Directional Routing for Wireless Mesh Networks: A Performance Evaluation

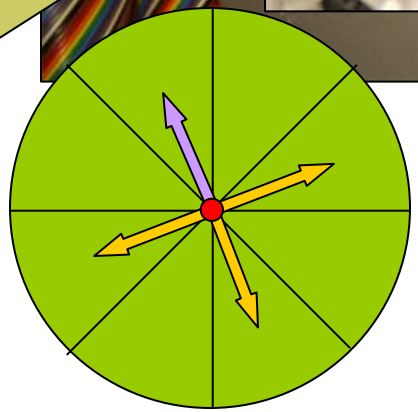
Bow-Nan Cheng
Murat Yuksel
Shivkumar Kalyanaraman

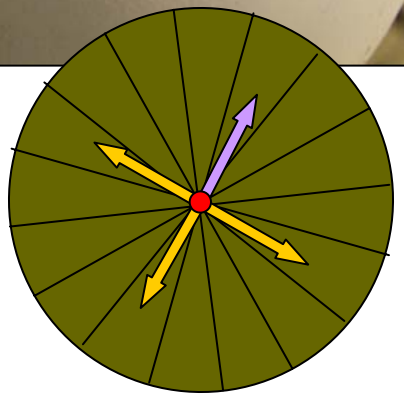
Motivation – Multi-directional Transmission Methods

Multi-directional Antennas

Tessellated FSO Transceivers

Can we use Directionality in Layer 3 Routing?



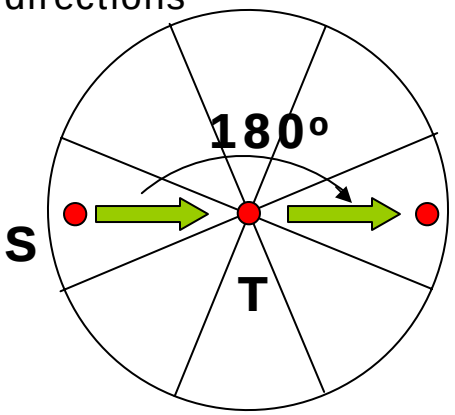


ORRP Big Picture

Orthogonal Rendezvous Routing Protocol

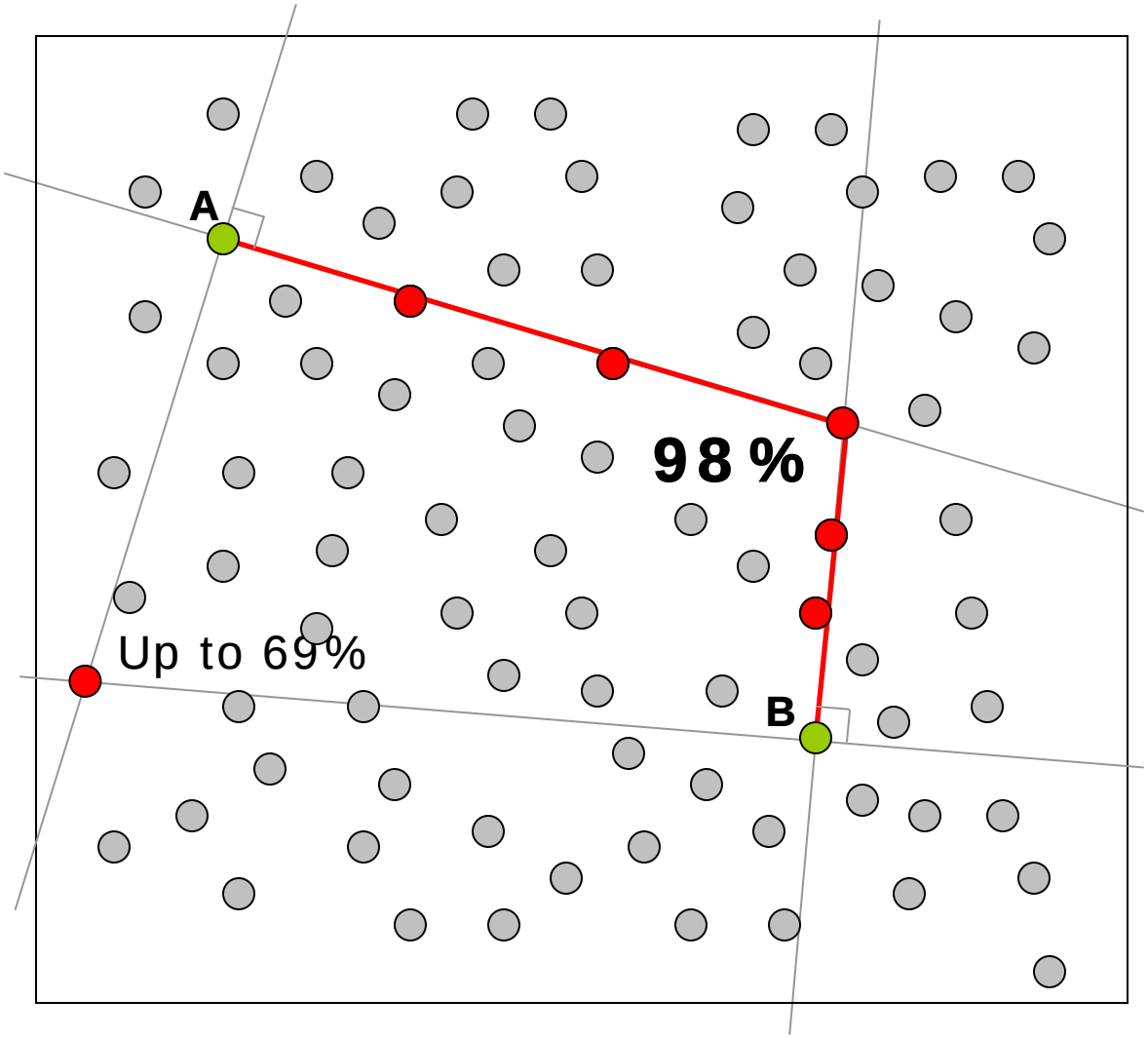
ORRP Primitive

- ***Local*** sense of direction leads to ability to forward packets in **opposite** directions

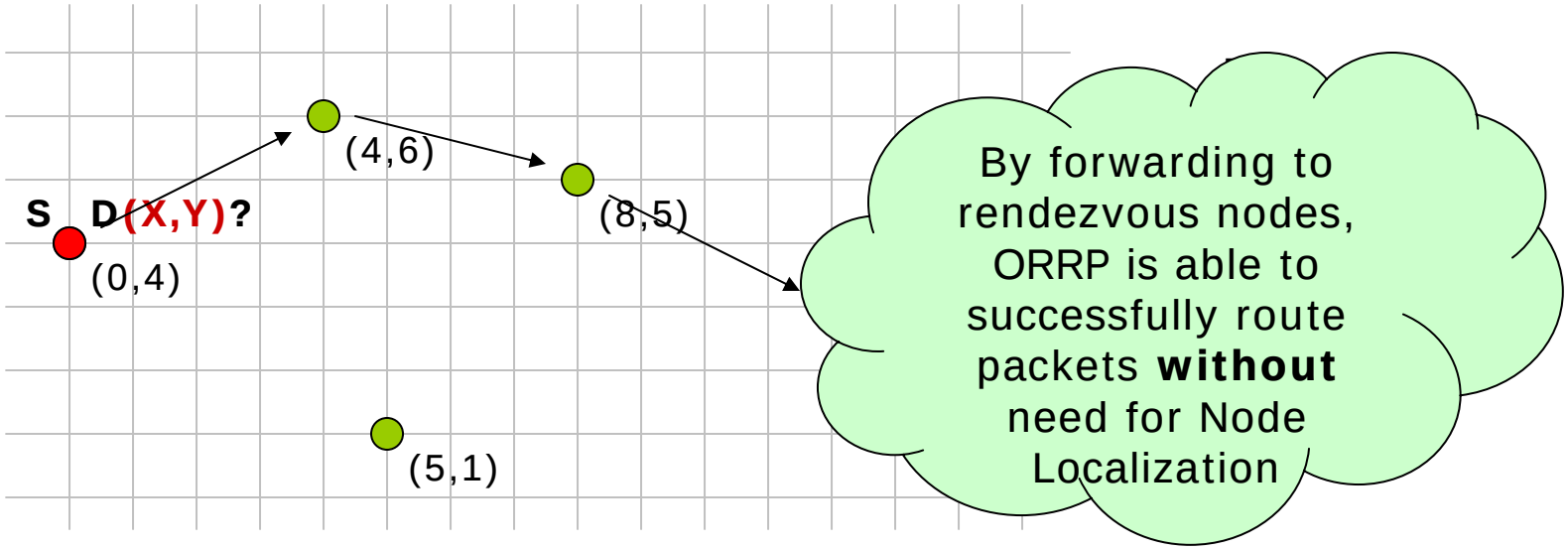


Multiplier Angle Method (MAM)

Heuristic to handle **voids, angle deviations,** and **perimeter cases**



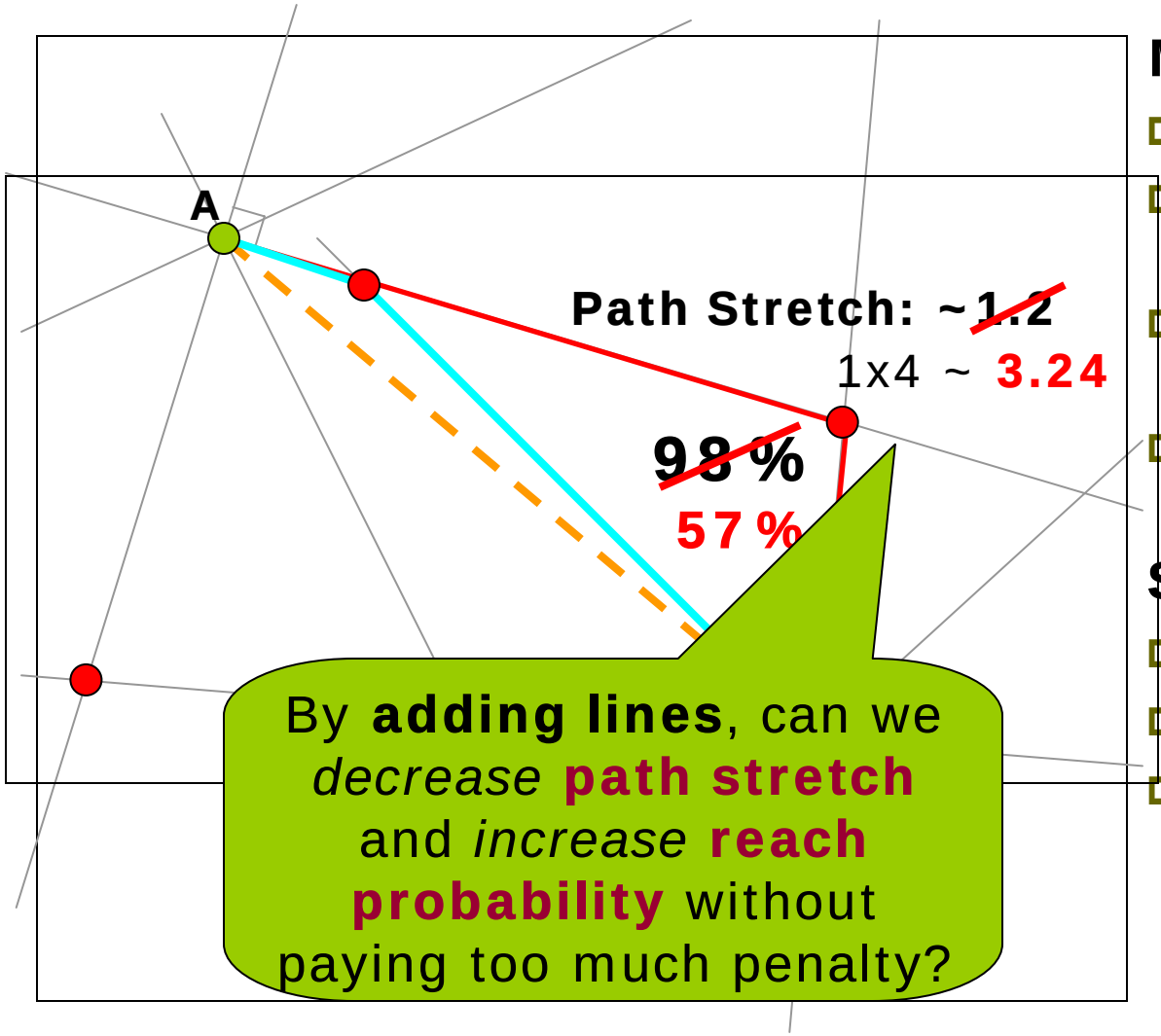
Benefits of ORRP



Issues in Position-based Schemes

L3: Geographic Routing using Node IDs (eg. GPSR, TBF etc.)	**ORRP**
L2: ID to Location Mapping (eg. GHT, GLS etc.)	
L1: Node Localization	**N/A**

Motivation



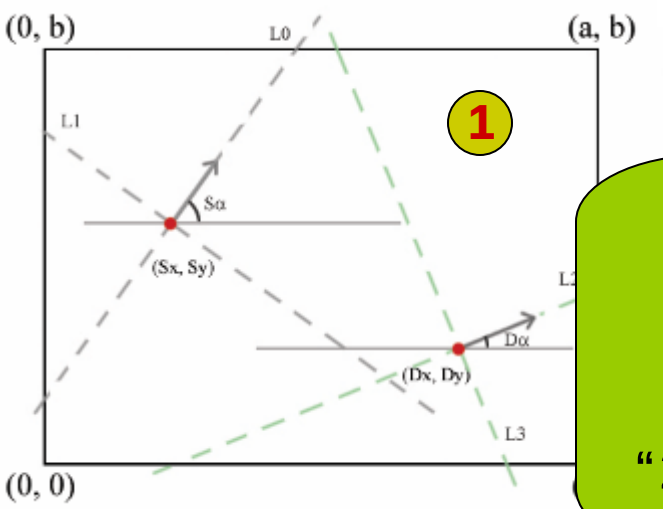
Metrics:

- *Reach* Probability
- *Path* Stretch / Average *Path* Length
- Total *States* Maintained
- Throughput

Scenarios Evaluated:

- Various Topologies
- Various Densities
- Network Voids

Reachability Numerical Analysis



2

$$L_0 : m_0 = tan(S_\alpha)$$
$$y_0(x) = x_i tan(S_\alpha) + S_y - tan(S_\alpha) \times S_x$$

P{unreachable} =

P{intersections not in rectangle}

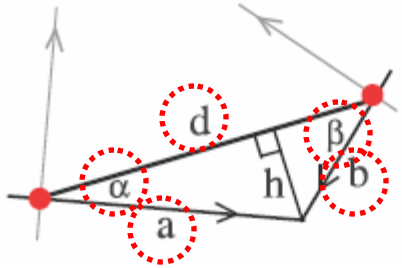
ible Intersection Points

$$: (x_{20}, y_{20}) \; s.t. \; y_0(x_{20}) = y_2(x_{20})$$
$$: (x_{21}, y_{21}) \; s.t. \; y_1(x_{21}) = y_2(x_{21})$$
$$: (x_{30}, y_{30}) \; s.t. \; y_0(x_{30}) = y_2(x_{30})$$
$$: (x_{31}, y_{31}) \; s.t. \; y_1(x_{31}) = y_2(x_{31})$$

Probability of *reach* does **not** increase dramatically with addition of lines above "2" (No angle correction)

Reach Probability vs. **Number of Lin** Numerical Analysis			
	1 Line (180º)	2 Lines (º)	3 Lines (60º)
Circle (Radius 10m)	58.33%	99.75%	100%
Square (10mx10m)	56.51%	98.30%	99.99%
Rectangle (25mx4m)	34.55%	57%	67.61%

Path Stretch Analysis



Stretch x = (a + b)/d

$0 \le \alpha < \pi/2$, $0 \le \beta$ …

$\alpha + \beta < \pi$

$$h = b\sin\beta = a\sin\alpha$$

$$d = b\cos\beta + a\cos\alpha$$

$$\frac{\sin\alpha + \sin\beta}{\sin(\alpha + \beta)}$$

$$E[X] = \int_0^{\frac{\pi}{2}} \int_0^{\frac{\pi}{2}-\alpha} \frac{\sin}{\sin}$$

$= 1.125$

Path stretch *decreases* with addition of lines but ***not as dramatically*** as between 1 and 2 lines (No angle correction)

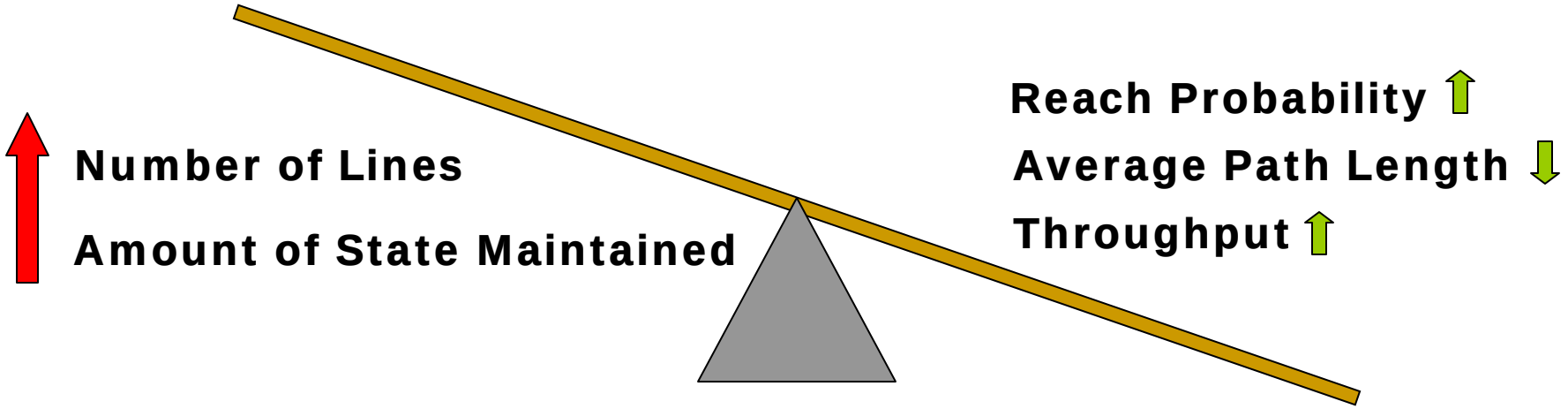
Path Stretch vs. Nu… …cal Analysis			
	1 Line (180º)	2 Li… …0º)	3 Lines (60º)
Circle (Radius 10m)	3.854	1.15…	1.031
Square (10mx10m)	4.004	1.255	1.039
Rectangle (25mx4m)	4.73	3.24	1.906
Grid (No Bounds)	1.323	1.125	1.050

NS2 Sim Parameters/Specifications

DEFAULT SIMULATION PARAMETER

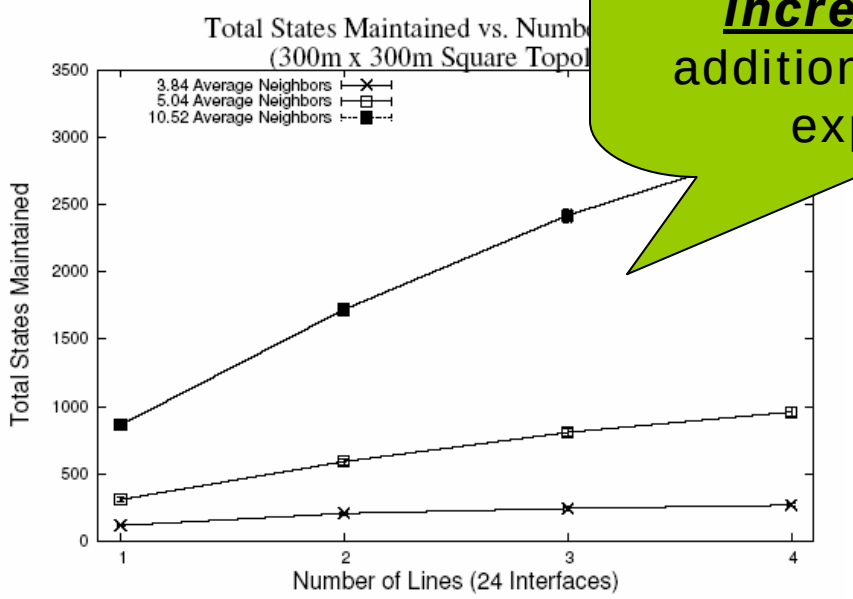
Parameter	Values
Transmission Radius	60m
Number of Interfaces	24
TTL for Control Pkts	10
Topology Boundaries	300m x 300m
Announcement Interval	2.0s
Route Timeout	10s
Simulation Time	50s
Mobility	None

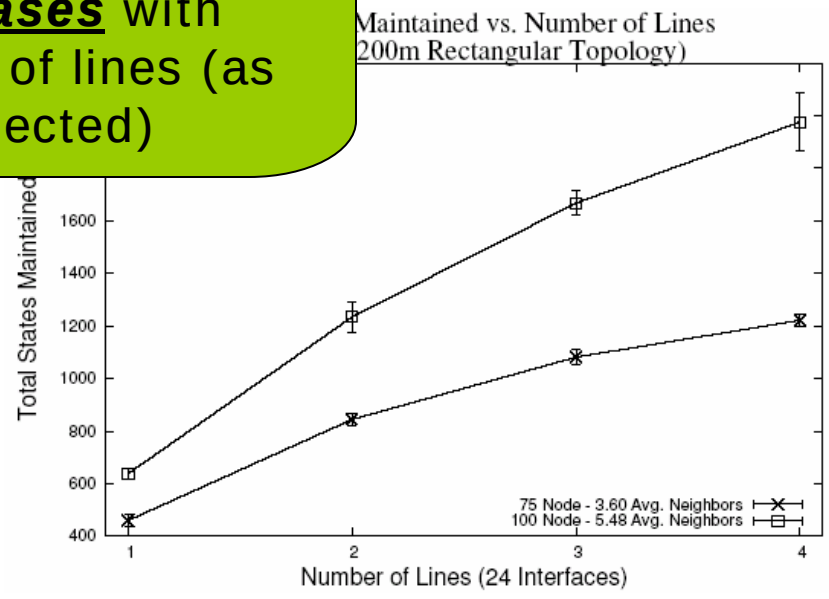
- All Simulations Run **30 Times, <u>averaged</u>,** and **<u>standard deviations</u>** recorded



Effect of Number of Lines on Various Topologies and Network Densities

Total States Maintained *increases* with addition of lines (as expected)





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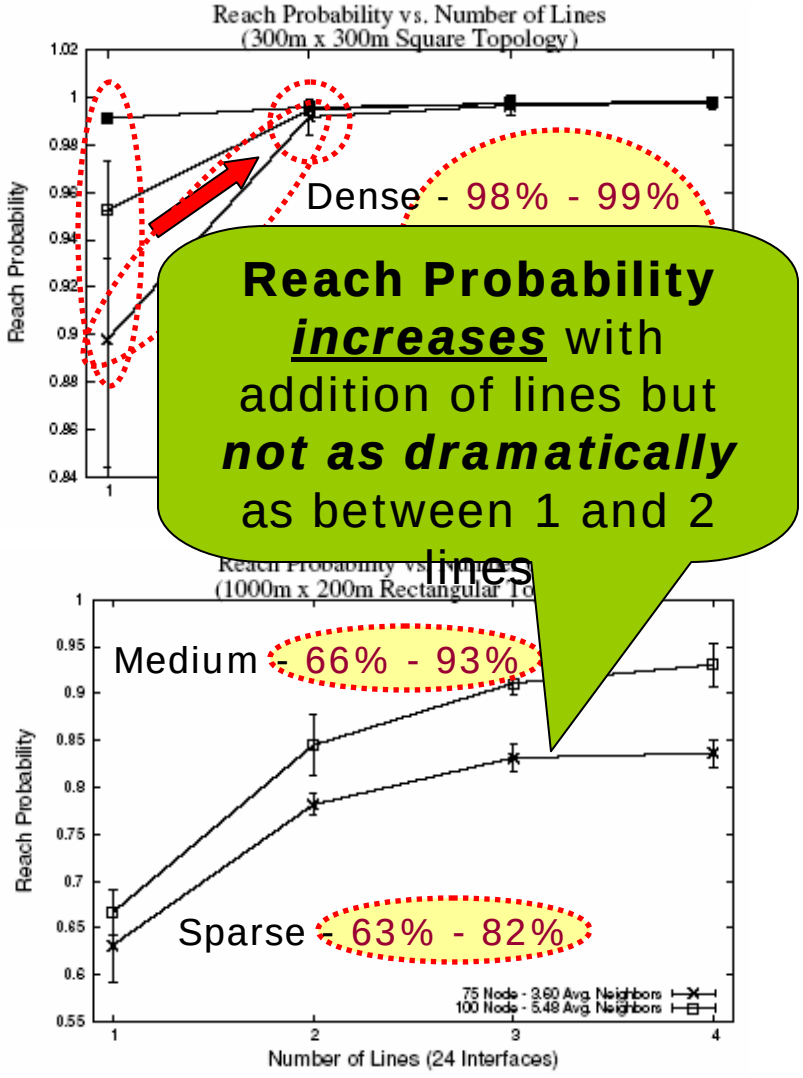
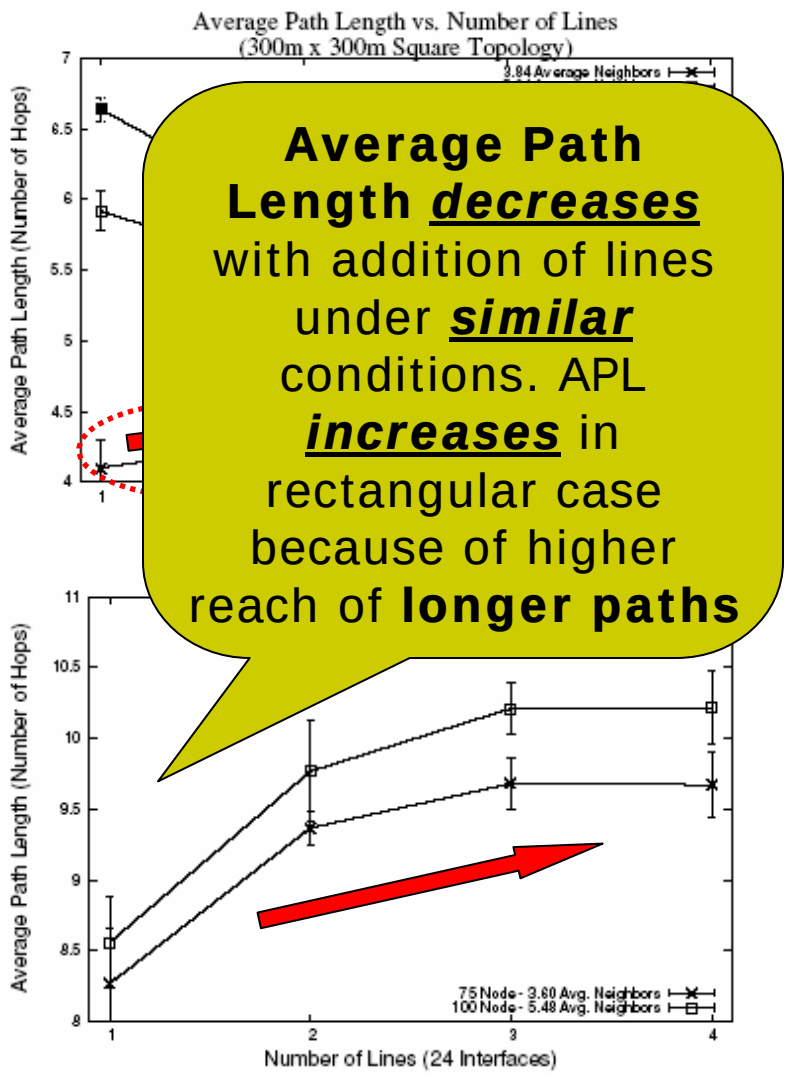


Reach Probability *increases* with addition of lines but ***not as dramatically*** as between 1 and 2 lines



Average Path Length *decreases* with addition of lines under ***similar*** conditions. APL ***increases*** in rectangular case because of higher reach of **longer paths**

Numerical Analysis vs. Simulations

Angle Correction with **MAM** ***increases*** **reach** dramatically!

Reach Probability (Num Anal						vg. Density)
	1 Line (18				**Lines (60º)**	
Topology Boundaries	*Analysis*	*Sim*	*nalysis*	*Sims*	*Analysis*	*Sims*
Square	56.51%	9[illegible]3%	98.30%	99.5%	99.99%	99.8%
Rectangle	34.55%	66.7%	57%	84.5%	67.61%	91.1%

Path Stretch (Num Analysis w/o MAM vs. Simulations)						
	1 Line (180º)		**2 Lines (90º)**		**3 Lines (60º)**	
Topology Boundaries	*Analysis*	*Sims*	*Analysis*	*Sims*	*Analysis*	*Sims*
Square	4.004	1.54	1.255	1.272	1.039	1.21

Additional Simulation Results

- **Network Voids**
  - Average path length fairly constant (Reach and State not different)
- **Throughput**
  - Higher average network throughput with additional lines (better paths and higher reach)
- **Mobility**
  - Significantly drops in reach (ORRP never designed for mobility)

Summary

- Addition of lines yields significantly ***diminishing returns*** from a **connectivity-state maintenance** perspective after 1 line
- Addition of lines yields ***better*** **paths** from source to destination and ***increases*** **throughput**
- Using **Multiplier Angle Method (MAM)** heuristic, even only 1 line ***provides a high degree*** of **connectivity** in symmetric topologies
- When *mobility* is added into the picture, addition of lines yields only ***marginally better*** **delivery success** and **average paths chosen**

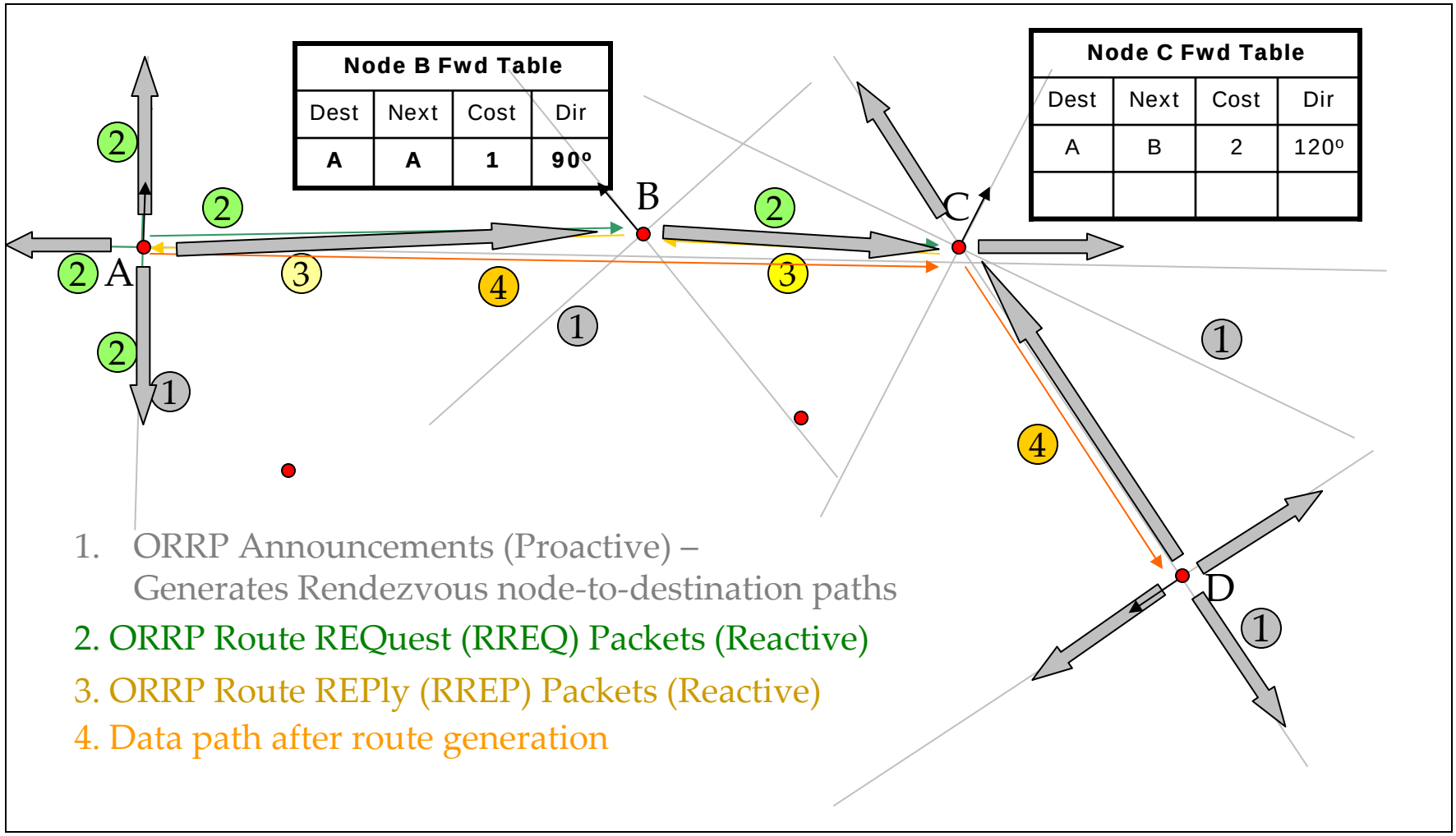
Future Work

- Mobile ORRP (MORRP)
- Hybrid Direction and Omni-directional nodes
- Exploring additional heuristics to maintain straight-line paths

Thanks!

Questions or Comments: chengb@rpi.edu

ORRP Basic Illustration



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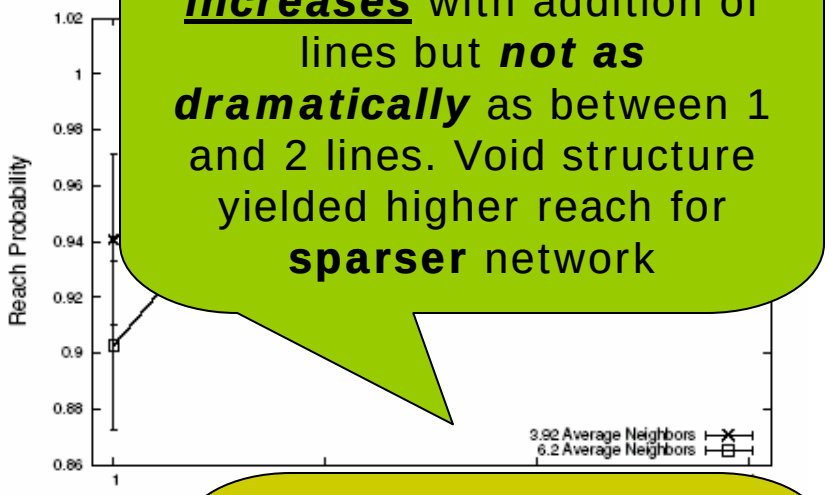
- All Simulations Run **30 Times, <u>averaged</u>,** and **<u>standard deviations</u>** recorded

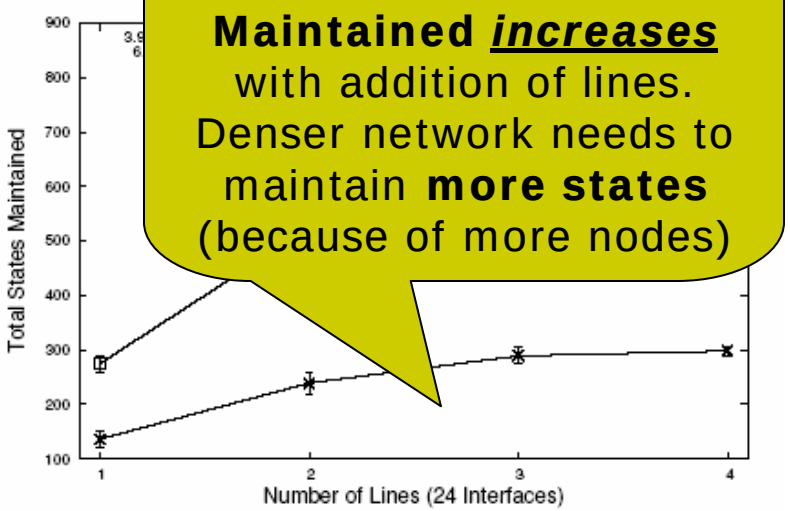
- **Reach Probability Measurements**
  - Send only 2 CBR packets (to make sure no network flooding) from all nodes to all nodes and measure received packets
- **Average Path Length Measurements**
  - Number of hops from source to destination. If no path is found, APL is **<u>not</u>** recorded
- **Total State Measurements**
  - Number of entries in routing table snapshot
- **Throughput Scenarios**
  - 100 Random CBR Source-Destination connections per simulation run
  - CBR Packet Size: 512 KB
  - CBR Duration: 10s at Rate 2Kbps
- **Mobility Scenarios**
  - Random Waypoint Mobility Model
  - Max node velocities: 2.5m/s, 5m/s, 7.5m/s
  - Connectivity Sampling Frequency: Every 20s
  - Simulation Time: 100s
  - Number of Interfaces: 12

Effect of Number of Lines on Networks with Voids

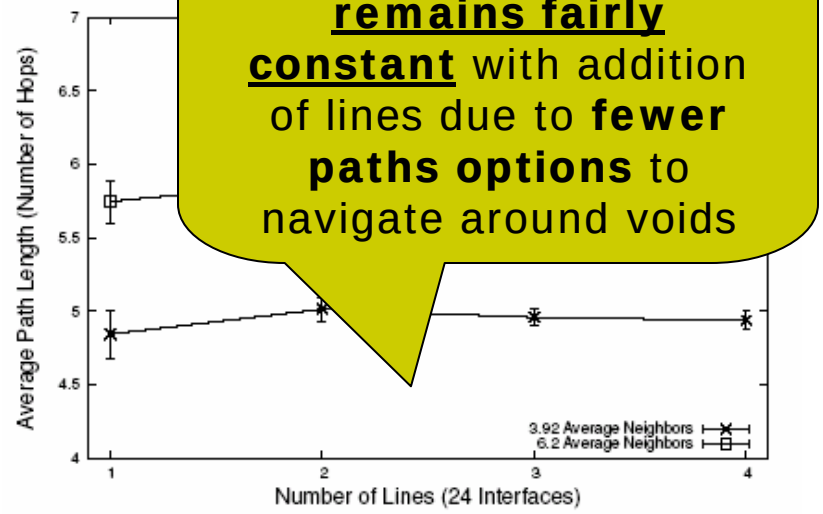
Reach Probability *increases* with addition of lines but ***not as dramatically*** as between 1 and 2 lines. Void structure yielded higher reach for **sparser** network



Total States Maintained *increases* with addition of lines. Denser network needs to maintain **more states** (because of more nodes)



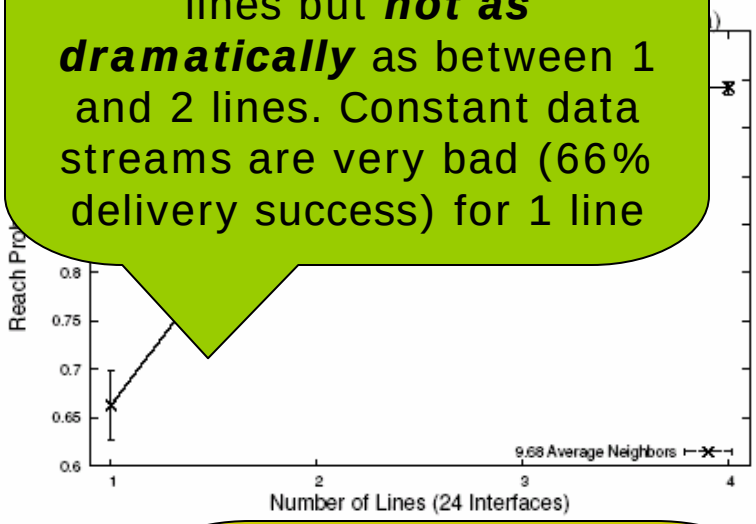
Average Path Length *remains fairly constant* with addition of lines due to **fewer paths options** to navigate around voids



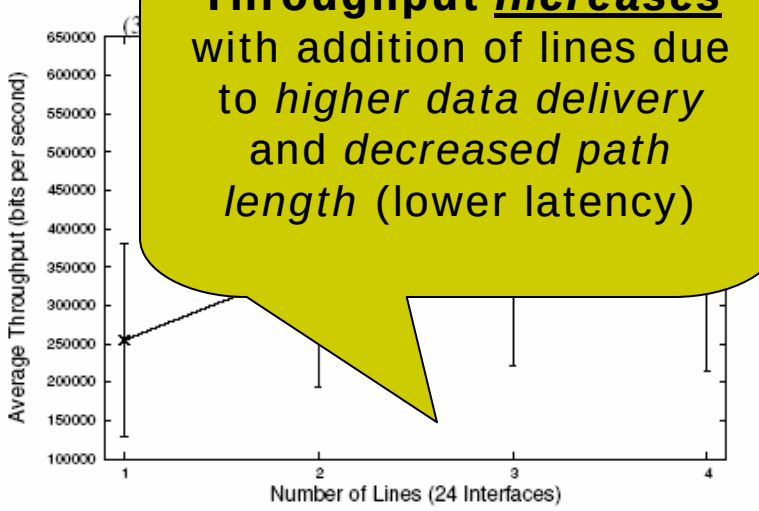
- **Observations / Discussions**
  - **Reach probability *increases*** with addition of lines but only dramatically from 1-2 lines.
  - Void structure yielded higher reach for sparse network (odd)
  - **Average Path Length *remains fairly constant*** (higher APL with denser network) with addition of lines due to fewer path options (there's generally only 1 way around the perimeter of a void)

Effect of Number of Lines on Network T

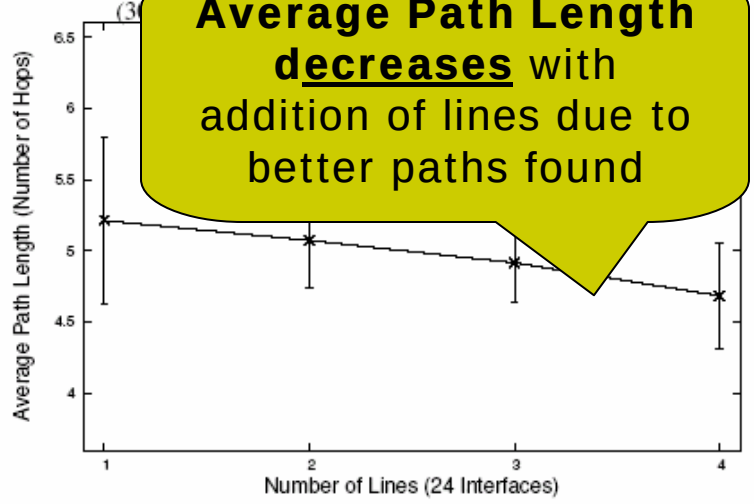
Packet Delivery Success *increases* with addition of lines but ***not as dramatically*** as between 1 and 2 lines. Constant data streams are very bad (66% delivery success) for 1 line



Throughput *increases* with addition of lines due to *higher data delivery* and *decreased path length* (lower latency)

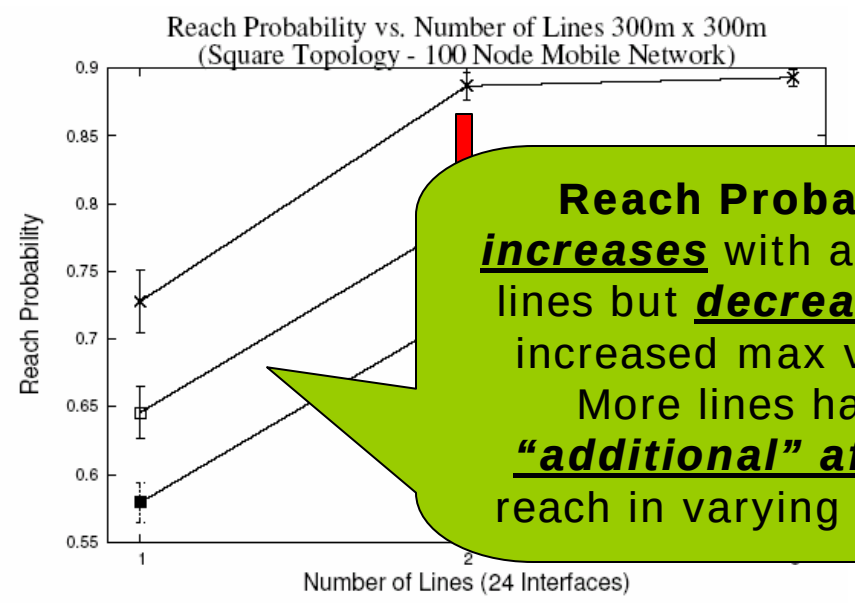


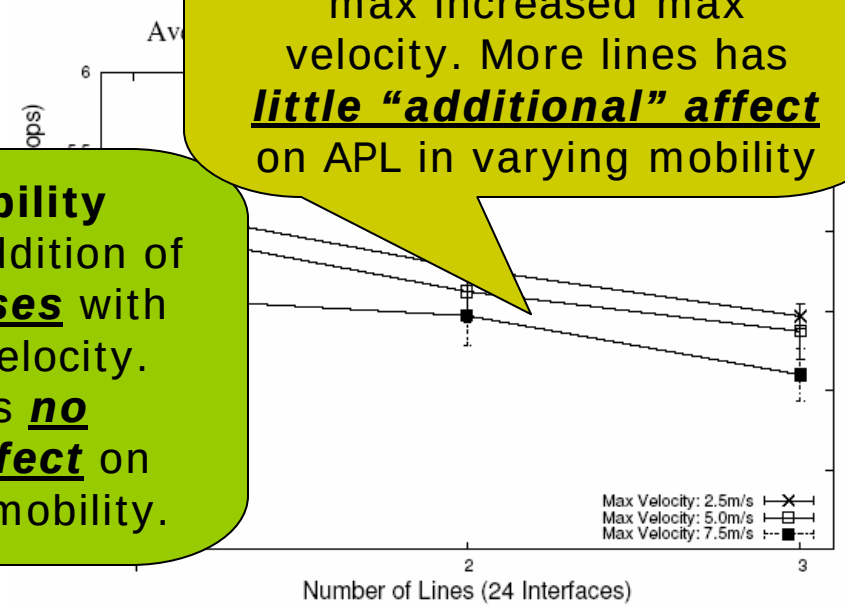
Average Path Length *decreases* with addition of lines due to better paths found



- **Observations / Discussions**
  - **Reach probability *increases*** with addition of lines but only dramatically from 1-2 lines.
  - Constant data streams are not very good with 1 line
  - **Average Path Length *decreases*** with addition of lines (better paths found)
  - **Throughput *increases*** with additional lines (higher data delivery + decreased path length and lower packet delivery latency)

Effect of Number of Lines on Varying Network Mobility





Reach Probability *increases* with addition of lines but ***decreases*** with increased max velocity. More lines has ***no "additional" affect*** on reach in varying mobility.

Average Path Length *decreases* with addition of lines and ***decreases*** with max increased max velocity. More lines has ***little "additional" affect*** on APL in varying mobility

- **Observations / Discussions**
  - **Reach probability *increases*** with addition of lines but **decreases** with increased max velocity
  - **Average Path Length *decreases*** with addition of lines (better paths found)
  - More lines yields ***little to no "additional" affect*** on reach and average path length in varying mobile environments