Topological Characteristic of Wireless Network

Its Application to Node Placement Algorithm

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Outline

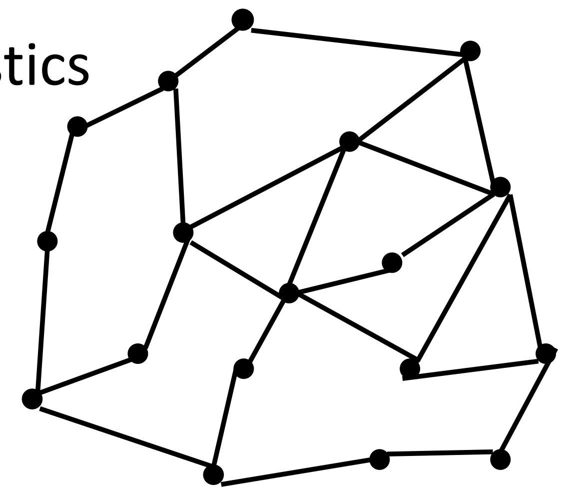
- Background
- Motivation
- Papers and Contributions
- First Paper
- Second Paper
- Third Paper
- Future Works
- References

Background: Network Science

Network Science : Studying of the theoretical foundations of network structure/dynamic behavior and its application to many fields.

Examples of Topological Characteristics

- Degree
- Path Length
- Clustering Coefficient



Background: Topological Characteristics Examples

Dif. Network	SMW	Regular N
Average Degree	3.6	4
Average Path Length	6.16	0.5
Clustering Coefficient	0.41	0.5

(A study on Topological Characteristic of Wireless Sensor Network Based on Complex Network, Ren Yueqing, Xu Lixin- 2010- Measure Comparison of Different Network)

Background: Extra Characteristics

- There are many other topological characteristics
  - Entropy
  - Diameter
  - Coverage
  - Connectivity
  - Biconnectivity
- Some of them only applicable to some networks
  - Coverage

Motivation: Importance of Topology Characteristics

- **Performance of Protocol**
  - Diameter
    - Bounds the maximum delay in message communication
  - Connectivity
    - Data dissemination from one part of network to another
    - Minimum size of connected component for useful work
- **Security**
  - Degree
    - Higher degree means higher node connectivity
- **Generate more realistic topologies for Simulations**

Papers and Contributions

- ***Topological Characteristics of Random Multihop Wireless Network*** by Keqin Li

- ***Analysis and Evaluation of Topological and Application Characteristics of Unreliable Mobile Wireless Ad-Hoc Network*** by Serdar Cabuk, Nipoon Malhotra, Longbi Lin, Saurabh Bagchi, and Ness Shroff

- ***NPART-Node Placement Algorithm for Realistic Topologies in Wireless Network Simulation*** by Bratislav Milic and Miraslow Malek

First Paper : Topological Characteristics of Random Multihop Wireless Network

- Related Works:
  - Ramanathan and Lyold: not arbitrary general graph
  - Sen and Houston: Point graphs to represent MWN
  - Paper related to this paper: *Topology Control of Multihop Wireless Networks* (set the transmission power of node to satisfy certain property.)
  - Not much have been done until this paper

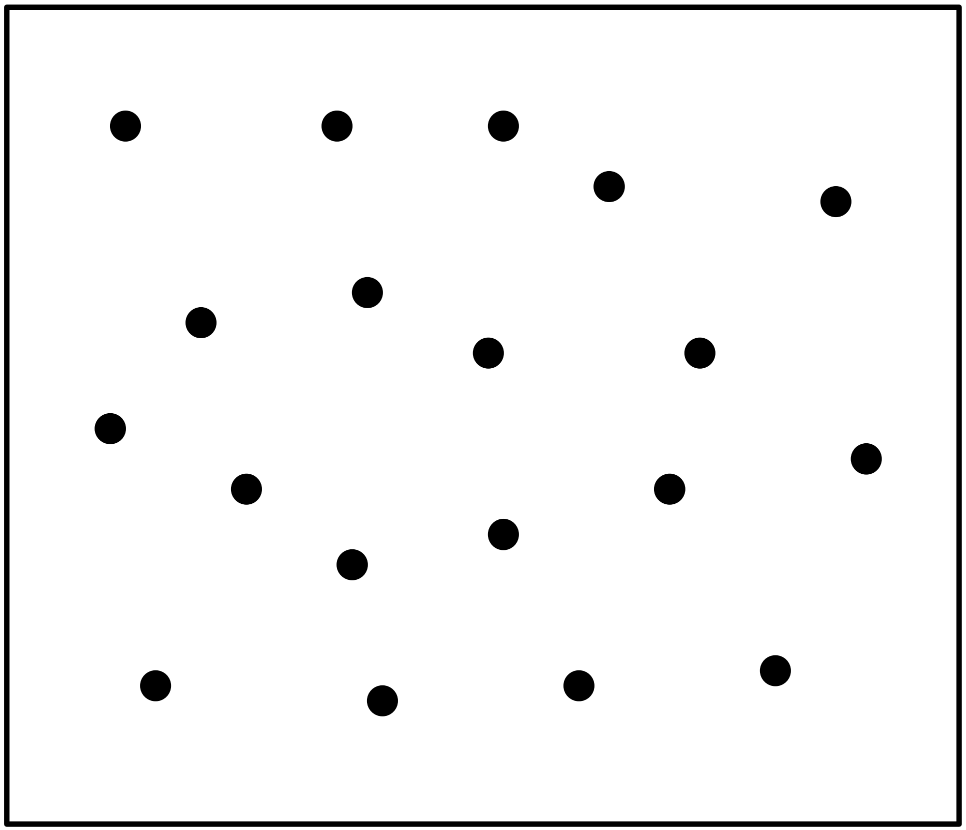
- Contributions:
  - Analyzing of topological properties of random wireless network.
  - Can be useful for real application
    - For example: Connectedness , Diameter for power efficiency

Analysis

- What is different in Wireless?
  - Random network in wireless is different than normal random networks
  - Connectivity : Depending on locations and distance among the nodes

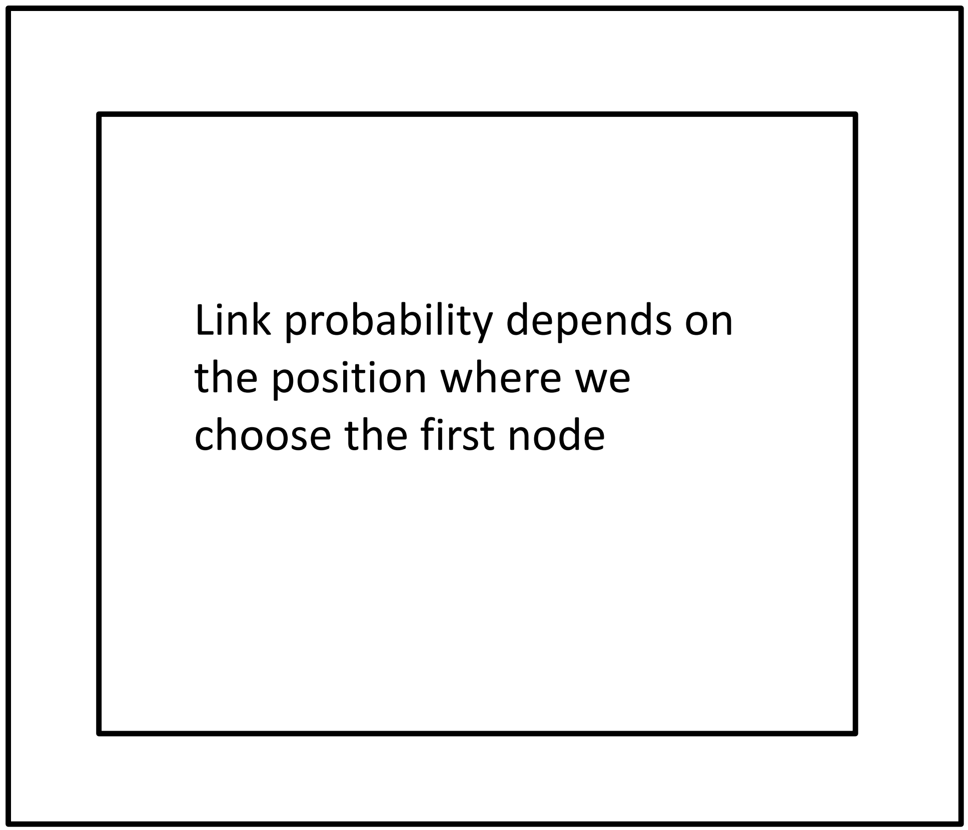
- Topology Characteristics which are studied:
  - Degree, connectivity, diameter, bandwidth (cutset, partition) and biconnectivity (fault tolerance, two disjoint path)
  - Link probability:
    - Needed for finding above characteristics

Link Probability



Interested field, 1 unit

Link Probability (Continue)



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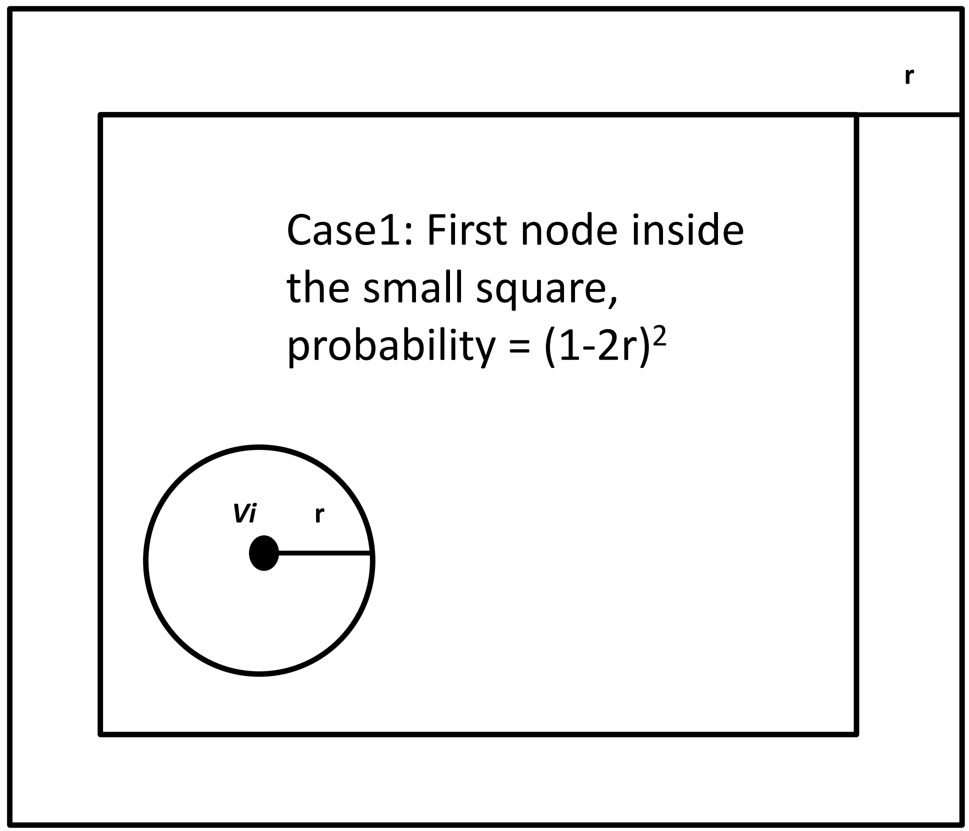

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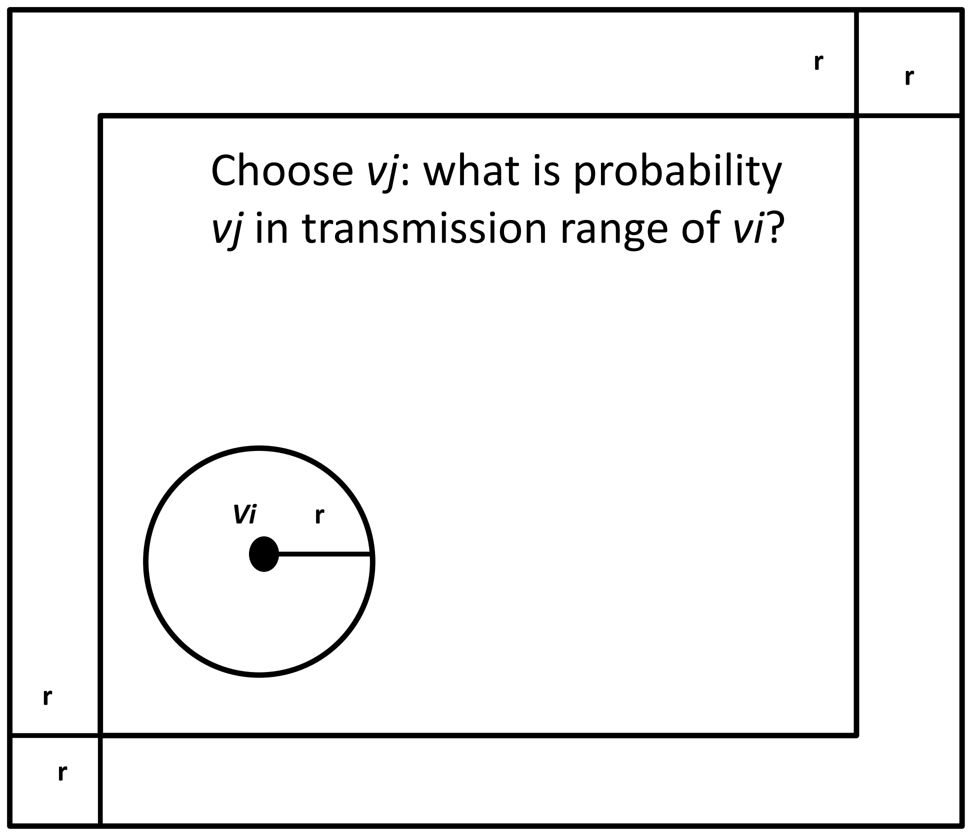

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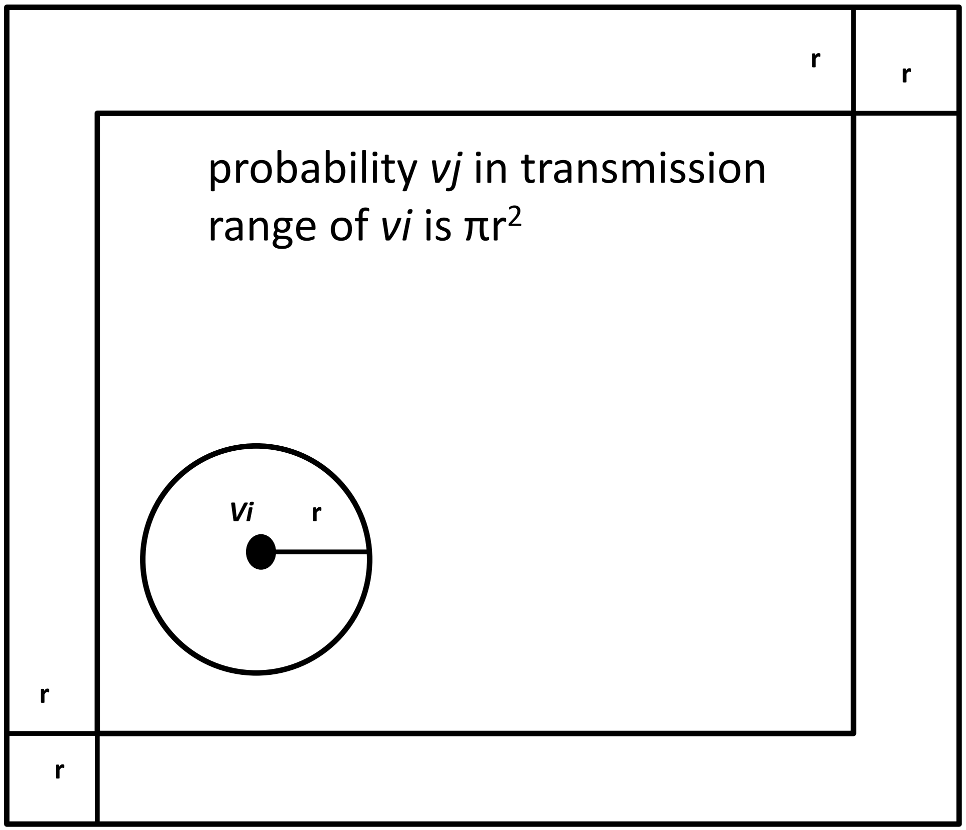
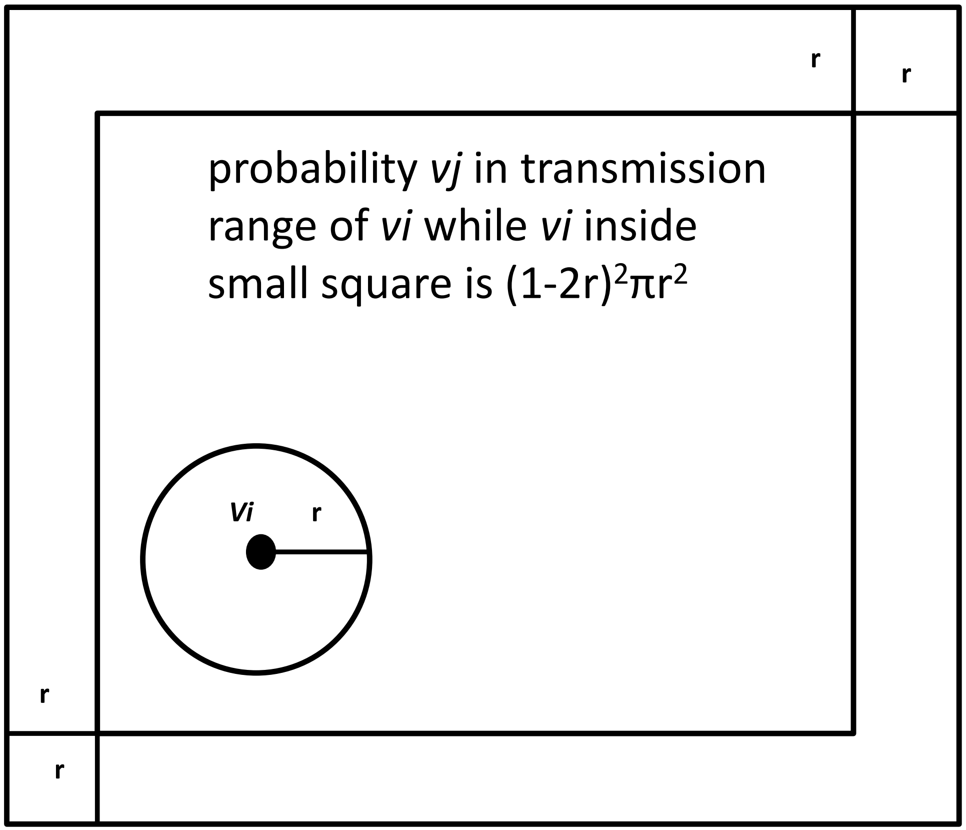
Link Probability (Continue)



Interested field, 1 Unit

Link Probability (Continue)



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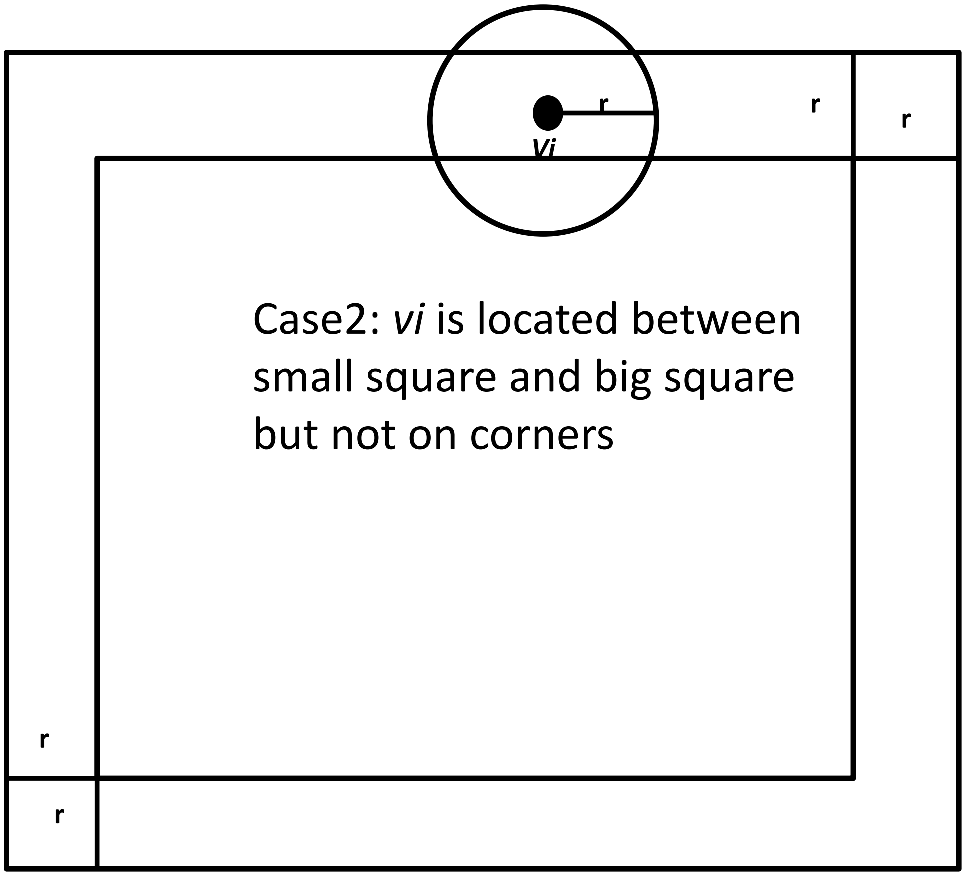
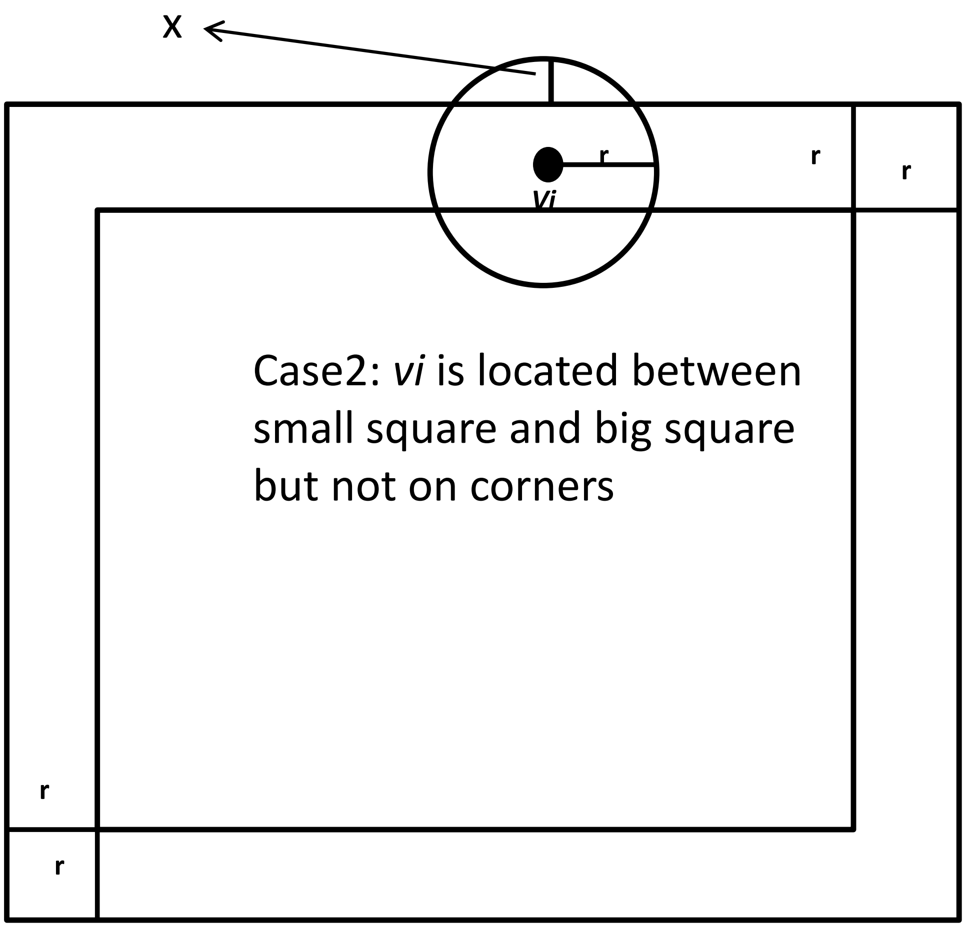
Link Probability (Continue)



Interested field, 1 Unit

Link Probability (Continue)



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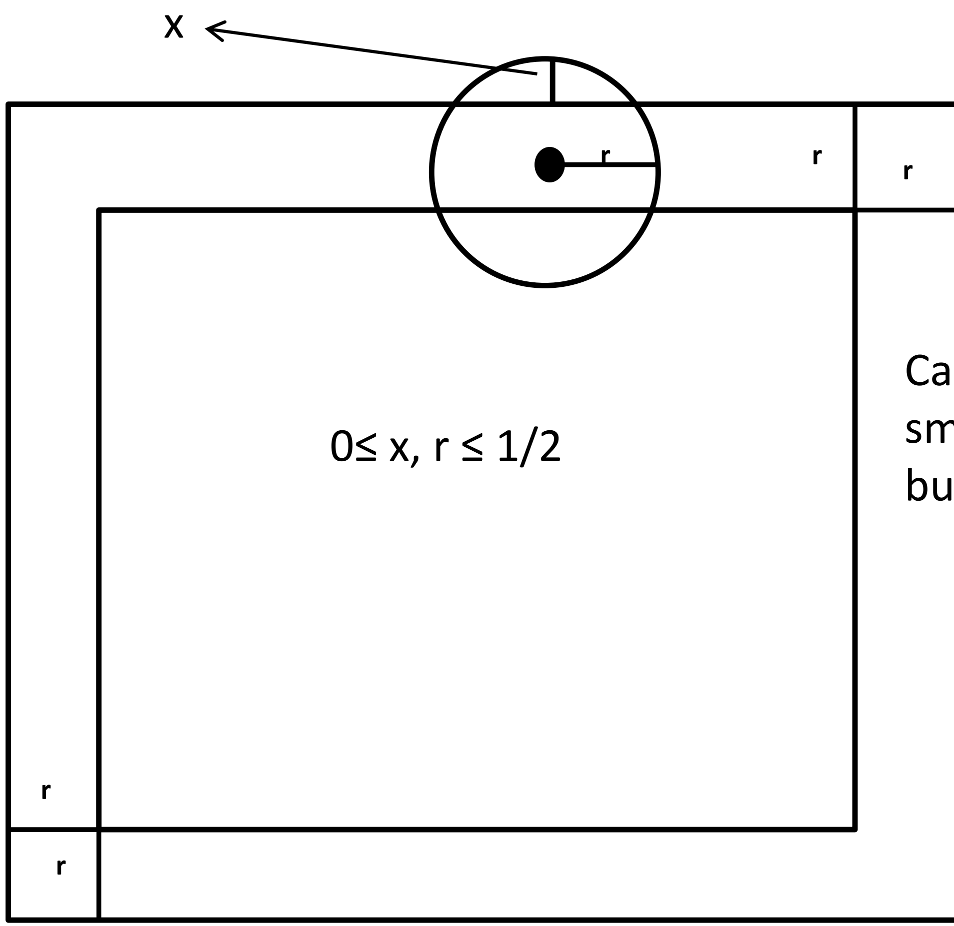


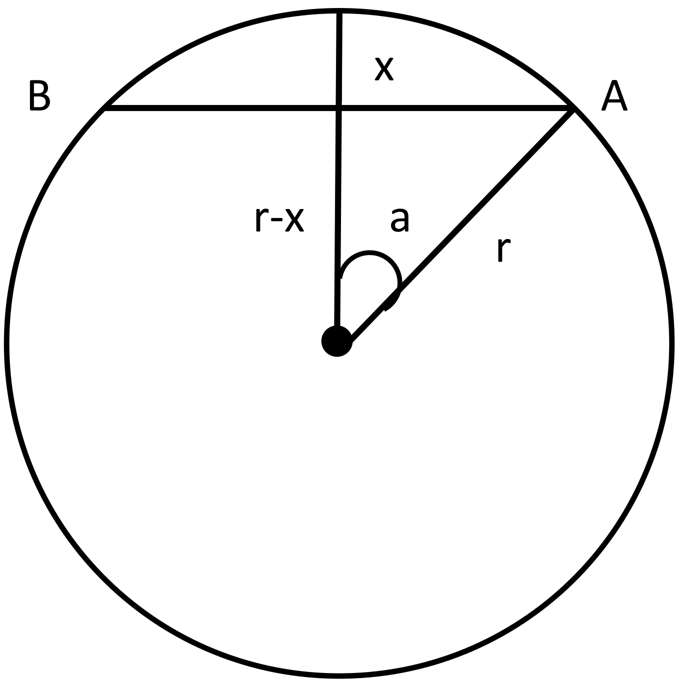
Interested field, 1 Unit

Case2: *vi* is located between small square and big square but not on corners

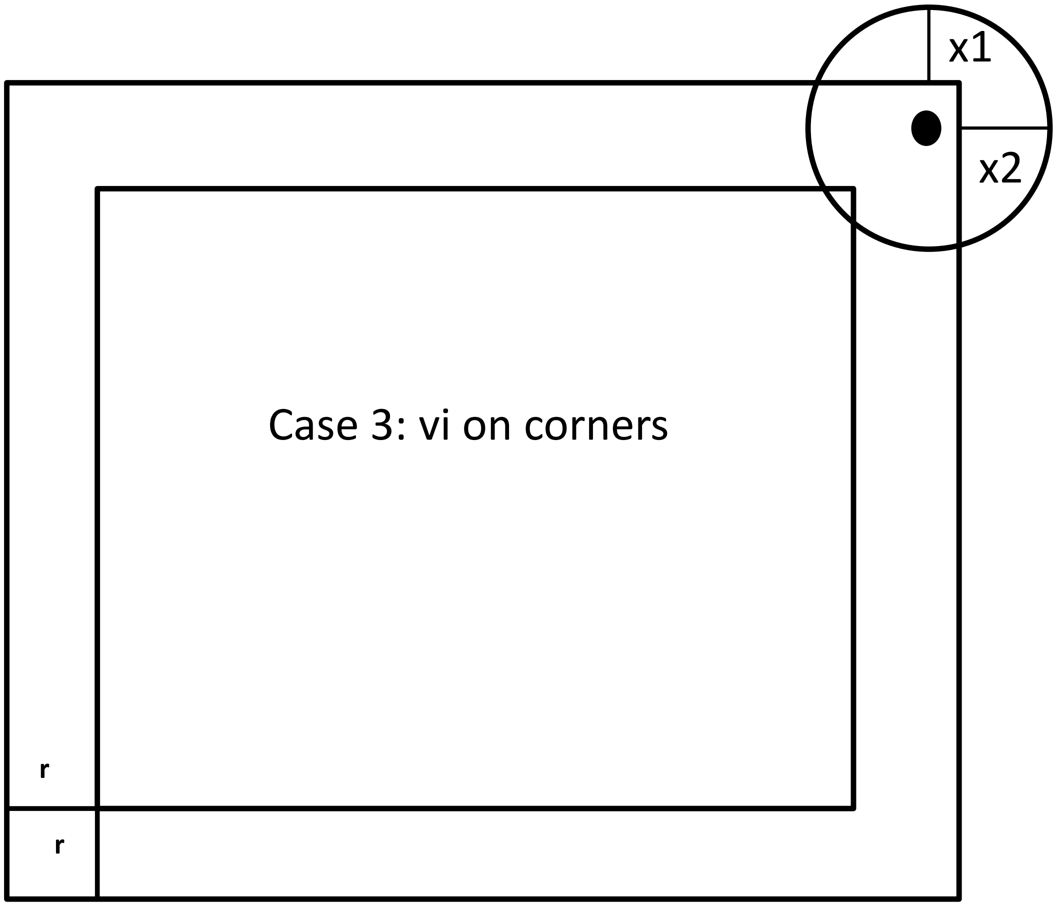
Link Probability (Continue)

Case 2: The area of circle under AB segment

$$4(1-2r)\left(\pi - \frac{2}{3}\right)r^3.$$



Link Probability (Continue)



Interested field, 1 Unit

Link Probability (Continue)

Case 3: The area of circle intersection with squares

$$\left(3\pi - \frac{5}{3}\right)r^4.$$

The link probability of *vi* has a link to *vj*

$$p_r = \pi r^2 - \frac{8}{3}r^3 + \left(\frac{11}{3} - \pi\right)r^4,$$

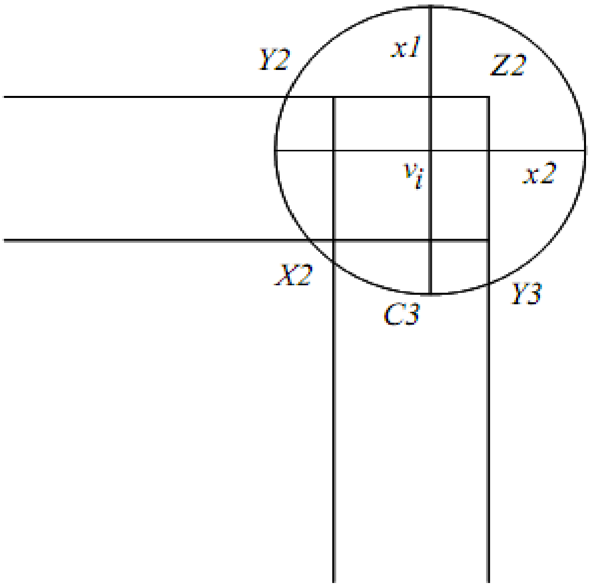


Figure 3. A circle at a corner of a square.

Effect of Link to Characteristics

- Expected Degree of nodes:

$$(n-1)\left(\pi r^2 - \frac{8}{3}r^3 + \left(\frac{11}{3} - \pi\right)r^4\right).$$

Expected node degree $(n-1)p_r$.

r

n	0.25	0.30	0.35	0.40	0.45	0.50
25	3.76	5.16	6.68	8.29	9.95	11.64
36	5.49	7.52	9.74	12.09	14.51	16.97
49	7.52	10.32	13.36	16.58	19.91	23.27
64	9.87	13.54	17.54	21.76	26.13	30.55
81	12.54	17.20	22.27	27.63	33.18	38.79
100	15.52	21.28	27.56	34.20	41.06	48.00
121	18.81	25.80	33.41	41.45	49.76	58.19
144	22.41	30.74	39.81	49.40	59.30	69.34
169	26.33	36.12	46.77	58.03	69.67	81.46
196	30.56	41.92	54.29	67.36	80.87	94.55
225	35.11	48.16	62.36	77.38	92.89	108.61
256	39.97	54.82	70.99	88.08	105.75	123.64

Effect of Link to Characteristics (Continue)

- Connectivity(after 1000 simulated networks for each r and n values):

Table 3
Probability of connectedness in random multihop wireless networks.

r

n	0.25	0.30	0.35	0.40	0.45	0.50
25	0.111	0.536	0.826	0.950	0.987	0.998
36	0.464	0.861	0.977	0.993	0.998	1.000
49	0.797	0.969	0.992	1.000	1.000	1.000
64	0.947	0.996	1.000	1.000	1.000	1.000
81	0.980	0.998	1.000	1.000	1.000	1.000
100	0.995	0.999	1.000	1.000	1.000	1.000
121	0.998	1.000	1.000	1.000	1.000	1.000
144	1.000	1.000	1.000	1.000	1.000	1.000
169	1.000	1.000	1.000	1.000	1.000	1.000
196	1.000	1.000	1.000	1.000	1.000	1.000
225	1.000	1.000	1.000	1.000	1.000	1.000
256	1.000	1.000	1.000	1.000	1.000	1.000

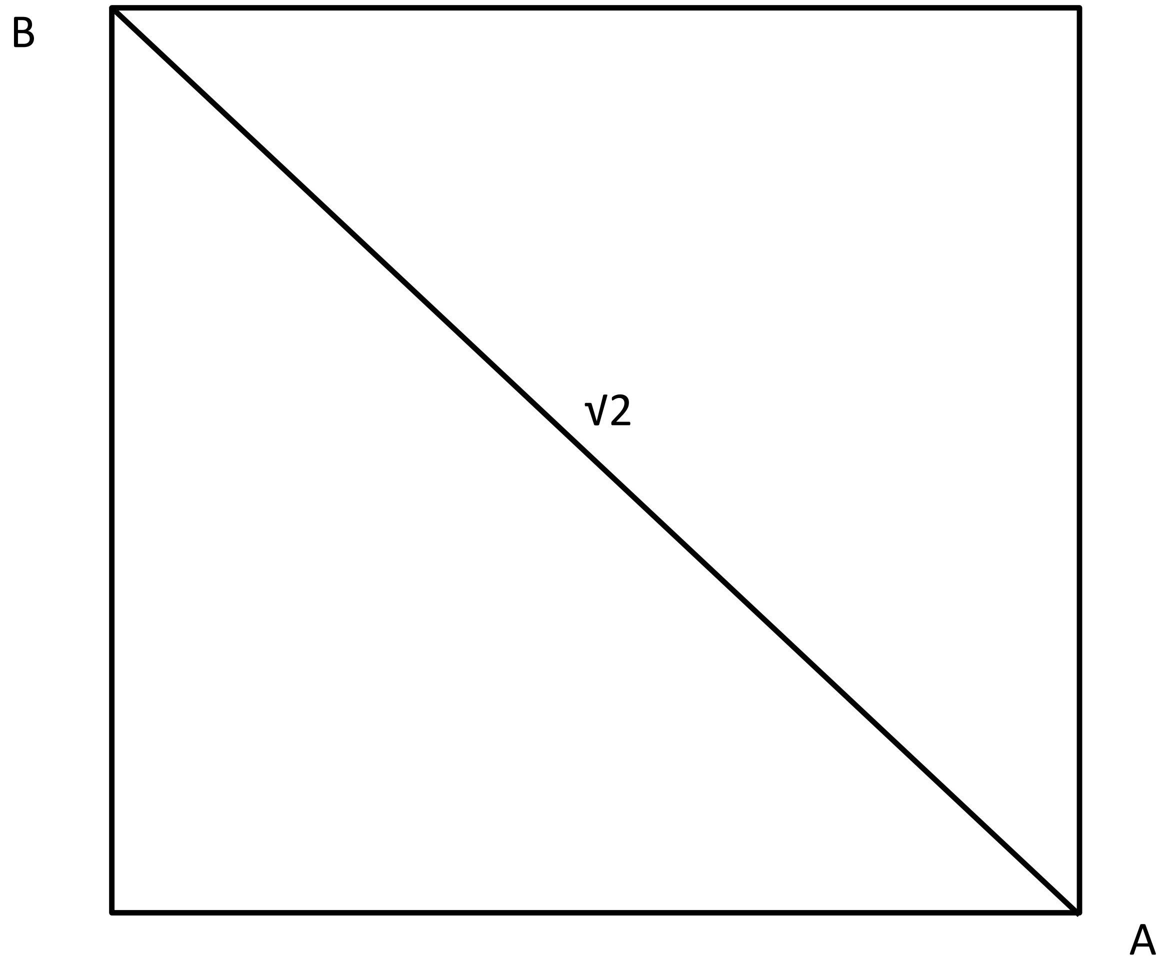
n

Effect of Link to Characteristics (Continue)

Diameter:

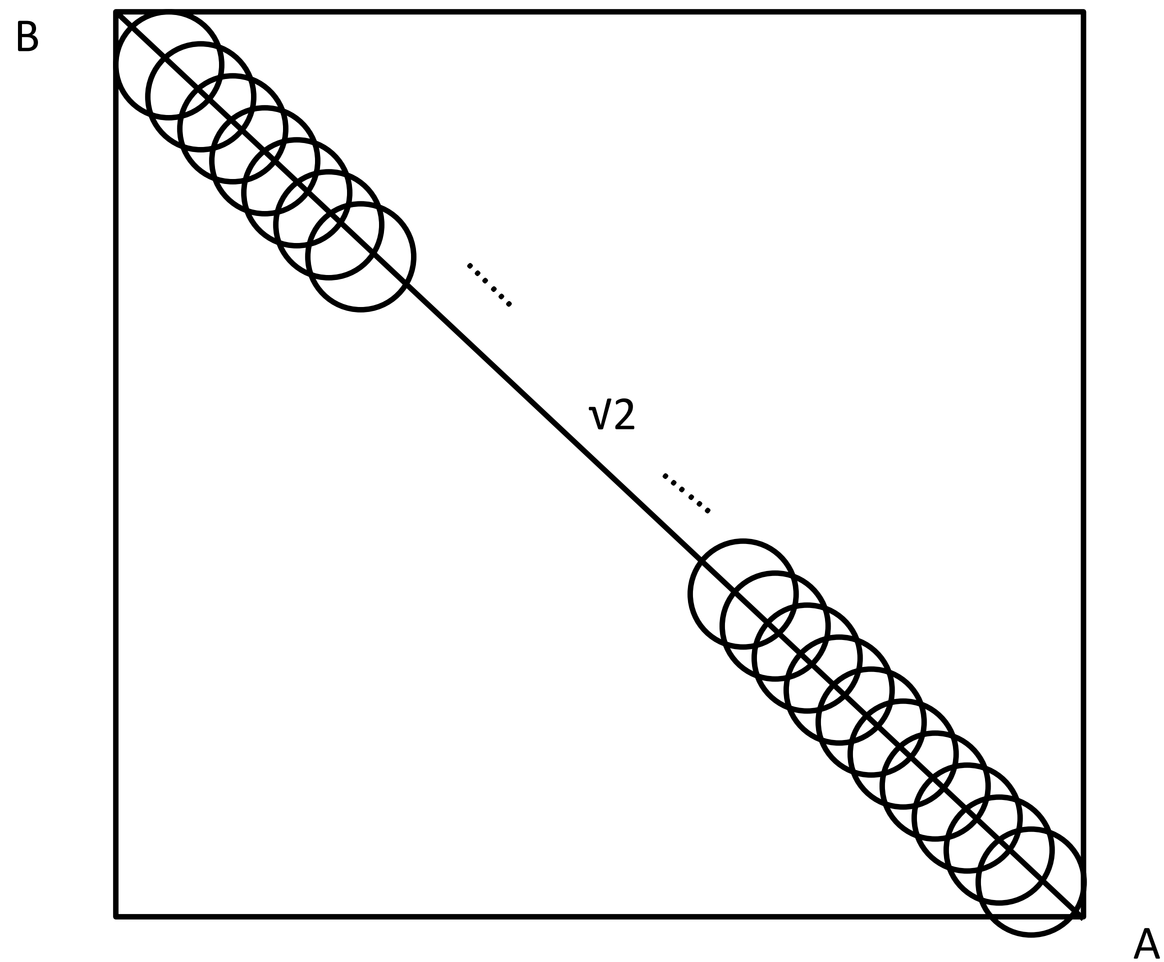
Effect of Link to Characteristics (Continue)

Diameter:



Effect of Link to Characteristics (Continue)

Diameter:



Effect of Link to Characteristics (Continue)

Diameter Prob.

$$d(n, r) = \left\lceil \frac{\sqrt{2}}{r} \right\rceil$$

approaches 1 as $n \to \infty$.

Table 4
Diameters of random multihop wireless networks. (99% confidence interval of ±3.734%).

n	0.25	0.30	0.35	0.40	0.45	0.50
25	8.597	6.712	5.253	4.302	3.656	3.183
36	8.505	6.157	4.921	4.106	3.606	3.101
49	7.695	5.772	4.734	4.042	3.584	3.063
64	7.106	5.558	4.697	4.010	3.588	3.034
81	6.827	5.434	4.638	4.009	3.618	3.022
100	6.673	5.338	4.605	4.000	3.652	3.007
121	6.558	5.273	4.579	4.000	3.652	3.005
144	6.465	5.184	4.571	4.000	3.681	3.002
169	6.375	5.147	4.541	4.000	3.683	3.001
196	6.293	5.092	4.532	4.000	3.728	3.002
225	6.230	5.064	4.516	4.000	3.740	3.001
256	6.157	5.038	4.497	4.000	3.780	3.000
∞	6.000	5.000	5.000	4.000	4.000	3.000

Effect of Link to Characteristics (Continue)

Expected Bisection Width:

$$b(n, r) = \frac{1}{2} n(n-1) q_r,$$

$$q_r = \frac{4}{3} r^3 - \left(\frac{11}{3} - \pi\right) r^4,$$

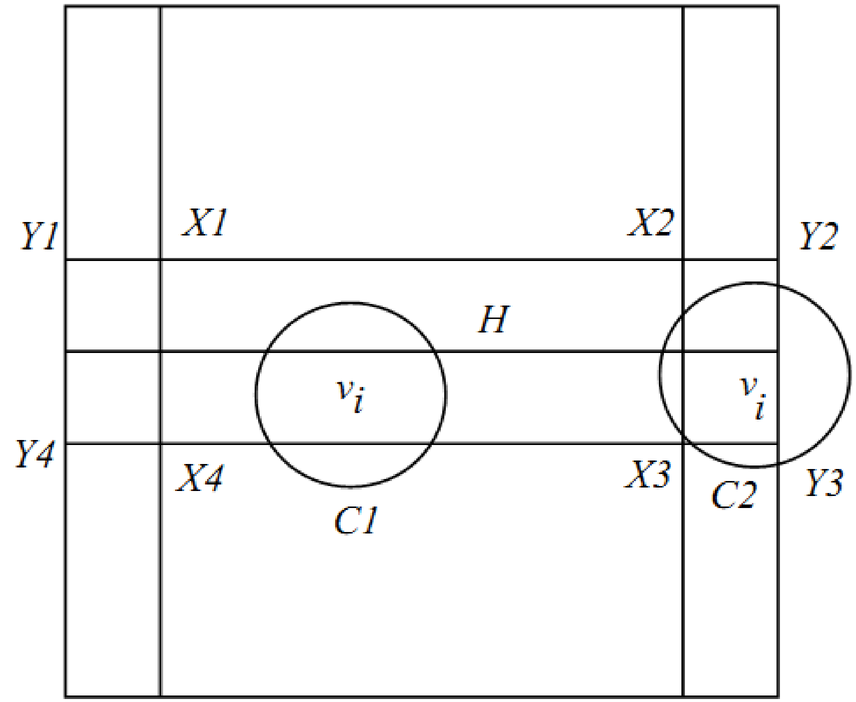


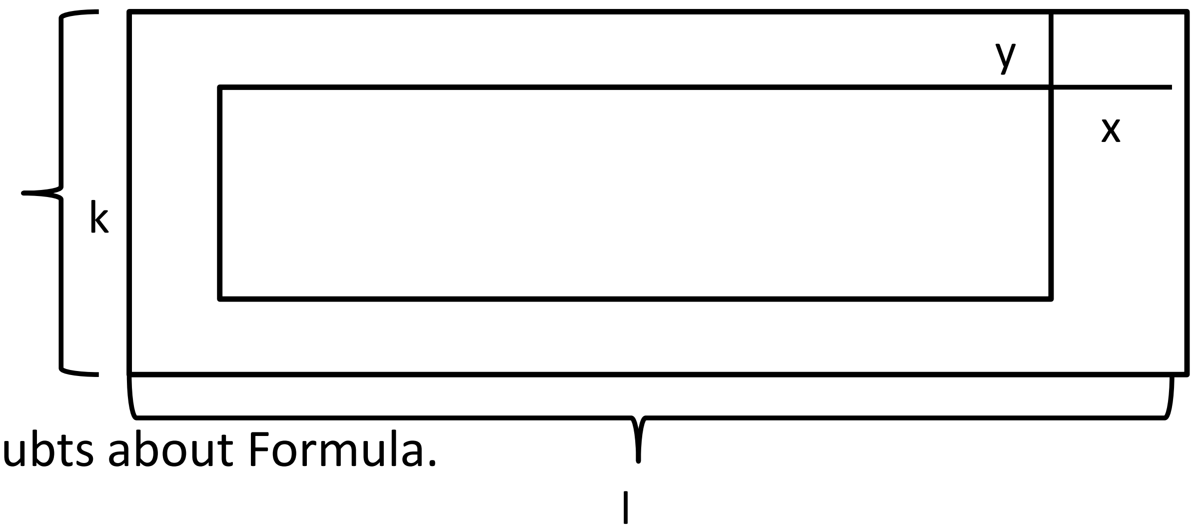
Figure 7. Links that are in cutset C_h.

Conclusion of First Paper

- Useful implication in real applications
  - Power save
  - Performance
- Critics about this paper
  - Why Unit Square, it can be rectangle:

Conclusion of First Paper

- Useful implication in real applications
  - Power save
  - Performance
- Critics about this paper
  - Why Unit Square, it can be rectangle, paper can be improvable



  - Doubts about Formula.

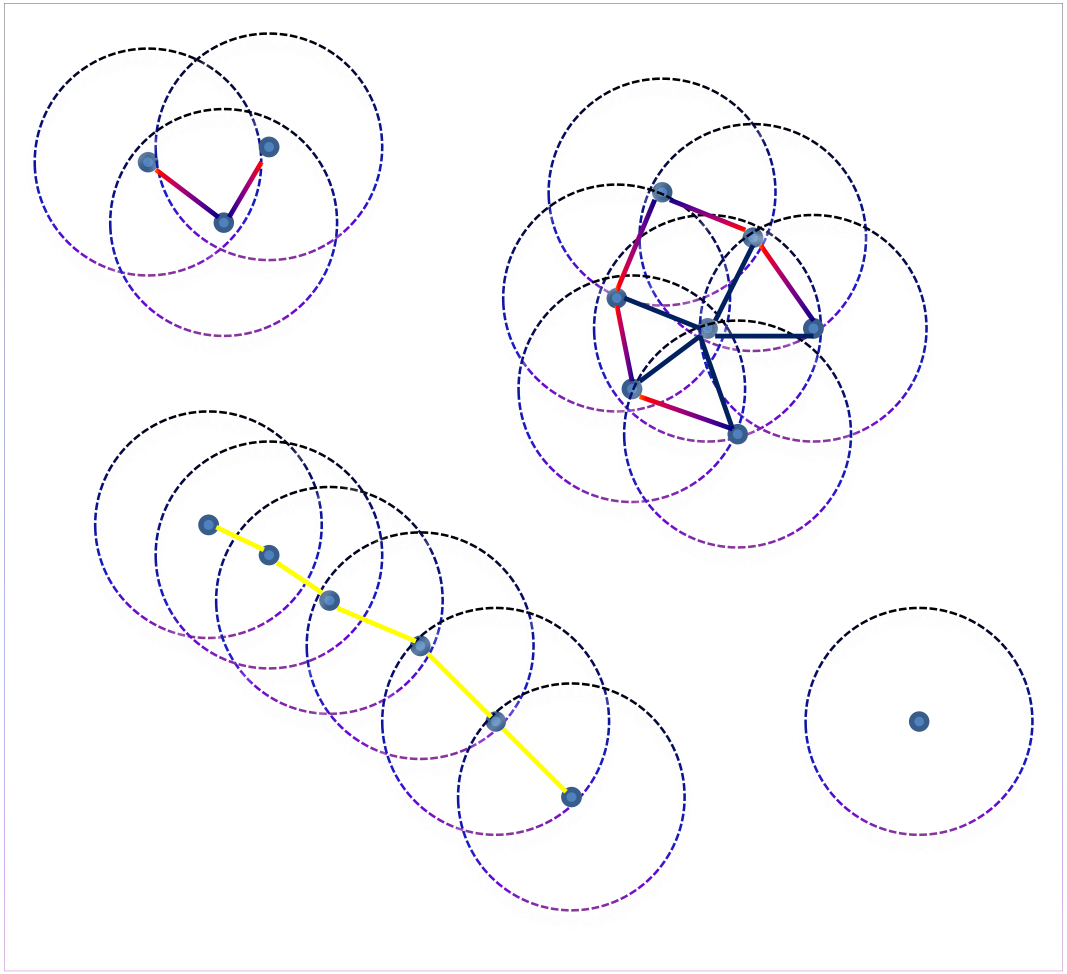
Second Paper : Analysis and Evaluation of Topological and Application Characteristics of Unreliable Mobile Wireless Ad-Hoc Network

Second Paper

- Related Works:
  - There have been studies which have looked only one or two parameters in static environment.
  - Random node placement
  - Stationary node failures

- Contributions:
  - Analyzing connectivity and coverage in mobile ad-hoc network with transient and permanent failure.
  - Goal directed algorithms (Mean shift Clustering -MSC, and Shift Neighbors Away - SNA)
  - Desired Network based on characteristics/ satisfies some of them together

Second Paper



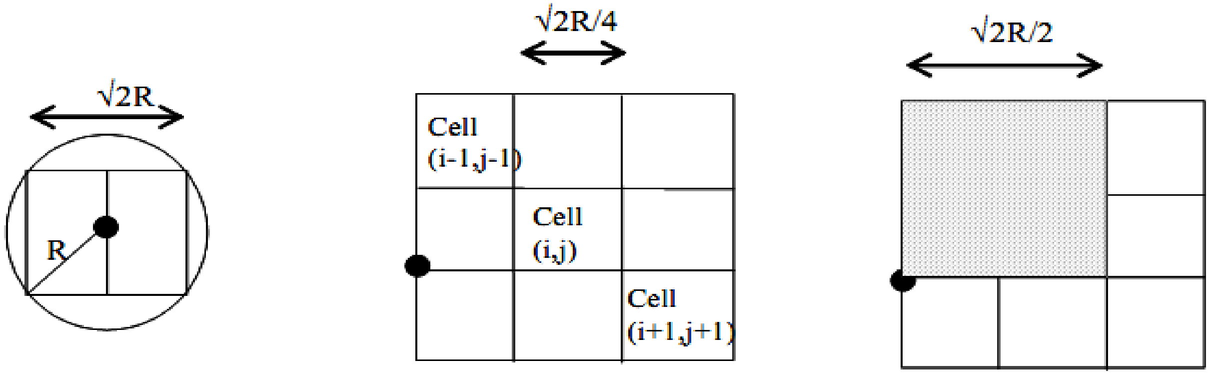
- Connectivity :

max. part covered/ total area

- Diameter: 4
- Coverage:
- total disk cov./ total area
- Degree : 5

Coverage Computation Simplification

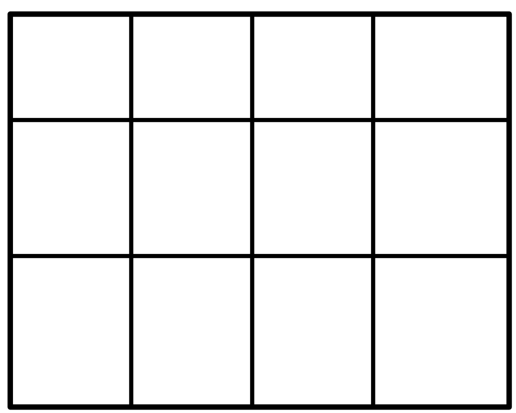
- Disk coverage computation is overhead
- By Converting square which gives lower bound on coverage



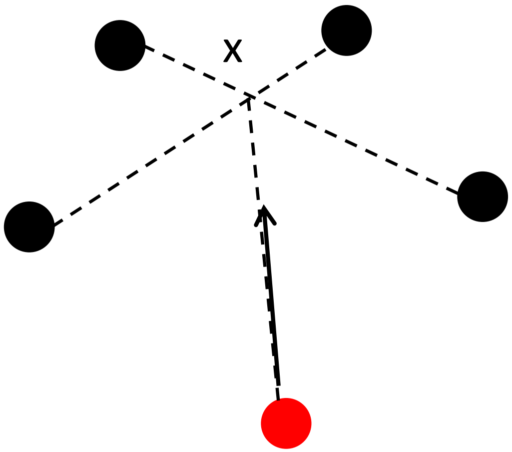
- A node covers √2R
- Cell (i,j) is covered by any adjacent 8 cells
- Coverage can be computed as number of covered cell/ total number of cell

System Models

- Sensor Network
- Each node has a sensing range separate from transmission range
- Moving any direction in two dimensional grid



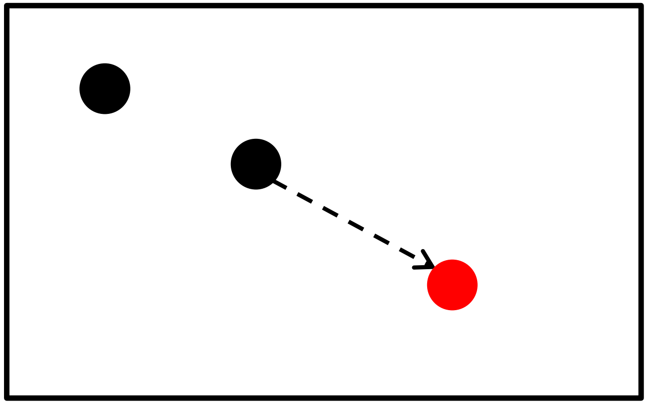
Mobility Algorithm: Mean Shift Clustering Algorithm



- Decreasing diameter
- Move node to the center of neighbors
- K or less neighbors are used for process
- Coverage can be significantly small
- Used a Local Evaluation Function (LEF) for coverage
- LEF = w1.sum of distance from k neighbors-w2.distance from center
- w1 and w2 can be adjusted depending on property

Mobility Algorithm:
Shift Neighbors Away Algorithm

- Increasing Coverage
- Pushing neighbors left to right or top to bottom
- Global Evaluation function for roll back

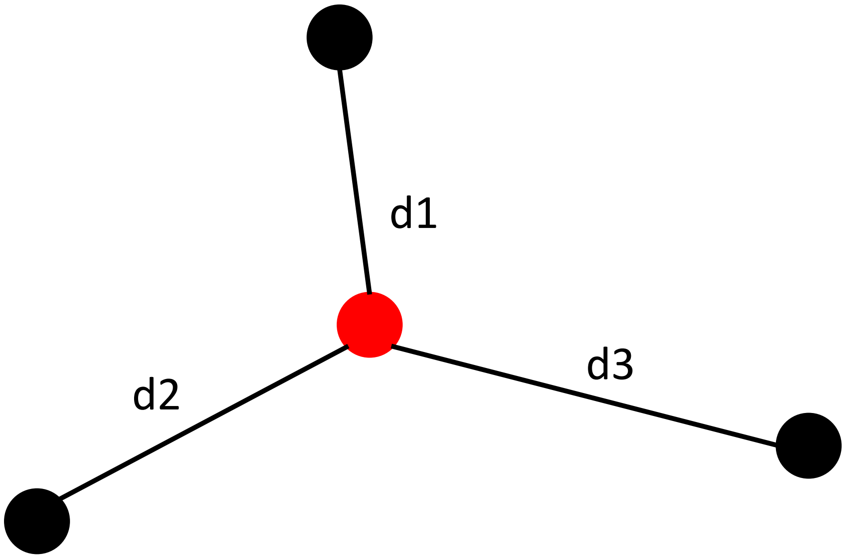


Mobility Algorithm: Global Evaluation Function

- It is needed for whether roll back is required
- GEF =w1.connectivity + w2.covereage – w3.diameter
- GEF positive: accept otherwise: roll back
- Roll back just artificial because the nodes perform evaluation before movement.
- General state cannot be know therefore to detect it, find it approximately, the portion of sensor network should be used

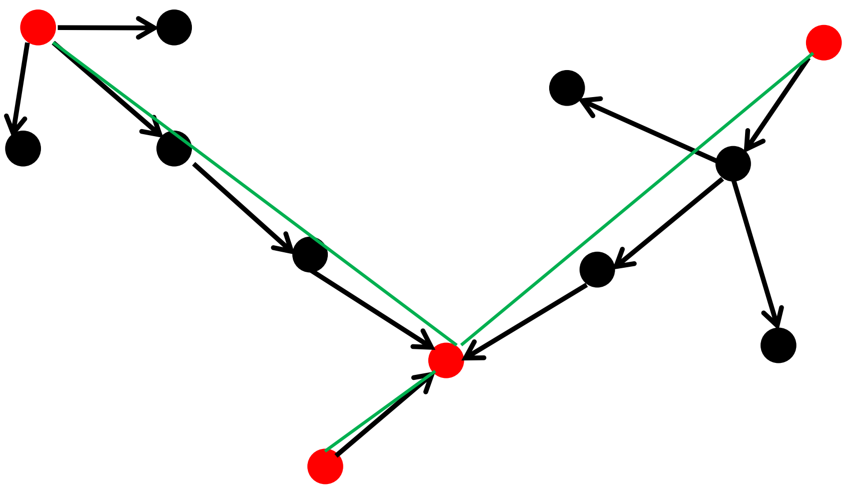
Mobility Algorithm:
Find Distance and Node Position

- *anchor* nodes
- Deducing location of all nodes
- Triangulation



Mobility Algorithm: Location Determination

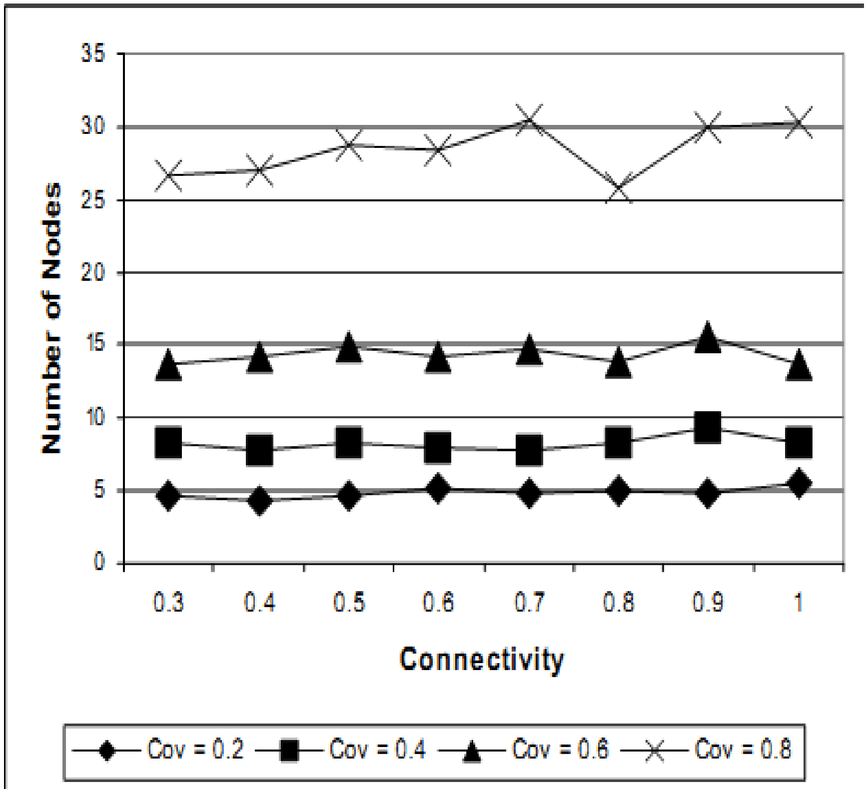
- Hop-Terrain and Refinement (Savarece and Rabaey)
  - How many nodes away from *anchors*
  - Use this knowledge to determine positions

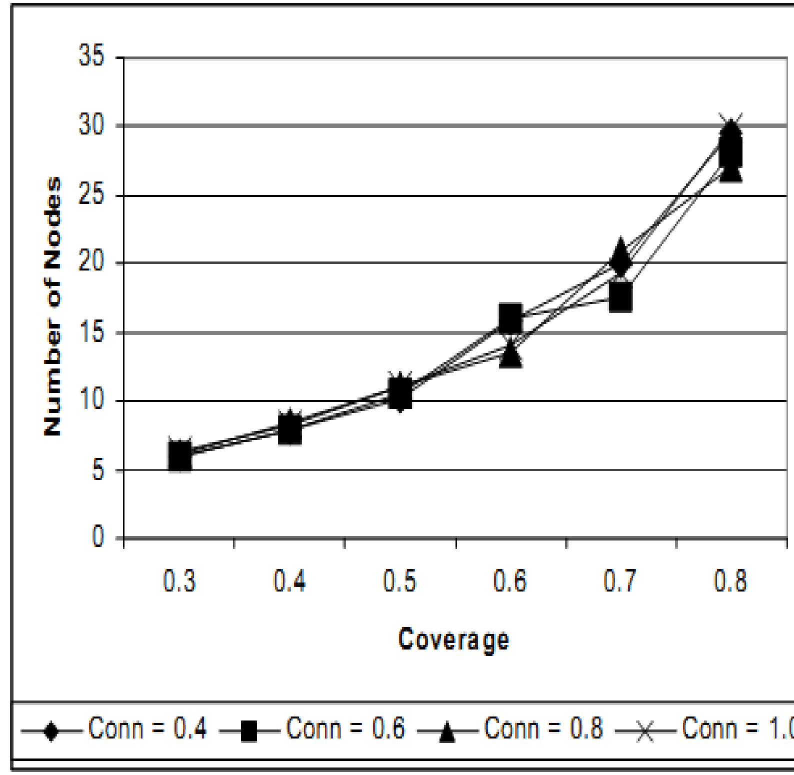


Mobility Algorithm: Analysis of Coverage and Connectivity and Result

- Mapping mobility to stationary unreliable grid
  - Impact of mobility
  - Impact of Unreliability
- Result
  - No significant difference between stationary case and Mobility (Constant factor)
  - Engineering Heuristics to ensure connectivity and coverage

Experiments: Without Failures





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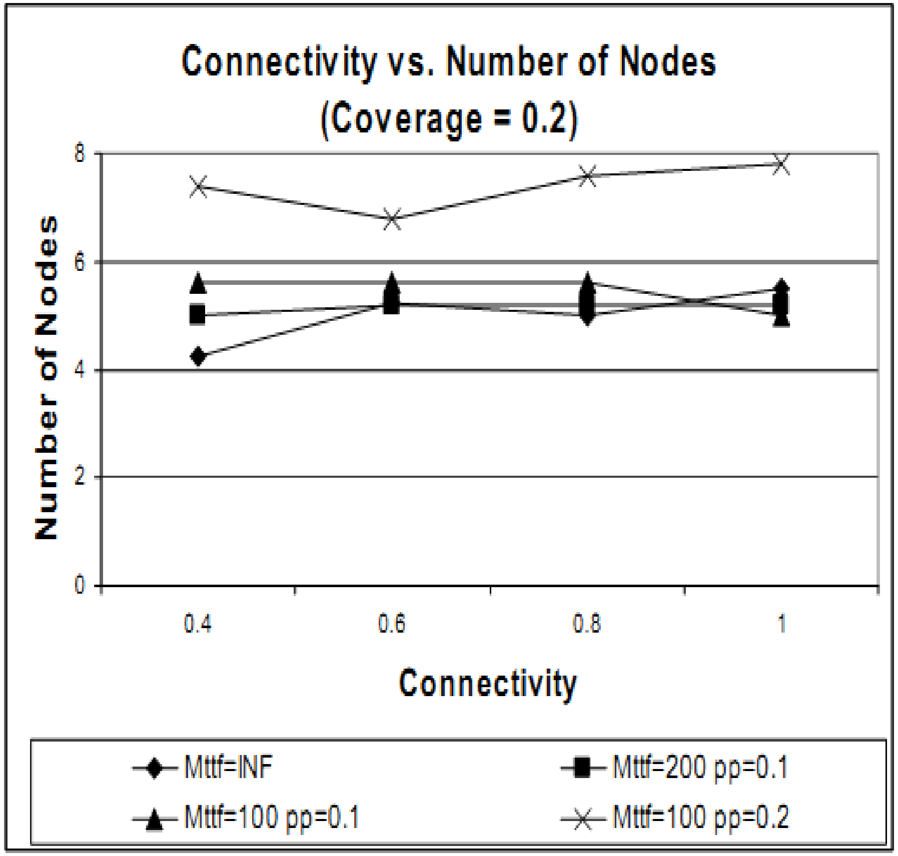
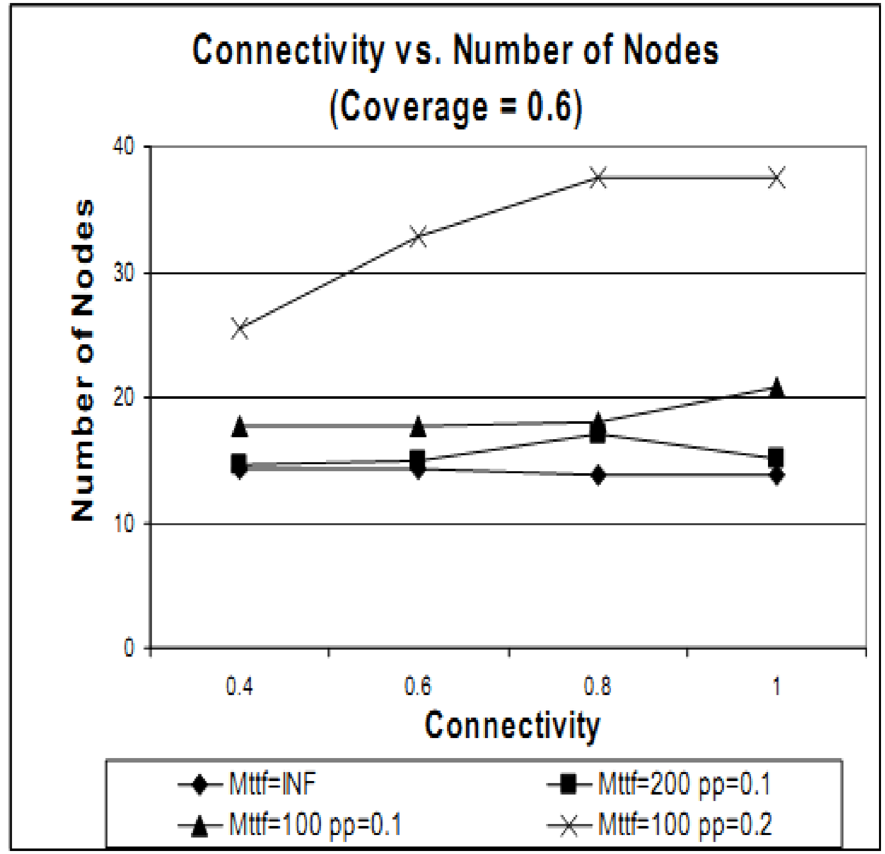




Conclusion of Second Paper

- Effect of Node failure to Characteristic of Network
- Proposing algorithm for node placement more wisely

- Future Work can be about this paper.
  - Obstacles
  - Energy efficiency of this algorithm
  - Heterogeneous sensors

Third Paper: NPART-Node Placement Algorithm for Realistic Topologies in Wireless Network Simulation

Third Paper

- Related Works:
  - Node placement algorithm in homogeneous nodes
  - Bettestter (Uniform and Thinning), Lui and Haenggi introduce some node placement algorithm,
  - Onat and Stajmenovij,

  new idea (connected high probability with degree (options)

	Average Nodes	Average degree	#Biconnected components	Network Diameter	Articulation points
Berlin	315	4.02	99.22	20.52	75.93
Leipzig	586	4.35	120.1	23.69	93.32
Uniform	400	5.31	30.6	37.76	32.46
RWM	400	7.6	31.7	25.15	21.22
20x20 Grid	400	3.8	1	38	0

Table 1. Comparison of real and synthetic topologies.

- Contributions:
  - Observing reality and creating a network has same properties
  - Increasing realistic topologies

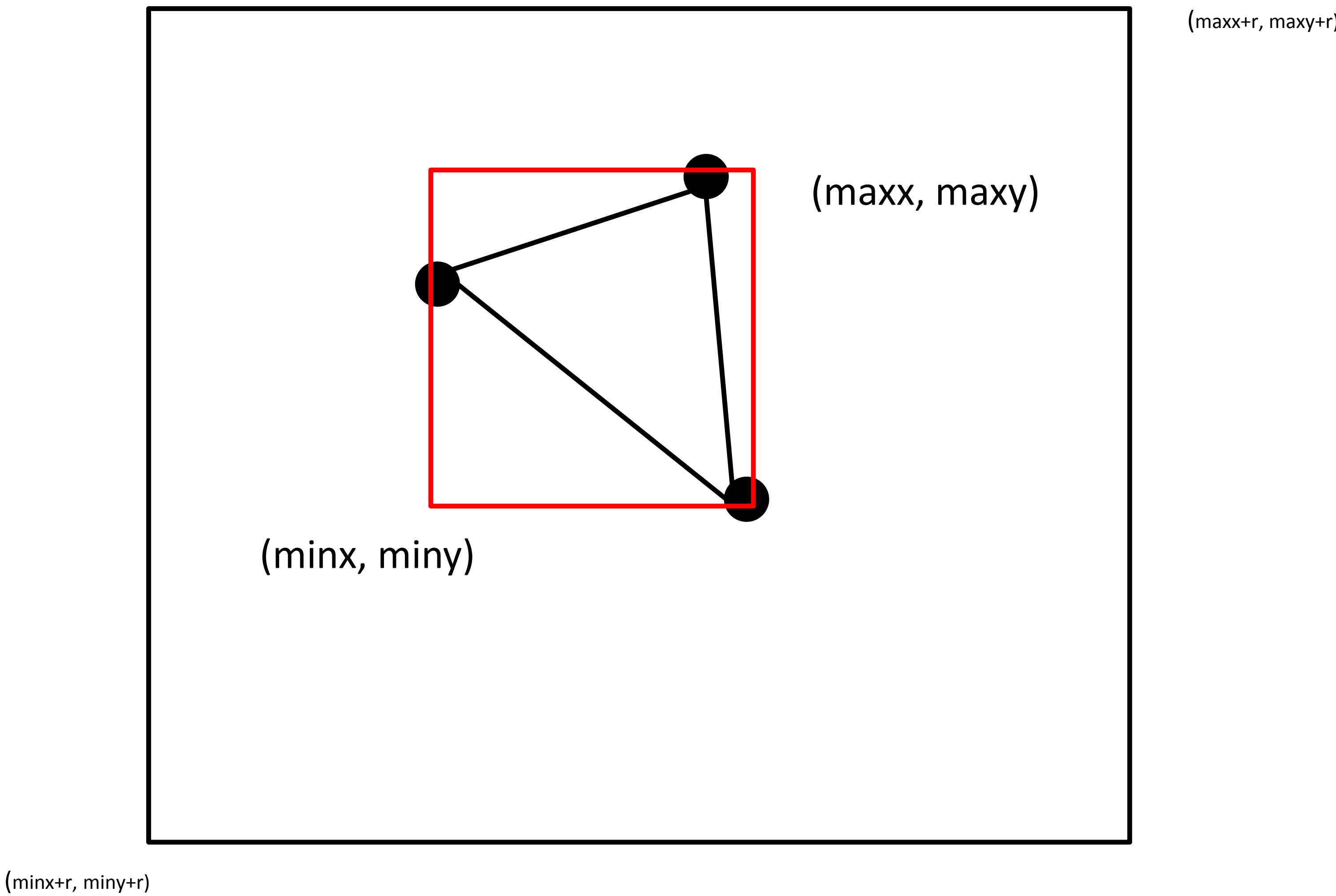
Model And Aimed Simulator

- Flexible
  - More than one node distribution model
- Realistic
  - Input real, output network should have same properties
- Random
  - Creating, random

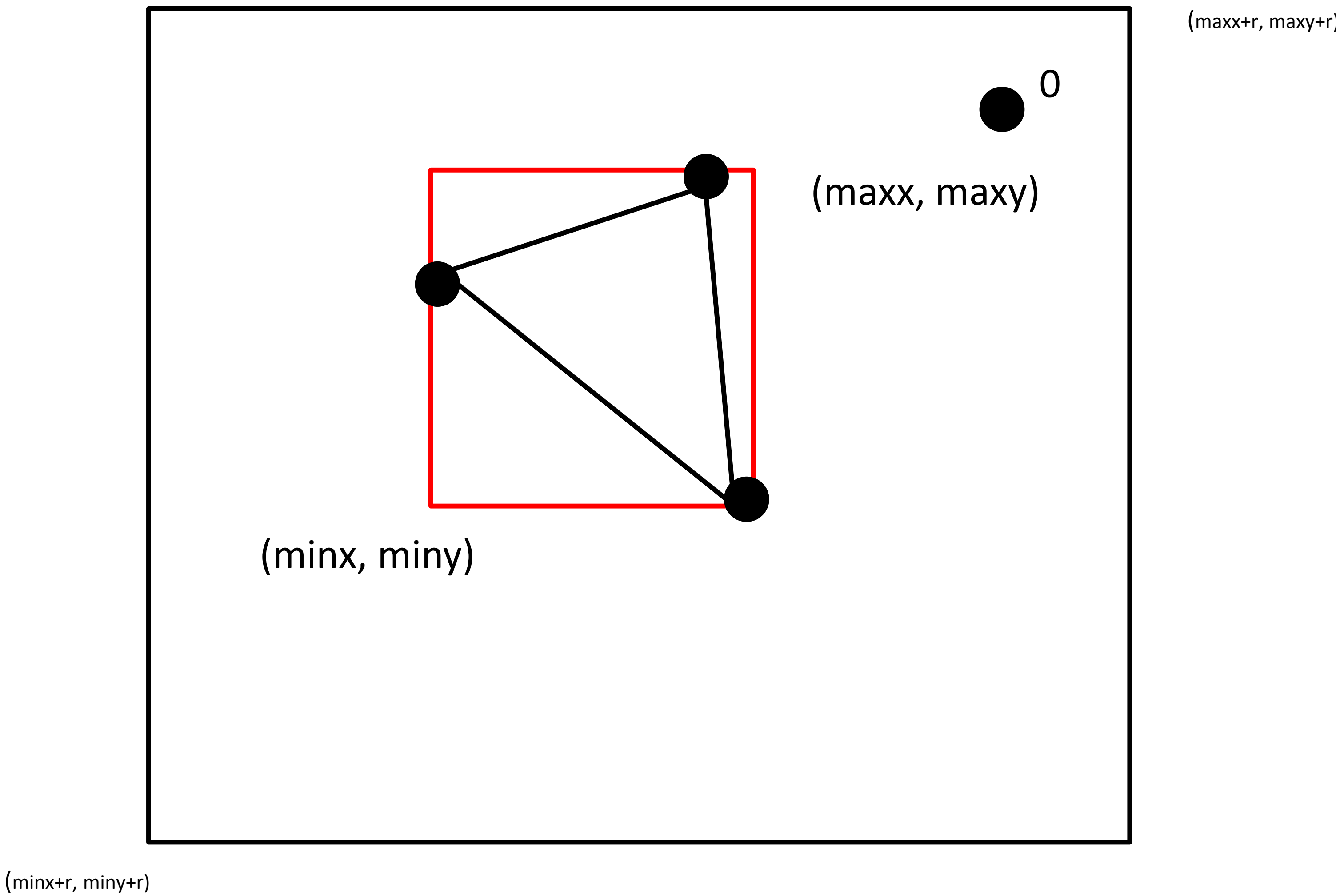
NPART Algorithm

- Inputs: Number of nodes, r
- Output : Network Topology
- Algorithm:
  - Initial node placement in (x, y) position
  - Initial minx and maxx = x, and miny and maxy = y
  - X coordinate simply placed in the range of (minx-r, maxx+r), same for y, (no need to predefine geo.)
  - Metric should be added depends on network needs

NPART Algorithm: Simulation



NPART Algorithm: Simulation



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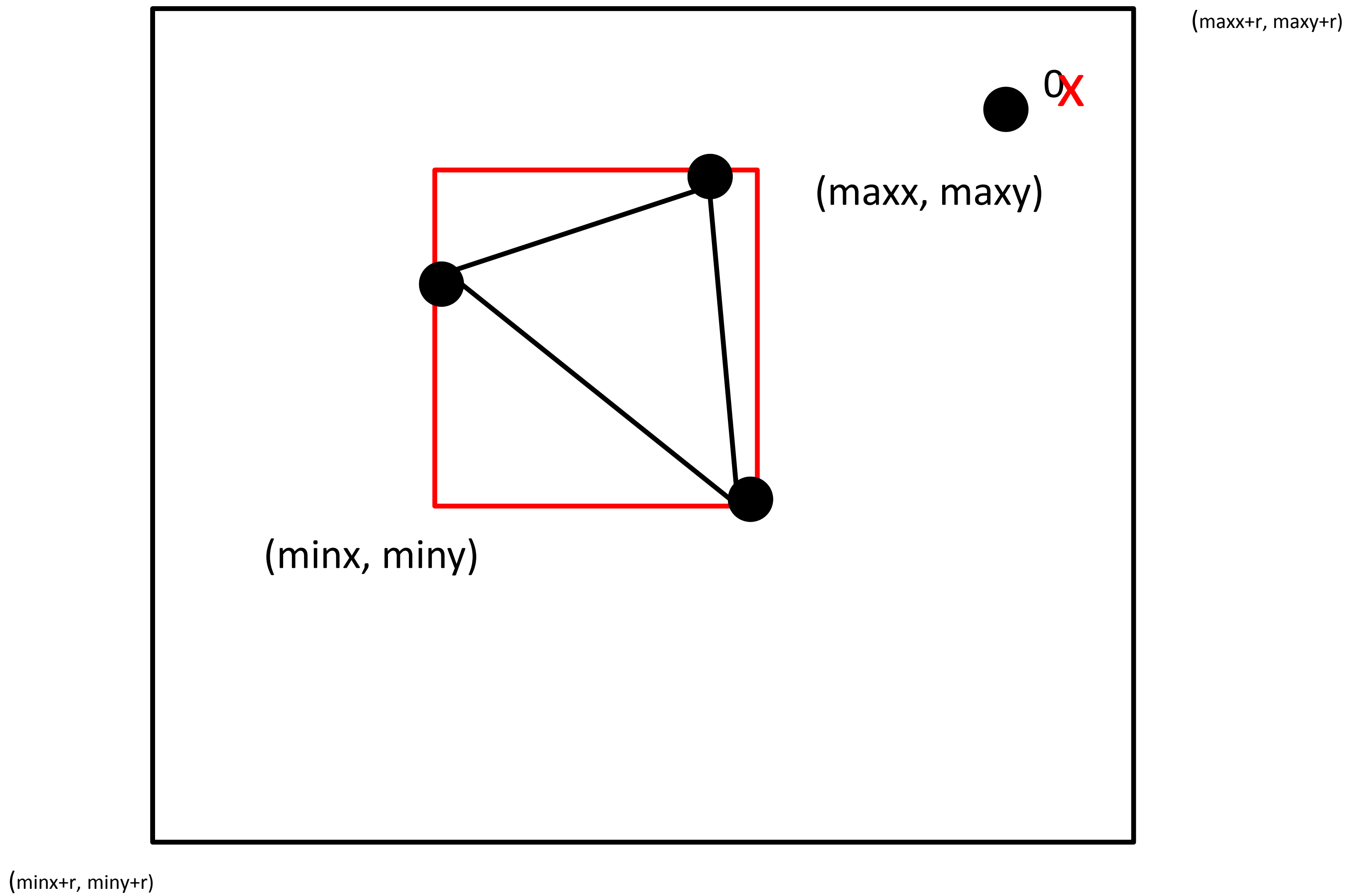
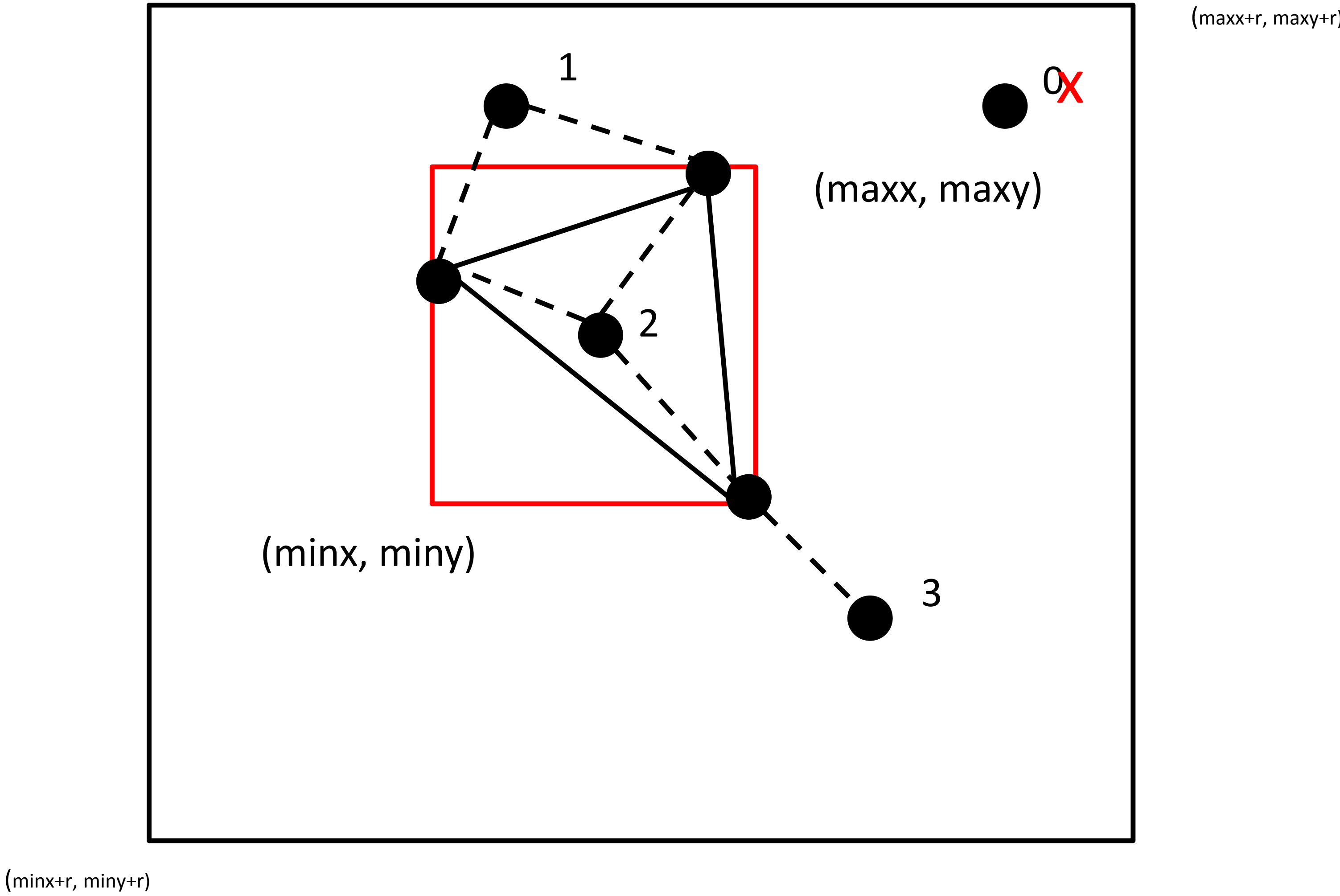


NPART Algorithm: Simulation



Metric Quality

- No universal Metric
- Real measurement from network
  - Hard (Heterogeneous , obstacles, frequency)
  - Not tolerable
  - Average degree is not enough
- Degree is not enough to generate more realistic one but it is easy, no need to deal with protocols.

Metric which is used by Authors

- Similar to *Manhattan Metric*

$$\sum_{degrees}^{d} (1_{target_d - candidate_d > 0} \cdot (target_d - candidate_d) + 1_{target_d - candidate_d < 0} \cdot p \cdot (candidate_d - target_d))$$

Metric which is used by Authors

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$$\sum_{degrees}^{d} (1_{target_d - candidate_d > 0} \cdot (target_d - candidate_d) + 1_{target_d - candidate_d < 0} \cdot p \cdot (candidate_d - target_d))$$

$$\sum_{degrees}^{d} (1_{target_d - candidate_d > 0} \cdot (target_d - candidate_d) \cdot w_d + 1_{target_d - candidate_d < 0} \cdot p \cdot (candidate_d - target_d))$$

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$$\sum_{degrees}^{d} (1_{target_d - candidate_d > 0} \cdot (target_d - candidate_d) \cdot w_d + 1_{target_d - candidate_d < 0} \cdot p \cdot (candidate_d - target_d))$$

$$w_d = \frac{|target_d - placed_d|}{\sum_{degrees}^{d} |target_d - placed_d|}$$

Metric which is used by Authors

- Similar to *Manhattan Metric*

$$\sum_{degrees}^{d} (1_{target_d - candidate_d > 0} \cdot (target_d - candidate_d) + 1_{target_d - candidate_d < 0} \cdot p \cdot (candidate_d - target_d))$$

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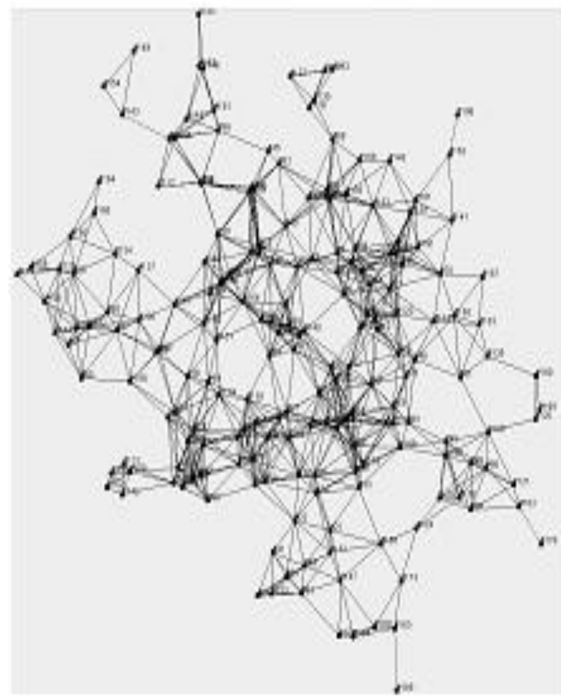
$$w_d = \frac{|target_d - placed_d|}{\sum_{degrees}^{d} |target_d - placed_d|}$$

Degrees	1	2	3	4	5	Distance metric	Adaptive metric
Absolute Target degree frequency	2	5	3	2	1	0	0
Absolute Placed degree frequency	0	3	0	0	0	10	2
Weights w_d	0.2	0.2	0.3	0.2	0.1		
Candidate 1	0	2	2	0	0	9	1.8
Candidate 2	0	0	4	0	0	15	6.9
Candidate 3	1	2	1	0	0	9	1.9

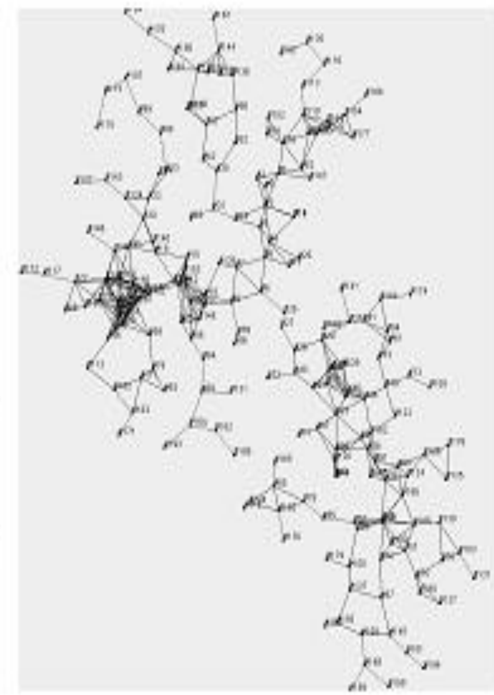
Table 2. Metric example for node candidates in Figure 2. Parameter p is set to five.

Experimental Result:

Sample from Berlin network



NPART without retirees



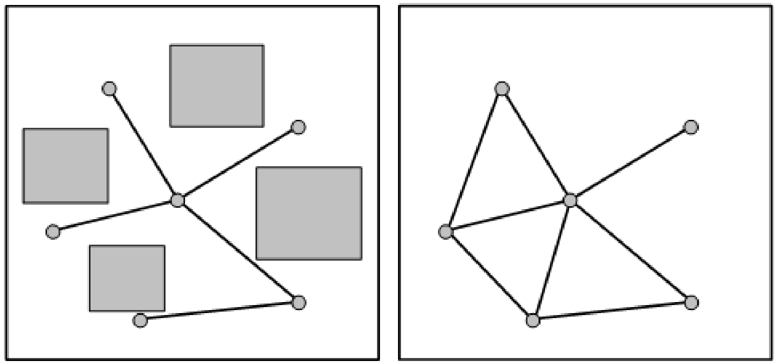
NPART with 150 retirees

Experimental Result (Continue):

- Degree distribution
  - Similar to Real Berlin and Leipzig
  - Uniform has its own distribution
- Bridge (component) and Articulation Point (Network)
  - Distribution same but it creates more point than it supposed
  - Uniform, only 1% of nodes is bridges an articulation point
- Component size after bridge removal

Experimental Result (Continue):

Can be improved by eliminating pendant links



Corelated Shadowing   No Corelated Shadowing

Conclusion of Third Paper

- New Simulation Model
- Realistic

- Future Work can be about this paper.
  - Increasing throughput or finding some universal metric

Future Work Can Be:

- 3D will be interesting for analyzing Topological Characteristics
- Proposing heterogeneous or Obstacle Goal Driven Algorithm

Questions

References

1. *Topological Characteristics of Random Multihop Wireless Network* by Keqin Li

2. *Analysis and Evaluation of Topological and Application Characteristics of Unreliable Mobile Wireless Ad-Hoc Network* by Serdar Cabuk, Nipoon Malhotra, Longbi Lin, Saurabh Bagchi, and Ness Shroff

3. *NPART-Node Placement Algorithm for Realistic Topologies in Wireless Network Simulation* by Bratislav Milic and Miraslow Malek

4. *A study on Topological Characteristic of Wireless Sensor Network Based on Complex Network*, Ren Yueqing, Xu Lixin

5. *Robust Positioning Algorithms for Distributed Ad-Hoc Wireless Sensor Networks* by Chris Savarese , Jan Rabaey

6. *Strategies and techniques for node placement in wireless sensor networks: A survey* by Mohamed Younis a, Kemal Akkaya

7. Network Science Theory and Application by Ted G. Lewis

Additional Slides: Formulas (Second Paper)

$$\bar{f}(x) = \left(\frac{\theta}{\pi}\right)\pi r^2 - (r-x)\sqrt{2rx - x^2}$$

$$= r^2 \cos^{-1}\left(1 - \frac{x}{r}\right) - (r-x)\sqrt{2rx - x^2}.$$

$$P_3 = 4\int_0^r \int_0^r g(x_1, x_2)\, dx_1 dx_2 = 4\int_0^r \int_0^r \left(\frac{1}{2}(f(x_1)\right.$$

$$\left. + f(x_2)) - \frac{1}{4}\pi r^2 + (r - x_1)(r - x_2)\right) dx_1 dx_2$$

$$= 4\int_0^r \left(\frac{1}{2}\left(\pi - \frac{2}{3}\right) r^3 + \frac{1}{2} r f(x_2) - \frac{1}{4}\pi r^3\right.$$

$$\left. + \frac{1}{2} r^2 (r - x_2)\right) dx_2 = 4\left(\frac{1}{2}\left(\pi - \frac{2}{3}\right) r^4\right.$$

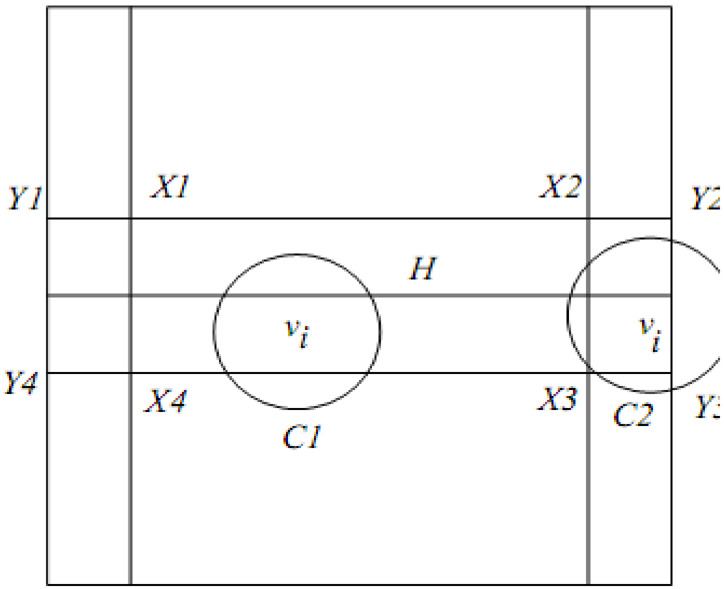
$$\left. + \frac{1}{2} r\left(\pi - \frac{2}{3}\right) r^3 - \frac{1}{4}\pi r^4 + \frac{r^2}{2} \cdot \frac{r^2}{2}\right) = \left(3\pi - \frac{5}{3}\right) r^4.$$

Additional Slides: Formulas (Second Paper)

$$Q_1 = 2(1-2r)\int_0^r \bar{f}(x)\,dx.$$

Since

$$\bar{f}(x) = \pi r^2 - f(x),$$



$$\begin{aligned}
Q_2 &= 4\int_0^r\int_0^r h(x_1,x_2)\,dx_1dx_2 \\
&= 4\int_0^r\int_0^r \left(\frac{1}{4}\pi r^2 - \frac{1}{2}(f(x_1)-f(x_2))\right. \\
&\qquad \left. -(r-x_1)(r-x_2)\right) dx_1dx_2 \\
&= 4\int_0^r \left(\frac{1}{4}\pi r^3 - \frac{1}{2}\left(\pi - \frac{2}{3}\right)r^3\right. \\
&\qquad \left. + \frac{1}{2}rf(x_2) - \frac{1}{2}r^2(r-x_2)\right) dx_2 \\
&= 4\left(\frac{1}{4}\pi r^4 - \frac{1}{2}\left(\pi - \frac{2}{3}\right)r^4\right. \\
&\qquad \left. + \frac{1}{2}\left(\pi - \frac{2}{3}\right)r^4 - \frac{r^2}{2}\cdot\frac{r^2}{2}\right) \\
&= (\pi - 1)r^4.
\end{aligned}$$

Additional Slides: Experiments (Second Paper)

Table 1. Simulation parameters

Parameter	Value
Sensor field dimension	500 m X 500 m (1 m grid)
Initial placement regions	Two bands: (0,0) – (70,70). (430,430) – (500,500).
Node transmission range	125 m
Mean epoch length (T_E)	200 ms
Mean Time to Failure	200 ms
Mean Time to Repair	20 ms
Permanent:Transient failures	10:90
Number of runs (N_r)	5
Epoch iterations (E_N)	40

Additional slides : Npart Pseudo code

```
place nodes(nodes n, comm.radius r,
candidates to evaluate in iteration retries):
   placedNodes = place first node arbitrarily at (x,y)
   minX=maxX=x
   minY=maxY=y
   repeat
     minMetric=∞, candidateN = null
     repeat
       repeat
         x-coordinate=U(minX-r, maxX+r)
         y-coordinate=U(minY-r, maxY+r)
         create node candidateN from coordinates
       until (candidateN ∪ placedNodes is connected)
       m=apply metric on placedNodes ∪ candidateN
       if(m < minMetric)
         bestCandidate = candidateN
         minMetric = m
       endif
     until(retries candidates evaluated)
     update minX, maxX, minY, maxY based on
bestCandidate location
     placedNodes = placedNodes ∪ bestCandidate
   until(all n nodes placed)
```

Fig. 1. NPART pseudo code description.

Why Do We Need?

- **Connectivity**
  - Data dissemination from one part of network to another
  - Minimum size of connected component for useful work
- **Coverage**
  - Can gather data about properties of covered region
- **Diameter**
  - Bounds the maximum delay in message communication
  - Important for data dissemination environments with real time needs
- **Degree**
  - Higher degree means higher node connectivity
  - Higher node connectivity means higher resilience to node failures
- **Bisection width**
  - A parameter which effects communication bandwidth of network
- **Biconnectivity**
  - A property related to fault tolerance and network robustness
- **Entropy, Average path length, Cluster Coefficient…**