The Impact of Delayed Topology Information in Proactive Routing Protocols for MANETs

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Probability of Successful Delivery of a Packet over a Link

Network layer failures
(Must be corrected by a layer above, i.e., TCP or APP)

No path in table (so packet is dropped)
The network is disconnected

Node failed to detect that the link has broken
(Neighbor Detection Algorithm had not yet reacted to link break)

This talk

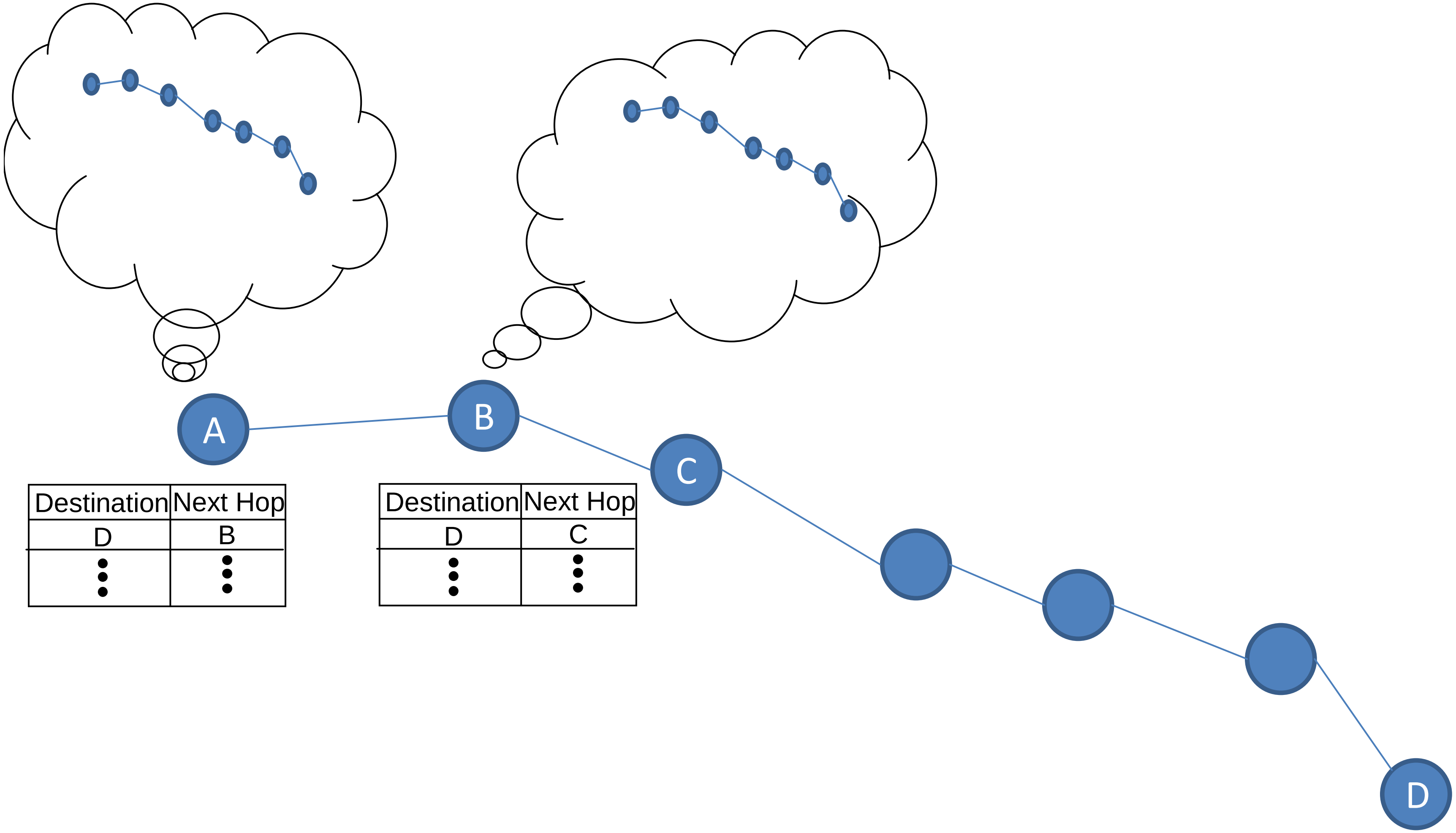
$$P(SD_i) = (1-P_{NoPath}) \times (1-P_{err}) \times (1-P_{linkFail}) \times (1-P_{Loop})$$

Successful
Transmission over a link

Transmission error
(With ARQ, this is small)

Network layer error
Caused by inconsistent topology information

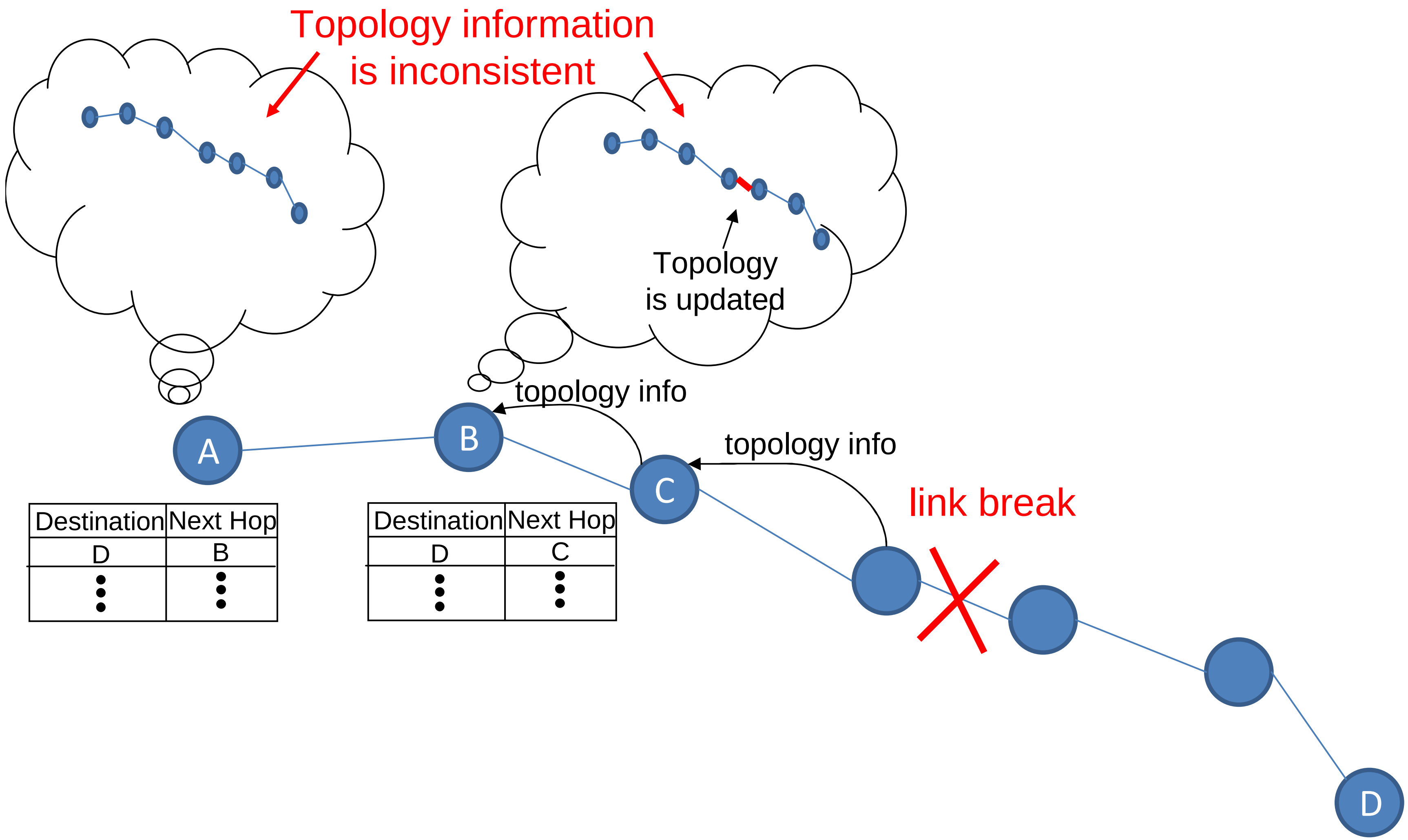
Topology Information Inconsistency



Destination	Next Hop
D	B
⋮	⋮

Destination	Next Hop
D	C
⋮	⋮

Topology Information Inconsistency



Destination	Next Hop
D	B
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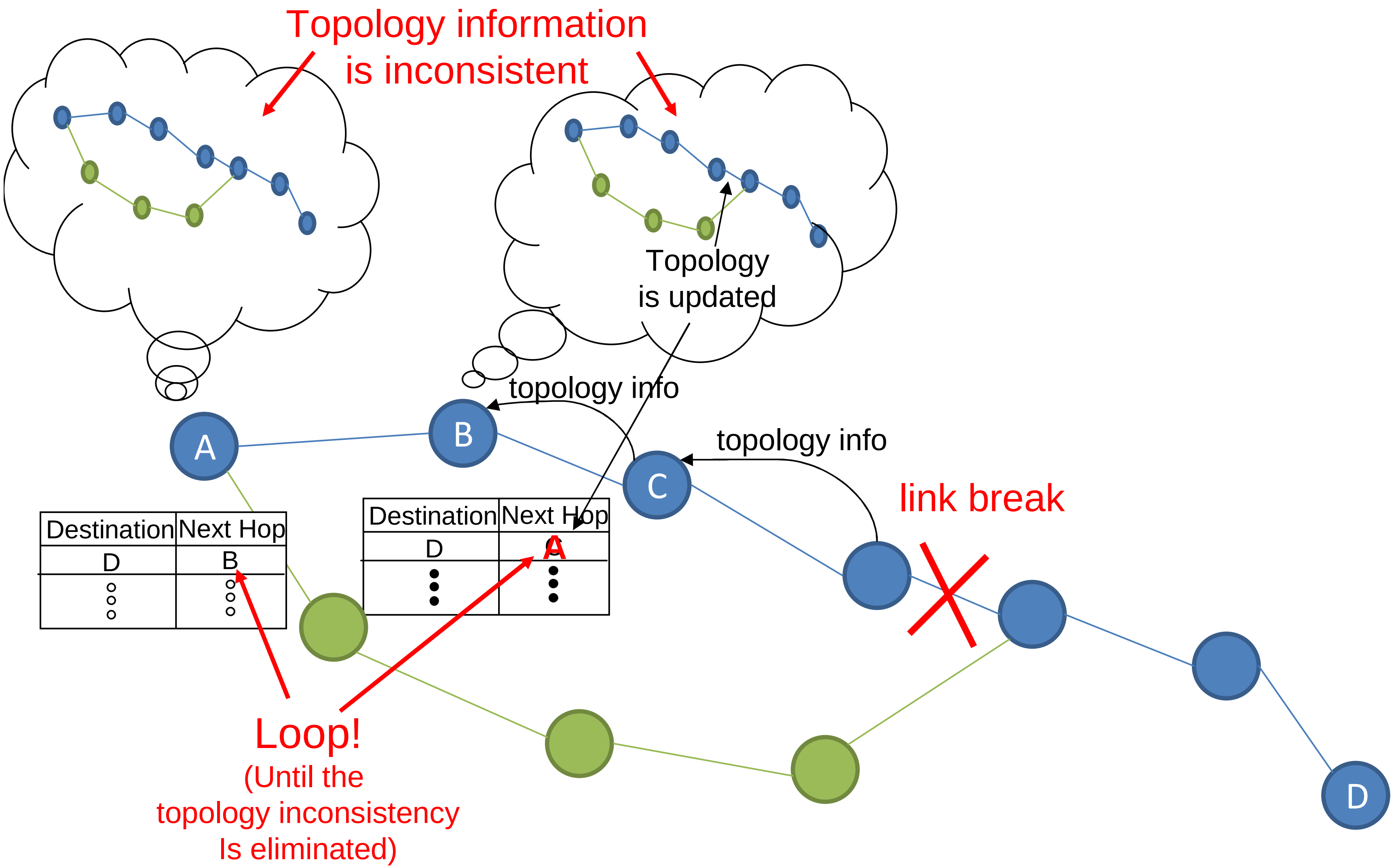
Topology Information Inconsistency



Ingredients for a Loop

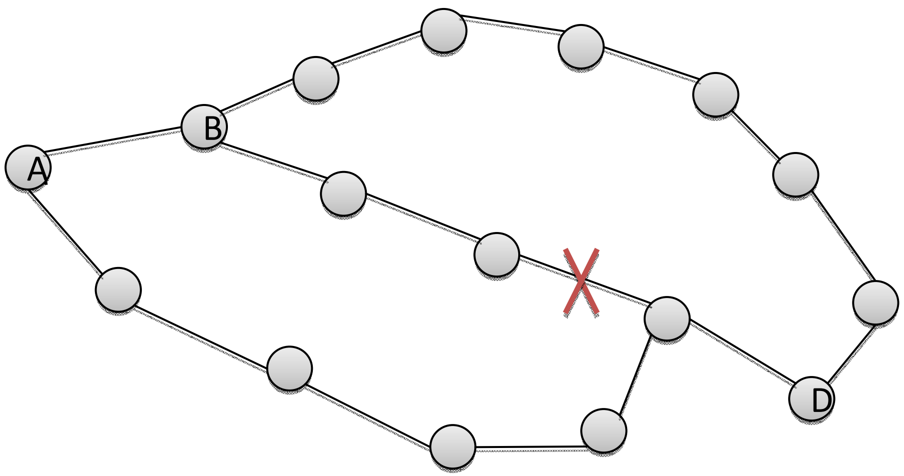
- Change in topology that induces a change in routing

- Topology information inconsistency
  - Neighboring nodes have different views of the topology

Loop forming

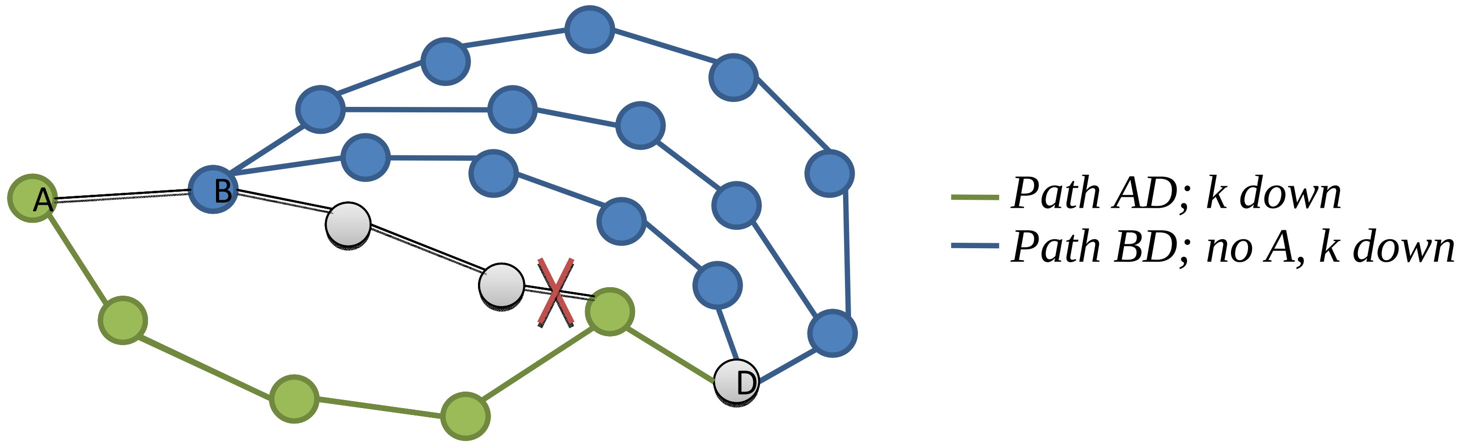
Some Definitions first…

1. $L(A)$: Original length of shortest path from A to D
2. $L(A;\ k\ down)$: Length of shortest path from A to D that avoids broken link k.
3. $L(B;\ no\ A,\ k\ down)$: Length of shortest path from B to D that avoids A and broken link k.



Loop forming: Events to consider

- If $L(B;\ no\ A,\ k\ down) > L(A;\ k\ down)+1$ then B must forward through A.
- If $L(B;\ no\ A,\ k\ down) = L(A;\ k\ down)+1$ then B may forward through A.
- If $L(B;\ no\ A,\ k\ down) < L(A;\ k\ down)+1$ then B won't forward through A.



$P_L(k;h)$: Probability that there is a loop in the first hop of a path of length h, given that the k-th link broke and information is inconsistent.

- An upper bound of P_L is given by:

$$P_L^{UB}(k;h) = \sum_{L(A)} P\left(L\left(B;\text{no } A,\ \text{no } k\right) \geq 1 + L\left(A;\text{no } k\right)\right)$$

- A lower bound of P_L is given by:

$$P_L^{LB}(k;h) = \sum_{L(A)} P\left(L\left(B;\text{no } A,\ \text{no } k\right) \geq 1 + L\left(A;\text{no } k\right)\right)$$

  - Since the lower bound makes special assumptions about the dissemination of topology information, we expect that the upper bound is a better estimate.

Probability of a loop given topology inconsistency

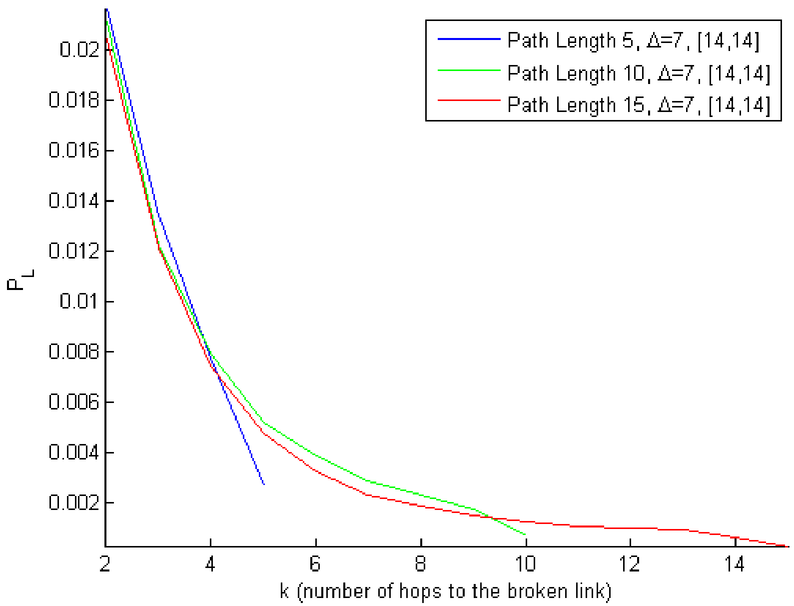
- PL was estimated using simulation for various scenarios.

Simulation Parameters
Network Sizes: 14x14, 15x15, 16x16,…, 20x20 transmission ranges
Average Node Degree: 4, 5, 6, … , 11
- Nodes randomly distributed in space - Nodes distributed in a 9x9 block in Chicago (Data from udelmodels.eecis.udel.edu)
Number of samples: 13×10^6

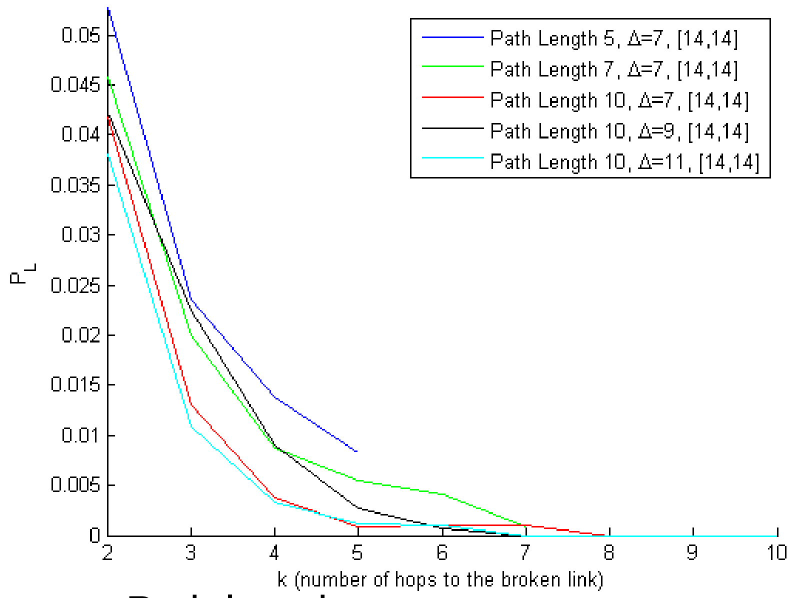
Probability of a loop given topology inconsistency

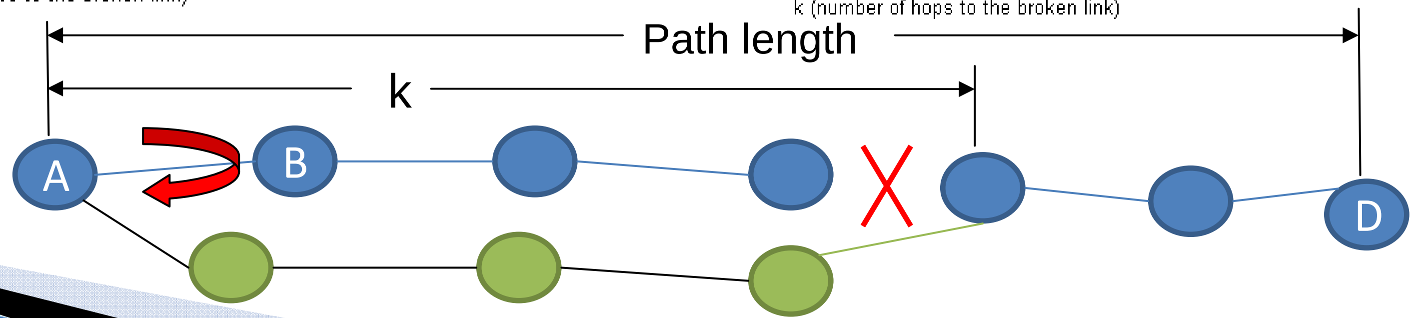
P_L: is the probability that a loop forms given a inconsistent topology information

Uniformly distributed nodes
Free-space propagation



Urban propagation





Probability of a Loop Forming

- $1/\mu$ = average link lifetime

- DT(k) = duration that a topology information inconsistency last, after a link breaks k hops away.

- Fraction of time that topology information is inconsistent
  - DT(k) / $(1/\mu)$

- $P_{Loop}(k;h)$ = Probability that a loop forms as a result of a link break k hops away on a path of length h
  - $P_{Loop}(k;h) = P_L(k;h)\ DT(k) / (1/\mu)$

- $P_{Loop}(h)$ = the probability that a node will transmit a packet to its neighbor, and its neighbor's routing table points back to this node (so the packet is dropped)

$$P_{Loop}(h) = \sum_{k=1}^{h} P_{Loop}(k;h)$$

  - This probability of loss occurs at each hop
  - (Loop can form when link come up (unbreak). The formulas are similar, but they are even more rare)

Ingredients for a Loop

- Change in topology that induces a change in routing

- Topology information inconsistency
  - Neighboring nodes have different views of the topology

The Duration of Topology Information Inconsistency - DT

- Let T(k) be the time between topology updates
  - In the case of hazy sighted routing, this time depends on the distance from the source of the information
- Let $P_{Flood}(k, ttl)$ be the probability that the topology dissemination reaches a node k hops away.
- Let P(if;k) the probability that the topology dissemination reaches a node k-1 hops away, but its neighbor at k hops away from the source did not receive it.

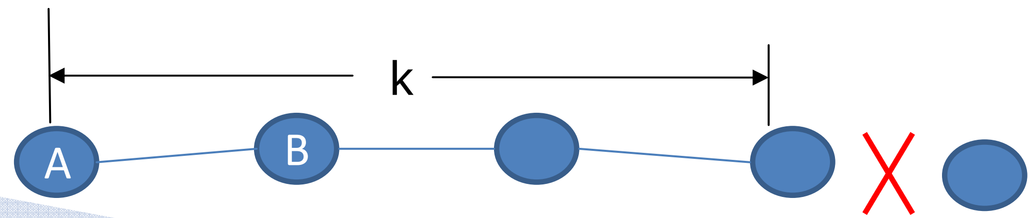
Probability that the next top info dissemination is successful

Probability that the first top info dissemination is unsuccessful, but the second is.

$$DT(k) = P(if;k) \left(T(k)\, P_{Flood}(k; ttl) + 2\times T(k)\, (1-P_{Flood}(k; ttl))\, P_{Flood}(k; ttl) + 3\times T(k)\, (1-P_{Flood}(k; ttl))^2\, P_{Flood}(k; ttl) + \ldots \right.$$

for k>2

This holds for any topology dissemination method, full flooding, MPR, CDS.



The Duration of Topology Information Inconsistency - DT
The Hazy-Sighted Case

- In hazy sighted topology information dissemination, the topology information packets are not flooded over the entire network (TTL=∞)

- Rather, TTL = 1, 2, 1, 4, 1, 2, 1, 8, 1, 2, 1, 4, 1, 2, 1, 16, 1, ….
  - TTL is at least 2^{k-1} every k periods
  - A topology dissemination message will reach a node k hops away every $2^{\lceil \log(k) \rceil} \times T(1)$, where T(1) is the frequency of flooding one hops

- Let $P_{Flood}(k; ttl)$ be the probability that the topology dissemination reaches a node k hops away

Probability that the next top info dissemination is successful

Probability that the first top info dissemination is unsuccessful, but the second is successful. Note that the second flood has a different TTL

$$DT(k) \approx P(if;k) \left(\overbrace{T(k)\, P_{Flood}(k; 2^{\lceil \log(k) \rceil})} + \overbrace{2 \times T(k)\, (1 - P_{Flood}(k; 2^{\lceil \log(k) \rceil}))\, P_{Flood}(k; 2^{\lceil \log(k) \rceil + 1})} + \ldots \right)$$

for k>2

P_{flood} and P_{if}

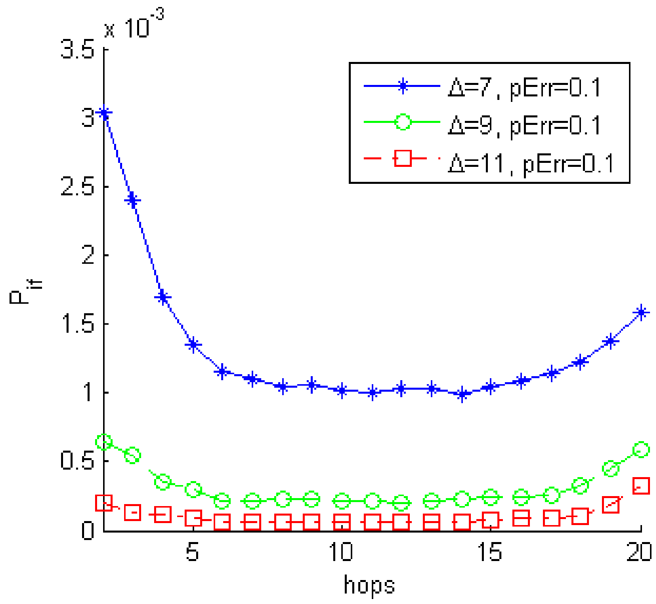
- P_{flood} and P_{if} were also estimated using simulation.

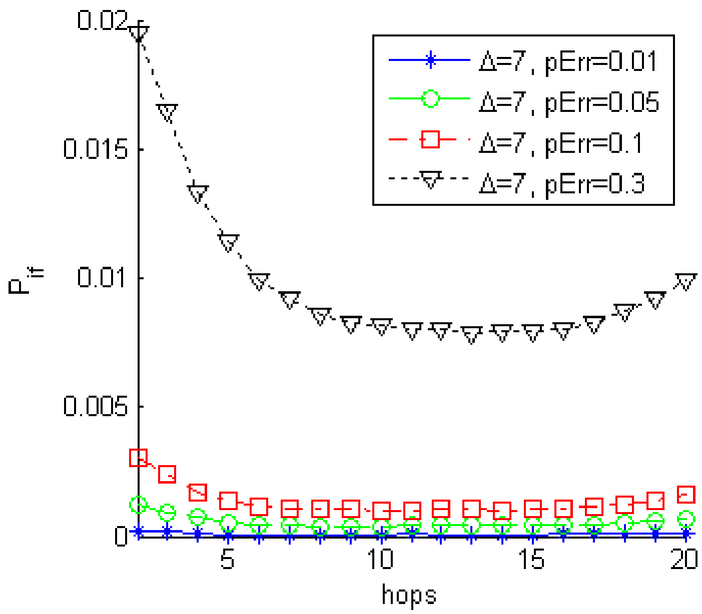
Simulation Parameters
Network Sizes: 14x14, 15x15, 16x16,…, 20x20 transmission ranges
Average Node Degree: 4, 5, 6, … , 11
Nodes randomly distributed in space
Number of samples: 4×10^5

The Duration of Topology Information Inconsistency - DT

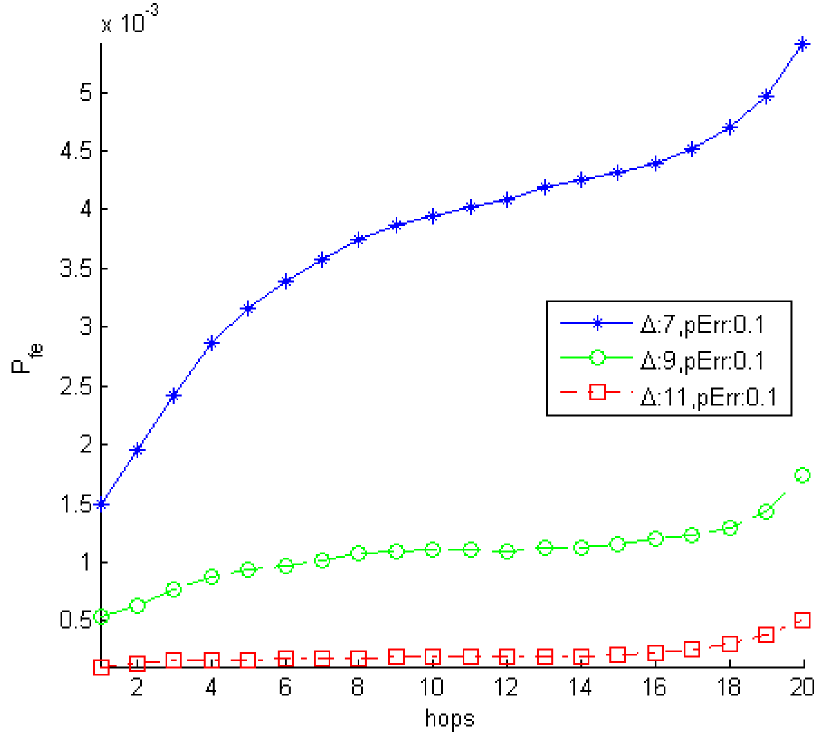
- Note that P(if; k) depends on the flooding
  - Perfect flooding would not have any topology information inconsistency

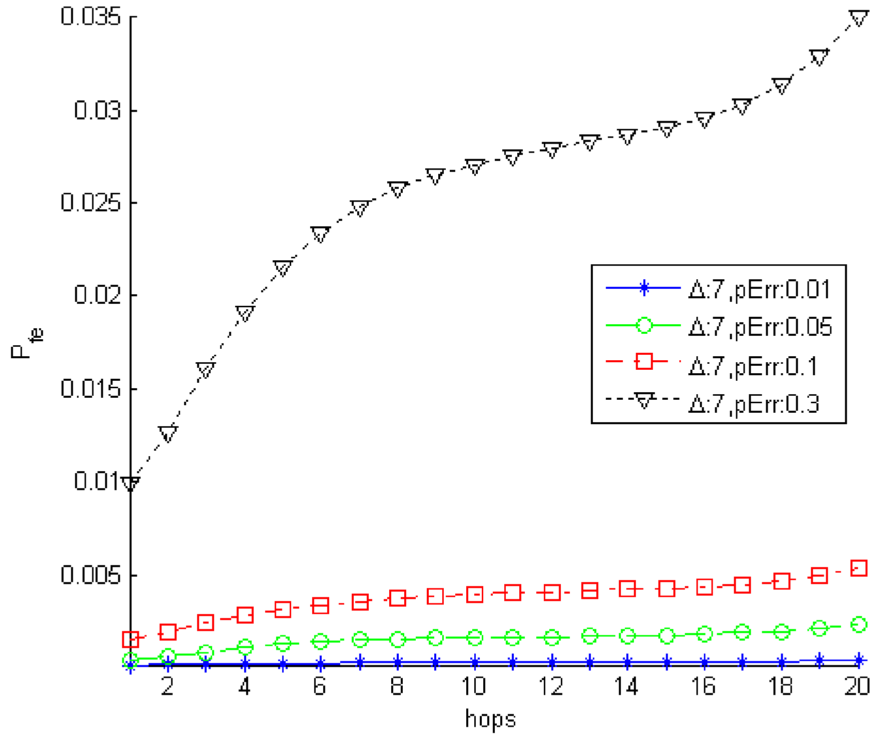
Inconsistency in the forward direction
(the node closer to the source has the more up-to-date info)





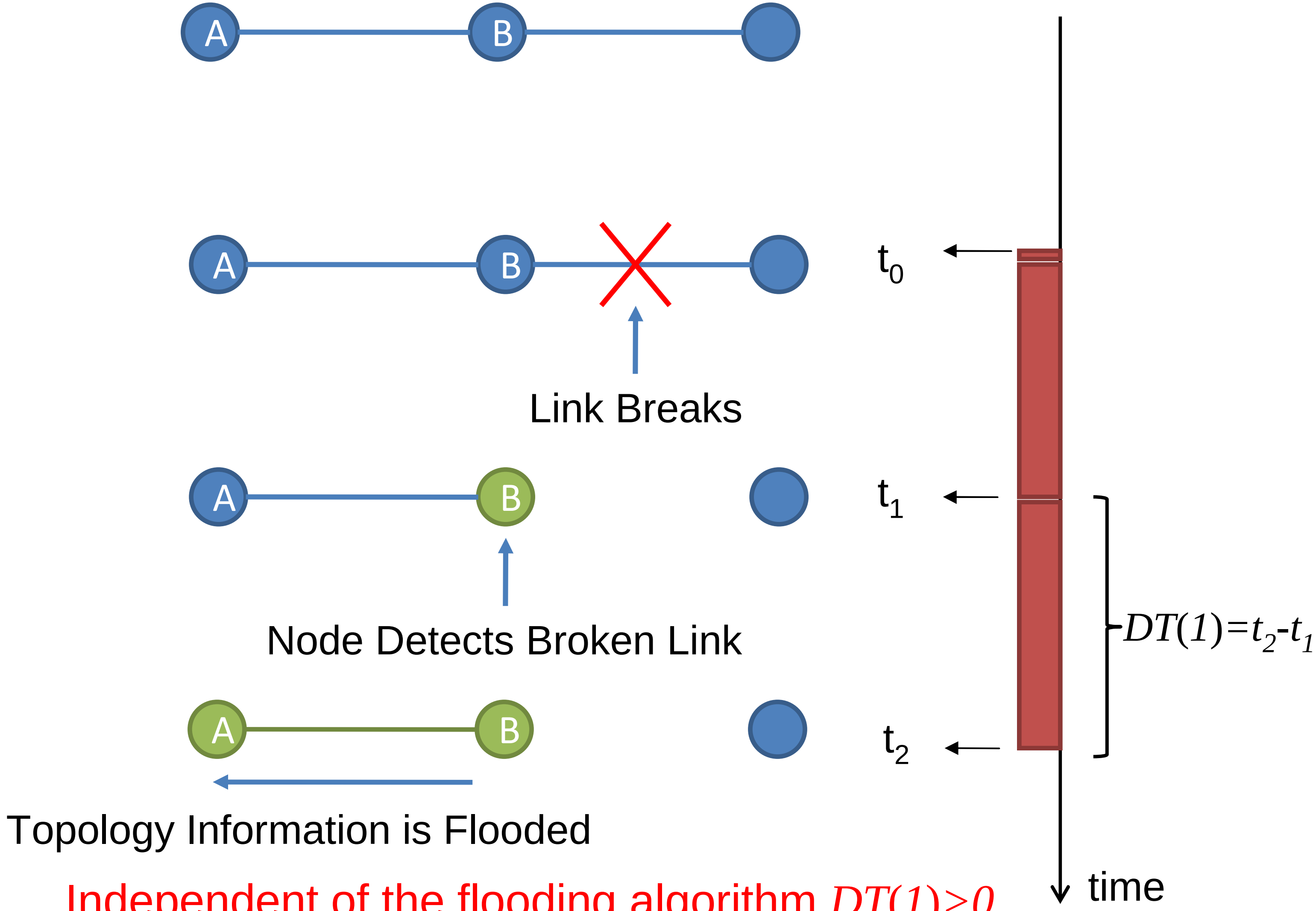
Probability of a failure to receive a flooding packet – Full Flooding





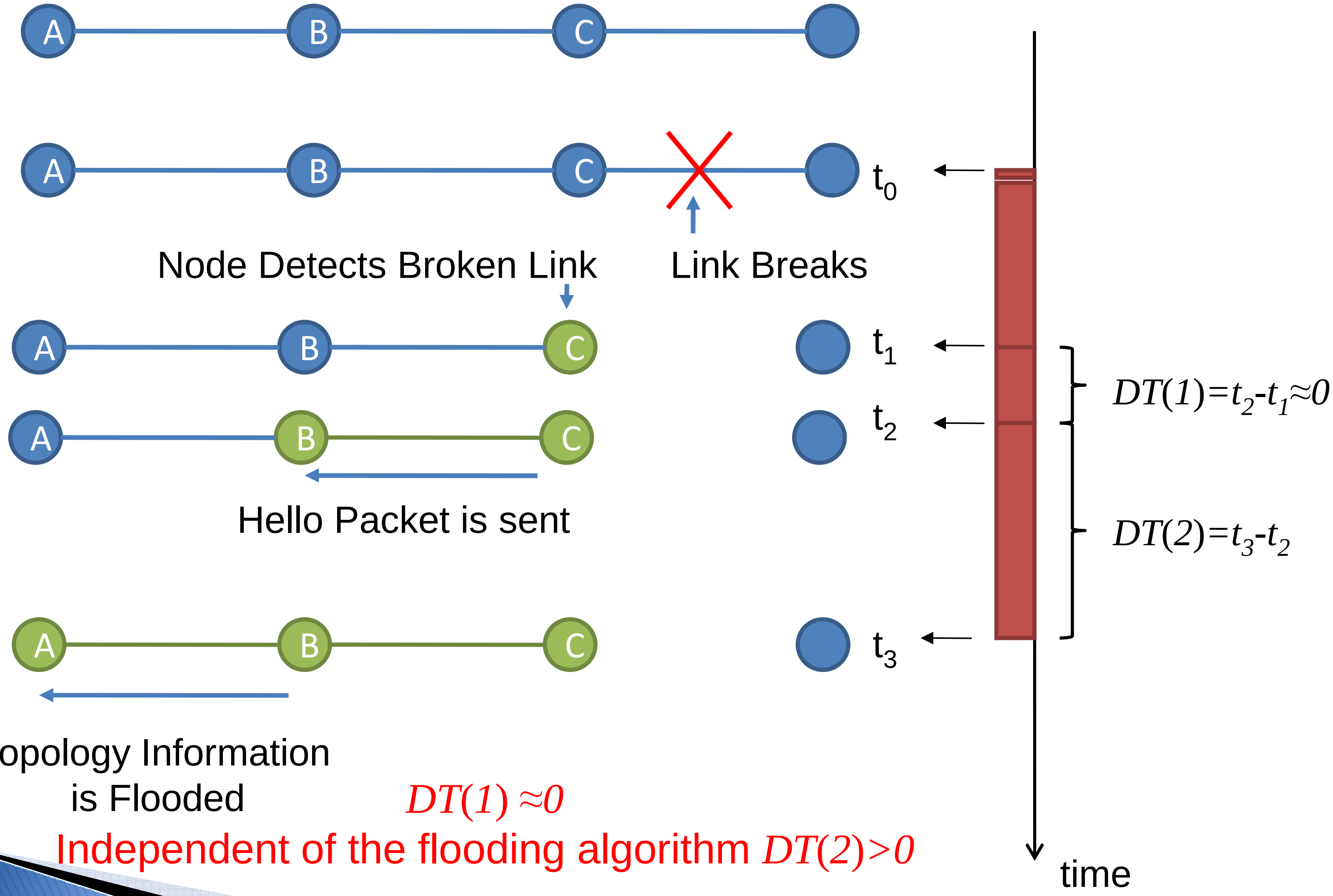
The message is less likely to reach a node further away

DT(1)



Independent of the flooding algorithm $DT(1)>0$

DT(2)



$DT(1) \approx 0$

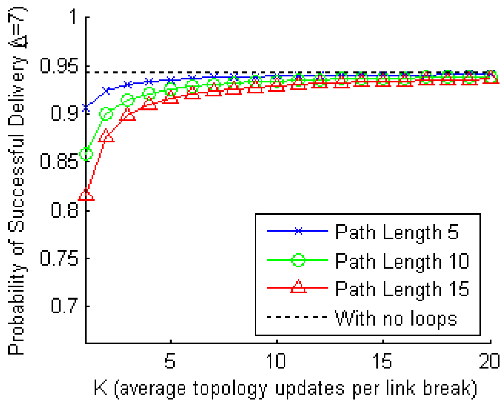
Independent of the flooding algorithm $DT(2)>0$

Probability of Delivery Error

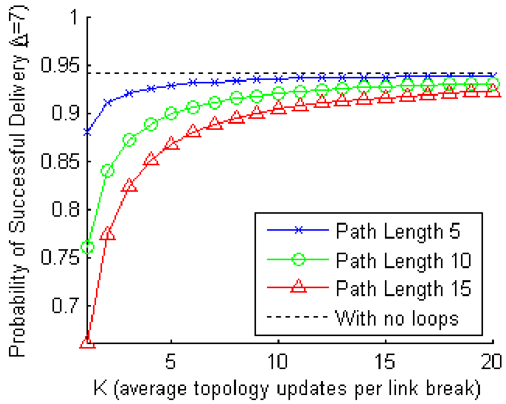
$$P(SD_i) \approx 1 - P_{NoPath} - P_{err} - P_{linkFail} - P_{Loop}$$

($P_{err} \to 0$, $P_{linkFail} \to 0$)

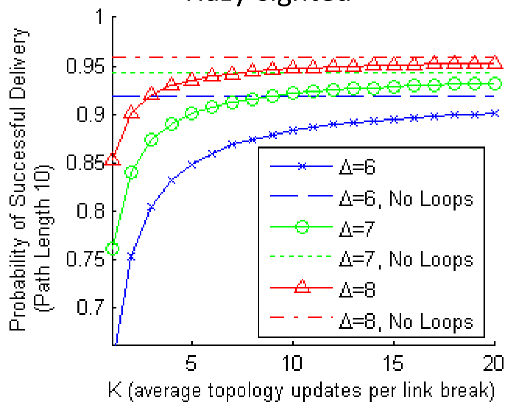
Nodes Uniformly distributed in Space
Full flooding



Nodes Uniformly in Space
Hazy-sighted



Nodes Uniformly in Space
Hazy-sighted



Conclusions

- It was shown how stale topology information impacts the probability of successful delivery of a packet. A tradeoff is highlighted between increasing this probability and reducing the overhead of the routing protocol.
- The probability of loops cannot be neglected if the rate of topology updates is low compared to node mobility.

Questions?