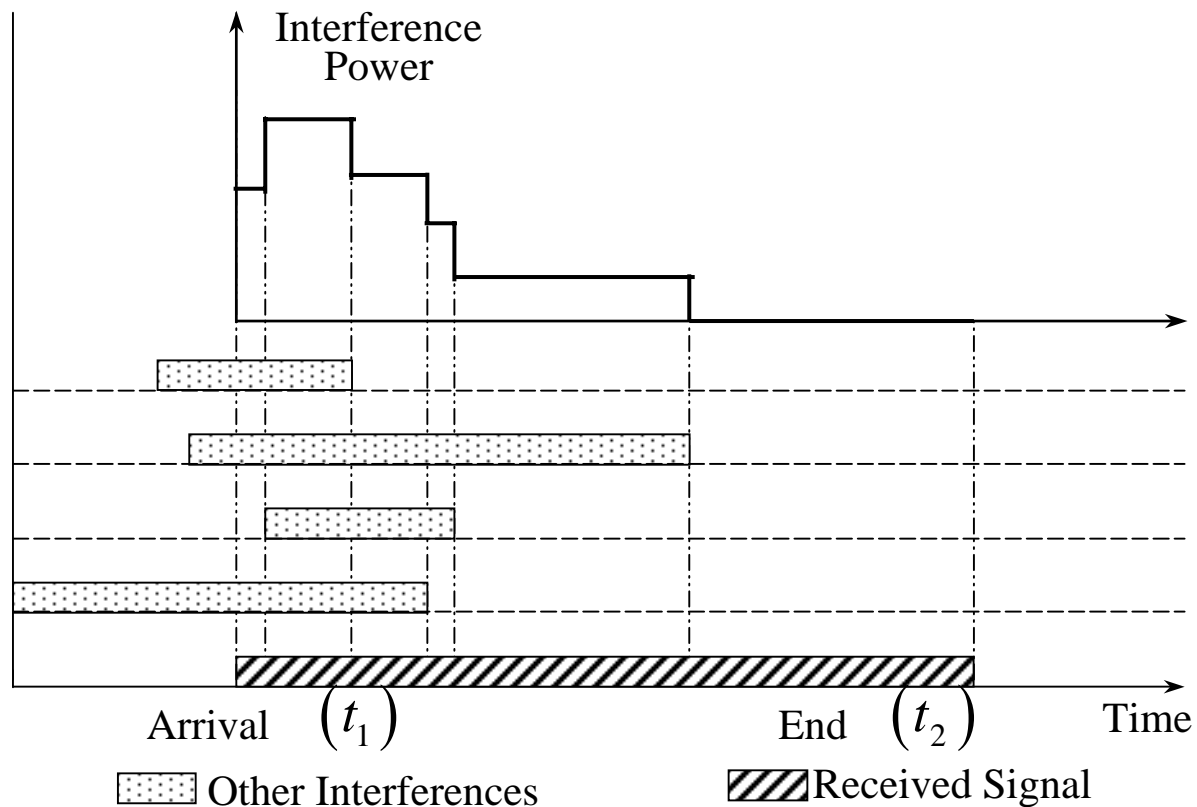
Lazy Event Scheduling

- No events scheduled for non-receivable signals



Corrective Retrospection

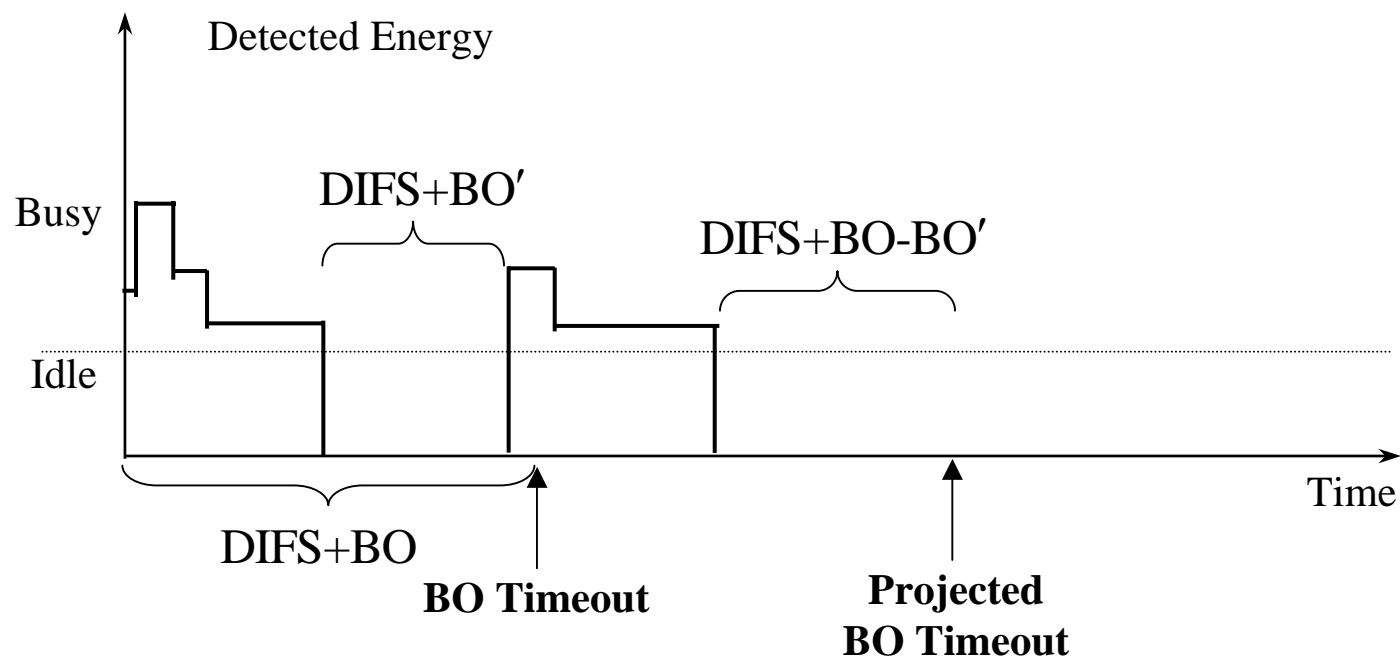
- Delayed packet error evaluation



Corrective Retrospection (cont')

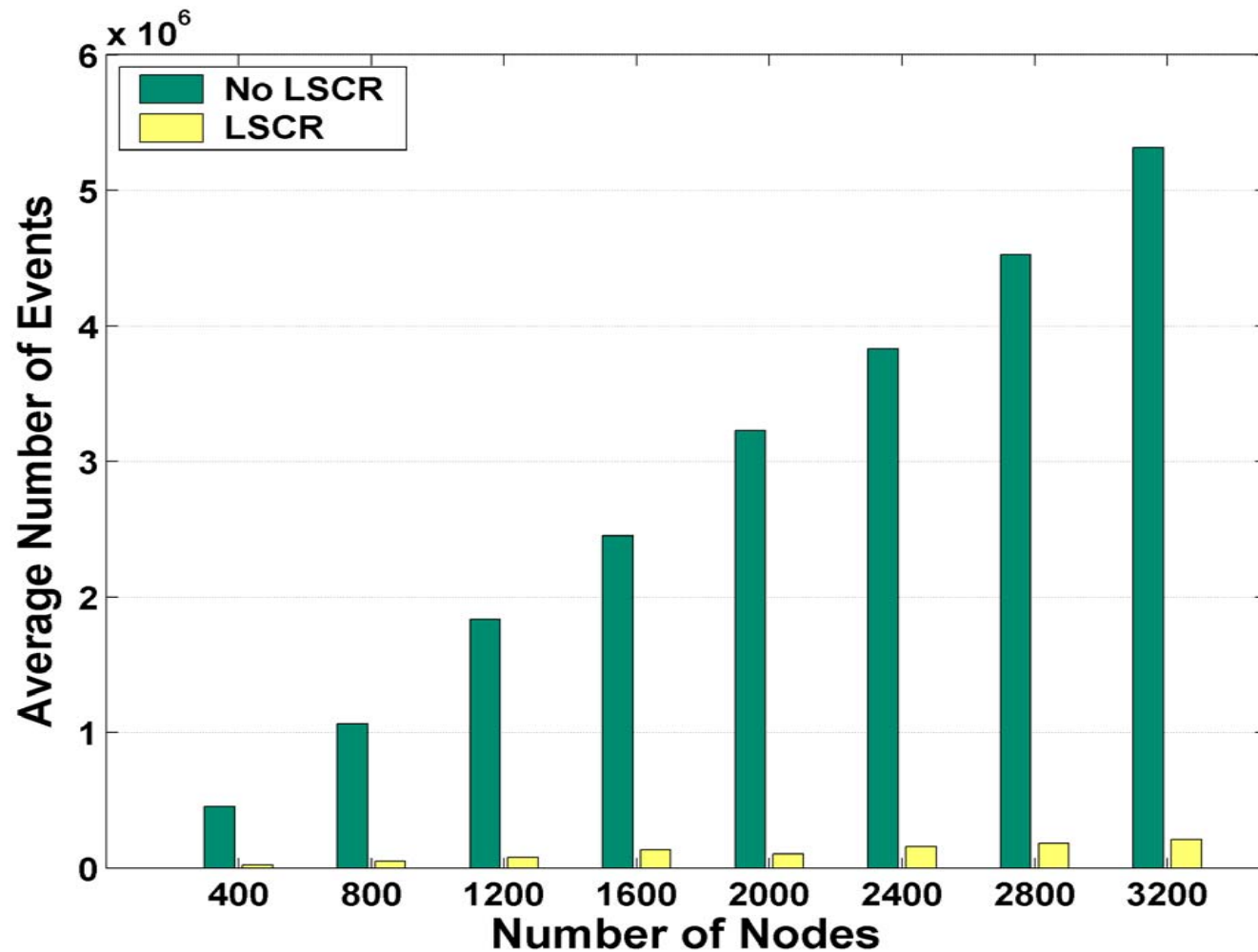
- **Timer corrections**

Keep adjusting timer's remaining time until actual remaining time and projected remaining time converges.

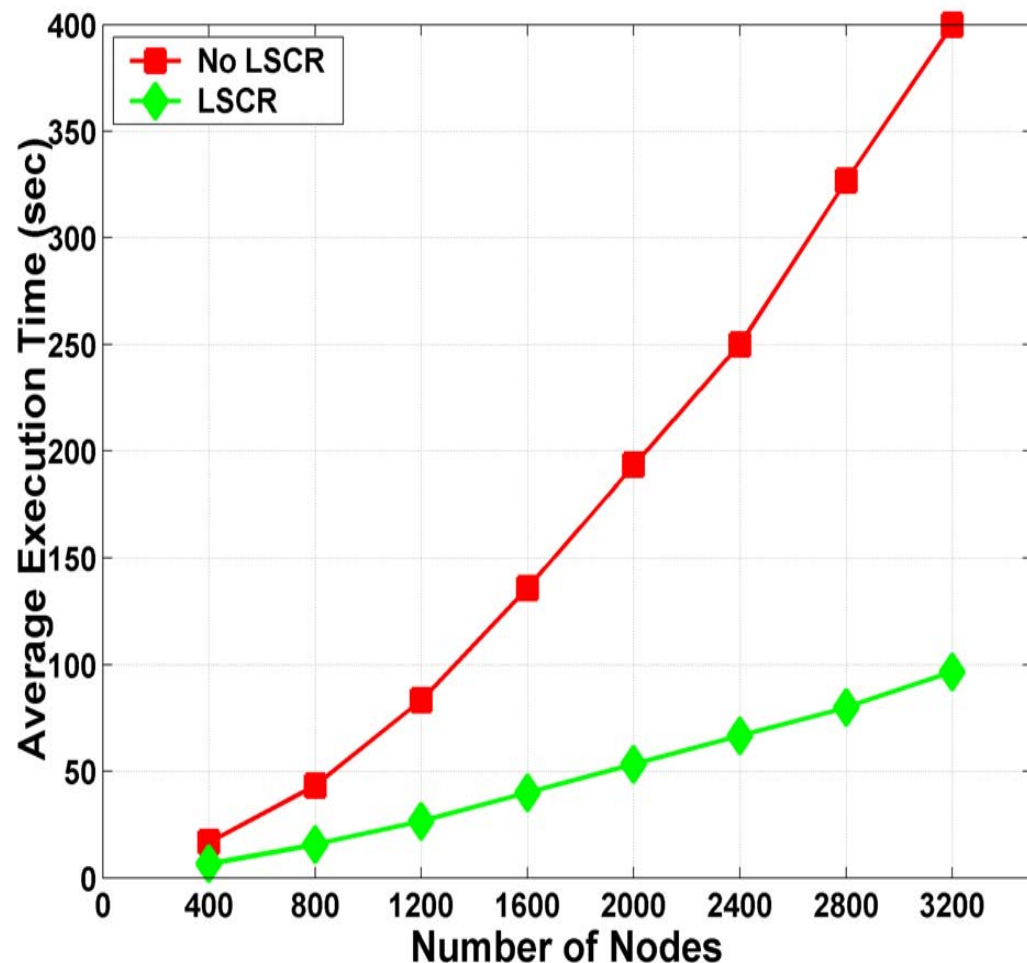


Events Reduction by LSCR

(per second in network simulation time)



Speedup of LSCR



Additional speedup of LSCR 2.5→4.2 as network size grows

Simulation results are exactly identical to those before this optimization

Note: The baseline for comparison has already included early optimizations

Conclusion

- Identified issue of inaccurate results due to CST propagation limit
- Derived appropriate formulation of distance limit as function of ignored-interference-power
- Showed good balance between accuracy and speedup with derived distance limit
- Proposed LSCR algorithm to further reduce physical layer simulation events without losing accuracy at all, and achieved up to 25 times events reduction and 4.2 speedup
- To investigate impact of inaccuracy at PHY/MAC layer to upper protocol layers

Thank you!

Any Questions?