

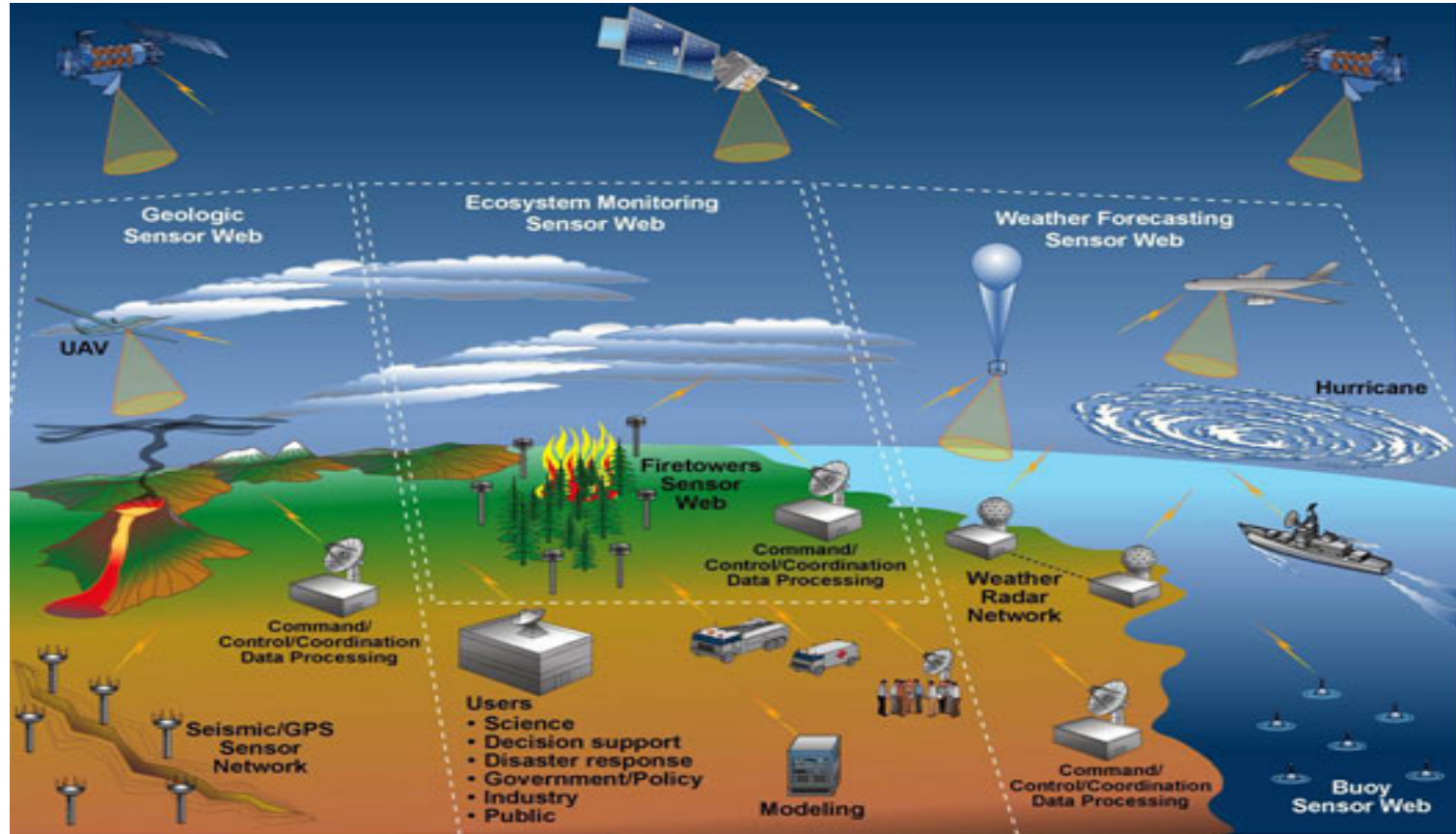
Highly-Resilient, Energy-Efficient Multipath Routing in Wireless Sensor Networks

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Deborah Estrin

**PRESENTED BY
MAYANK KAUL**

- **INTRODUCTION**
- **DISJOINT AND BRAIDED MULTIPATH**
- **EVALUATION METHODOLOGY**
- **SIMULATION RESULTS**
- **CONCLUSION**

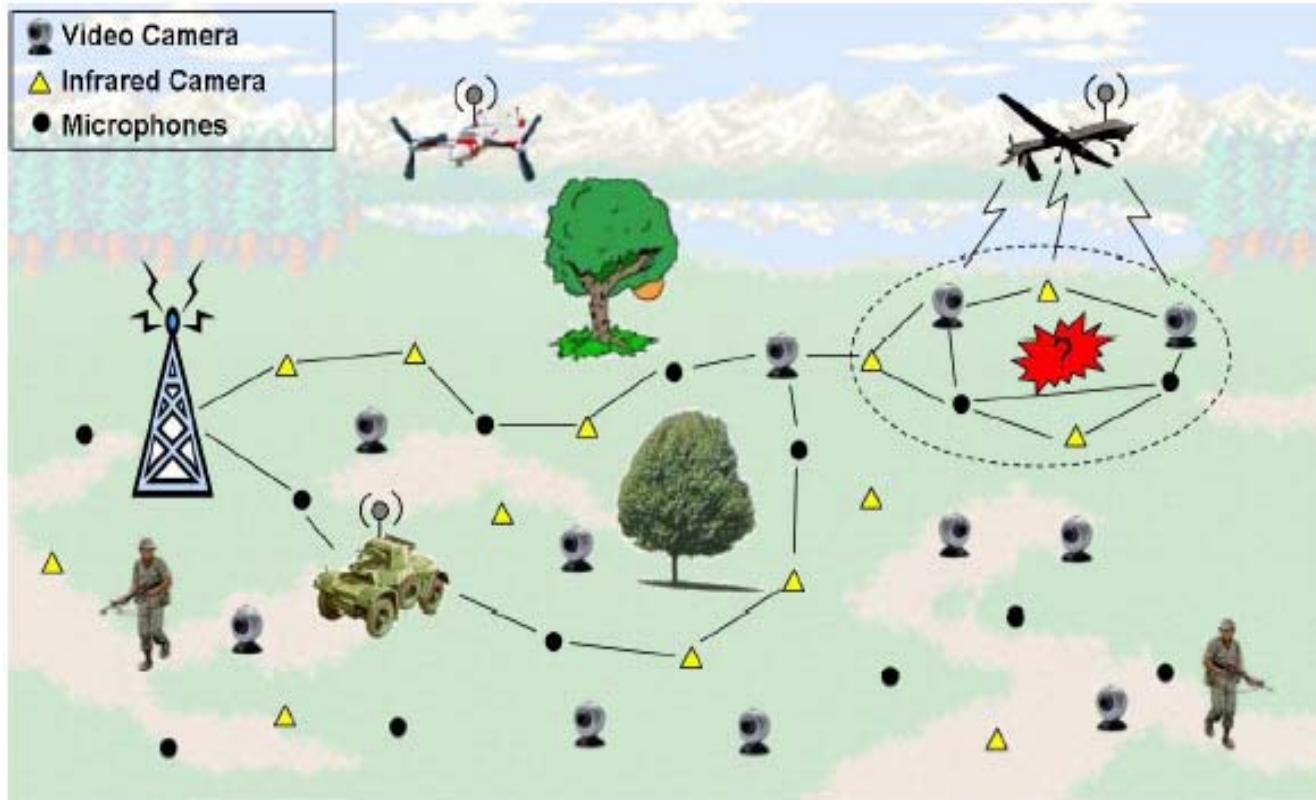
INTRODUCTION



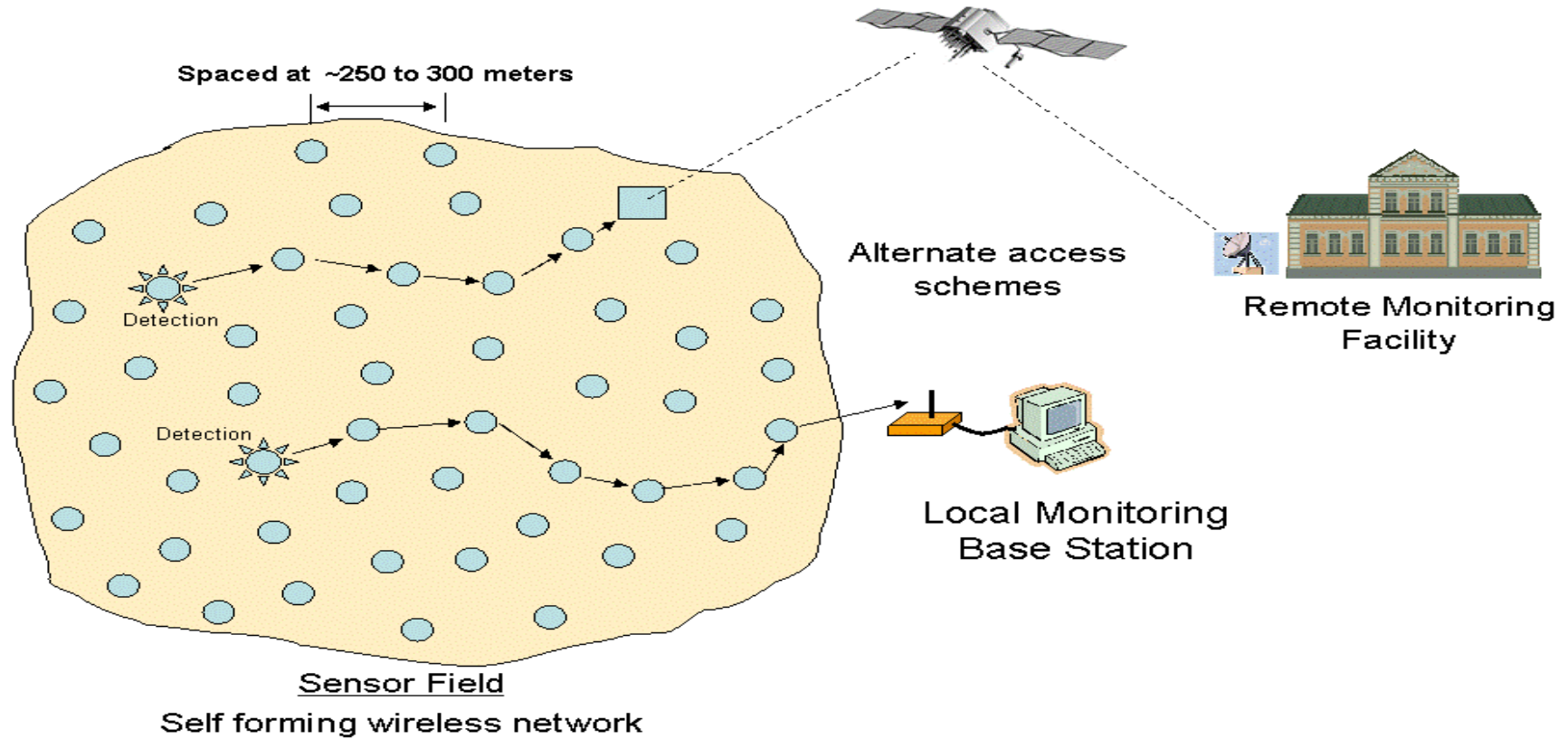
Sensor Web as predicted by Matt Heavner at University of Alaska

WIRELESS SENSOR NETWORKS

- Military Applications



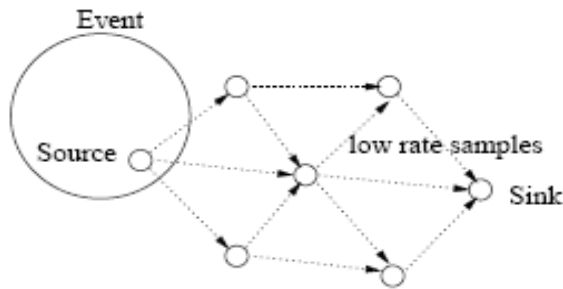
WIRELESS SENSOR NETWORKS



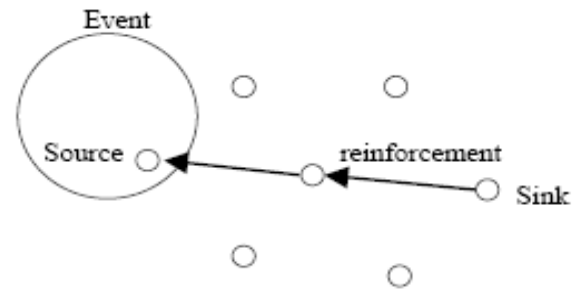
SENSOR NETWORKS

- Sensor Network design governed by three major Factors:
 - a) Scalability- Network might involve thousands of nodes.
 - b) Energy Efficiency- For wireless networks.
 - c) Robustness- To node and link failures.

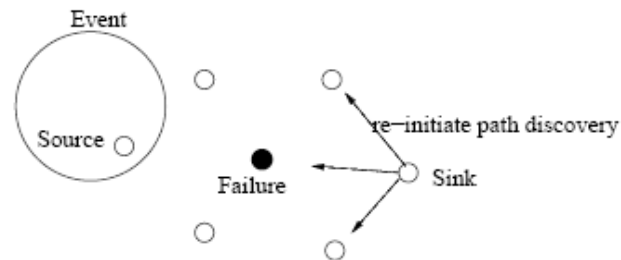
DIRECTED DIFFUSION



(a) Low Rate Samples



(b) Path Reinforcement



(c) Recovery from failure along reinforced path

Source: Highly resilient energy efficient multipath routing in Wireless Sensor Networks- Ganesan et al

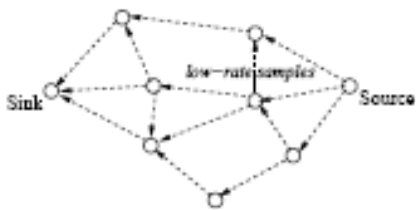
PROBLEMS

- For energy efficiency reasons, paths are constructed on demand and not proactively.
- Periodic flooding of low rate events for restoration of paths from source to sink.

DISJOINT AND BRAIDED MULTIPATHS

- Multipath Routing used for two main purposes:
 - a) Load Balancing.
 - b) Increase likelihood of reliable data delivery.

- Disjoint Multipaths



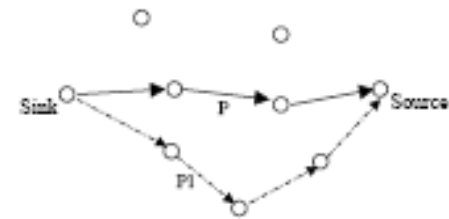
(a) Low-Rate samples



(b) Primary-Path P



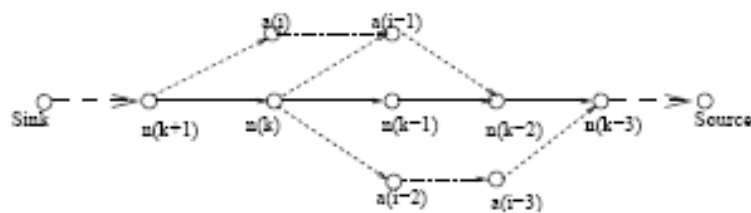
(c) Alternate-Path -
Negative Reinforcement



(d) Alternate-Path P_1

DISJOINT AND BRAIDED MULTIPATHS

- Braided Multipaths



Idealized Braid



Localized Braid



Perfect Braid

EVALUATION METHODOLOGY

- Maintenance Overhead

Source floods low rate data over all alternate paths to keep them alive to permit fast recovery from failures.

Interested in the total energy expended and likelihood of total multipath failure.

Normalized Maintenance overhead metric = $(L_a - L_p)/L_p$

- Failures

a) Isolated Failures: Independent node failures, each node in the multipath has a probability of failure P_i . Resilience to Isolated Failure is the probability of at least one alternate being available when at least one node on the primary path has failed.

EVALUATION METHODOLOGY

b) Patterned Failures: Geographically correlated failure.

A Patterned failure results in failure of all nodes in a circle of radius R_p .

Number of patterned failures within a time interval T is Poisson distributed.

Resilience to patterned failure is the probability that within time interval T , at least one alternate path is available between source and sink given that at least one node on the primary path falls within the circle defining the patterned failure.

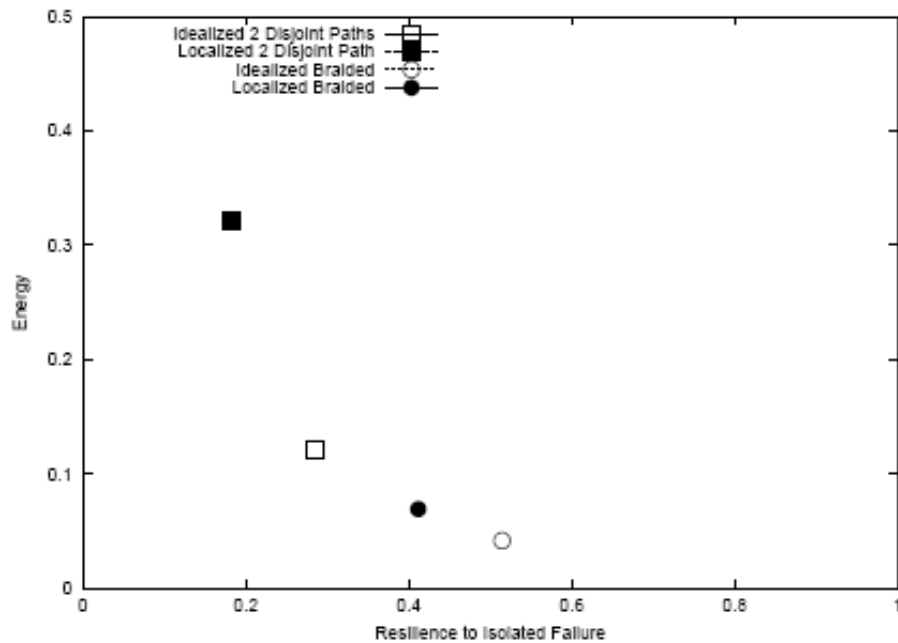
- Details of Methodology: For the case of Isolated Failures, fail each node on the multipath with probability P_i . If a node on the primary path has failed, assign a value of 1 to this set if at least one alternate path is available, 0 otherwise.

The resilience on multipath to failure is the average value assigned to sets in which at least one node in primary path fails.

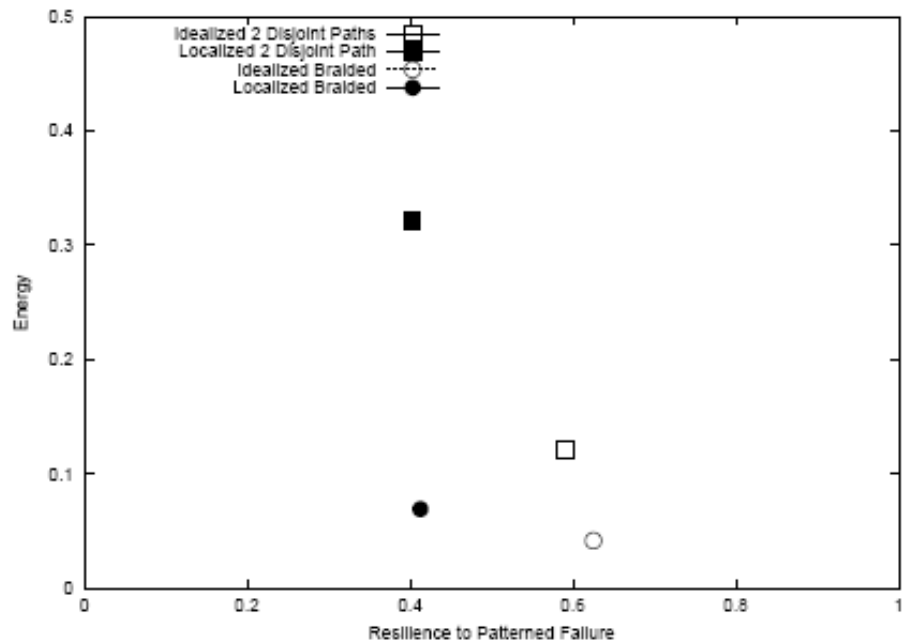
SIMULATION RESULTS

- Maintenance Overhead
- Resilience to Isolated Failures
- Resilience to Patterned Failures
- Sensitivity to Increasing Disjointedness

MAINTENANCE OVERHEAD



(a) Isolated: 400 nodes, 6 hop source-sink separation, $p_i = 0.2$



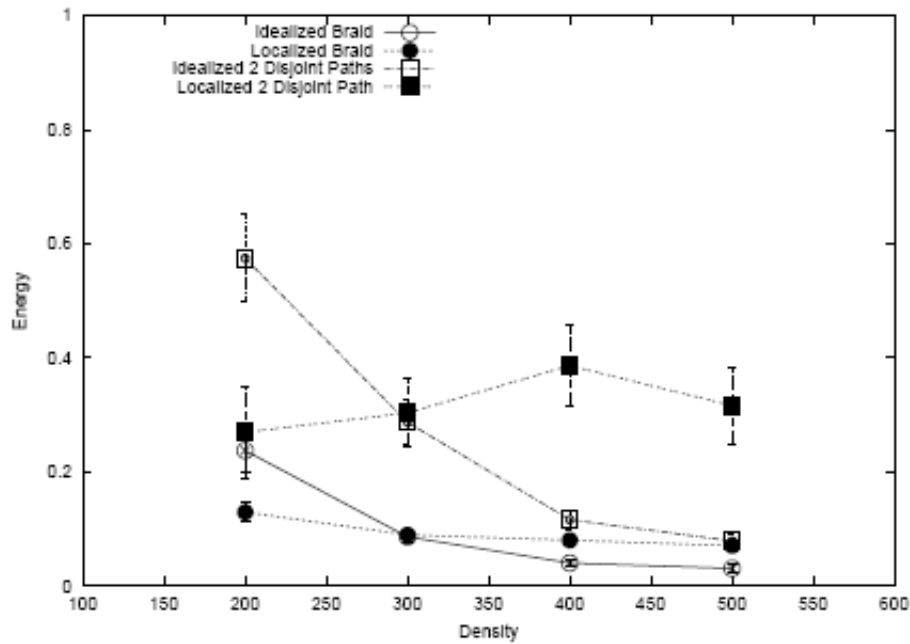
(b) Patterned: 400 nodes, 6 hop source-sink separation, $\lambda_p = 3$, $R_p = 20$

Illustrating the Energy vs Resilience Tradeoff

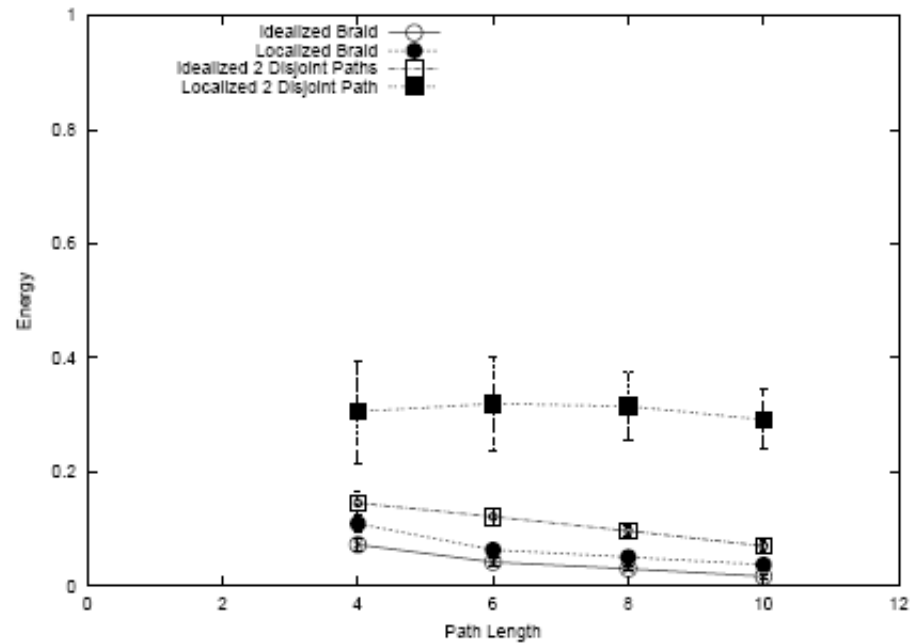
SIMULATION ANALYSIS

- For Isolated Failures 2-disjoint idealized multipath are significantly less resilient and have higher maintenance overhead than idealized braided multipath.
- For patterned failures, the idealized schemes have comparable resilience, but 2-disjoint has higher maintenance overhead. Similar distinctions exist for the localized mechanisms.

MAINTENANCE OVERHEAD



(a) Density: 6-hop source-sink separation



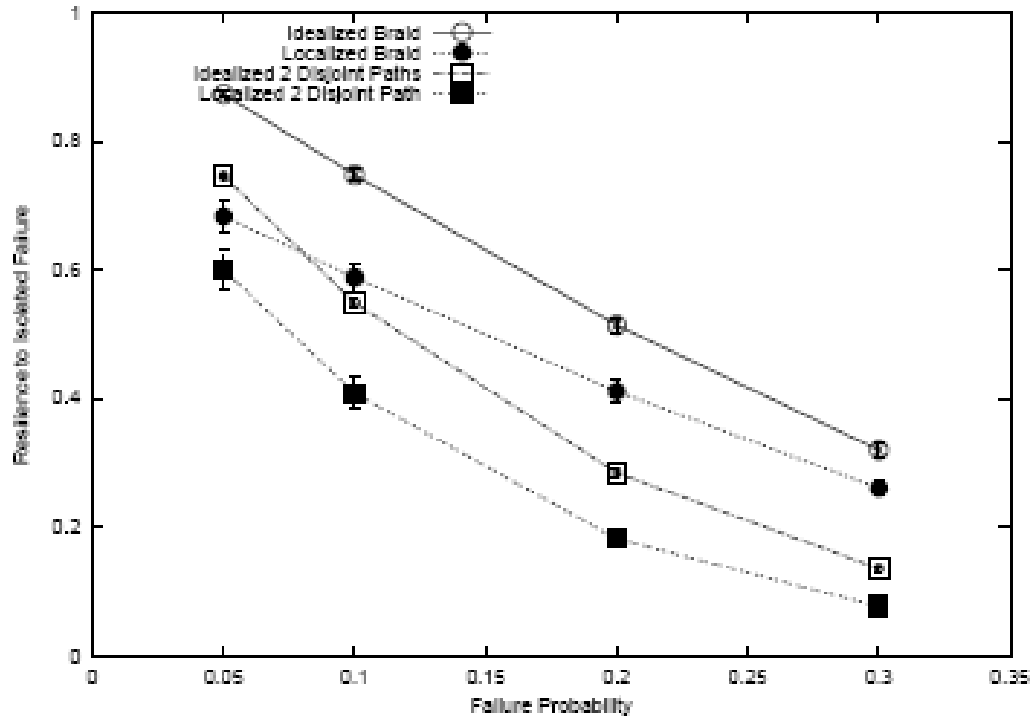
(b) Source-sink separation: 400 nodes

The impact of density and Source-Sink separation on maintenance overhead.

MAINTENANCE OVERHEAD SIMULATION ANALYSIS

- Braided idealized multipath require lower maintenance overhead than 2-disjoint idealized multipath.
- At low densities, 2-disjoint idealized multipath incur 3 times the maintenance overhead of idealized braided multipath, at higher densities, this difference decreases as disjoint alternate paths are comparable in length to the primary path.
- The localized braided multipath has lower maintenance overhead as compared to its idealized counterpart, however at higher densities, the localized braid tracks the idealized braid.
- Maintenance overhead of localized 2-disjoint is higher than localized braid at high densities because local algorithms do not have enough information for low latency paths.

RESILIENCE TO ISOLATED FAILURES

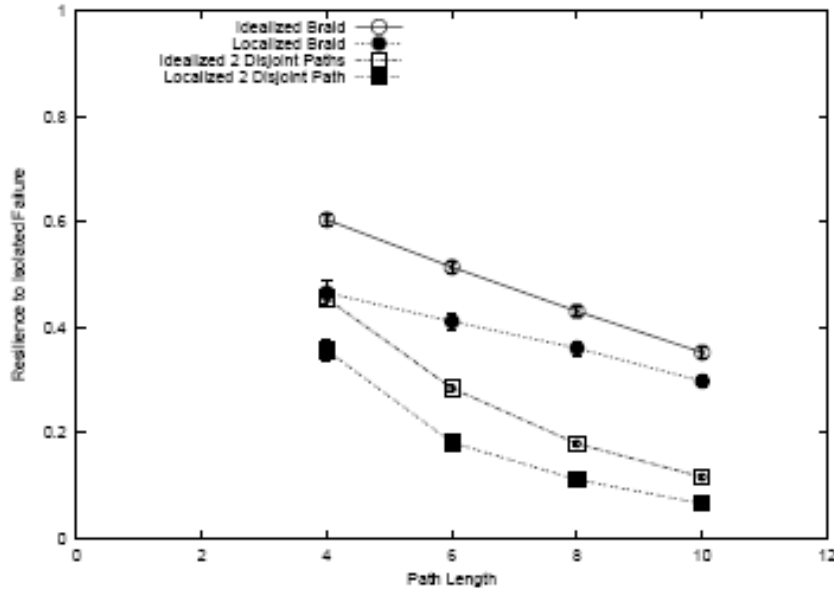


Impact of failure probability on resilience: 400 nodes, 6 hop source-sink separation.

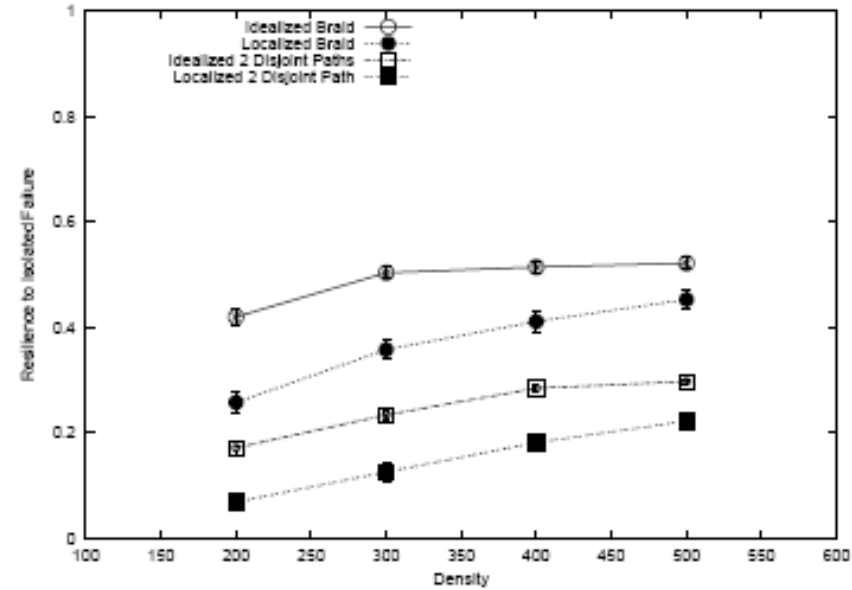
SIMULATION ANALYSIS

- The idealized braid is more resilient than the idealized disjoint multipath.
- This is because in a 2-disjoint idealized multipath the number of ways in which 2 nodes can simultaneously fail and sever the multipath is proportional to n^2 , whereas the in a perfect braid case this number is proportional to n .
- Localized algorithms are less resilient than their idealized counterparts.
- This is because the localized braids and localized disjoint multipath can discover longer paths than their idealized counterparts.

RESILIENCE TO ISOLATED FAILURES



(a) Source-sink separation: 400 nodes, $p_i = 0.2$



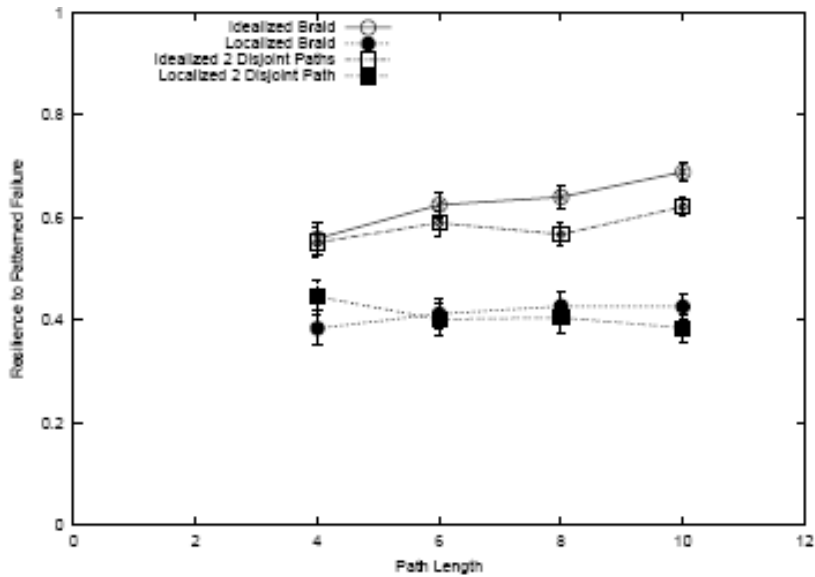
(b) Density: 6-hop source-sink separation, $p_i = 0.2$

The impact of density and source-sink separation on resilience to Isolated failures.

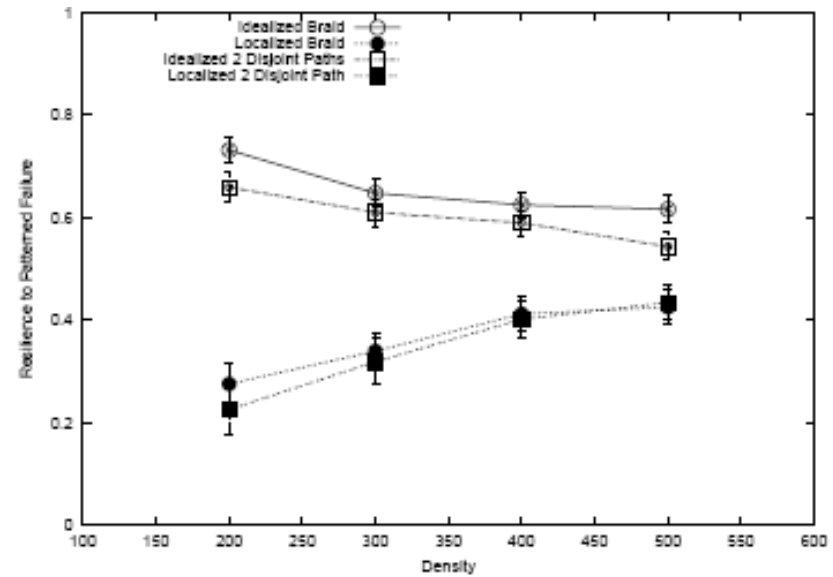
SIMULATION ANALYSIS

- As seen Resilience decreases with increasing separation.
- This is because, as separation increases, n increases and so does the number of ways in which either the braid or the disjoint can be severed.
- Similarly as density increases, the lengths of the available alternate paths decrease, resulting in fewer ways for severing the multipath and consequently increased resilience.

RESILIENCE TO PATTERNED FAILURES



(a) Source-sink separation: 400 nodes, $\lambda_p = 3$, $R_p = 20$



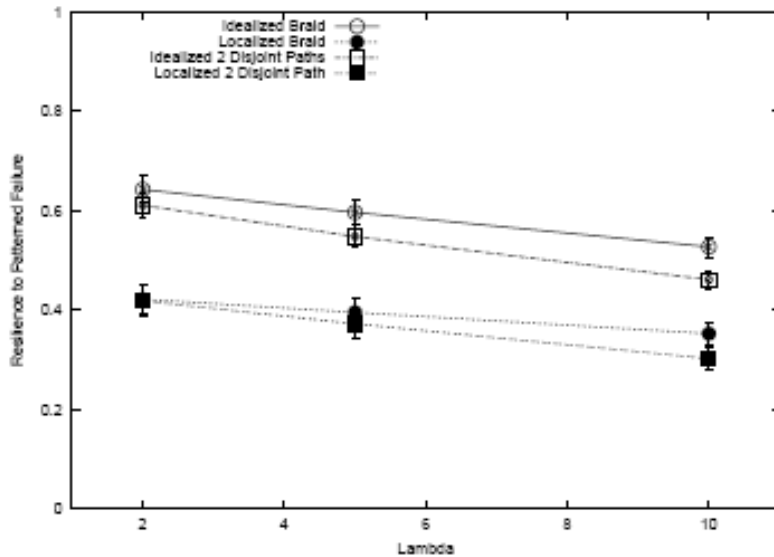
(b) Density: 6-hop source-sink separation, $\lambda_p = 3$, $R_p = 20$

The impact of density and source-sink separation on resilience to patterned failures.

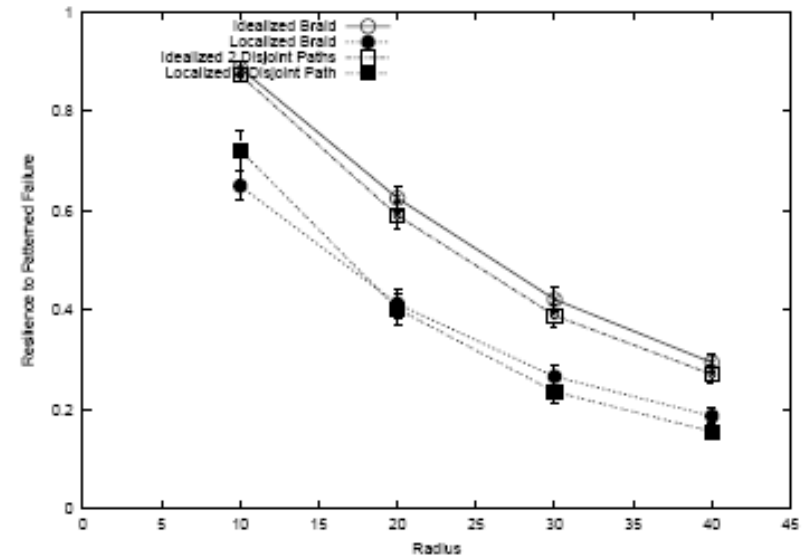
SIMULATION ANALYSIS

- The resilience of the idealized braid is comparable to that of idealized 2-disjoint which expend more energy, suggesting that 2-disjoint paths do not give adequate geographic spreading.
- With increasing source-sink separation there is a small increase in resilience.
- With increasing density, the resilience of the idealized schemes decreases because the alternate paths are spatially closer to the primary path.
- However with localized schemes at low densities, the localized joint doesn't find an alternate path and with increase in density these effects decrease resulting in higher resilience.

RESILIENCE TO PATTERNED FAILURES



(a) Frequency of patterned failure: 400 nodes, 6-hop src-sink separation, $R_p = 20$



(b) Radius of patterned failure: 400 nodes, 6-hop src-sink separation, $\lambda_p = 3$

The impact of λ_p and R_p on resilience to patterned failure

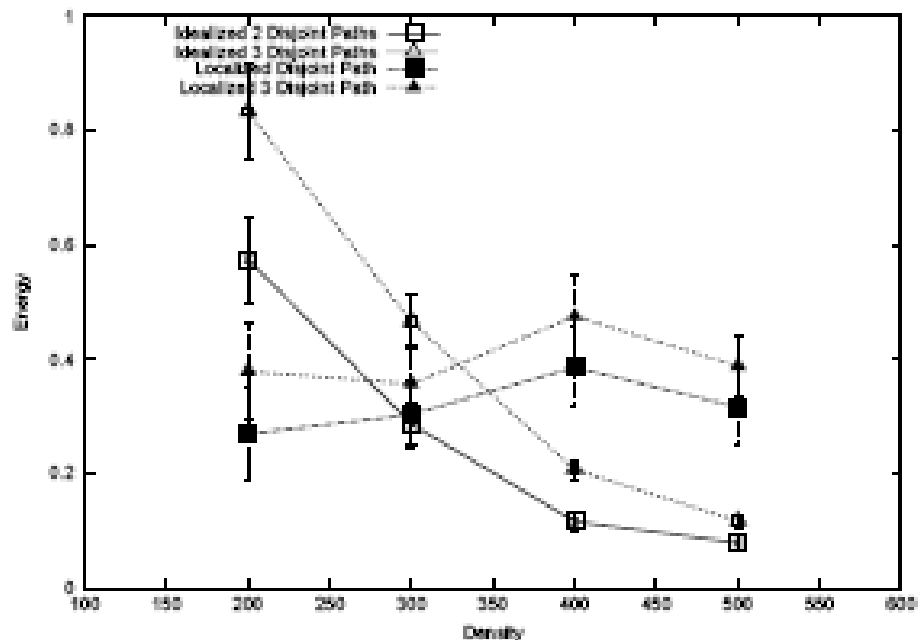
SIMULATION ANALYSIS

- With increasing frequency of failure or radius of failure, the resilience decreases.

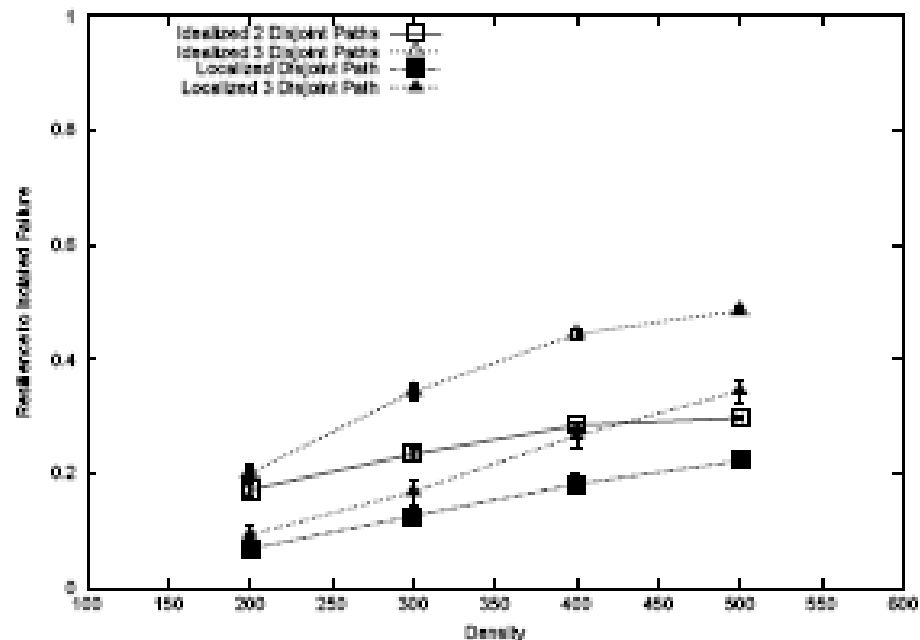
λ_p = Arrival Rate of patterned failures.

R_p = Radius of patterned failures.

SENSITIVITY TO DISJOINTEDNESS



(a) Maintenance Overhead: 6 hop source-sink separation



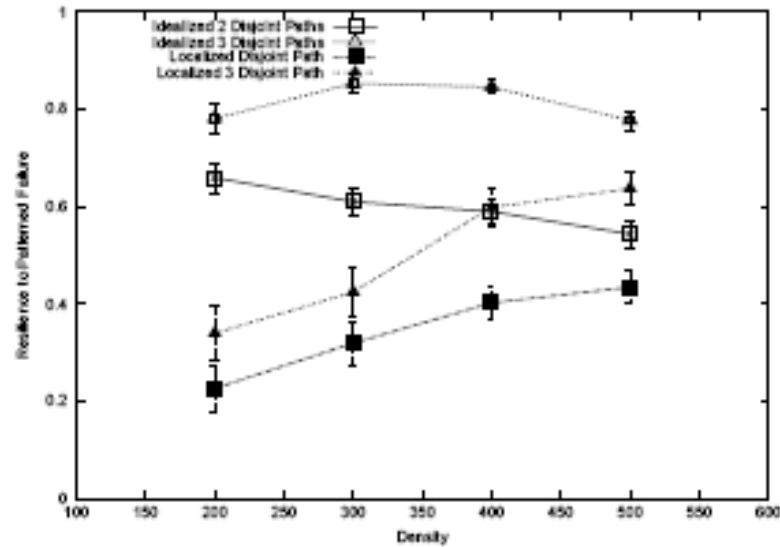
(b) Resilience to Isolated Failure: 6 hop source-sink separation, $p_i = 0.2$

Impact of increased disjointedness.

SIMULATION ANALYSIS

- By increasing the disjointedness from 2 to 3 we get modest improvements (about 25% for patterned failure and about 40% for isolated failures) in resilience with approximately 30% increase in maintenance overhead.
- Thus with the expenditure of energy one can improve the performance of disjoint paths, but this is not without its cost.

SENSITIVITY TO DISJOINTEDNESS



(c) Resilience to Patterned Failure: 6-hop src-sink separation, $\lambda_p = 3$, $R_p = 20$

Impact of increased disjointedness.

CONCLUSIONS

- For a disjoint multipath configuration whose patterned failure resilience is comparable to that of a braided multipath, the braided multipath has 50% higher resilience to isolated failures and a third of overhead maintenance.
- It is harder to design localized energy efficient mechanisms for constructing disjoint alternate paths because the algorithms lack the information to find low latency paths.
- Increasing the number of disjoint paths does increase the resilience of disjoint multipath but with a proportionately higher cost. It is not the case that a small energy expenditure dramatically improves the resilience.

- QUESTIONS AND COMMENTS !