On Delay and Disruption Tolerant Networks (DTNs)

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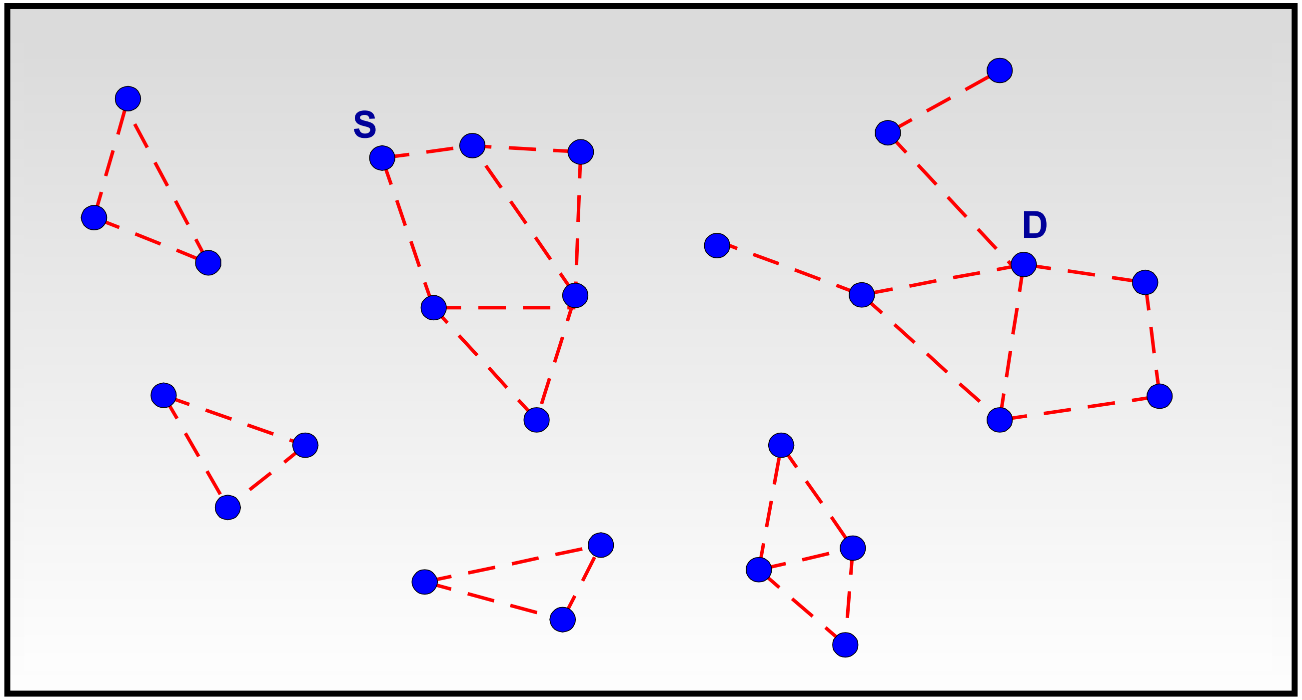
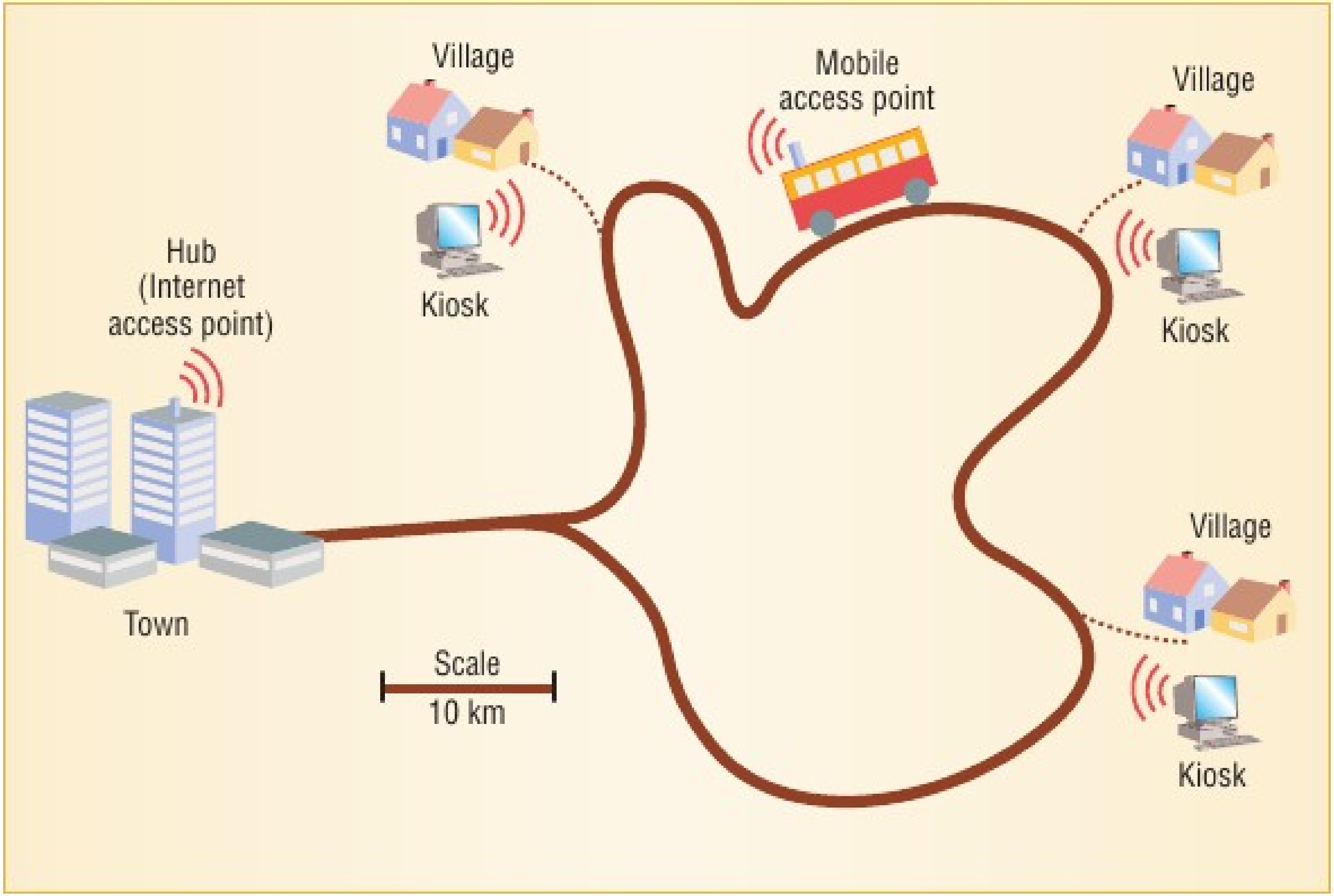
Delay/Disruption Tolerant Networks (DTNs)

- Intermittently connected mobile wireless networks
  - sparse and partitioned
- No contemporaneous end-to-end path!

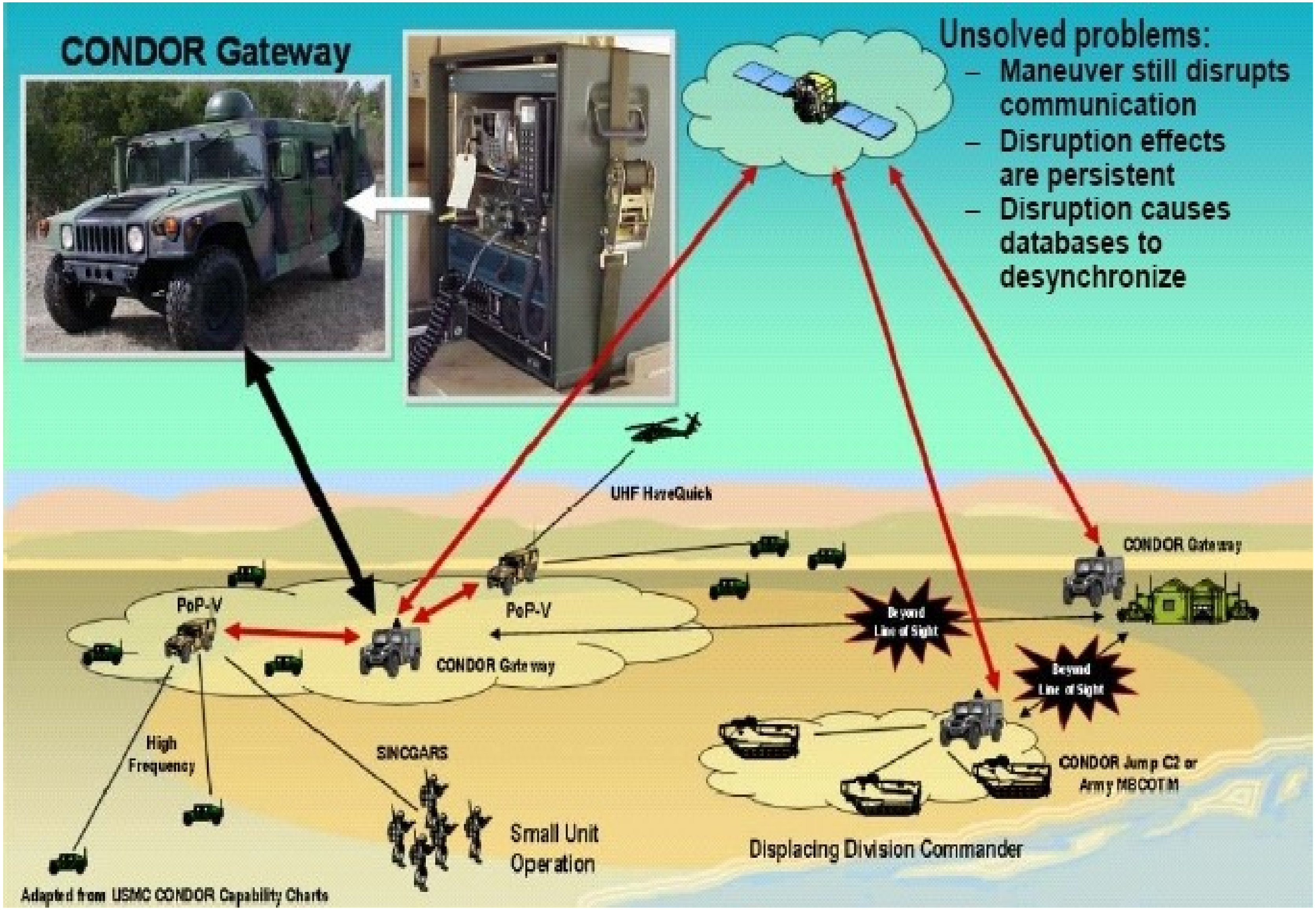


* Figure borrowed from authors.

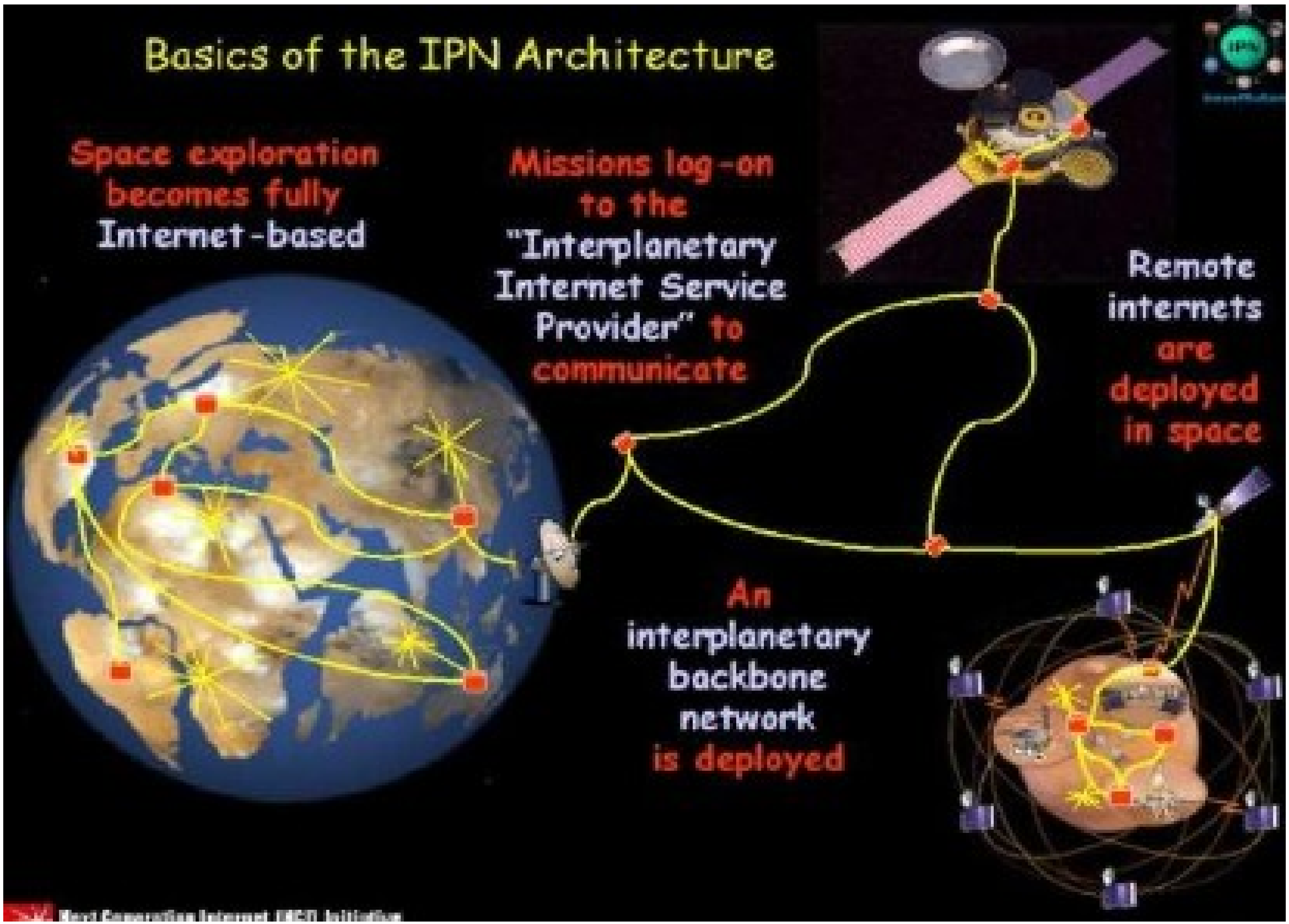
Delay/Disruption Tolerant Networks



Delay/Disruption Tolerant Networks



Delay/Disruption Tolerant Networks



Delay/Disruption Tolerant Networks

Why Delay/Disruption?

- Sparseness
- Powering down to conserve energy
- High mobility
- Low Probability of Interception and Detection (LPI/LPD)
- Intermittent availability
  - Lectures Tuesday and Thursday 3:30-4:45pm Only!

Conventional Routing Protocols Fail ...

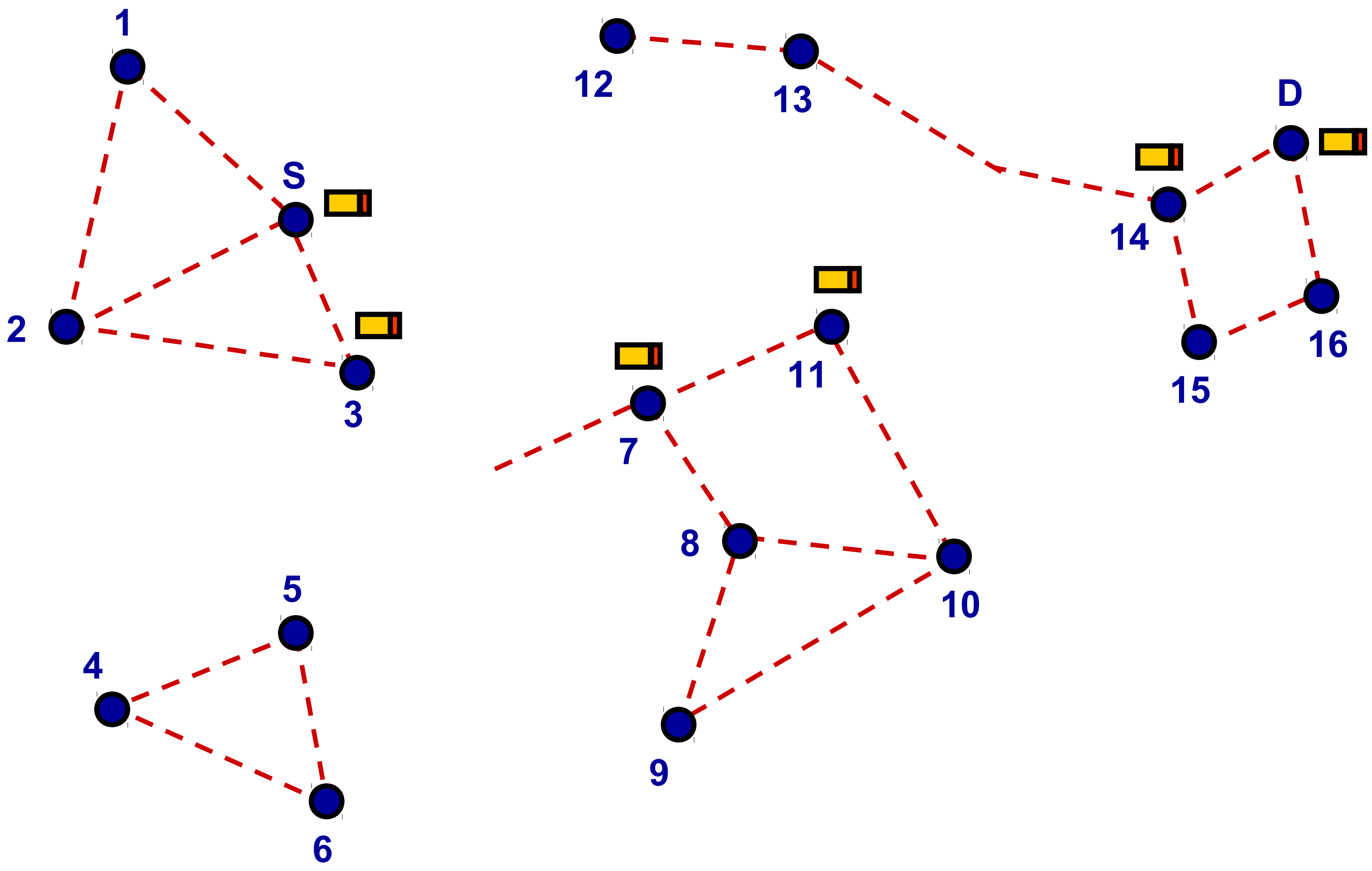
- Reactive protocols
    - Route requests cannot reach destination
    - Paths break right after or even while being discovered

- Proactive protocols
    - Fail to converge
    - Deluge of topology update packets

A Different Routing Paradigm

- Exploit mobility of nodes to deliver messages
- A snapshot of connectivity graph is always disconnected
  - Idea: If we overlap many snapshots over time, an end-to-end path will be formed eventually
- Store-carry-and-forward
  - A node stores a message and carries it until an appropriate communication opportunity arises

Store, Carry, and Forward

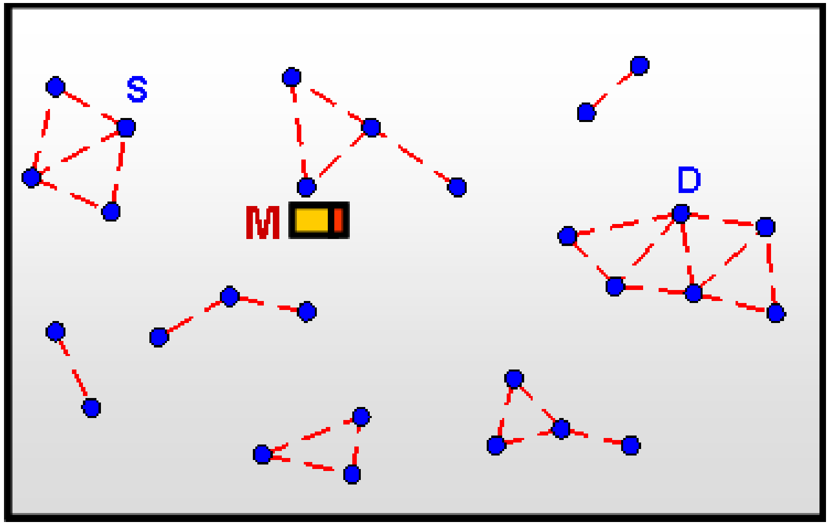


Main Issue: What is an "appropriate" next hop?

* Figure borrowed from authors.

Single-Copy vs. Multi-Copy Routing

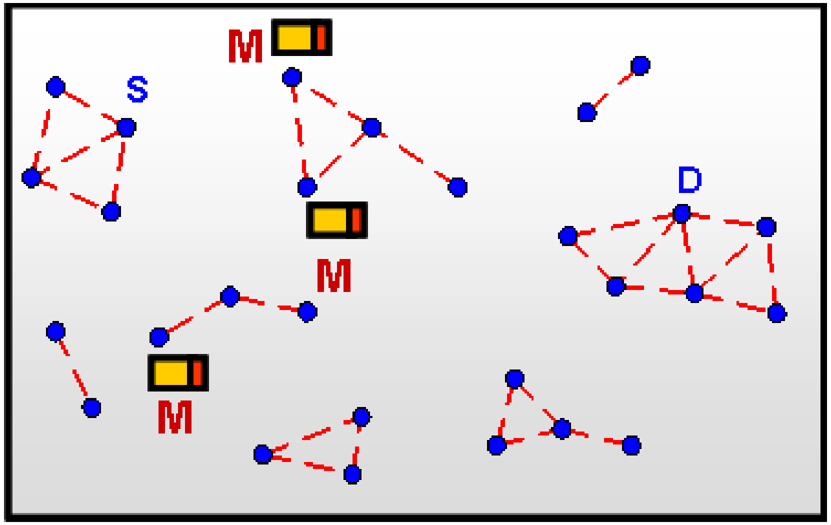
- "Single-Copy": only a single copy of each message exists in the network at any time



+ lower number of transmissions

+ lower contention for shared resources

- "Multiple-Copy": multiple copies of a message may exist concurrently in the network



+ lower delivery delay

+ higher robustness

* Figure borrowed from authors.

Primary Sources

T. Spyropoulos, K. Psounis, and C. Raghavendra, *"Efficient Routing in Intermittently Connected Mobile Networks: The* ***Single****-copy Case,"* IEEE/ACM Transactions on Networking, 2008.

T. Spyropoulos, K. Psounis, and C. Raghavendra, *"Efficient Routing in Intermittently Connected Mobile Networks: The* ***Multi****-copy Case,"* IEEE/ACM Transactions on Networking, 2008.

Single-Copy Routing

Single-Copy Schemes

- Direct Transmission
  - Source forwards message only to its destination when they come into range of each other
  - The expected delay is upper bound for any other scheme
- Randomized Routing
  - Node A forwards message to node B with constant probability p
  - Many transmissions for marginal gain (forwards messages blindly)

Utility-based Routing

- Every node A maintains a timer $T_A(D)$ for every other node D it has encountered
  - An indication of D's location (relative to A's location)
  - Timer is updated at every encounter
  - Location info gets diffused through mobility process
- Define an appropriate utility function $U_A(D)$ based on timer value $T_A(D)$
- Utility-based routing:

  Node A forwards a message for node D to node B iff $U_A(D) + U_{th} < U_B(D)$

Utility-based Routing (Cont'd)

+ Takes advantages of indirect location info to make better forwarding decisions

- It may take a long time until a good next hop is found

Seek and Focus

A Hybrid Routing Strategy

- Seek phase: If utility of the node is below some predefined threshold, perform randomized forwarding to quickly search nearby nodes
- Focus phase: When a high utility node (i.e. above a threshold) is discovered, switch to utility-based forwarding

Look for a good lead to the destination and follow it

Oracle-based Optimal Routing

- Assume all nodes trajectories (future movements) are known
- Then, the algorithm picks the sequence of forwarding decisions that minimizes delay

Multi-Copy Routing

Spray and Wait

- Two phases:
  - "Spray phase": spread L message copies to L distinct relays
  - "Wait phase": wait until one of the L relays finds the destination (i.e. direct transmission)

- Source Spraying
  - Whenever source encounters a new node, it hands <u>one</u> of the L copies
  - The <u>slowest</u> among all opportunistic spraying schemes
- Binary Spraying
  - Whenever a node with n > 1 copies finds a new node, it hands <u>half</u> of the copies it carries
  - <u>Faster</u> than any other spraying scheme

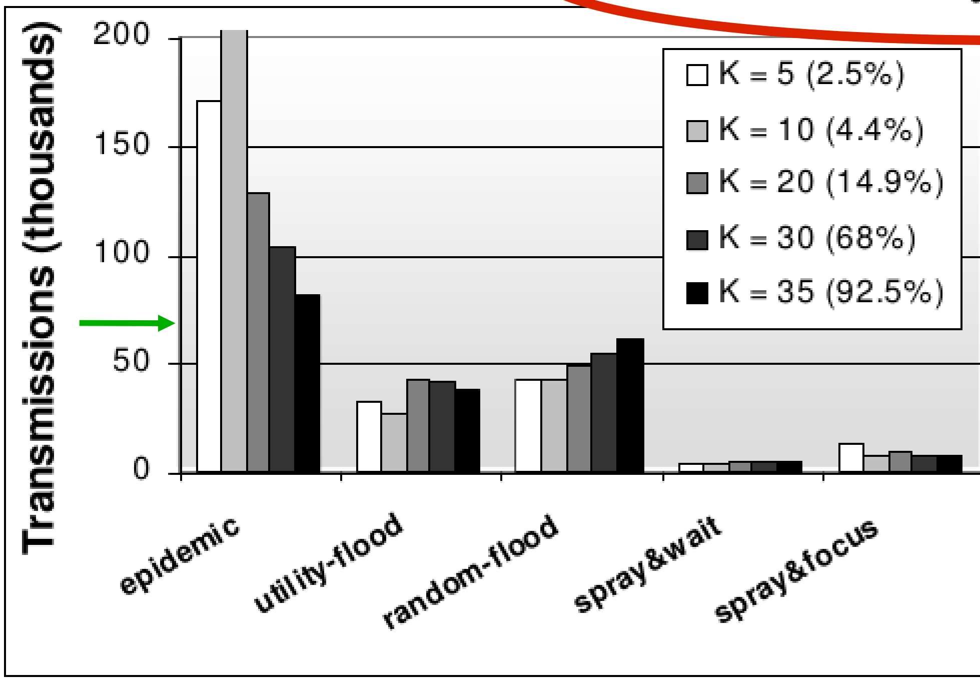
Spray and Wait (Cont'd)

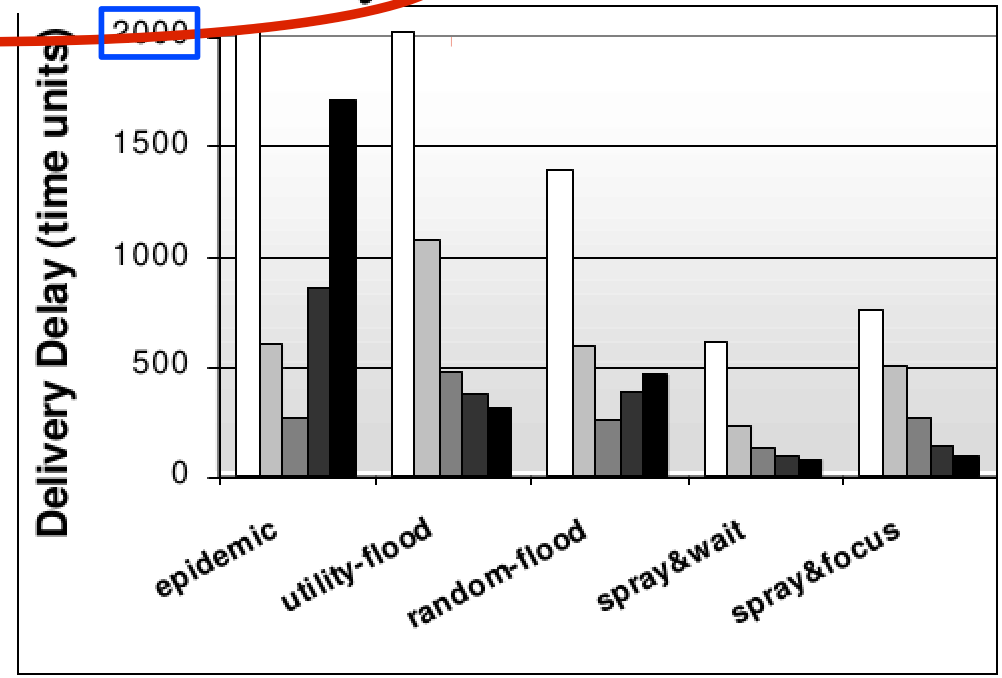
- Spreads all its copies quickly to the node's immediate neighborhood
  - Problematic under local mobility
  - A relay naively waits until it moves within range of the destination itself

Spray and Focus

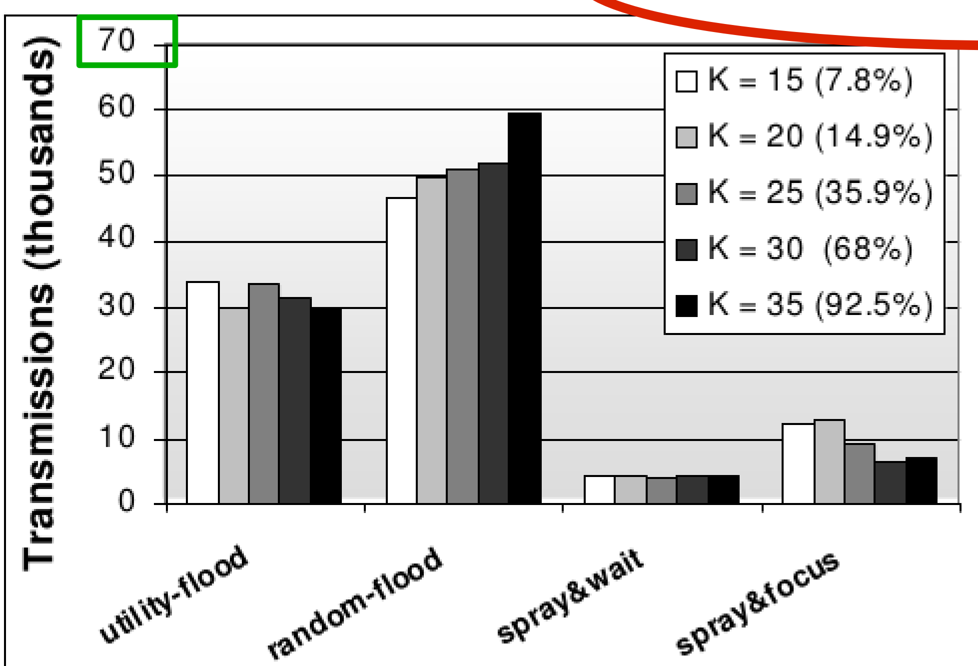
- Two phases:
  - "Spray phase"
  - "Focus phase": a node A, carrying a copy for destination D, forwards the copy to a new node B it encounters, iff $U_B(D) > U_A(D) + U_{th}$

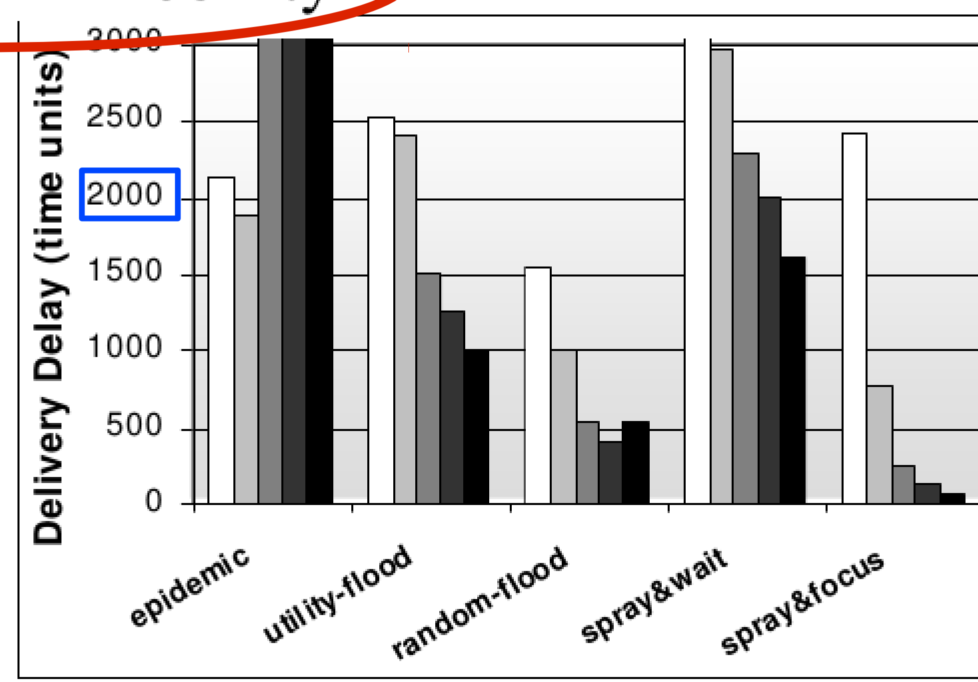
Random Waypoint Mobility

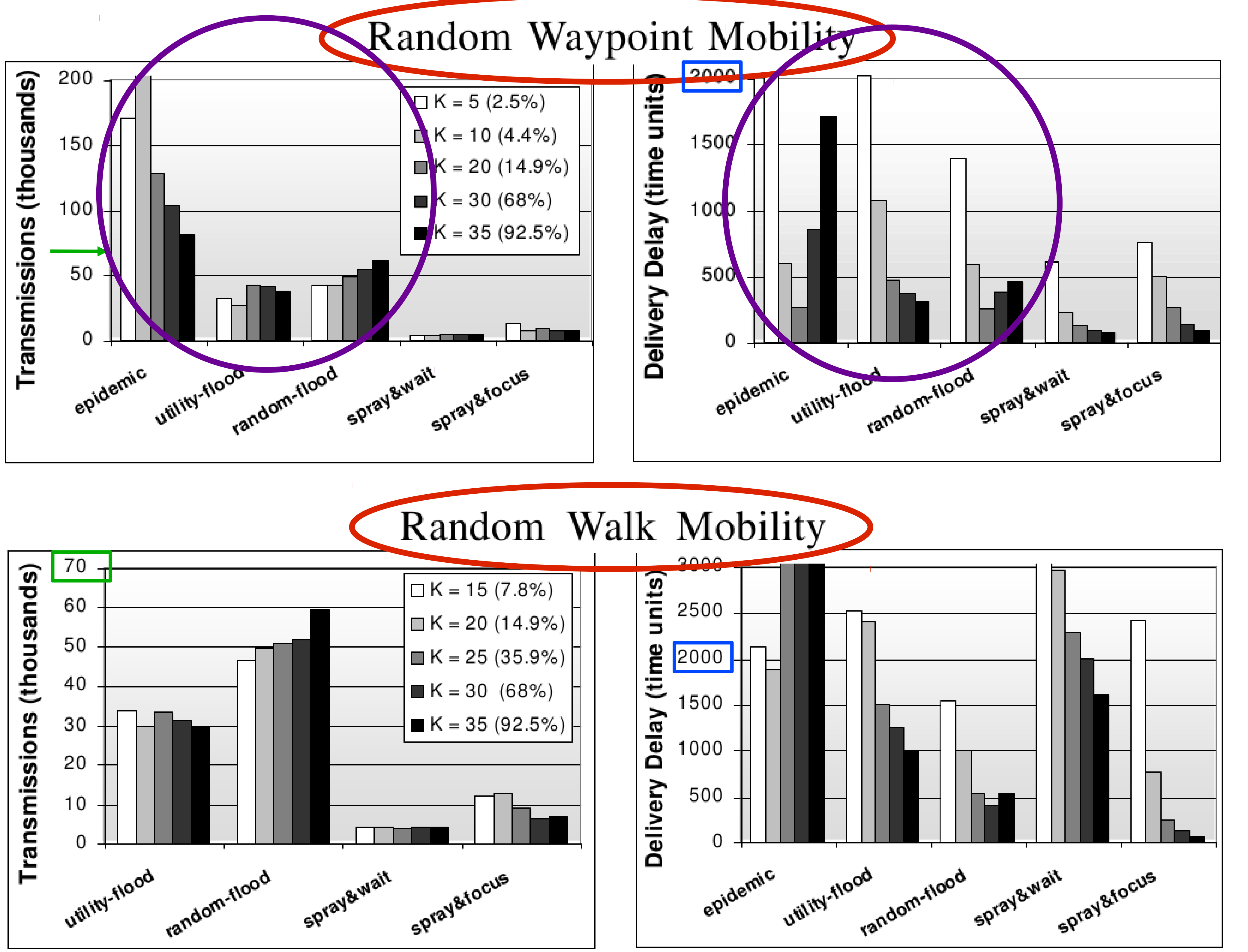




Random Walk Mobility







Random Waypoint Mobility
Transmissions (thousands)
200
150
100
50
0
K = 5 (2.5%)
K = 10 (4.4%)
K = 20 (14.9%)
K = 30 (68%)
K = 35 (92.5%)
epidemic
utility-flood
random-flood
spray&wait
spray&focus
Delivery Delay (time units)
2000
1500
1000
500
0
epidemic
utility-flood
random-flood
spray&wait
spray&focus
Random Walk Mobility
Transmissions (thousands)
70
60
50
40
30
20
10
0
K = 15 (7.8%)
K = 20 (14.9%)
K = 25 (35.9%)
K = 30 (68%)
K = 35 (92.5%)
utility-flood
random-flood
spray&wait
spray&focus
Delivery Delay (time units)
3000
2500
2000
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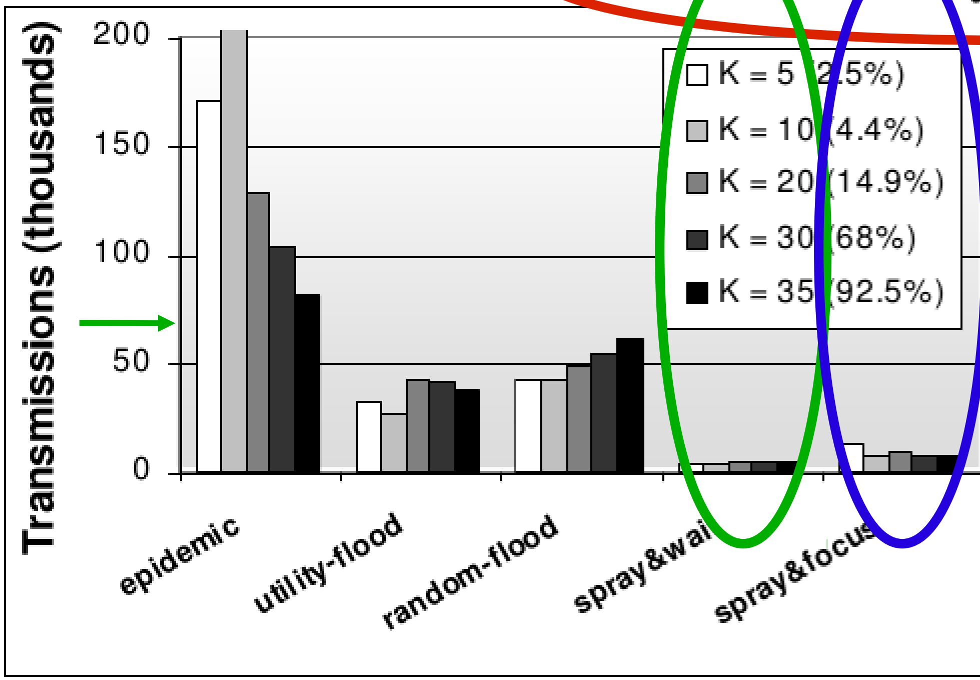
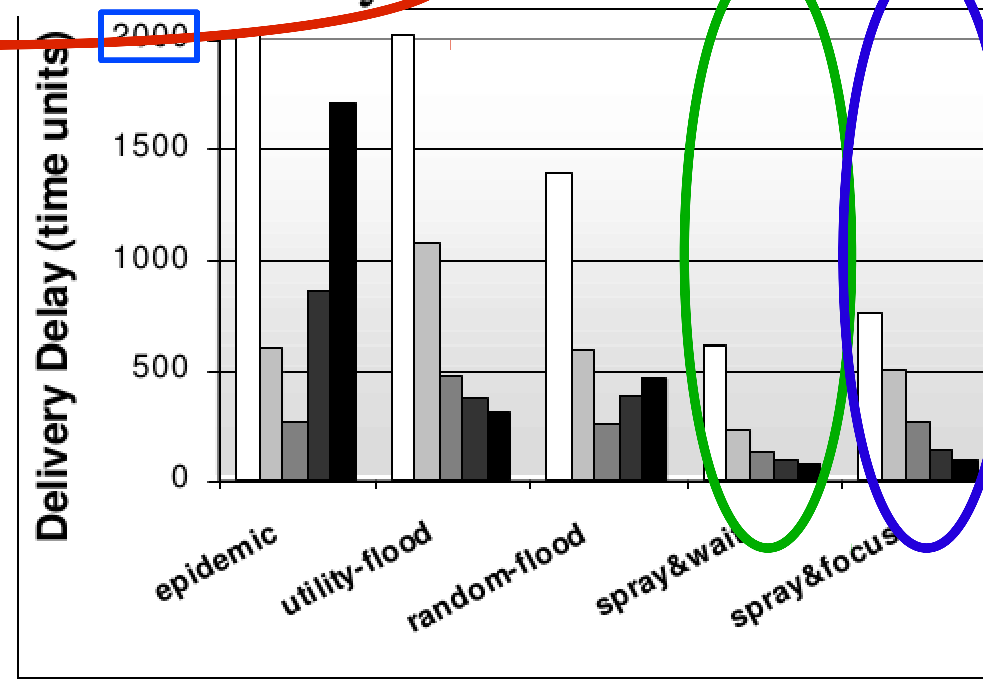
Random Waypoint Mobility





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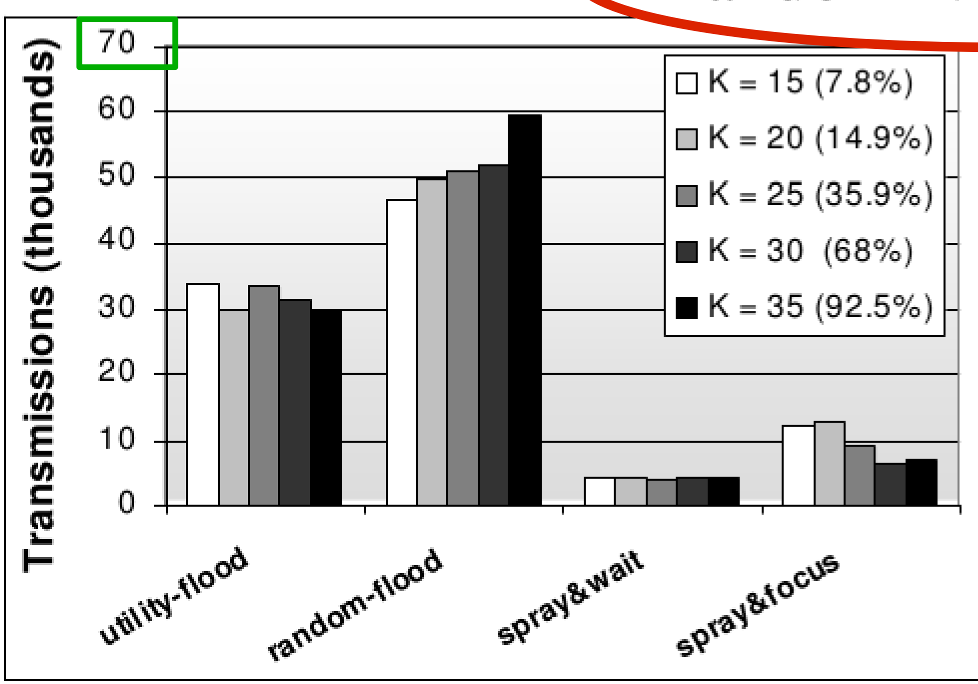

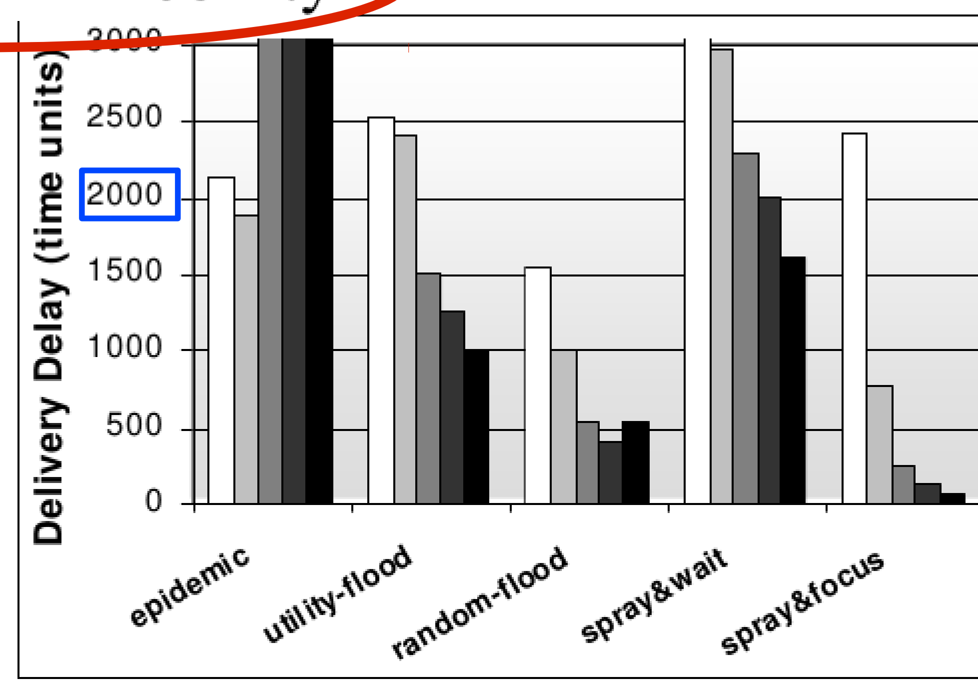

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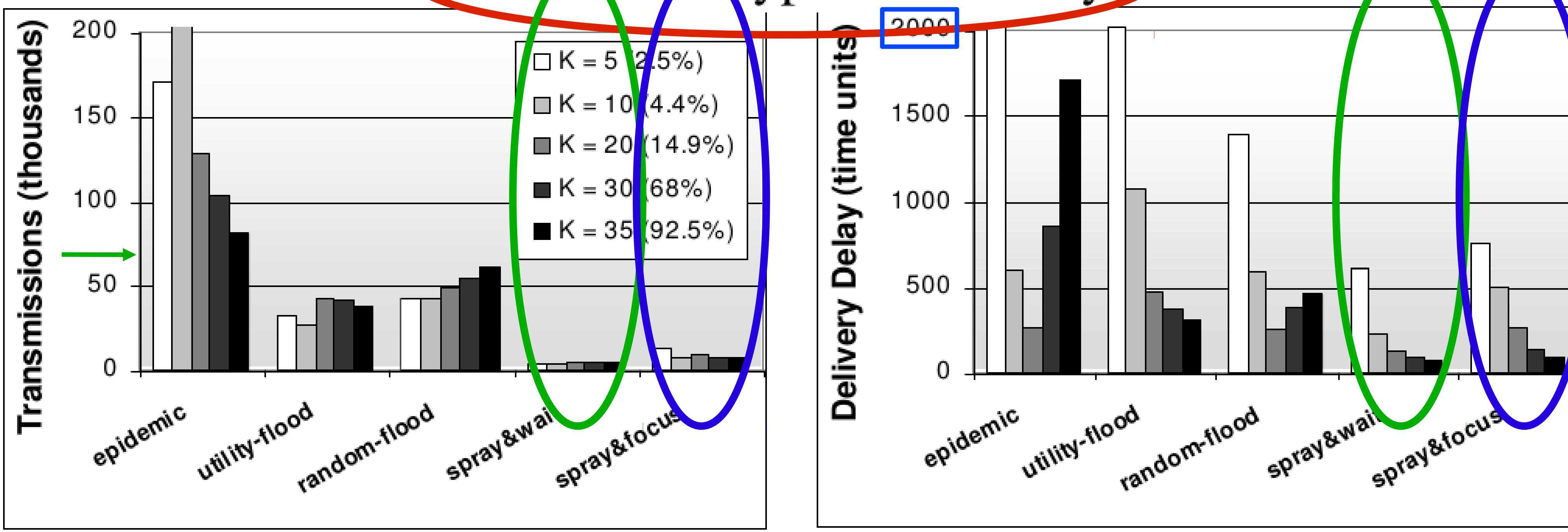

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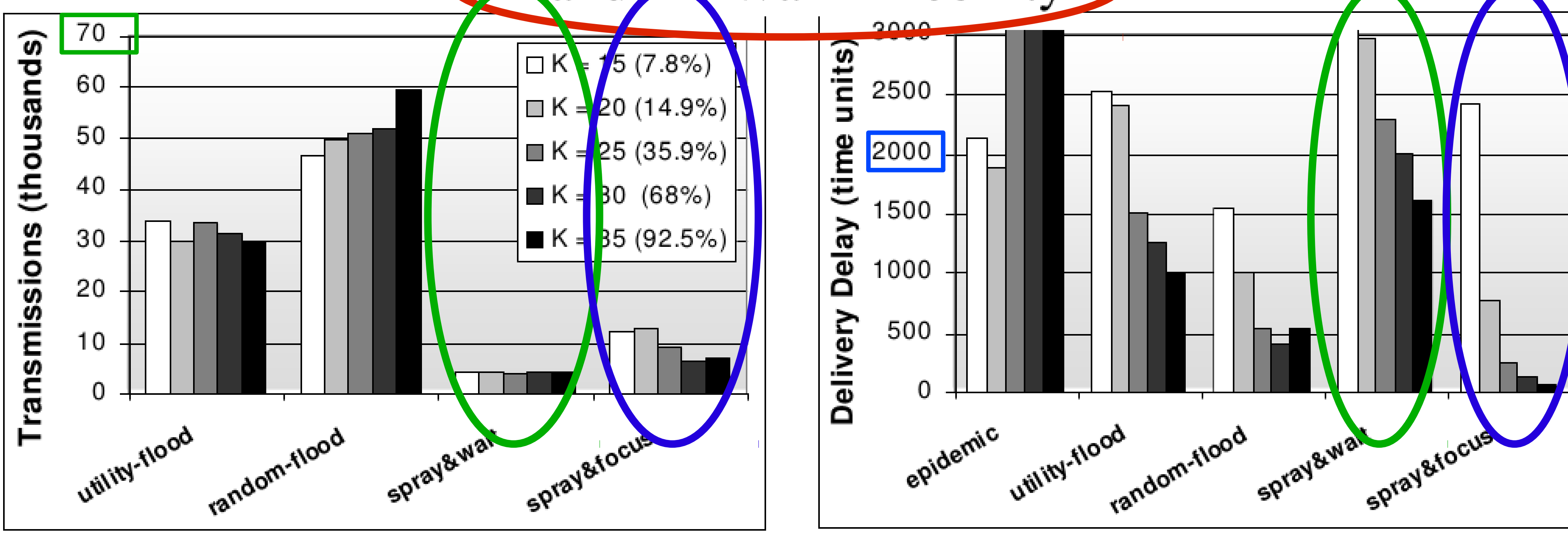


DTN Applications

Examples of DTNs

- **Animal Research:** animals can go into caves during which there is no reception.
- **“Rural” Networks**: network can be intermittent due to power outages and sparsity of resources in country.
- **Taxi Cab Networks:** vehicles may go places where land characteristics obstructs signal; vehicles do not move in a fixed pattern and is dependent on demand.
- **Military Networks:** In combat, locations can become bombed, and hence the node that they represent may be disrupted.

Comparison of Issues

Type of network	***Disconnectivity***	***End-to-end path***	***Propagation delay***
Internet	close to none	almost always available	short, low variability
Animal Research	low frequency, long duration	not guaranteed, but changes over the day	medium, medium variability
rural network	moderate frequency, 1-2 hours	can become unavailable during power outages	short, low variability
mobile network	High-frequency, short bursts	changes randomly, but available	medium, high variability
Military Network	unpredictable	not guaranteed and changes over course of combat	short, high variability

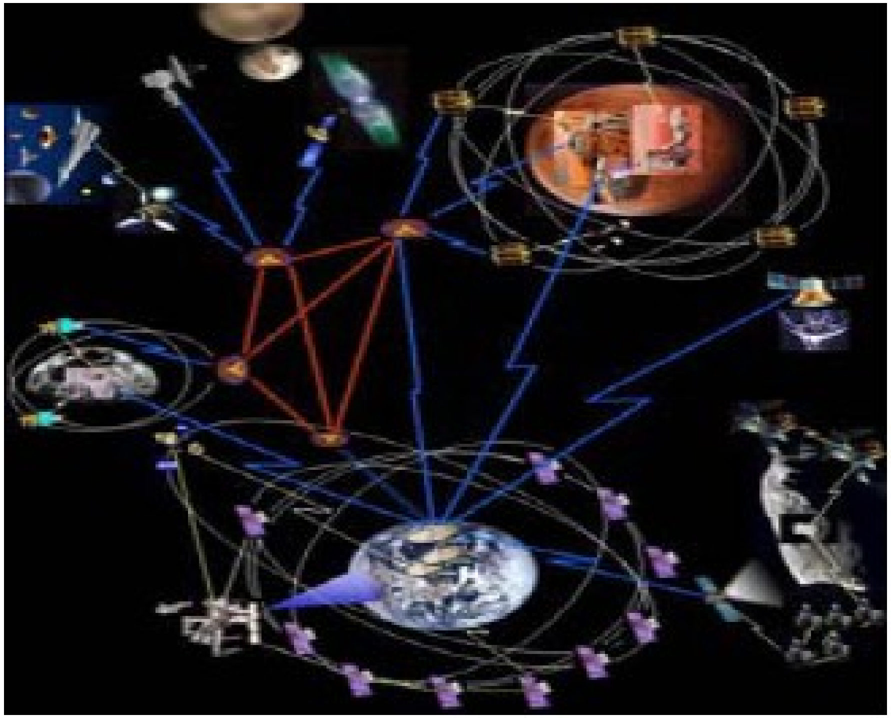
Interplanetary Internet

- Robots need to communicate with each other on surface of one planet.

- Satellites need to communicate with each other to avoid collision.

- Need to collect data from various parts of solar system, and analyze this data back on earth.

- Two satellites orbiting different planets need to communicate with each other.

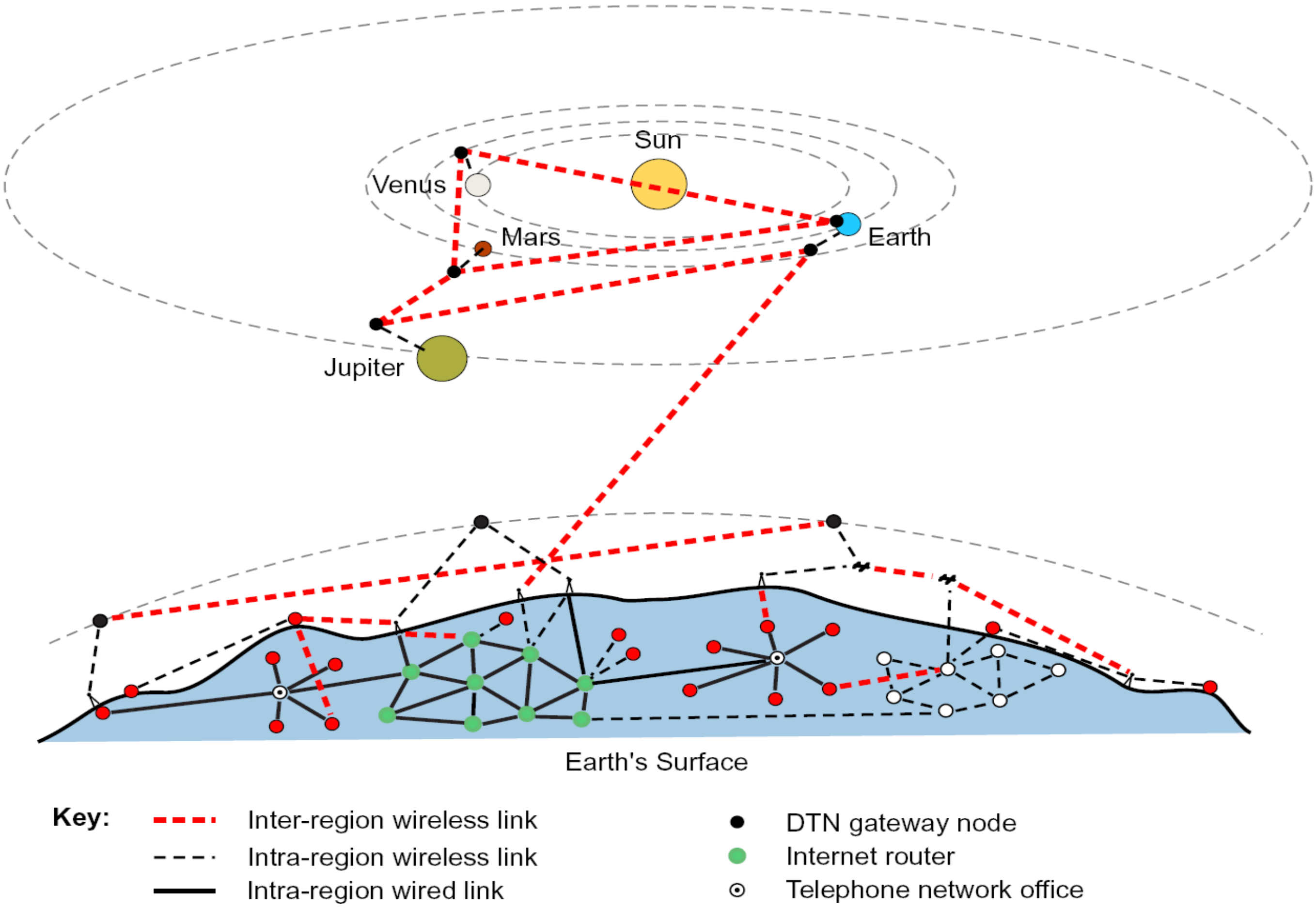


Source: Cerf et al. *Delay-Tolerant Network Architecture: The Evolving Interplanetary Internet.*

Issues to deal with for Interplanetary Networks

- Speed of light is constraint.
- Bandwidth is important and “precious”.
- Objects can come in the way of transmission, creating temporary disruption.
- Network components need to be power-efficient.
- Network components need to be reliable for several years.

IPN Use Case Example



Source: Different Methods of Transmission - Forrest Warthman, Delay-Tolerant Networks.(DTNs): A Tutorial v1.1, Mar 2003

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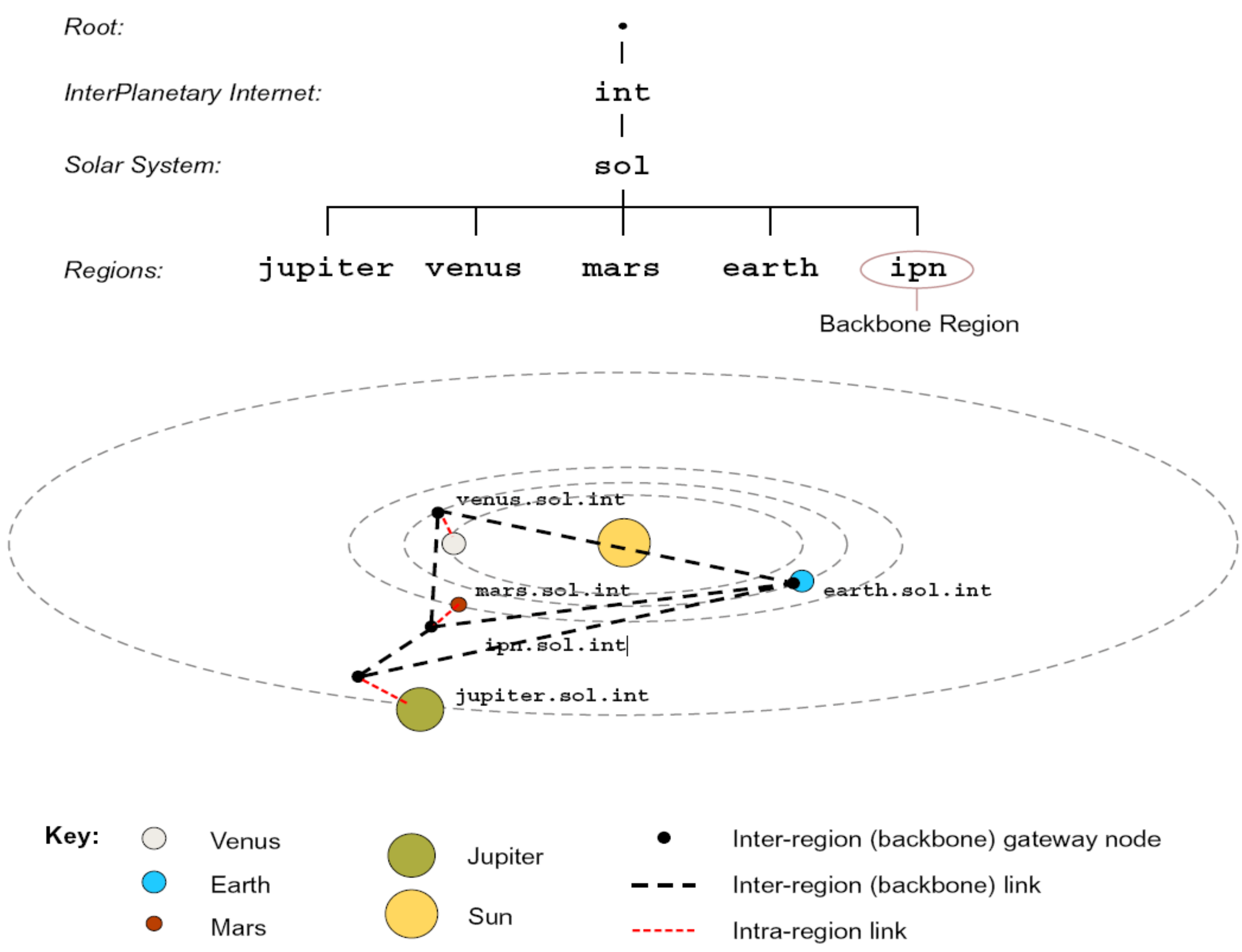

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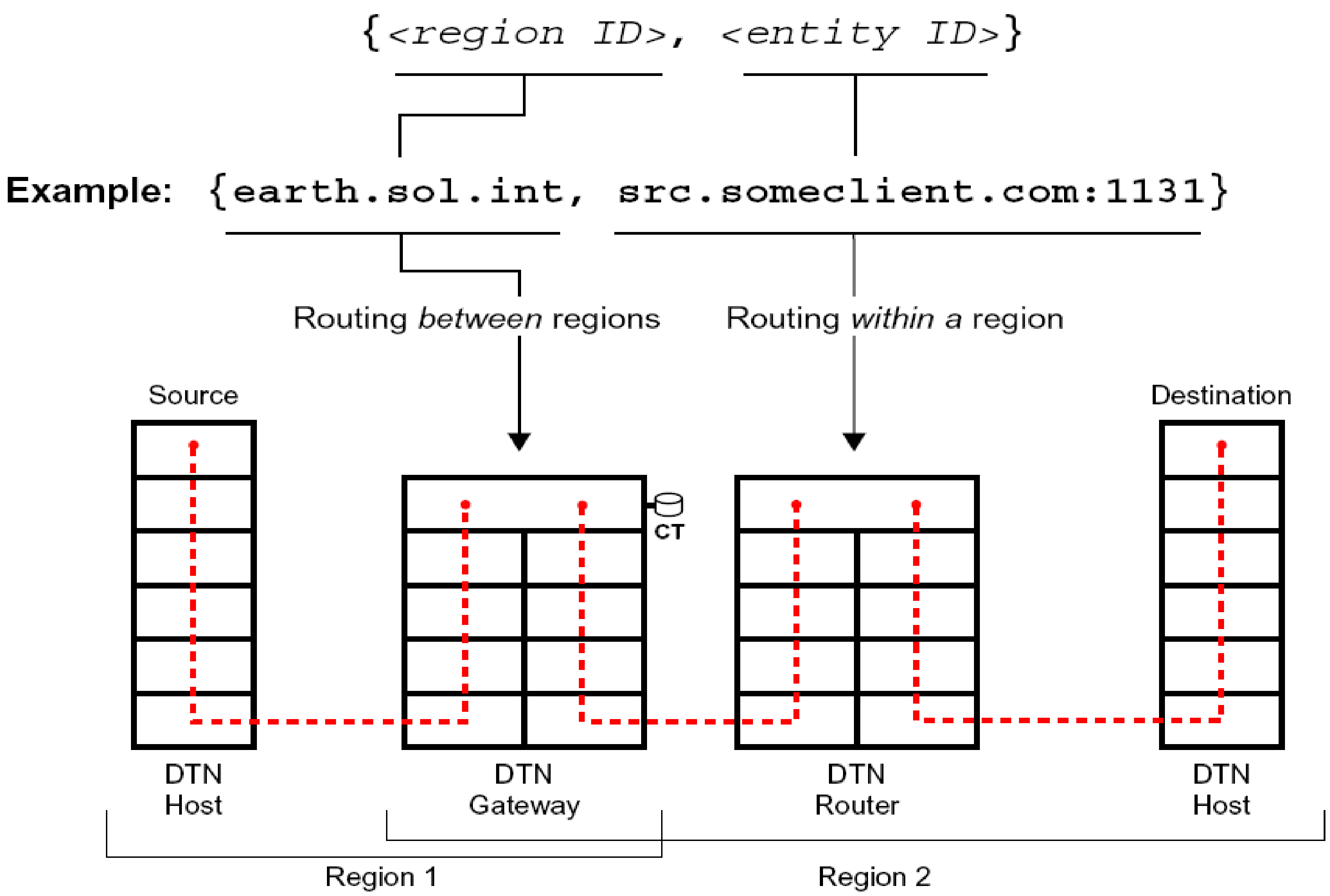

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Conclusions

- Several characteristics differentiate DTNs from regular networks.
- New routing schemes are needed for certain network that involve large delays or disruptions. Specifically, we discussed *single-copy* and *multi-copy* routing schemes.
- The way to engineer DTNs is dependent on the domain or context in which a DTN is used.

Summary

Single-copy routing schemes:

- Direct transmission
- Randomized routing
- Utility-based routing
- Seek and Focus
- Oracle-based optimal routing

Multi-copy routing schemes:

- Flooding-based routing
- Utility-based routing
- Spray and Wait
- Spray and Focus

Discussion

- For what other scenarios, not listed here, would DTNs be useful? Which routing scheme would be appropriate for each scenario you chose?
- Would a connection-oriented scheme be required, or even feasible, in DTNs?
- What are the potential issues of security in DTNs?

Sources

- T. Spyropoulos, K. Psounis, and C. Raghavendra, *"Efficient Routing in Intermittently Connected Mobile Networks: The **Single**-copy Case,"* IEEE/ACM Transactions on Networking, 2008.
- T. Spyropoulos, K. Psounis, and C. Raghavendra, *"Efficient Routing in Intermittently Connected Mobile Networks: The **Multi**-copy Case,"* IEEE/ACM Transactions on Networking, 2008.
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Thank you.

Questions, Comments, …?