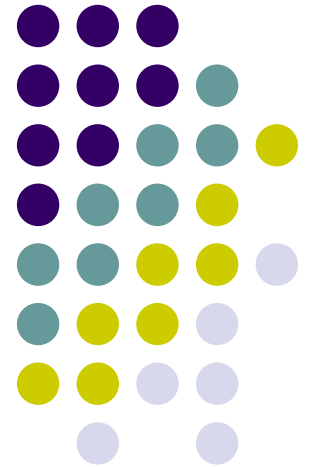


Capacity Enhancement using Throwboxes in Mobile DTNs



Delay Tolerant Networks (DTN)



- DTNs: *non-Internet-like* networks
 - Intermittent connectivity
 - Large delay
 - High loss rates
- Examples of DTNs
 - Tactical networks, disaster relief, peacekeeping
 - Interplanetary networks, rural village networks
 - Underwater acoustic networks
- DTN features
 - Store-and-forward
 - Message switching





Capacity Limitation in DTNs

- DTNs may suffer from intermittent connectivity
 - Low throughput, large delay
- Question: how to enhance network capacity?
- Previous approaches
 - Use radios with longer range
 - Deploy a mesh network as infrastructure
 - Infostation
 - Message ferrying (or data mules)

Throwbox

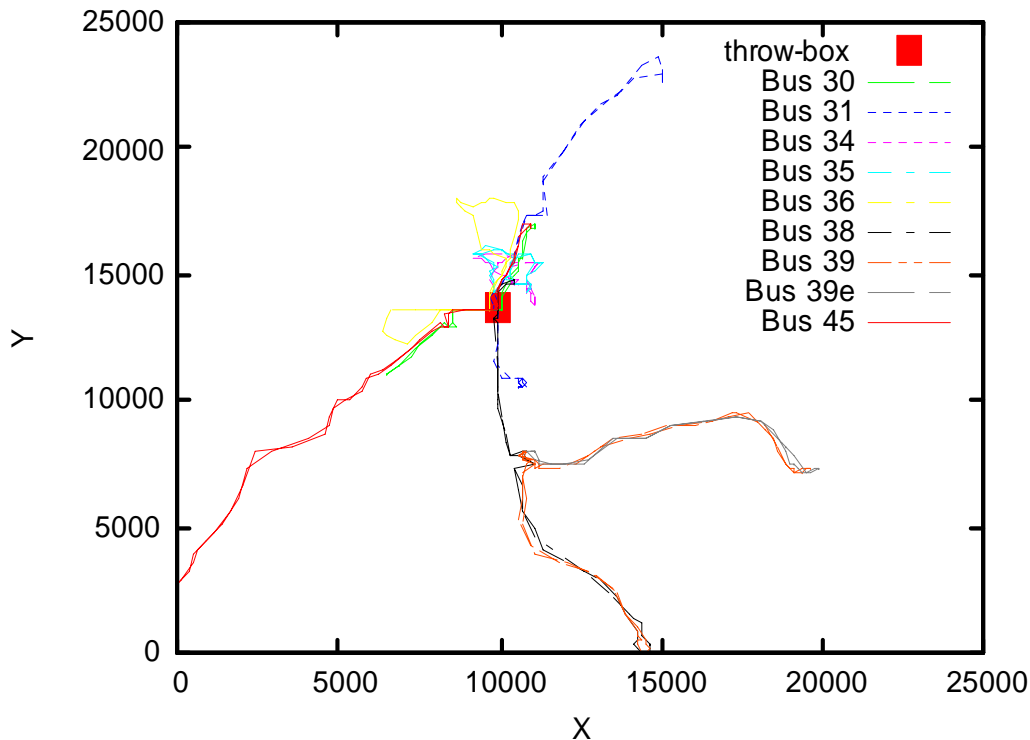


- Mobile DTNs
 - Network performance depends on opportunistic contacts between nodes
 - More contacts lead to better performance
- Throwbox approach
 - Idea: *create more contacts using relaying devices*
 - Throwboxes are small and dispensable wireless devices
 - Throwboxes relay data between mobile nodes passing by at *different* times

Example



UMassDiesel DTN Example



Performance between bus 38 and 45

# of throwboxes	None	One
Total contact duration (sec)	631	11927
Effective capacity (Kbps)	3.5	66.3
Delay (sec)	63012	3120

- A single throwbox achieves an improvement factor of 19 for capacity and 20 for delay



Throwbox Characteristics

- Throwboxes need to support opportunistic transmissions
 - High availability
 - Supporting bursty operations
 - High energy efficiency
- Potential platforms
 - Crossbow Stargate, UMass Triage
- UMass Triage
 - Combine a Stargate board with MicaZ mote
 - Always-on mote achieves high availability and energy efficiency
 - Stargate supports bursty operations

Throwbox Approach



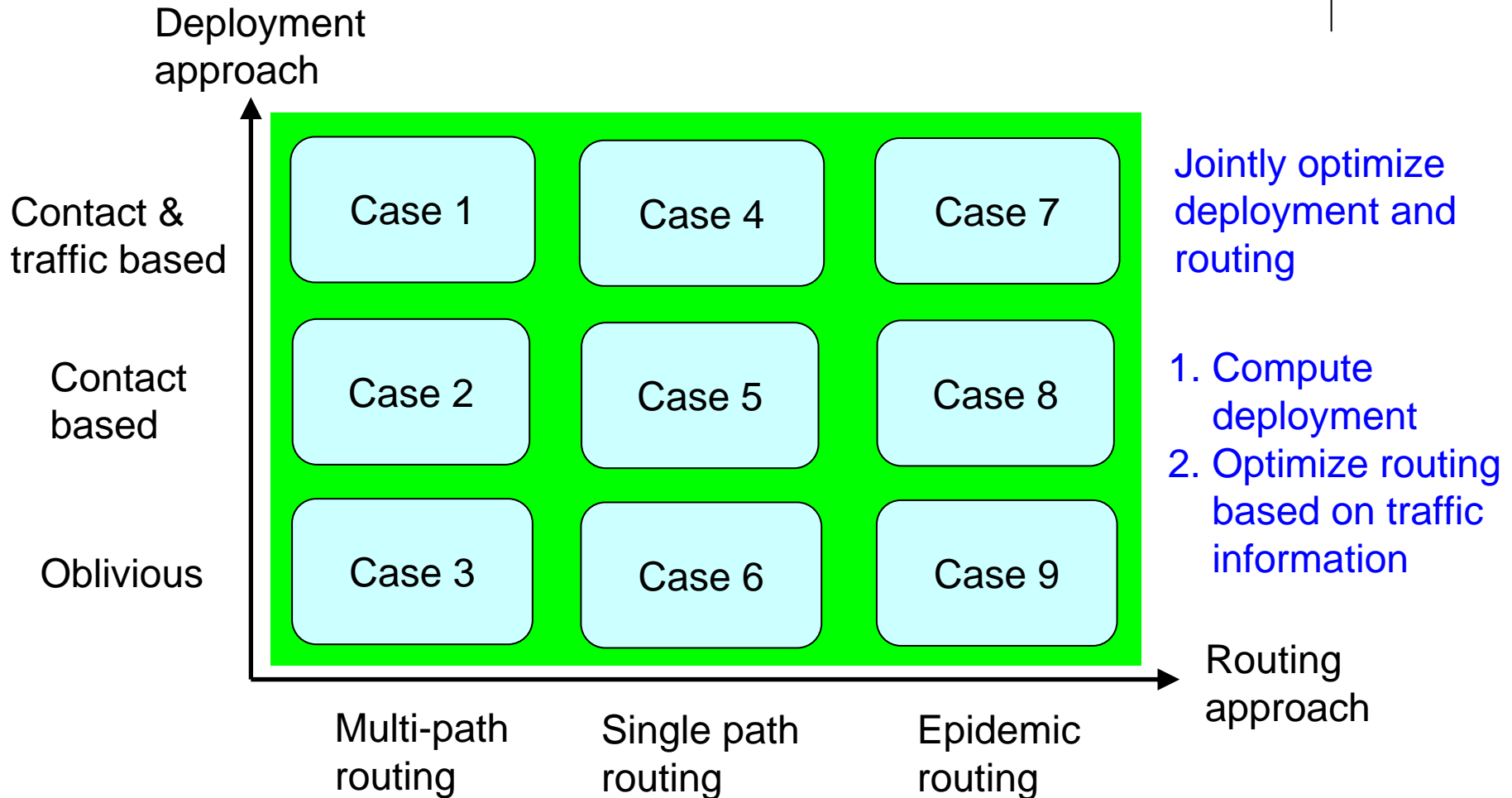
- Flexible deployment
 - Deployed by airplanes
 - Thrown by users
 - Attached to vehicles
- Cost effective
 - Throwboxes are dispensable
 - Deployed at large numbers to improve robustness
- Easy operation and maintenance
 - Can operate without coordination among throwboxes
 - Inherently tolerate disconnection

Throwbox Deployment & Routing Framework



- Focus on throughput improvement
- Question: *how to utilize throwboxes to maximize throughput?*
 - Deployment: where to place throwboxes?
 - Routing: how data are forwarded?
- Deployment and routing approaches
 - What information is available to deployment?
 - Contact and traffic based
 - Contact based
 - Oblivious
 - What flavor of routing algorithm is used?
 - Multi-path routing
 - Single path routing
 - Epidemic routing

Throwbox Deployment & Routing Framework (2)





Network Model

- A DTN consists of mobile nodes
- Relative traffic demand between nodes b_{ij}

$$\sum_{i,j} b_{ij} = 1$$

- Throwbox deployment
 - Deployed to fixed locations
 - Sufficient energy supplies
 - No interaction between throwboxes

Multi-Path Routing – CTB Deployment



Input

m throwboxes

capacity between nodes C

traffic demand matrix $B_{n \times n}$

Objective

maximize supported traffic $\lambda B_{n \times n}$

Output

throwbox locations

data forwarding decisions

Multi-Path Routing – CTB Deployment (2)



- Formulated as an integer linear programming problem
 - Numbers of throwboxes deployed at each location are integers
 - NP-hard to solve optimally
- Greedy algorithm
 - Deploy throwboxes one by one

for $i=1$ **to** m **do**

find location L that maximize λ
deploy a throwbox at location L

end

compute routing

linear programming
problem

Multi-Path Routing – Contact Based Deployment



- Deployment based on contact information, but not traffic information
 - Benefit all kinds of traffic, but not optimal for specific traffic
 - Maximize contacts between nodes
- Absolute contact enhancement
 - Maximize absolute enhancement of contacts between nodes
- Relative contact enhancement
 - Maximize relative enhancement of contacts between nodes

Single Path Routing – CTB Deployment



- Data are forwarded along a single path between source and destination
 - NP-hard to solve optimally
- Greedy algorithm for single path routing
 - Adapt deployment algorithm for multi-path routing
 - Enforce “single path” requirement

compute routing under multi-path routing

choose a single path between source and destination

compute routing under single paths

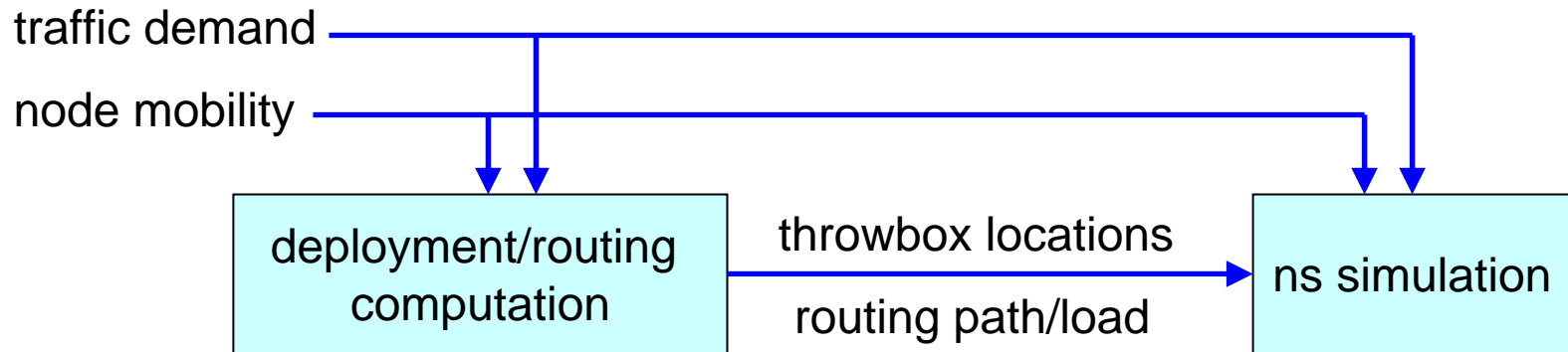
Epidemic routing - CTB Deployment



- Focus on deployment only
- Basic idea: ER exploits all paths to propagate data
 - Multi-path heuristic
 - Proportional allocation heuristic



Performance Evaluation



- Objectives

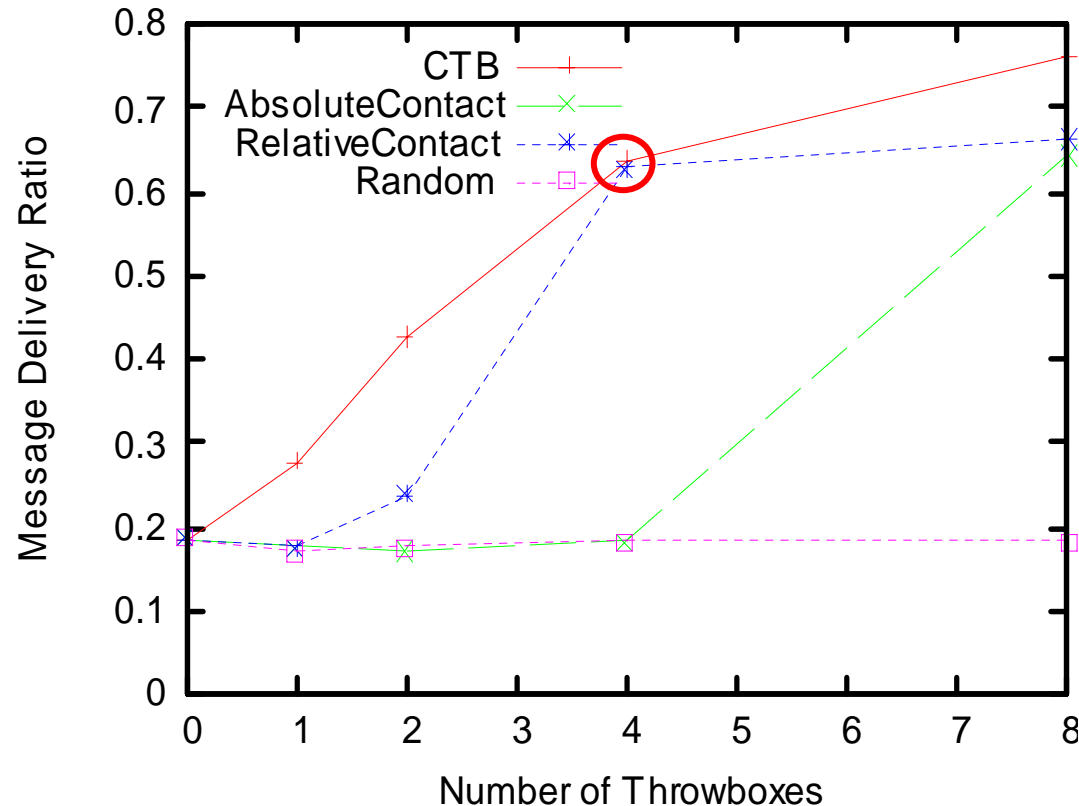
- Utility of throwboxes in performance enhancement
- Performance impact of various routing and deployment approaches



Simulation Settings

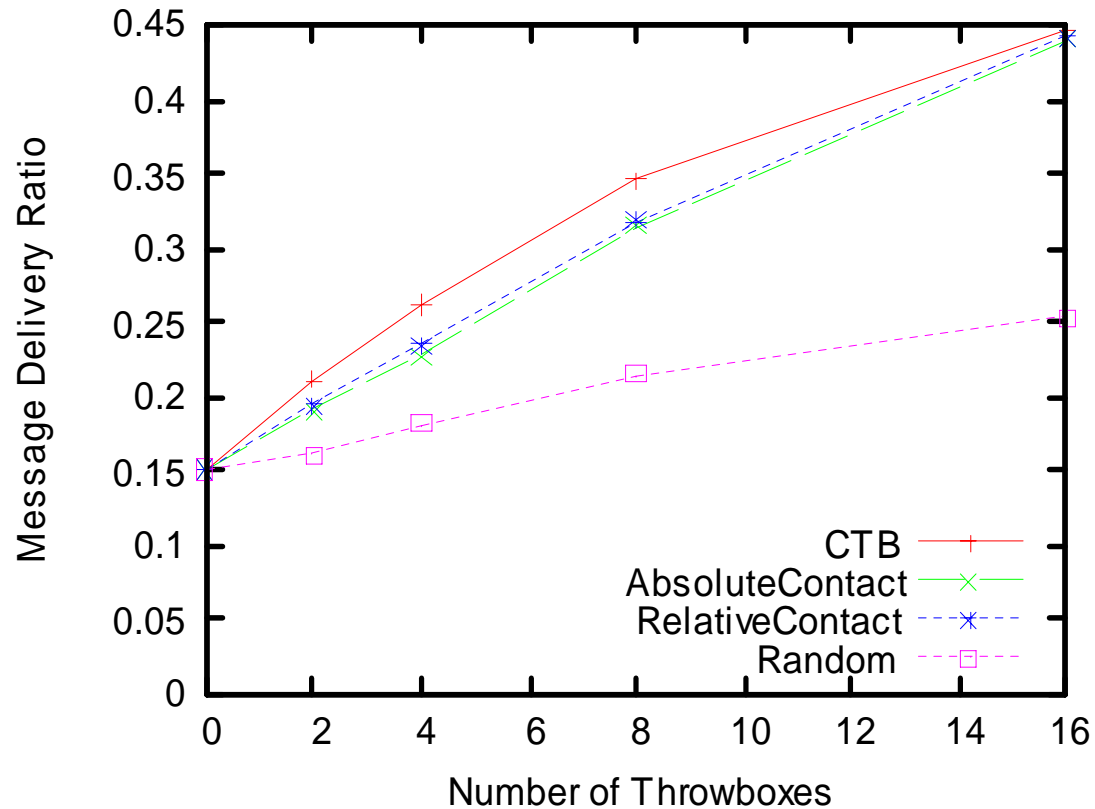
- Node mobility models
 - Predictable/constrained: UMass model based on measured bus trace
 - Random/unconstrained: Random waypoint model
 - Random/constrained: Manhattan model
- UMass model
 - 9 buses in a 25Km x 25 Km area
 - 802.11 MAC, radio range: 250m, bandwidth: 1Mbps
 - 20 source-destination pairs, message size is 1,500 bytes, Poisson message arrival with same data rate
 - FIFO buffer, buffer size is 50,000 messages

Multi-Path Routing



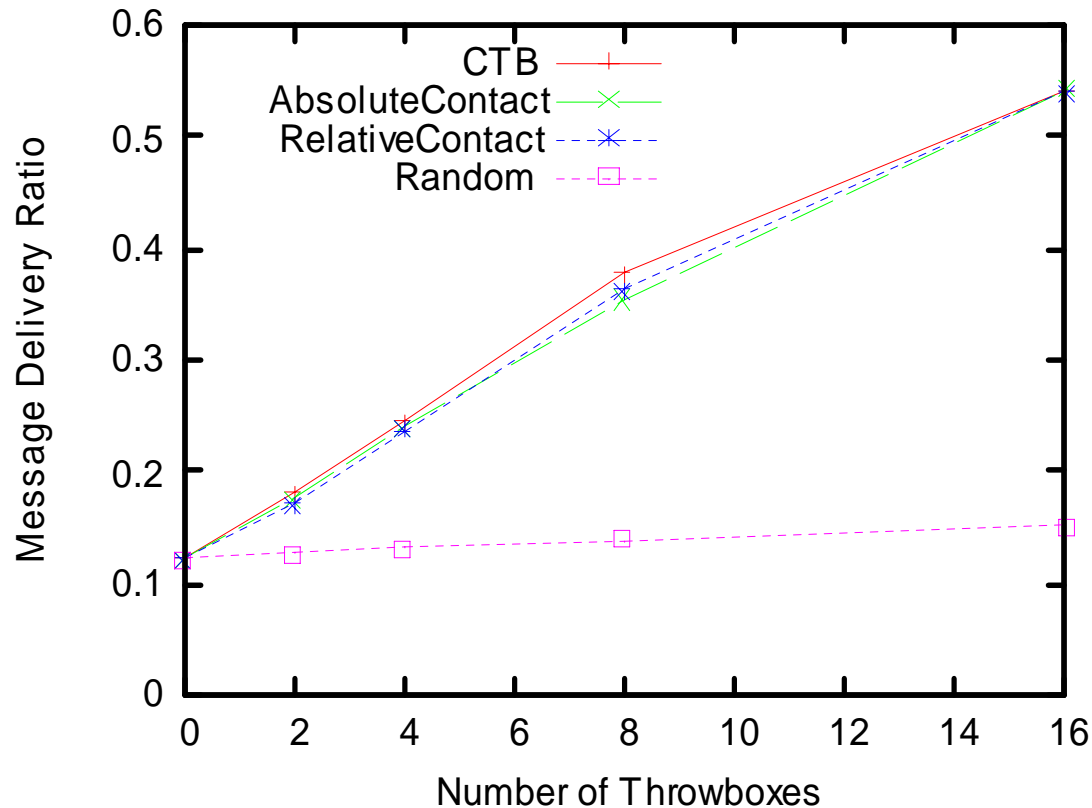
- Throwboxes are very effective in improving delivery ratios
- Contact and traffic-based deployment achieves best delivery ratio

Multi-Path Routing - RWP



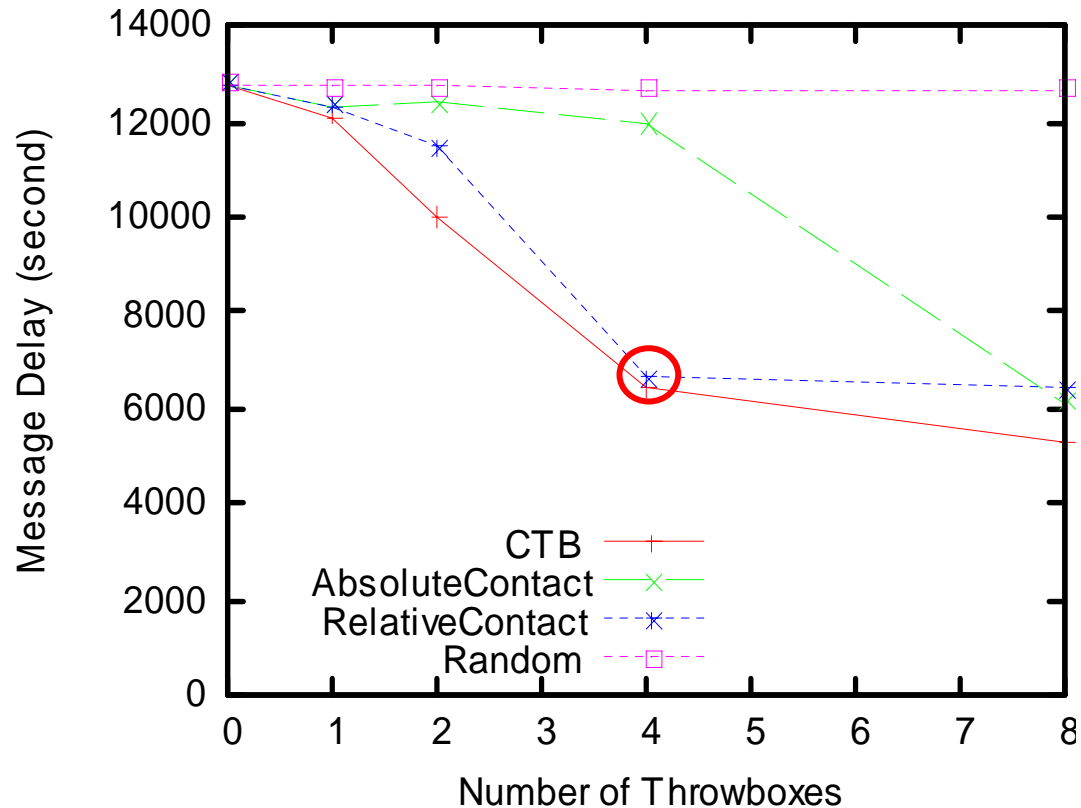
- Delivery ratio

Multi-Path Routing - Manhattan



- Delivery ratio

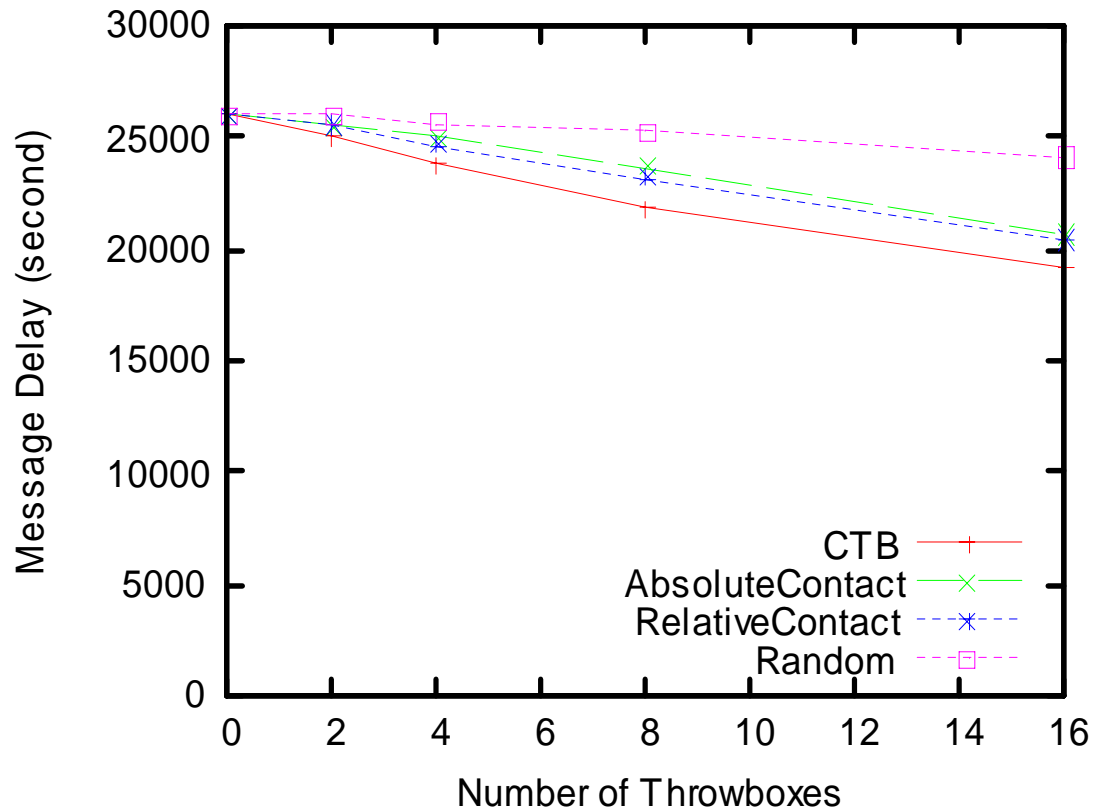
Multi-Path Routing



- Throwboxes can reduce message delay, even when the traffic load is low

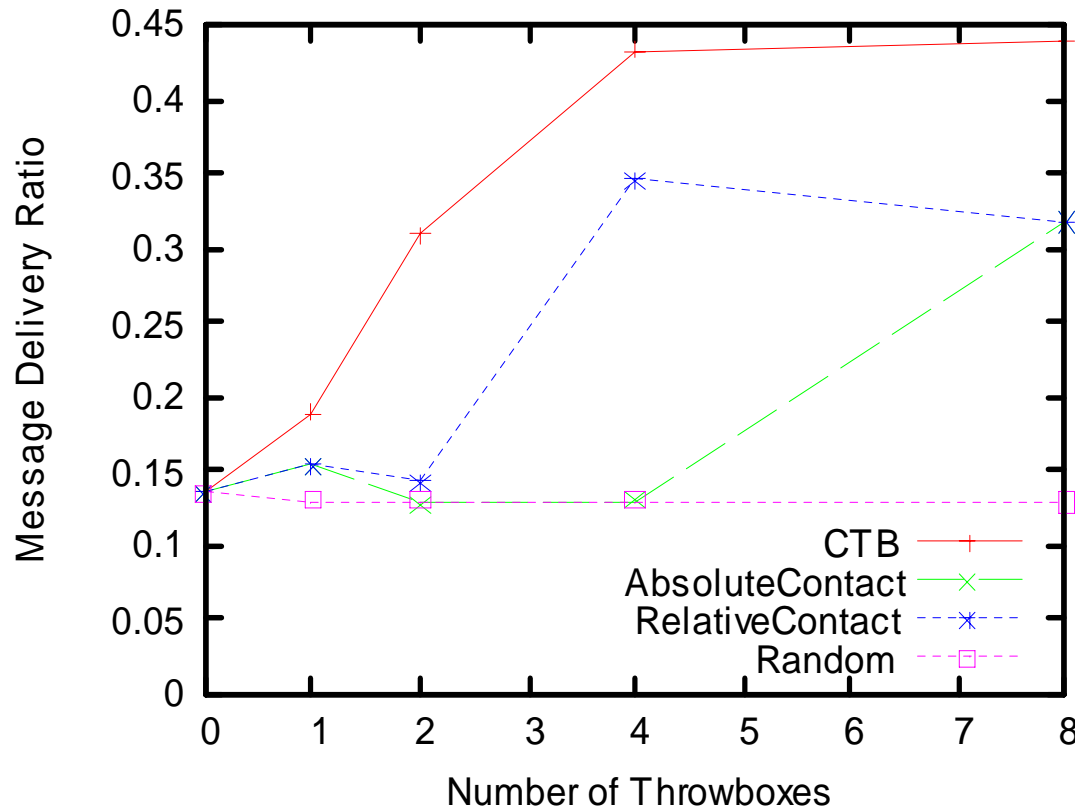


Multi-Path Routing - RWP



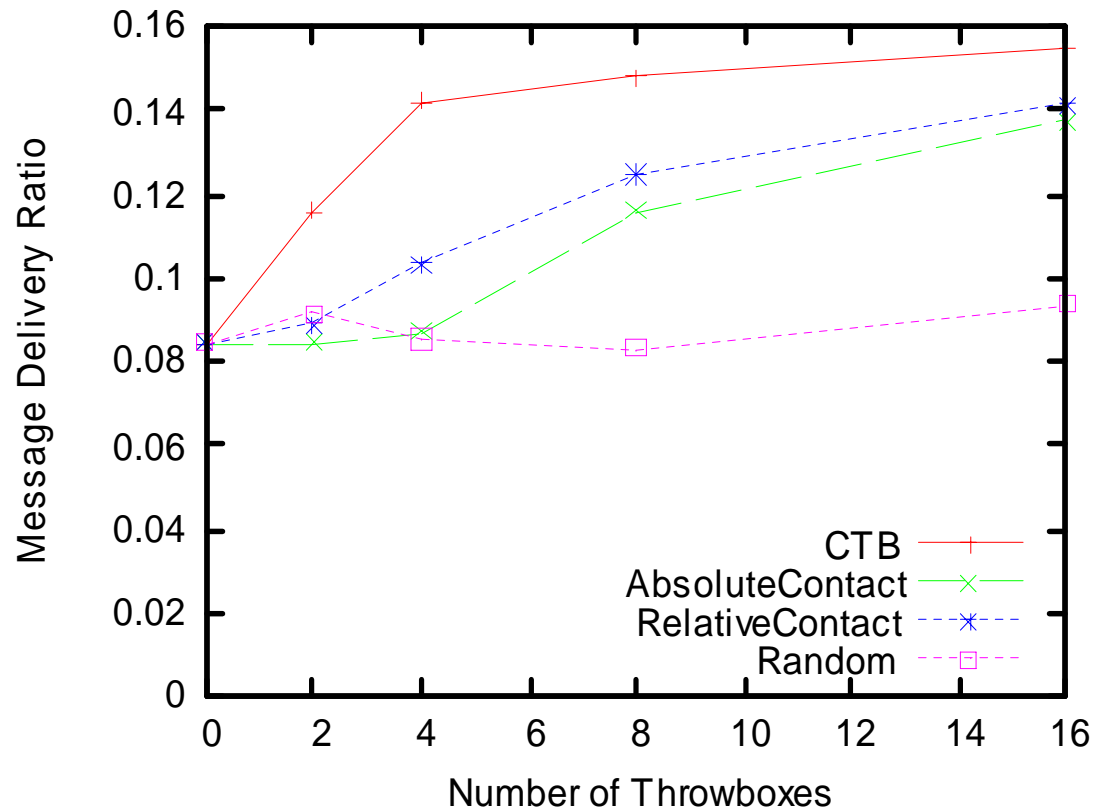
- Delivery delay

Single Path Routing



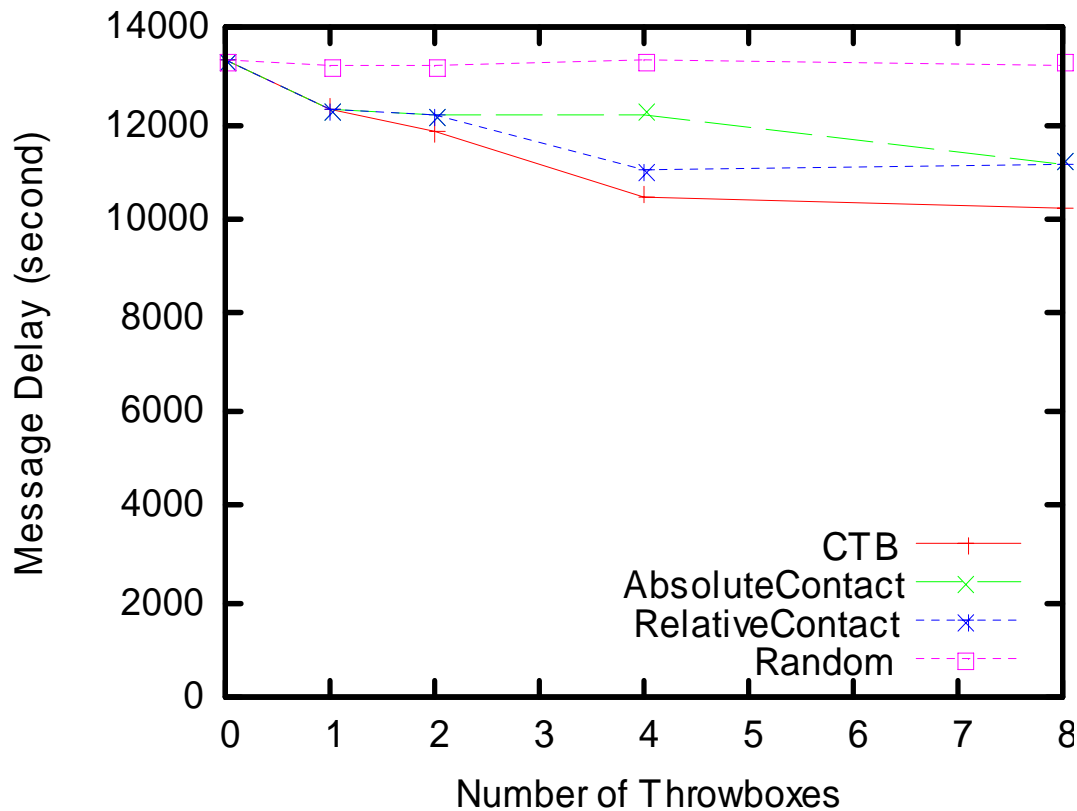
- Throwboxes significantly improve delivery ratios for single path routing

Single Path Routing - RWP



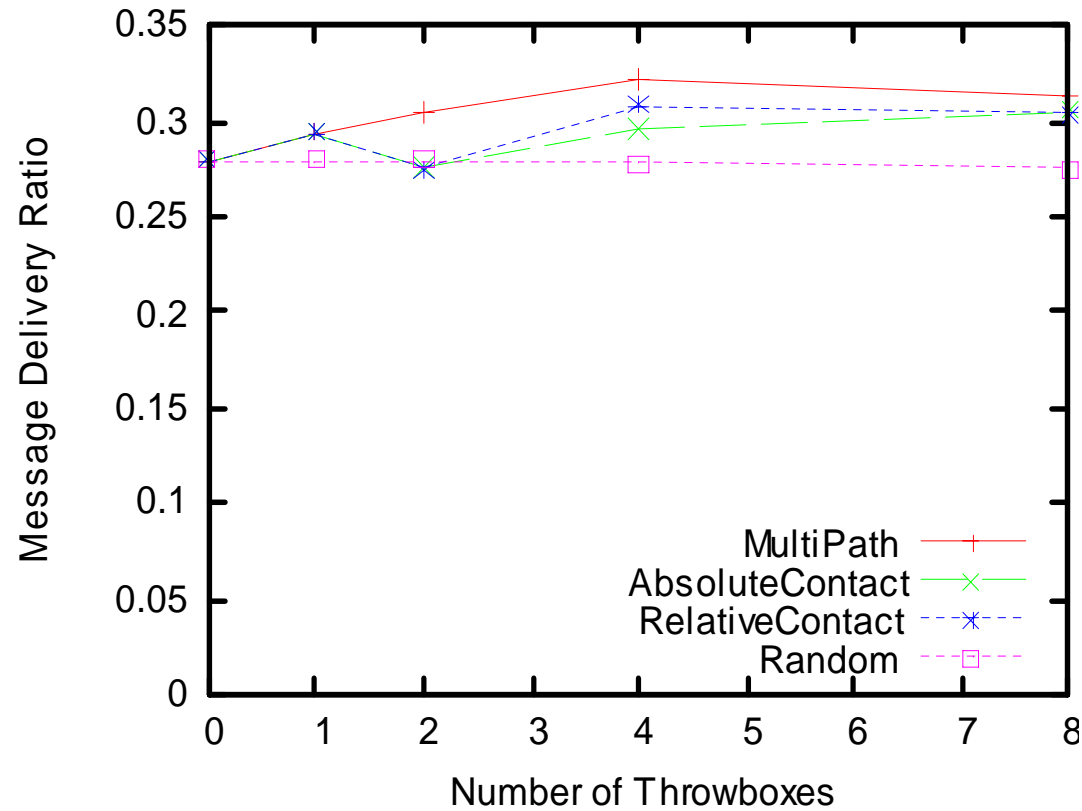
- Delivery ratio

Single Path Routing - UMass



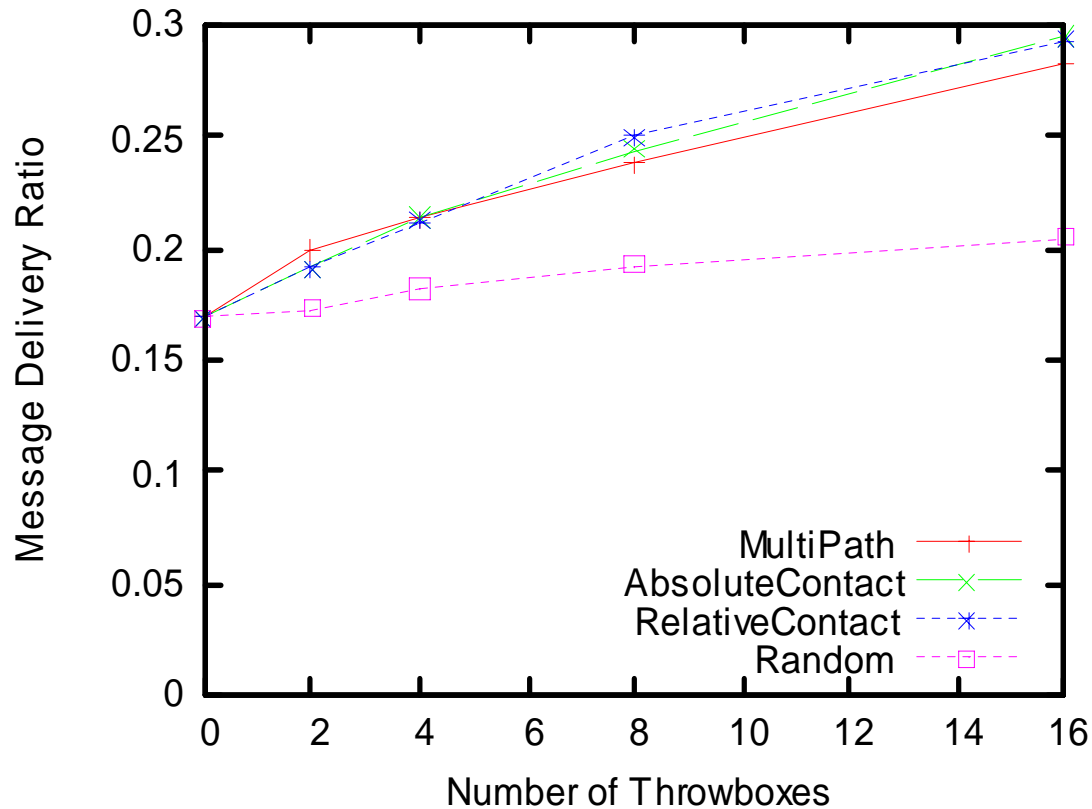
- Delivery delay

Epidemic Routing - UMass



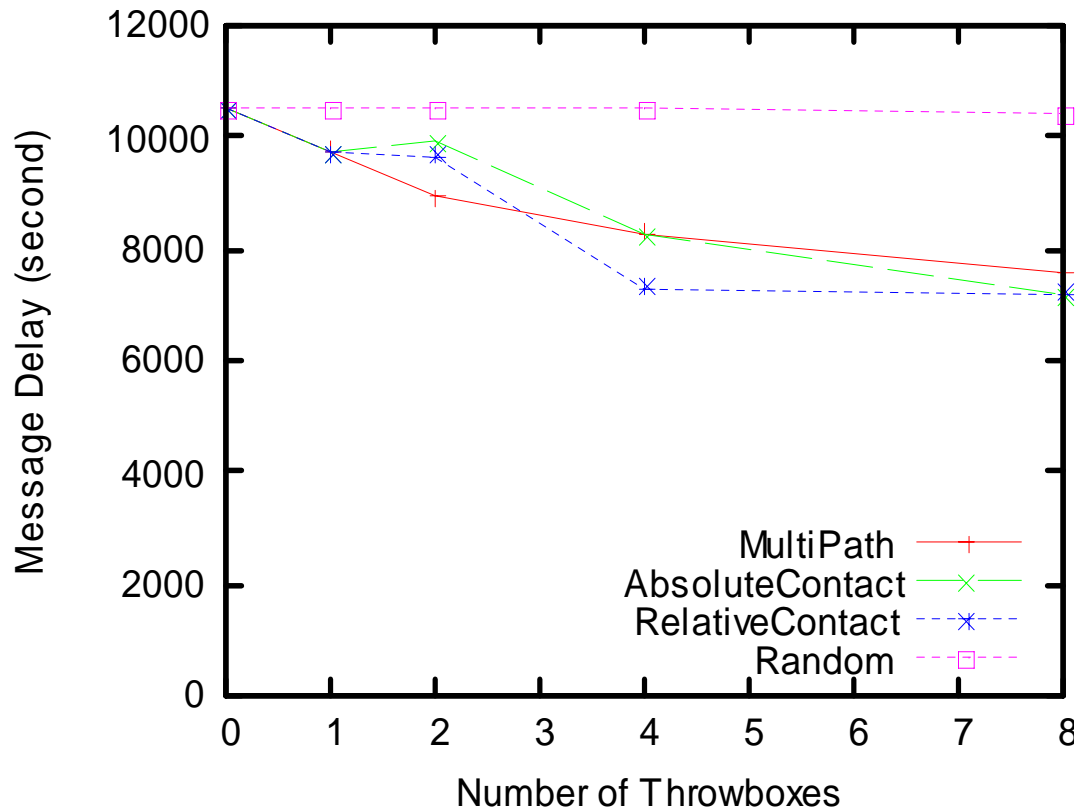
- Delivery ratio

Epidemic Routing - RWP



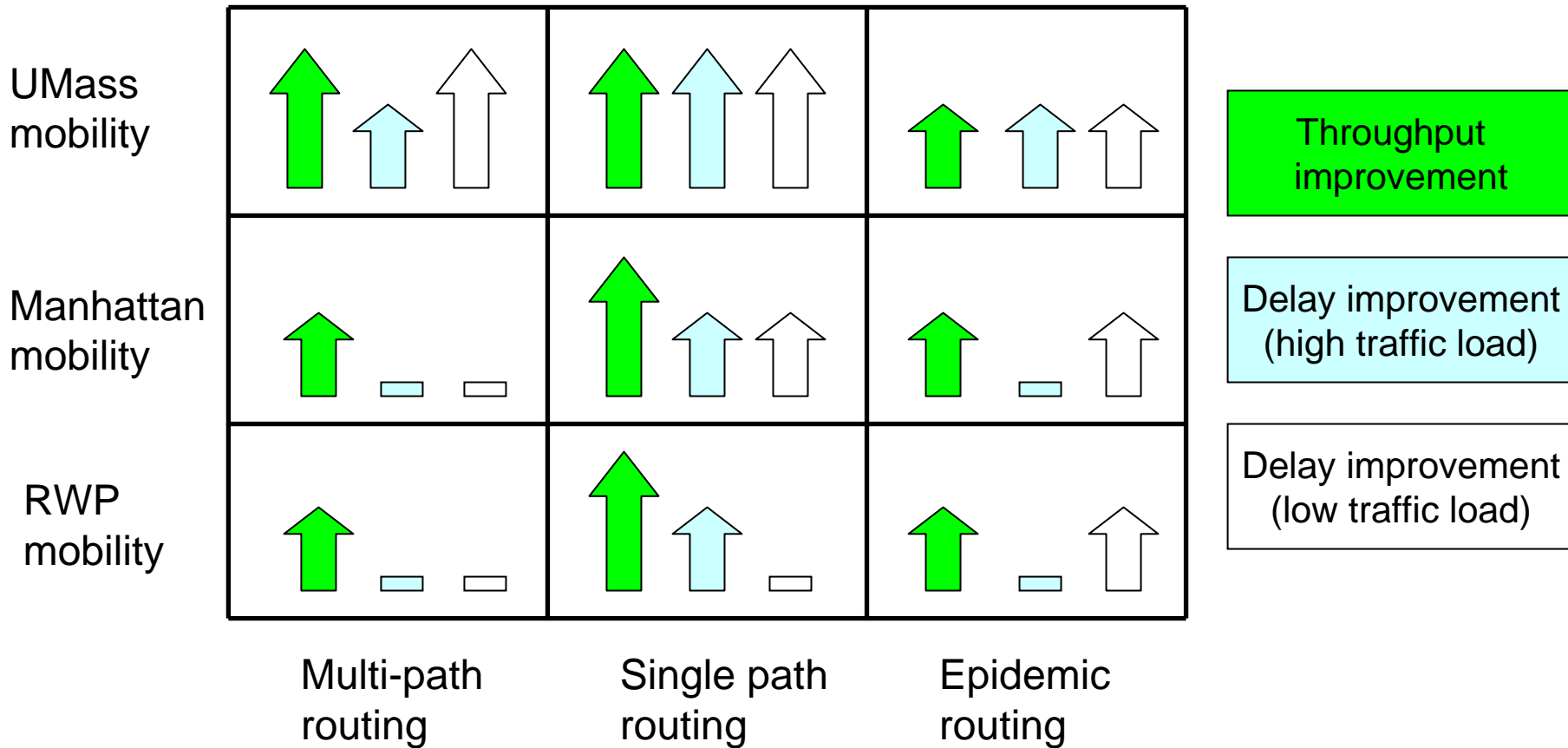
- Delivery ratio

Epidemic Routing - UMass



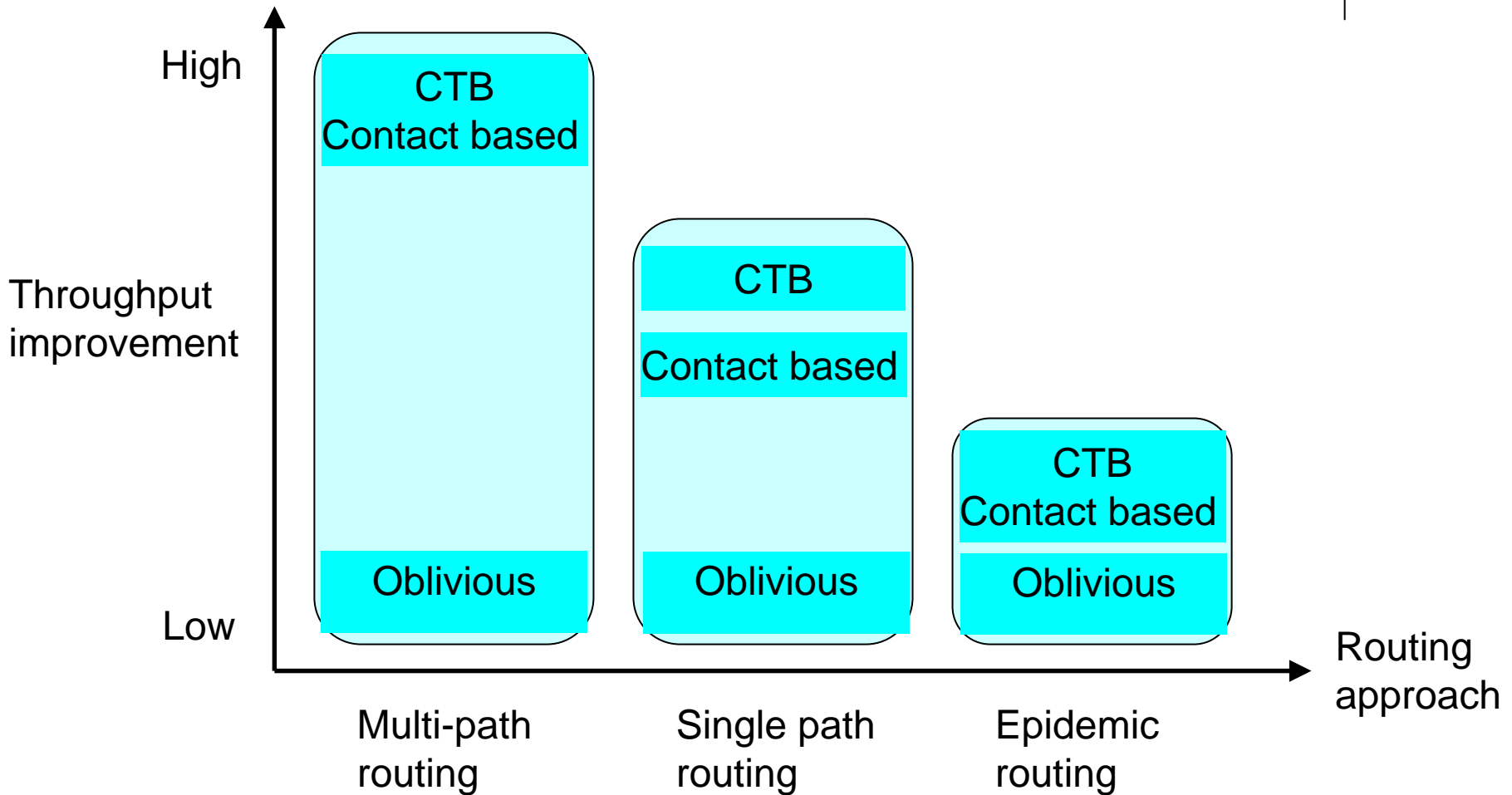
- Delivery delay

Summary of Simulation Results

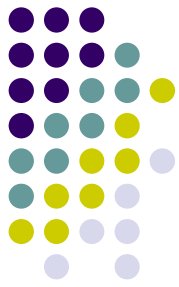




Summary of Simulation Results (2)



Summary



- Study the use of throwboxes for capacity enhancement in mobile DTNs
- Develop algorithms for throwbox deployment and routing
- Evaluate the utility of throwboxes and various routing/deployment approaches
 - Throwboxes are effective in improving throughput and can reduce delay