Reactive Routing Overhead in Networks with Unreliable Nodes

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Objective/Motivation

- Propose a new mathematical framework for quantifying the reactive routing overheads
- Capture the limits of scalability of reactive routing overheads with different traffic patterns

Traffic Patterns and Routing Scalability

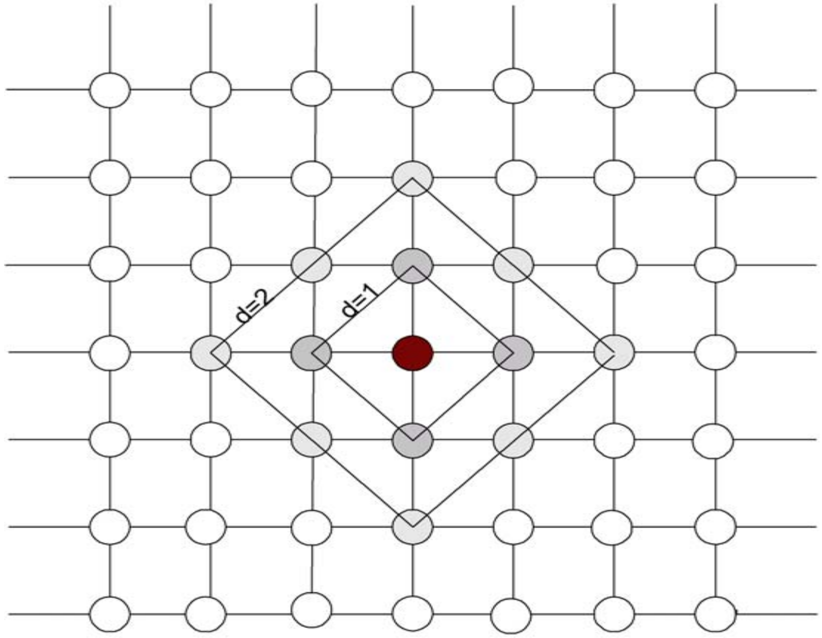
- Argument: If all nodes communicate with all other nodes with equal probability, routing overhead grows without bound as N grows.

- Question: If nodes tend to communicate with "nearby" nodes, will the routing overhead be bounded (i.e. O(1)) as "N→∞"?

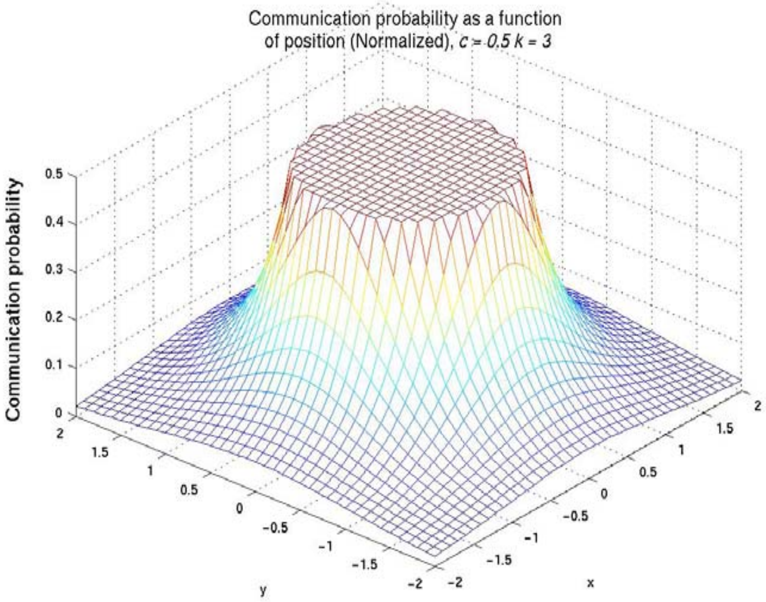
Overall Outline

- Network Model
- Analysis
- Simulations

Network Model - I



A Manhattan grid (degree 4 graph). Nodes have ON/OFF status. Network is always connected.



Communication probability as a function of the distance between nodes

Network Model - II

Two nodes i and j at a distance $r_{i,j}$ hops have an active path (i.e. $I = 1$) with probability

$$P[I = 1] = P(r_{i,j}) = \frac{c}{r_{i,j}^{k}}$$

- c is a scaling constant
- k is a design-controlled constant
- What is the minimum k to guarantee scalable operation?

Network Model - III

- Nodes enter to an “OFF” state, randomly
- Time interval that a node is OFF is much shorter than the time interval that a node is ON
- For our analysis, if a node fails, assume all other nodes are still ON
- Transmission range is limited to the direct communication between immediate neighboring nodes

Reactive Routing

- Route Discovery
- Route Maintenance

Reactive Routing – Route Discovery

- Route discovery is the mechanism initiated by a node upon the arrival of a “new path request” in order to discover a new path to the destination node
    - RREQ
    - RERP

- Similar to other reactive routing protocols, our generic protocol uses a “flooding” technique for control packets

Reactive Routing – Route Maintenance - I

- Route maintenance is the mechanism by which a node is notified that a link along an active path is broken such that it can no longer reach the destination node through that route – RERR
    - Local repair with distance-vector based notifications
    - Local repair with source route based notification
    - No local repair and source route based notification

Reactive Routing – Route Maintenance - II

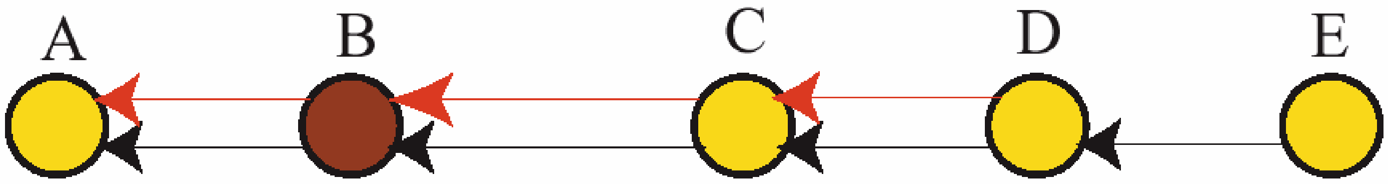


Figure 1: Node failure example. Two sessions (paths) exist, one from D to A and another from E to A. Node C detects that node B has failed and hence notifies D and E by sending RERR packets.

Analysis

- $T(\alpha)$:= Min Time To Live "T" such that the probability of not finding the destination node is less than a small value "α"
- N_{find}:= number of RREQ packets if a node need to request a new route
- N_{off} := number of RERR packets if a node fails

- S_i := number of sessions initiated by a node
- S_t := number of sessions destined to a node
- S_r := number of sessions passing through a node
- $S := (S_i + S_t + S_r)$ number of total sessions for a node
- $P_r := S_r / S$ percentage of passing-through sessions over total sessions
- Z := session length

- E[] represent the average of a random variable

Summary of Results

For an (infinite network) N→ ∞:

$$T(\alpha) = \min\{ i \mid \sum_{r=i+1}^{\infty} \frac{1}{r^{k-1}} \leq \alpha f(k-1)\};\, k > 2$$

$$N_{find} = 1 + T(\alpha)(T(\alpha)+1);\, k > 2$$

$$E[N_{off}] = 4c^*(f(k-2) - f(k-1));\, k > 3$$ (local repair with source route notification)

$$E[N_{off}] = 2c^*(f(k-3) - f(k-2));\, k > 4$$ (source route notification)

where $f(k) \equiv \sum_{r=1}^{\infty} \frac{1}{r^k}$

Main Result: k>3 necessary for bounded overhead.

Summary of Results

For an (infinite network) N→ ∞:

$$E[S_t] = E[S_i] = 4c * f(k-1); k > 2$$

$$E[S_r] = 4c * (f(k-2) + f(k-1)); k > 3$$

$$E[S_r] = 4c * (f(k-2) - f(k-1)); k > 3$$

$$p^r = 1 - \frac{2f(k-1)}{f(k-2) + f(k-1)}; k > 3$$

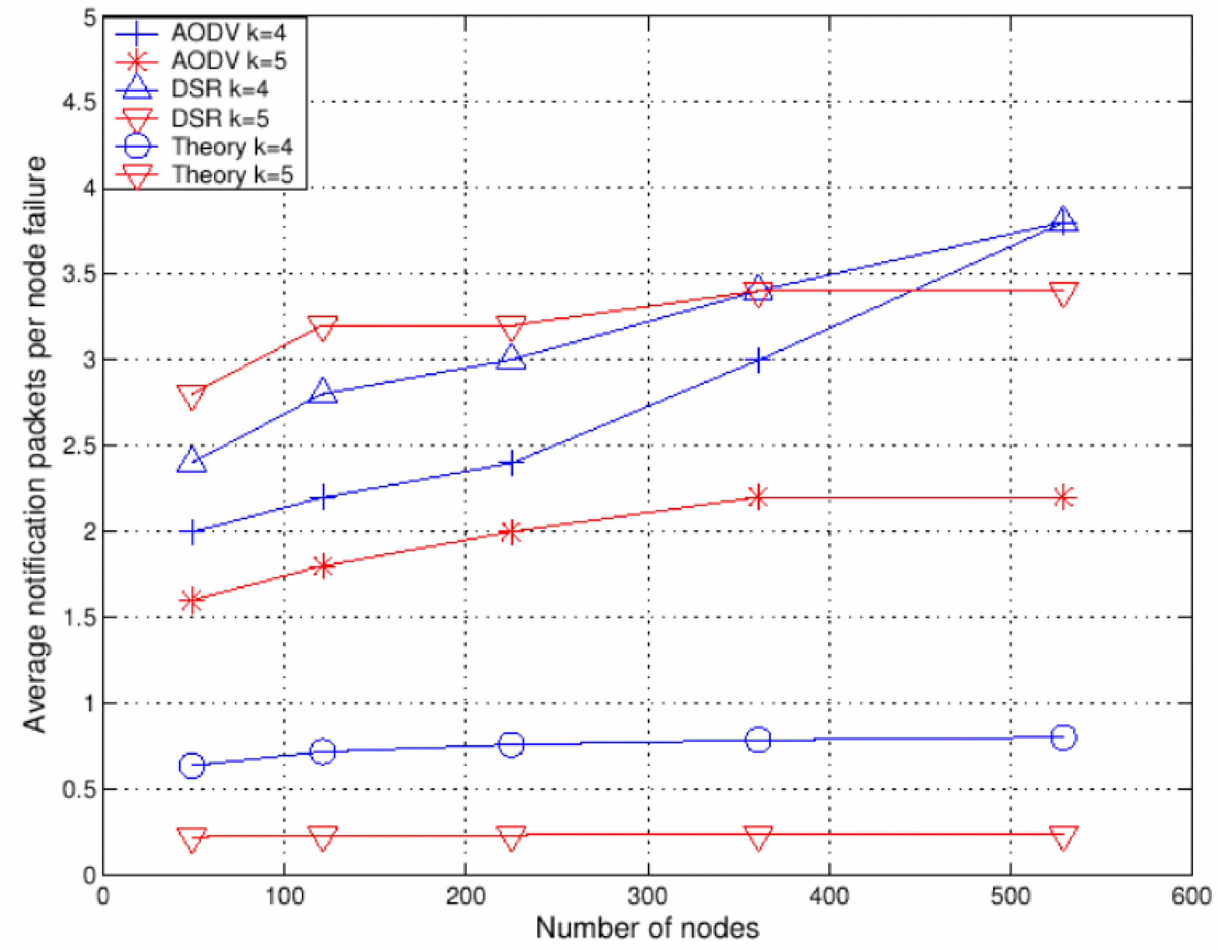
$$E[Z] = \frac{f(k-2)}{f(k-1)}; k > 3$$

Main Result: k>3 necessary for bounded overhead.

Simulation Outline

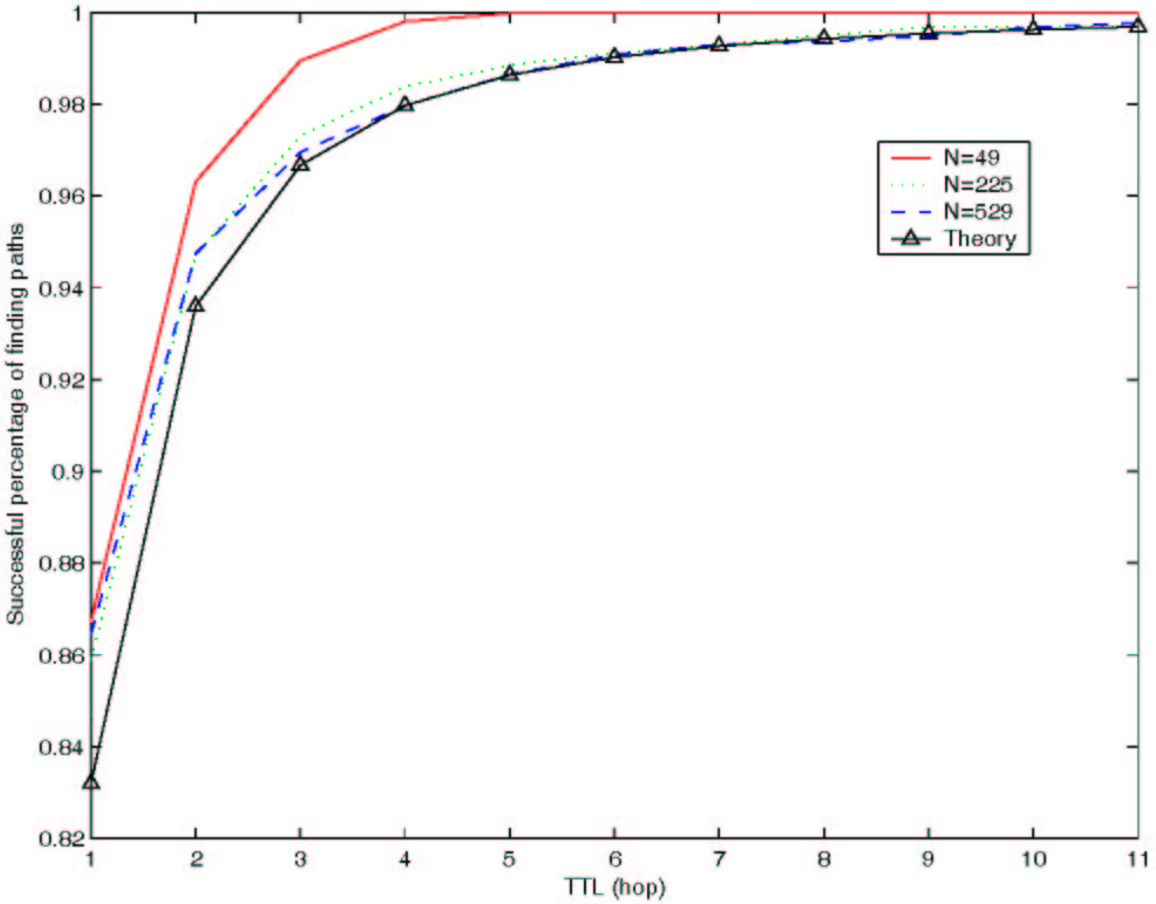
- *ns-2* simulator
- Purpose: validate the dependencies (trends) rather than absolute values
- DSR and AODV
- Difficulty: cannot simulate very large networks
- Networks of size N=49, 121, 225, 361 and 529
- Use CBR
- Each point in following figure represents average of 5 runs with same topology but different random seed

E[N_{off}] (AODV, DSR and Theory)



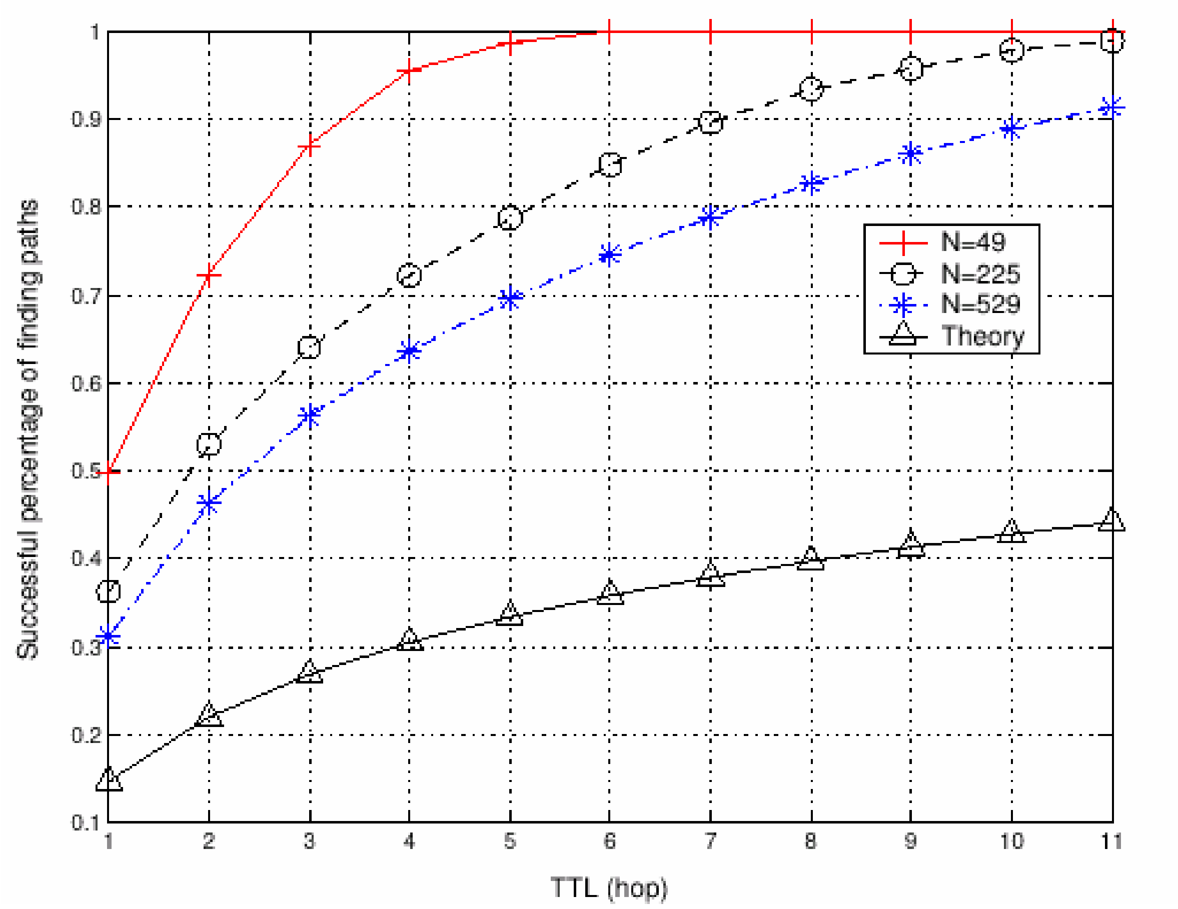
- k>4

Time-To-Live $T(\alpha)$ (AODV, k = 4)

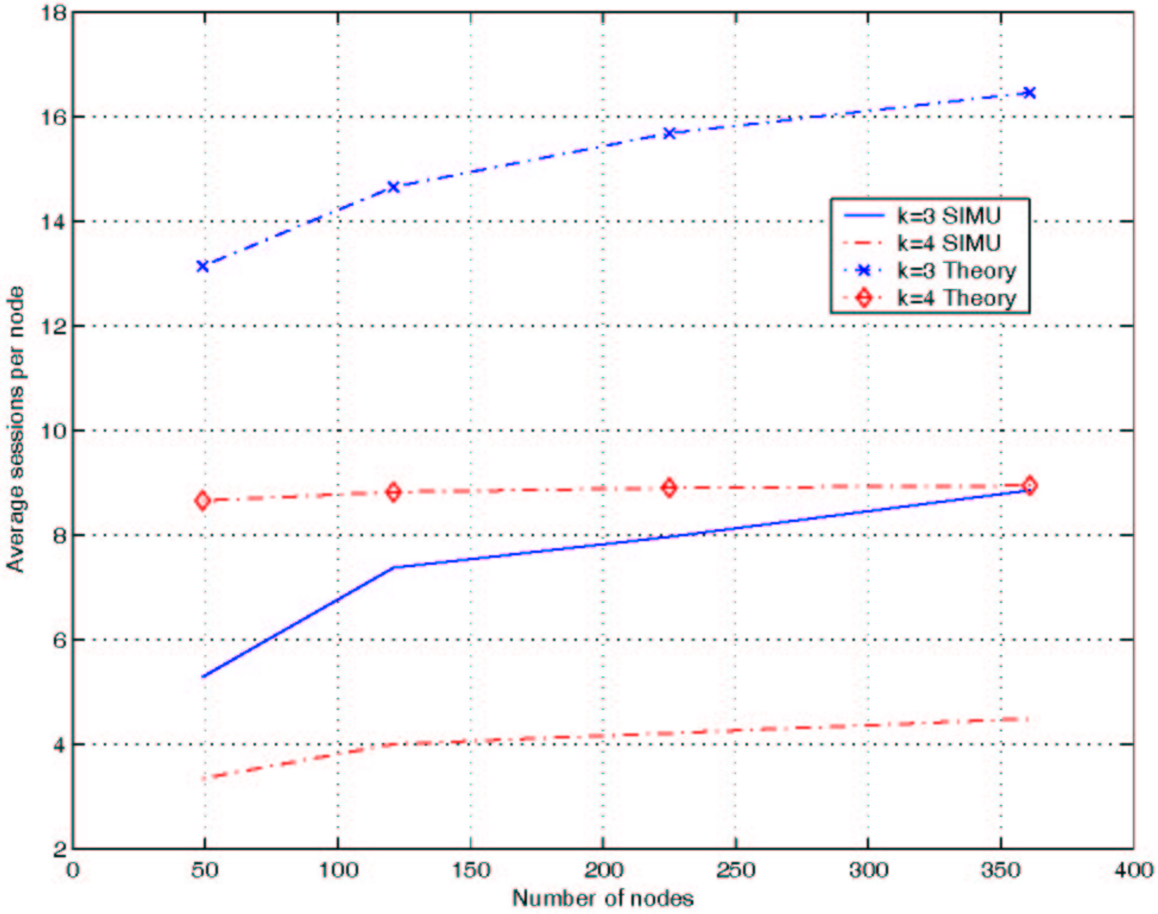


- k>2

Time-To-Live T(α) (AODV, k = 2)

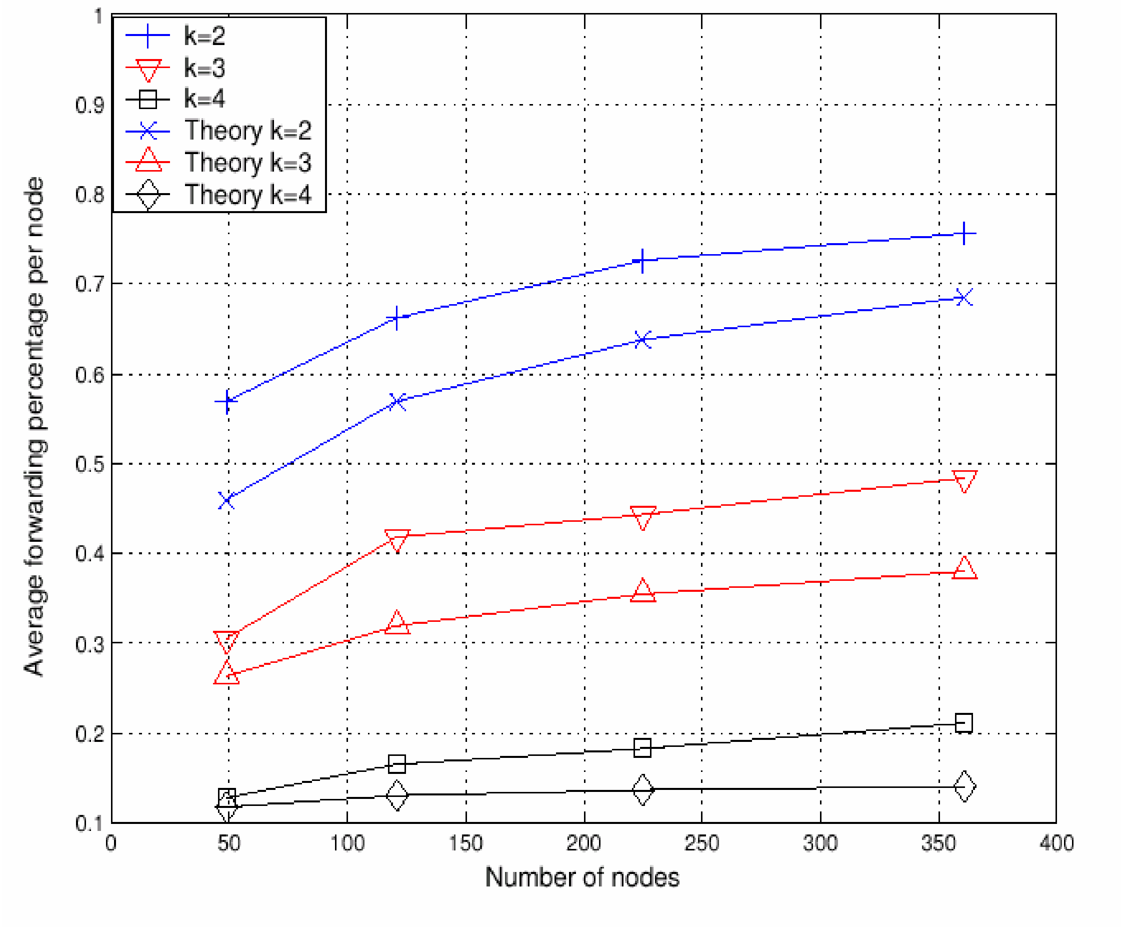


E[S] (AODV, k=3,4)



- k>3

q

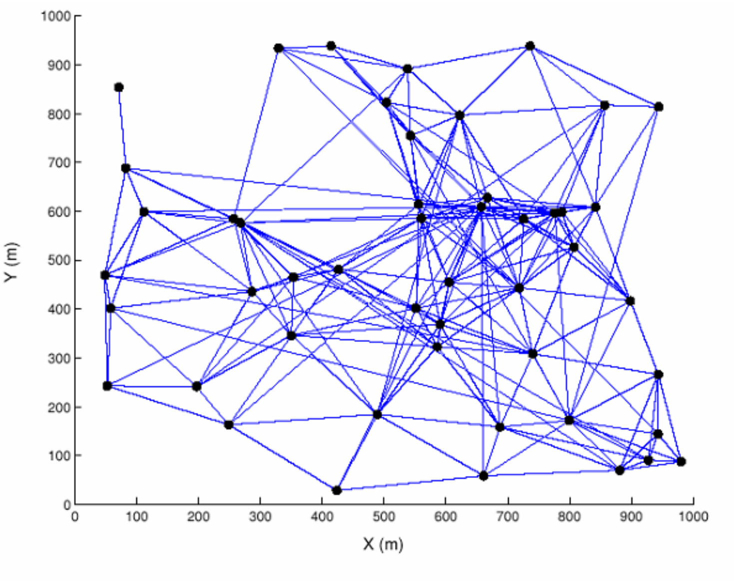

k=2
k=3
k=4
Theory k=2
Theory k=3
Theory k=4
Average forwarding percentage per node
Number of nodes
0
50
100
150
200
250
300
350
400
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

- k>3

More Realistic Network Model

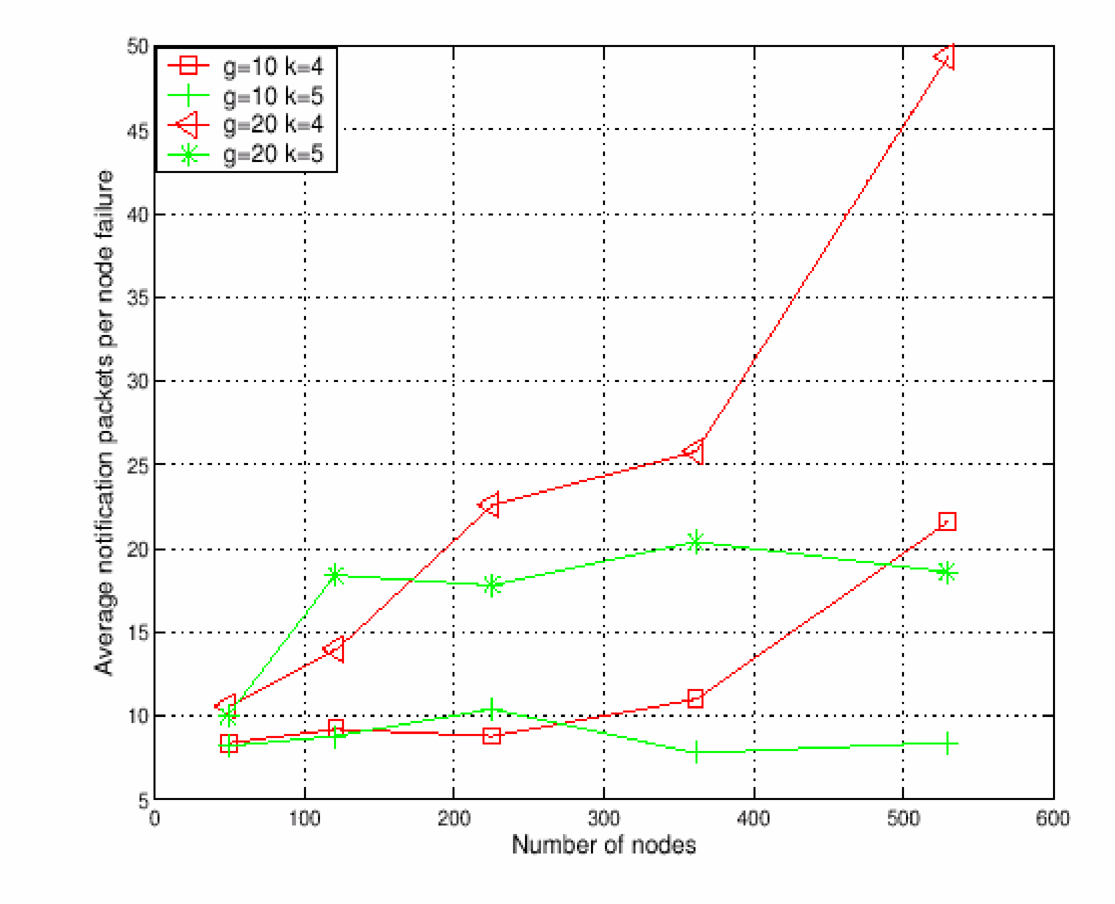
$$P_N(n) = \frac{(\lambda A)^n}{n!} e^{-\lambda A}$$

$$g = \lambda \pi r_0{}^2$$

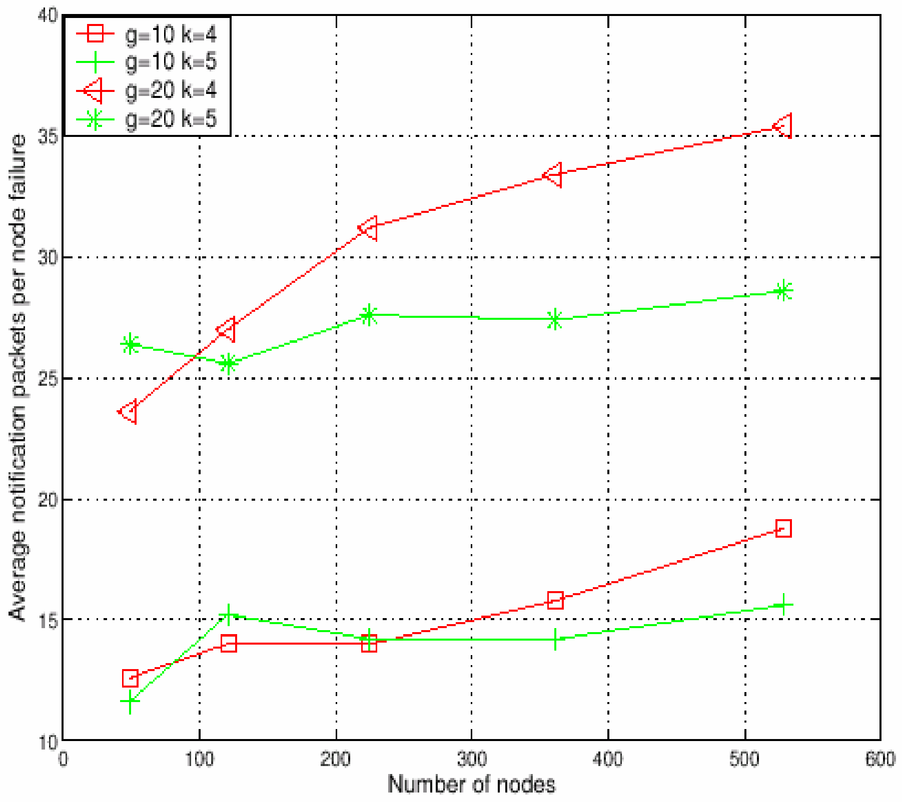


Random distribution (Poisson Field) with average node degree g=10 (above conectivity threshold)

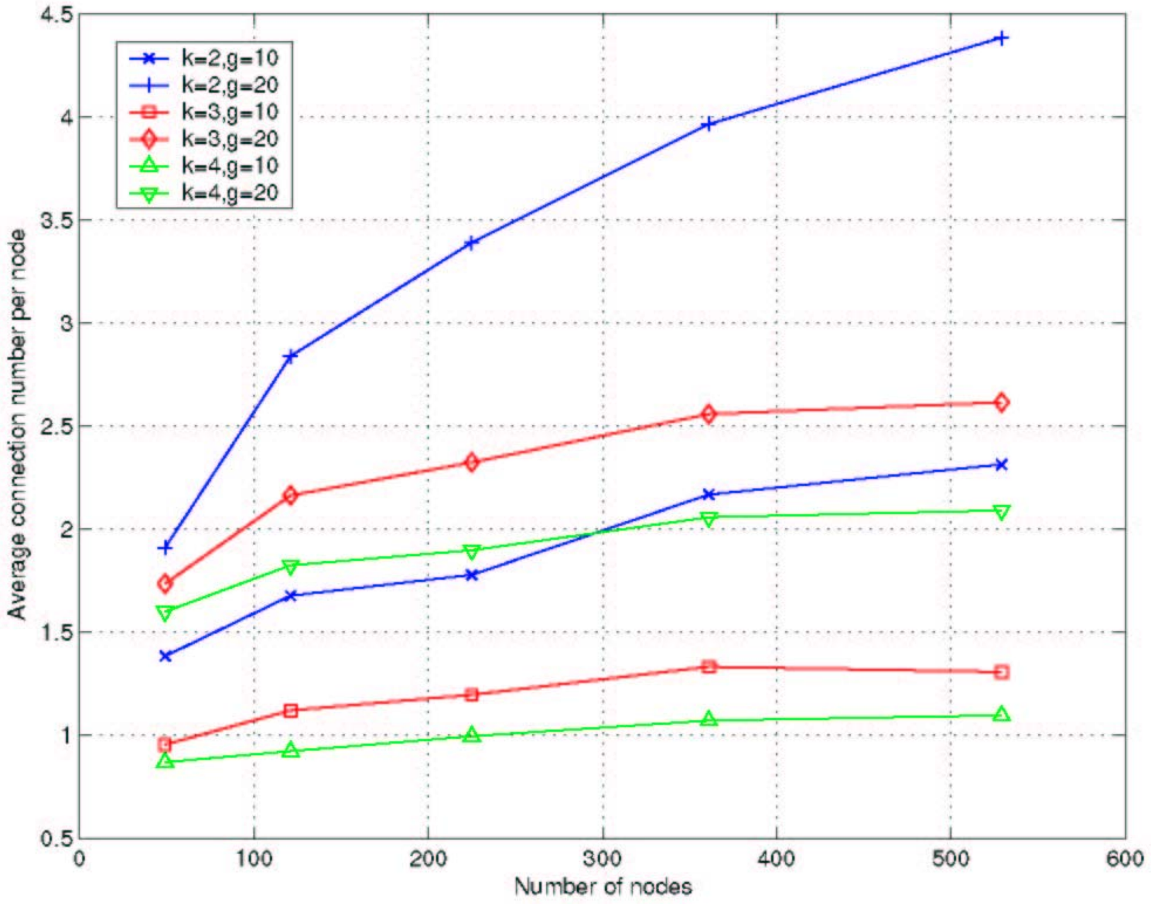
$E[N_{off}]$ (AODV, k=4, 5)



E[N_{off}] (DSR, k=4, 5)



E[S_t]



k=2,g=10
k=2,g=20
k=3,g=10
k=3,g=20
k=4,g=10
k=4,g=20
Average connection number per node
Number of nodes
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100
200
300
400
500
600

- k>2

Summary

- Proposed a new mathematical framework for quantifying reactive routing overheads
  - Driven the mathematical expressions of various network quantities

- Captured the limits of scalability of reactive routing overheads
  - Different network quantities have different scalable conditions that are determined by k
  - Irrespective of protocol used, the Manhattan grid is not infinitely scalable if the coefficient k is less than or equal to 3

- Our results are validated by simulation

Future Work

- Theoretical analysis of random topology (to appear in IEEE JSAC, March 2005)
- Analysis of the overhead of other types of routing protocols such as hierarchical routing
- Aid the design of routing protocols in the future (any takers?)