EE 579: Wireless and Mobile Networks Design & Laboratory

Lecture 9

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Lecture notes and course design based upon prior semesters taught by Bhaskar Krishnamachari and Murali Annavaram.

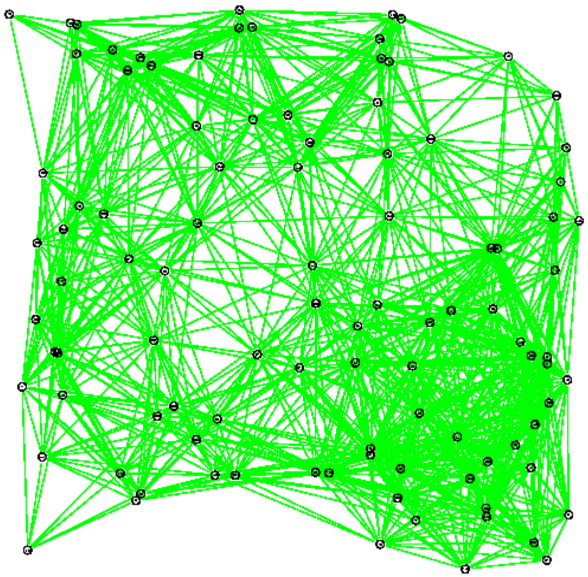
Outline

- Administrative Stuff
- Topology Control in Sensor Networks
- Localization in Sensor Networks with Testbed Experiments - Suvil

Why Topology Control?

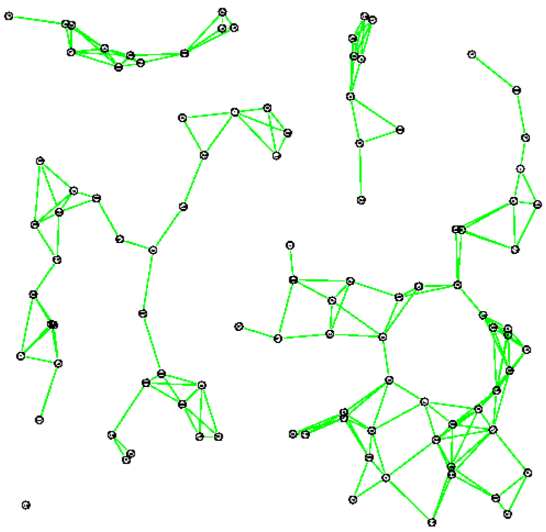
Topology Control: Given a network connectivity graph, compute a subgraph with certain properties: connectivity, low interference etc.

- No topology control: nodes transmit at max power levels



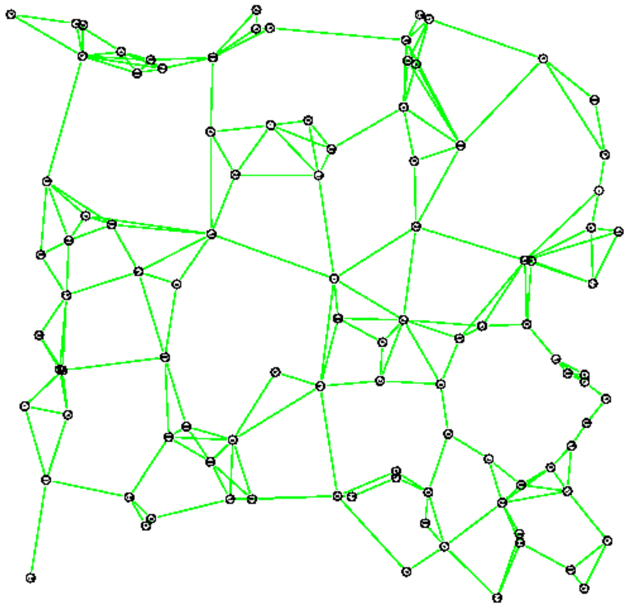
- High energy consumption
- High interference
- Low throughput

- No topology control: nodes transmit at min power levels



- Network may partition

An Example



Benefits

- Global connectivity
- Low energy consumption
- Low interference
- High throughput

Problem

- To find optimal transmission power levels using local information such that network connectivity is maintained.

3-Dimensional Networks

Challenges:

- Is very high density deployment practical in 3D?
- Do 2D algorithms readily extend to 3D?
- Structural restrictions

Applications: Structural Health Monitoring, Marine-life monitoring

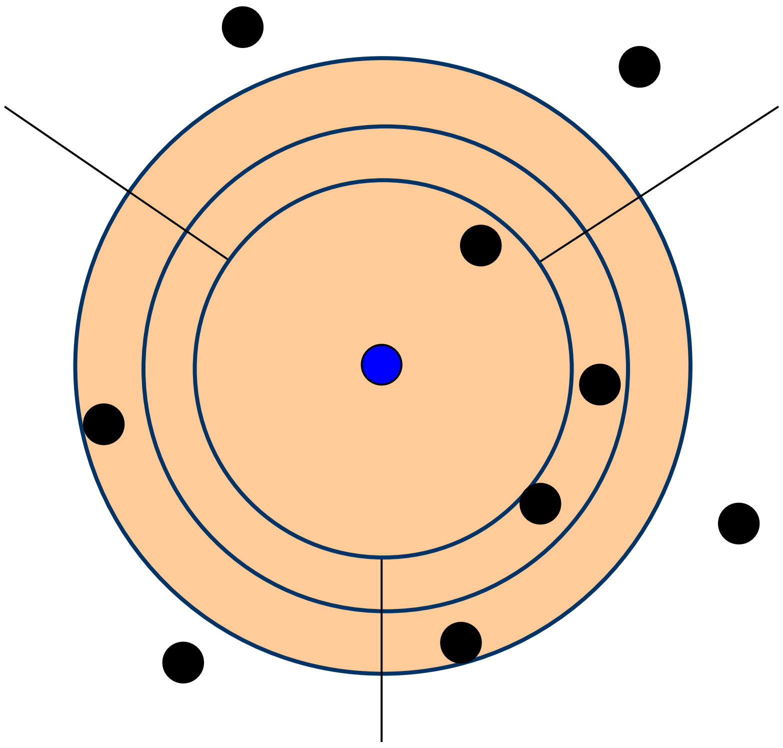
- Under random deployment, node density required to ensure connectivity is prohibitively high in 3D!

  Critical Transmission Radius: $O((\log n/n)^{1/d})$ for a unit cube $[0,1]^d$ [Goel '06]

  Critical avg. node deg: **15 in 2D** vs. **34 in 3D** (for n=1000) [Poduri, EmNet'06]

- Many 2D algorithms are not extensible to 3D (e.g. geographic routing)
- Very high complexity
- No ordering of nodes based on angular information in 3D

Can you think of a smart Strategy?



Cone-Based Topology Control

2D CBTC

Global connectivity from local geometric constraints [Wattenhofer, Infocom '01]
[Li Li, PODC '01, TON '05]

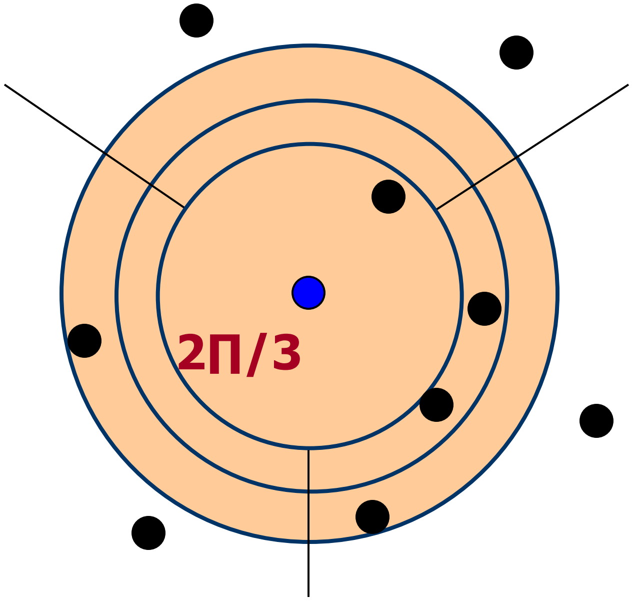
Assumptions

- Maximum Power Graph G=(V, E) is connected
- Assume receivers can determine direction of senders

Main Result

If every node adjusts its power level, such that there exists at least one neighbor at every **2Π/3** sector around itself, then network is connected

- Complexity **O(d log d),** d = avg node deg
- Not (efficiently) extensible to 3D



3D Topology Control

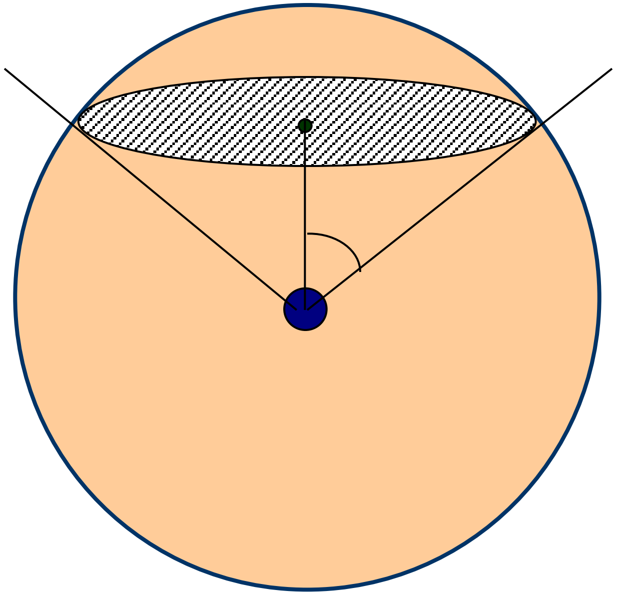
3D CBTC [Bahramgiri, ICCCN'05, Wireless Networks '06]

Basic Idea

Each node increases its power level until there is at least one neighbor at every **3D cone** of apex angle **$2\pi/3$** around it

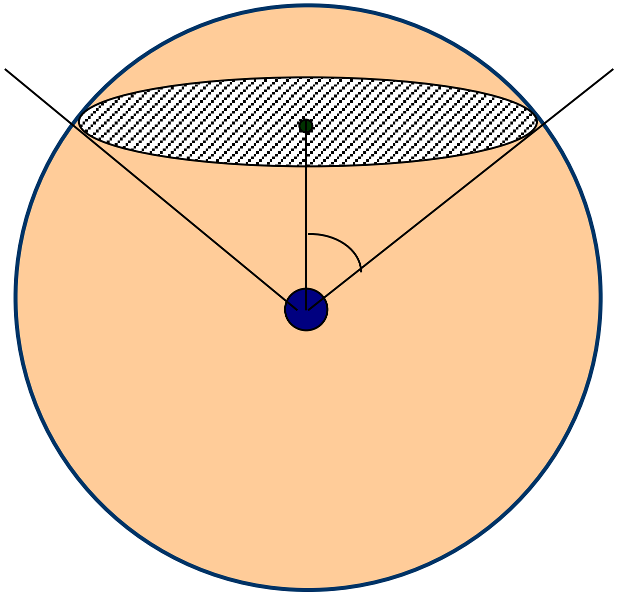
Limitations

- Assumes directional information
- High time complexity – **$O(d^3 \log d)$**



Reduce Complexity in 3D

- Can you think of a smart strategy to do the power control in 3D with reduced complexity?



Our Approach

- Phase 1
  - Use Multi-Dimensional Scaling (MDS) to find relative location maps for each node's neighbors when they use P^{max}
- Phase 2
  - **Simplify the 3D problem**
    - Orthographic Projections
      - Convert the 3D problem into similar problems in 2D
    - Solve the 2D problems using CBTC and infer about the 3D solution
  - **Solve the 3D problem directly**
    - Use Spherical Delaunay Triangulation (computational geometry tool)

Phase I: Multi-Dimensional Scaling

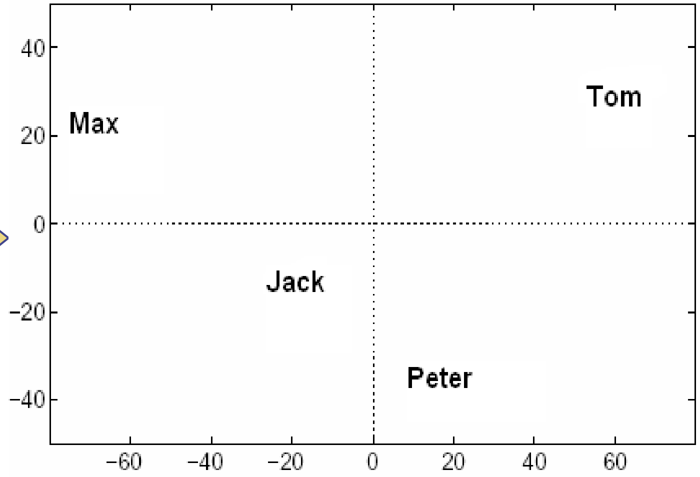
Classical MDS

Input: pairwise distances
Output: relative positions

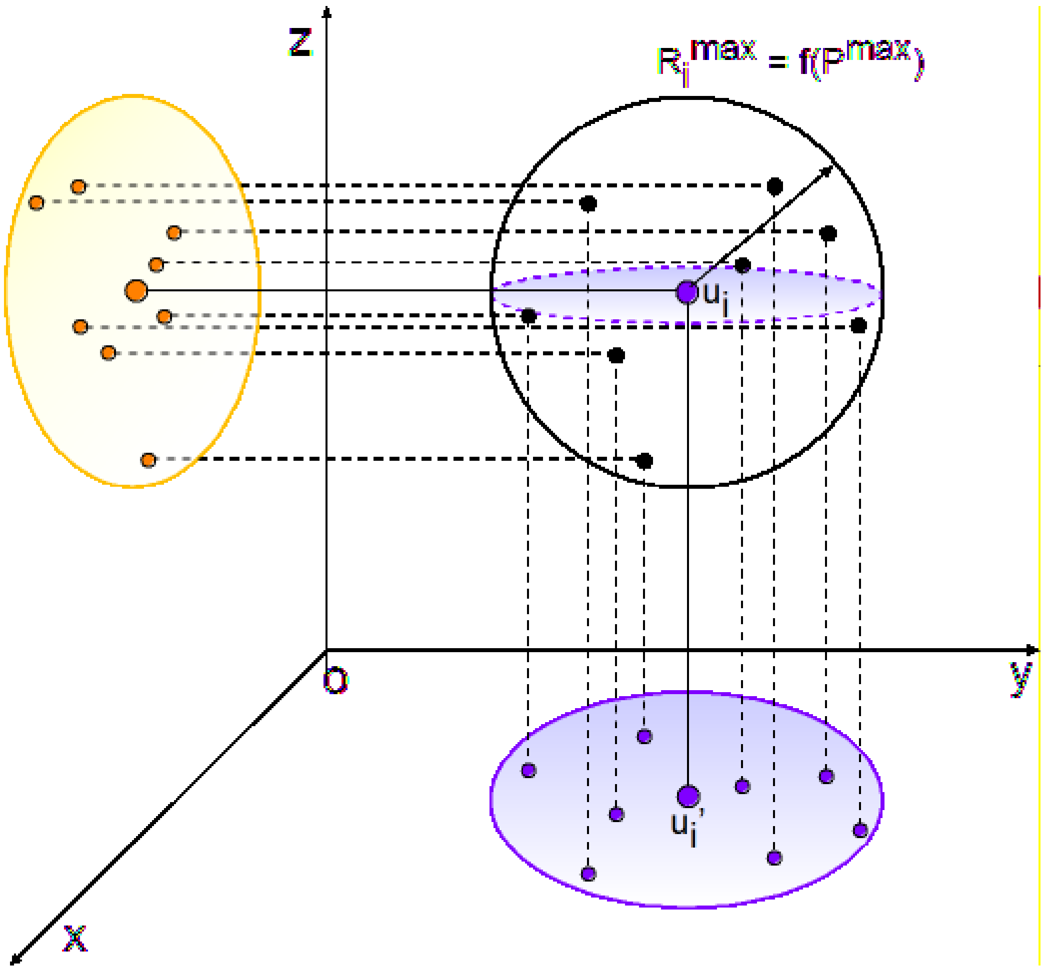
Example: (2D case)

	Tom	*Jack*	*Peter*	*Max*
Tom	0	93	82	133
Jack	93	0	52	60
Peter	82	52	0	111
Max	133	60	111	0

Classical MDS



Phase 2: Orthographic Projections



Phase 2: Orthographic Projections

Algorithm:

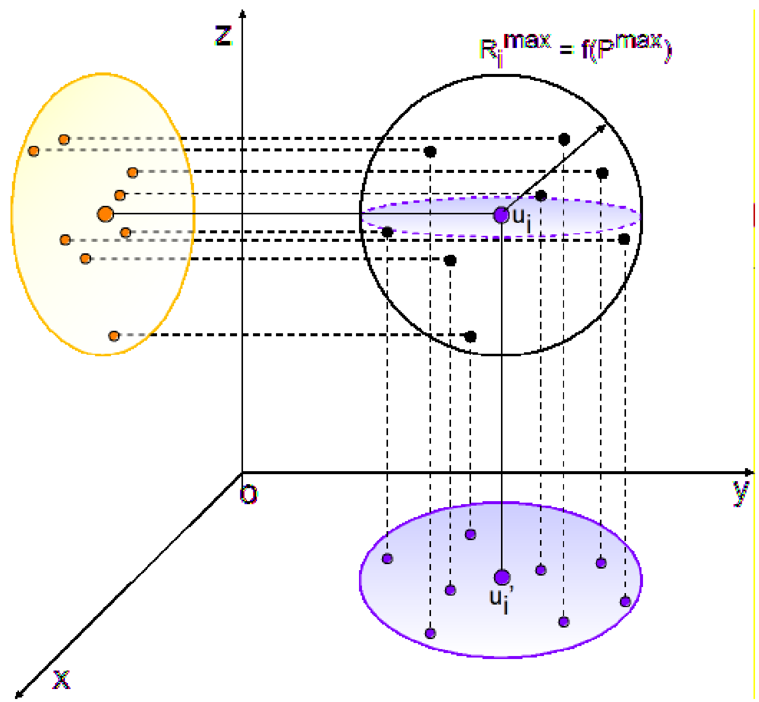
Hope that by satisfying CBTC on 3 planes => non-empty 3D cones

1. Each node starts with minimum tx. power

2. For a given tx power, project the neighbors on xy, yz, and zx

3. Run 2D CBTC on each plane
   - If any of the 3 planes do not satisfy the **2Π/3** constraint, increase power to the next level
   - Else STOP, settle with current power

4. Go back to Step 2 unless P^{max} is reached.

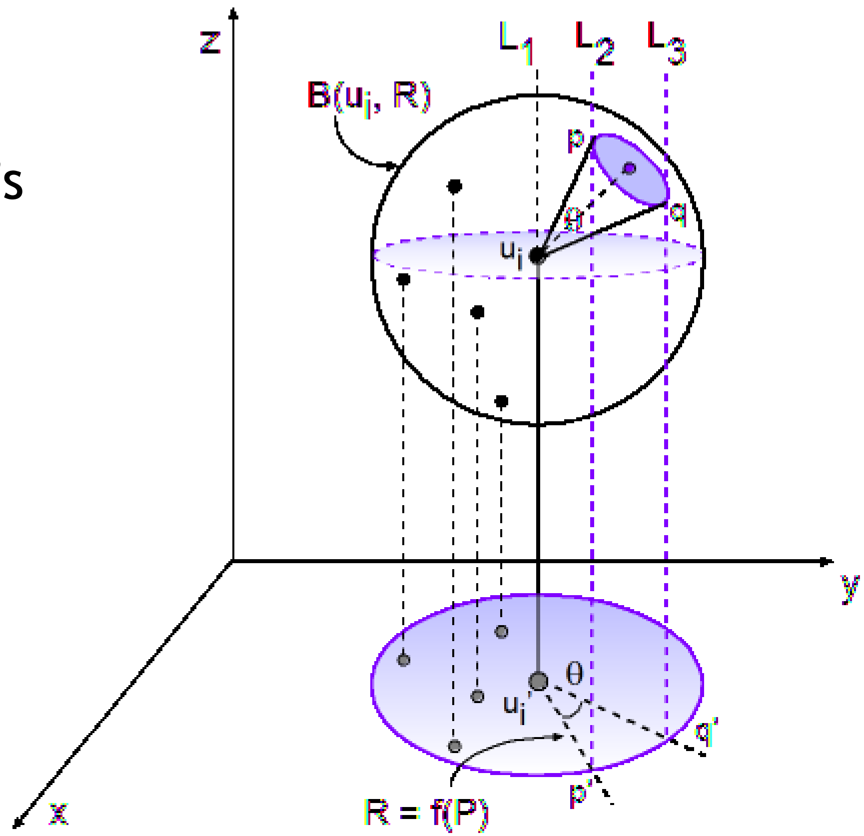


Phase 2: Orthographic Projections

Lemma 1:

Consider the projections of a node u_i's neighbor on the three planes: xy, yz, and zx.

If there exists at least one empty sector of angle θ in any one of the planes, then there exists an infinite number of empty 3D cones with apex angle θ around u_i.



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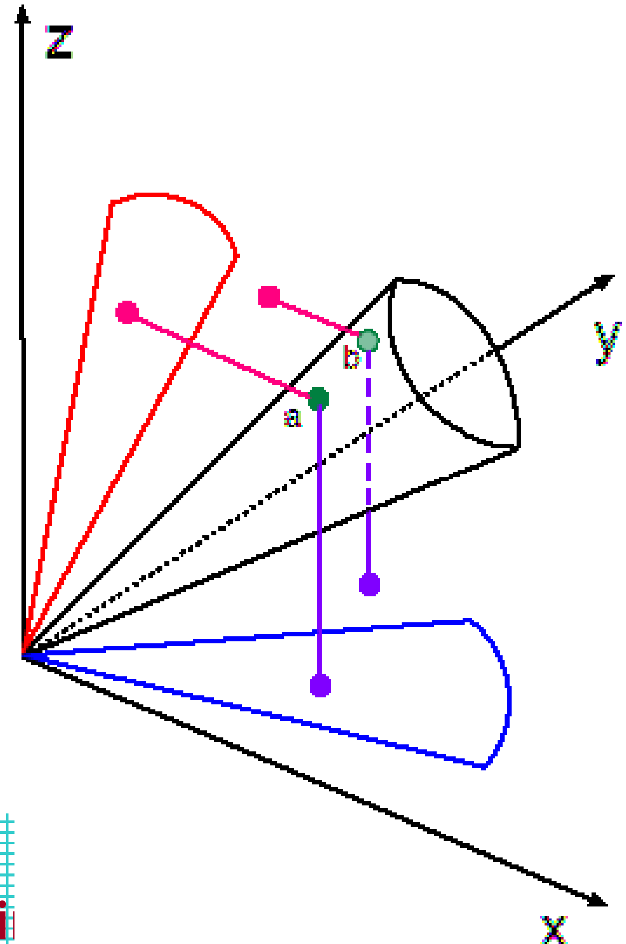
Phase 2: Orthographic Projections

Does it preserve connectivity?

Theoretically: NO
Practically: YES



The 3D cone can be empty even if all the 3 planes satisfy the **θ constrai**

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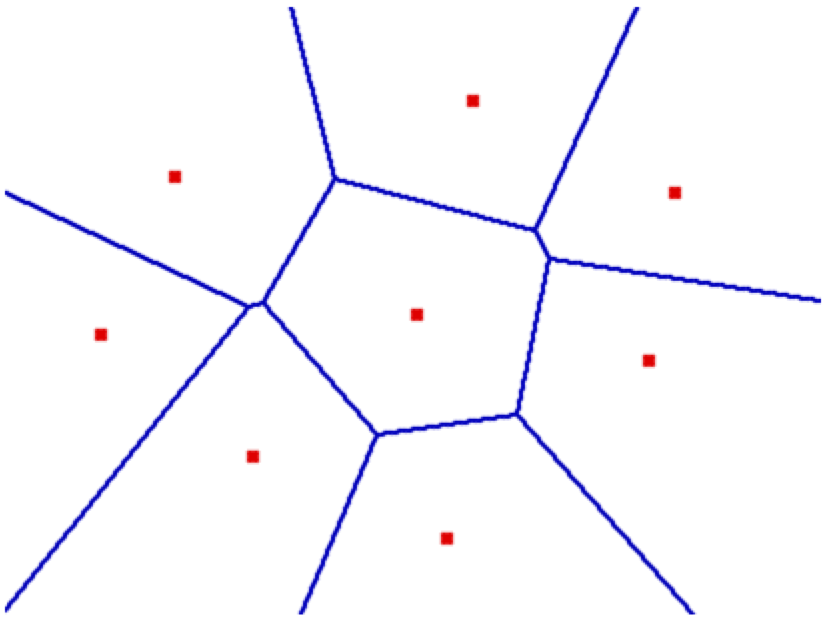
Voronoi Diagrams

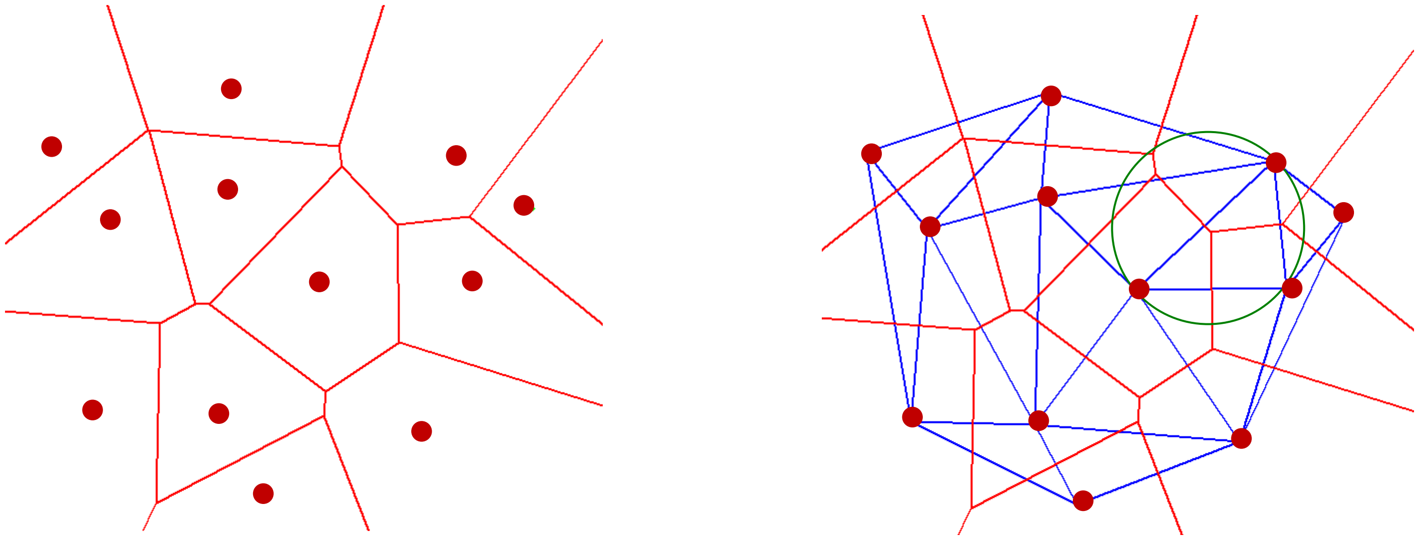
Given N points in 2D, a Voronoi diagram tessellates the plane into N convex polygons, such that any point within a polygon is closest to the site (given point) that lies in that polygon



Delaunay Triangulation

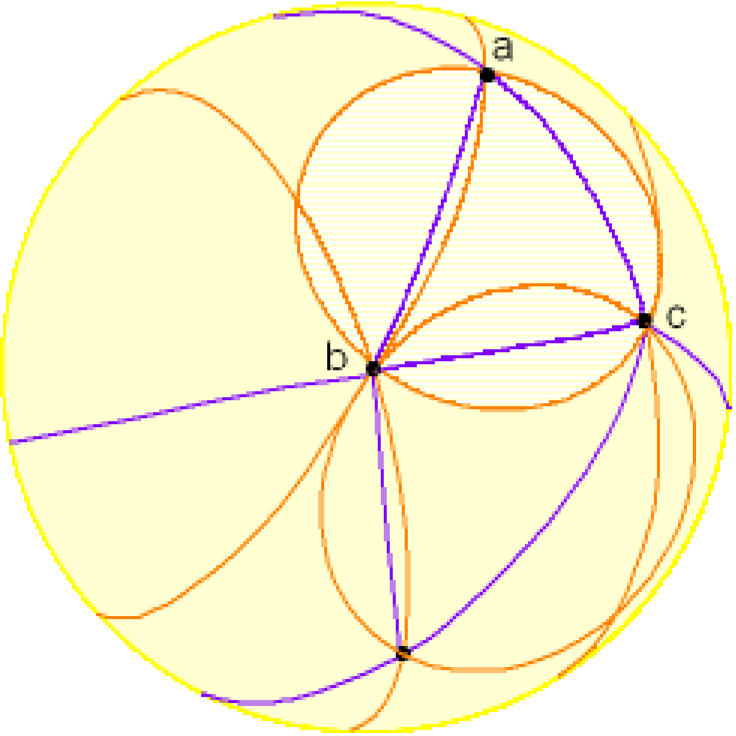
Dual of Voronoi diagram

Empty circumcircle property of DT



Spherical Delaunay Triangulation

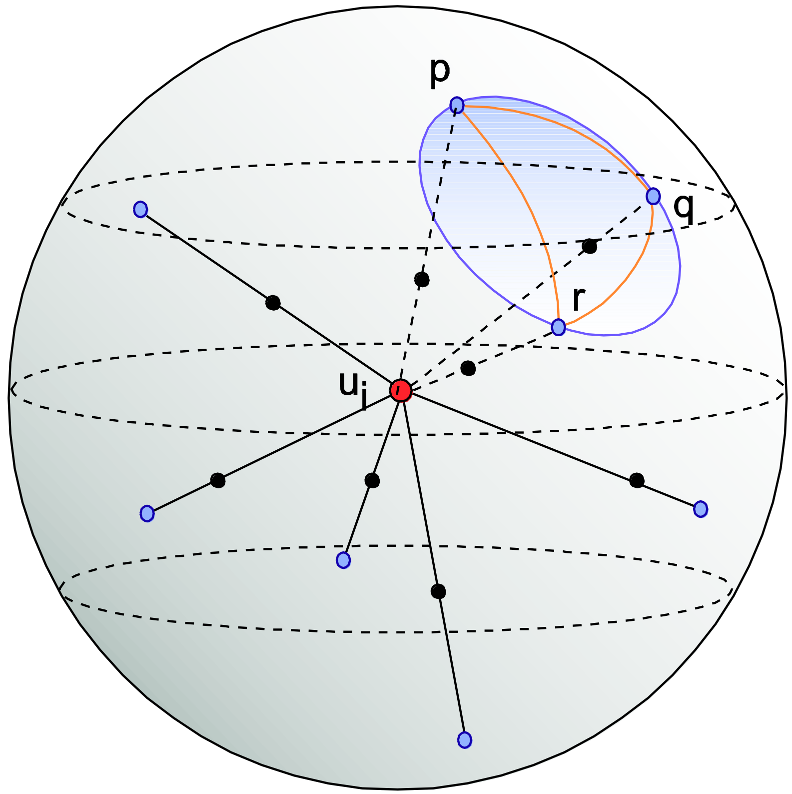
- When we do the DT on the surface of a sphere



Spherical triangles,
and spherical caps

Phase II: SDT

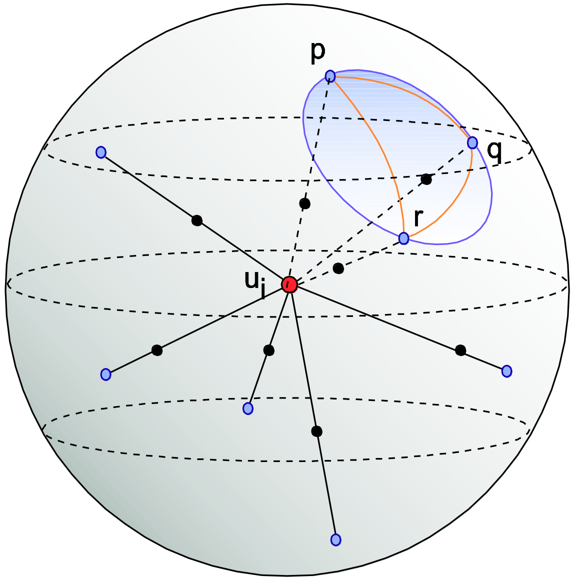
- Construct a SDT by projecting the node locations on the surface of a sphere



Phase II: SDT

Algorithm: SDT

1. Each node starts with minimum tx. Power
2. For a given tx. power, project the neighbors on the spherical surface
3. Construct Delaunay triangulation on the surface of the sphere
4. Calculate the area of the (empty) spherical caps
5. If any cap area is > 2.7 R^2
    - Increase the power to next level; go to Step 2
6. Else
    - Stop, settle down with current power level

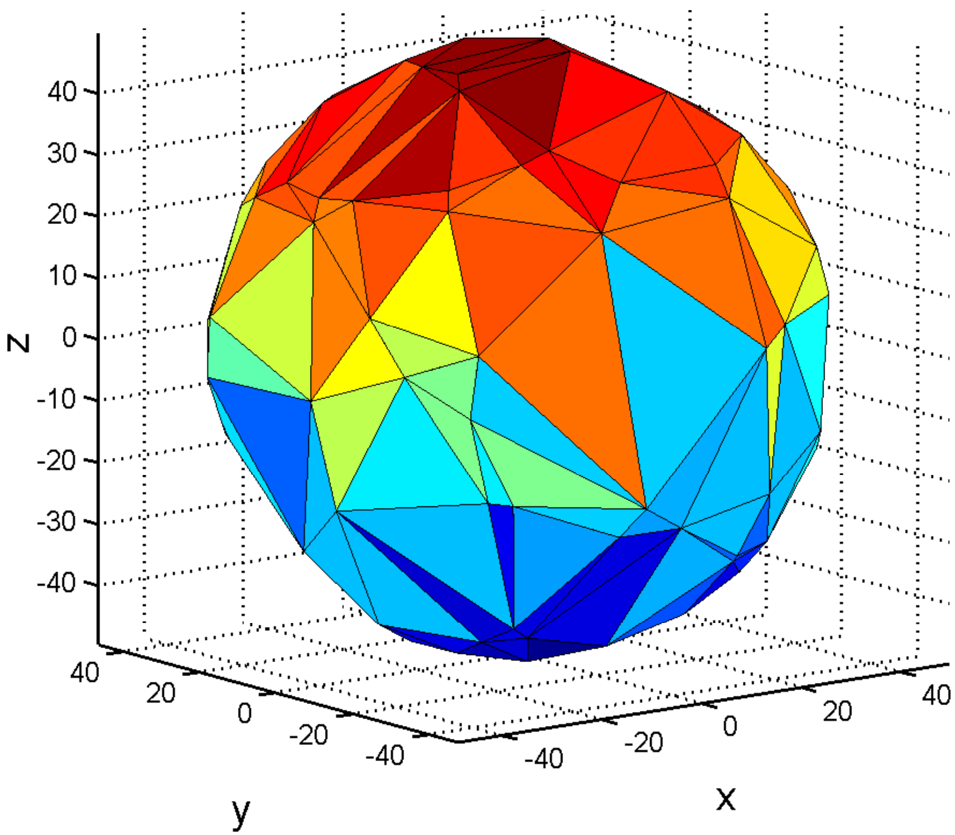


O(d log d)

Lemma 2

If none of the spherical caps have a surface area greater than **2.7R^2**, the network is at least one-connected.

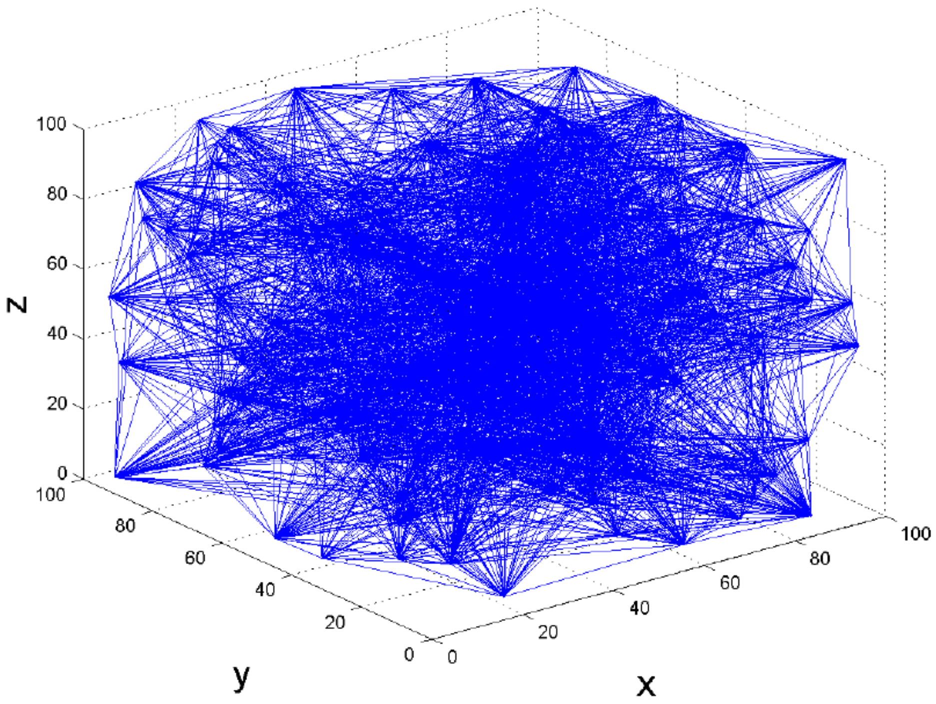
Visualization of SDT in Matlab

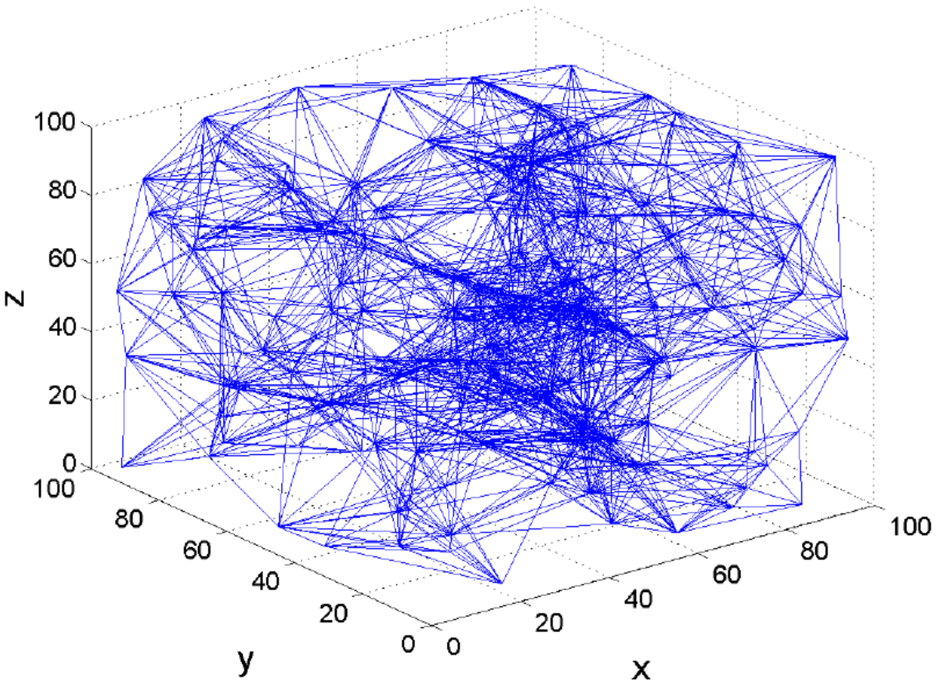


Spherical Delaunay Triangulation using Quickhull for 100 points randomly distributed on the surface of a sphere of radius 50

Simulation Results

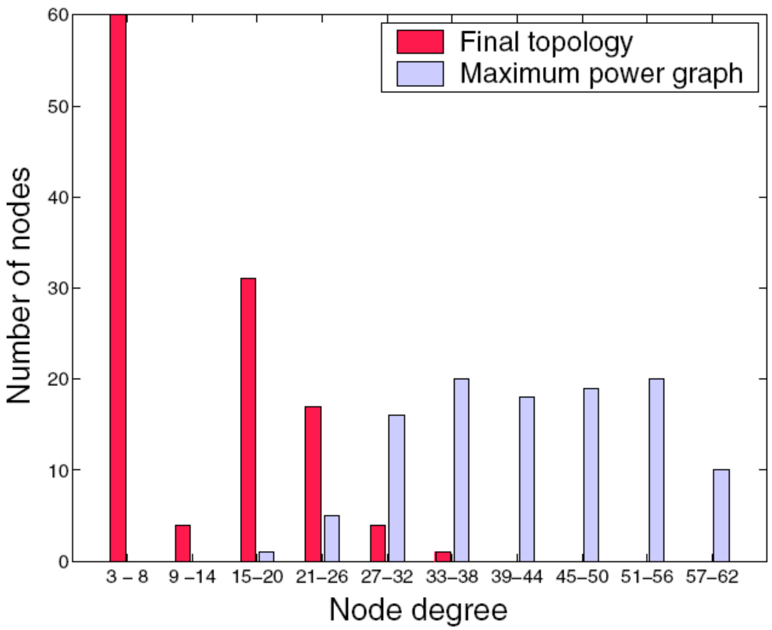
- Maximum power graph vs. Graph after topology control

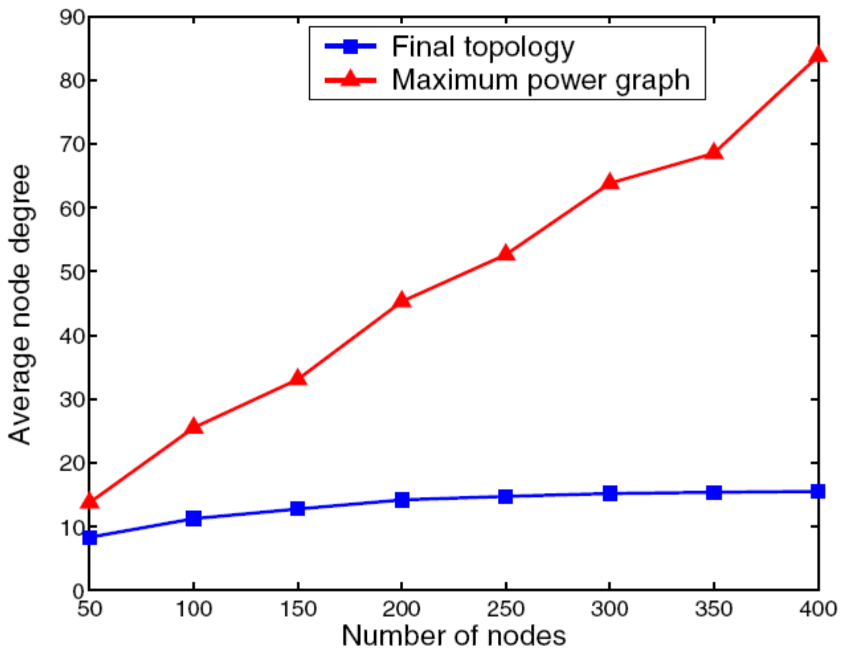




Simulation Results

- Average node degree and how it scales with topology control





Simulation Results

- Comparison of complexity