Networks Laboratory – Wireless Research Group

A Review on 3-Dimention in Wireless Networks

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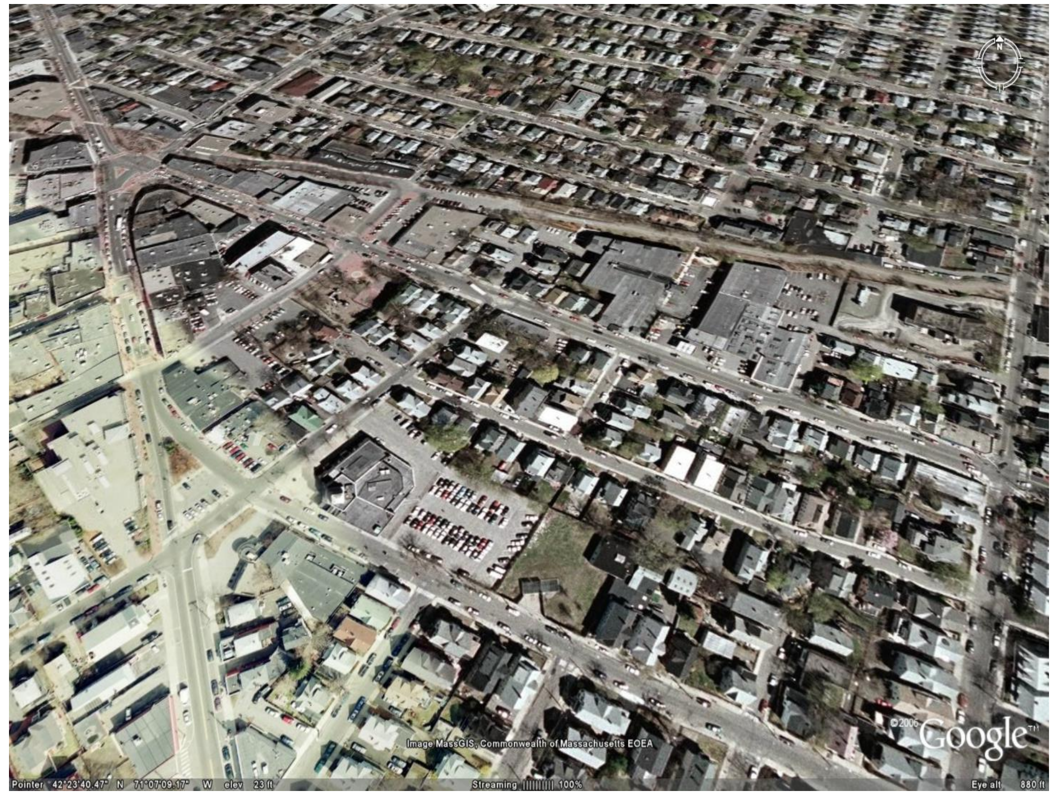
Introduction



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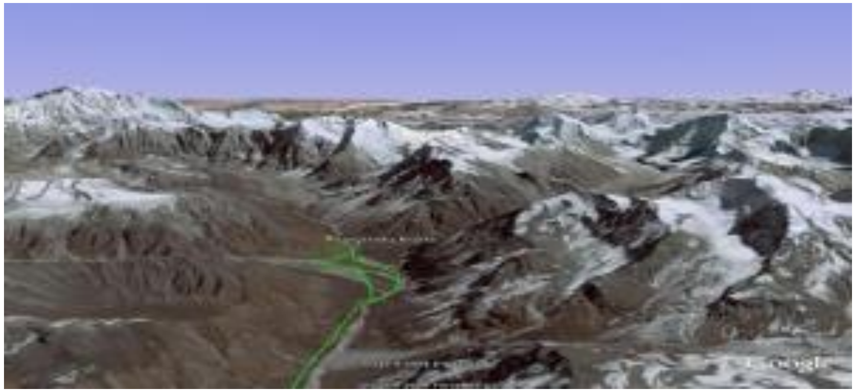

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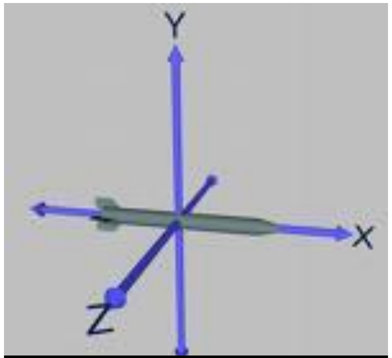

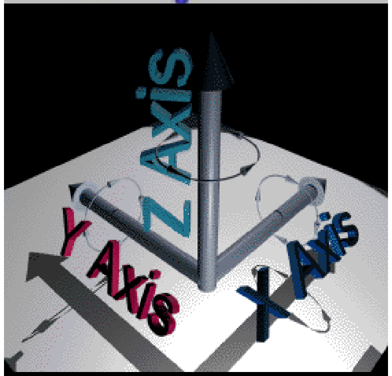

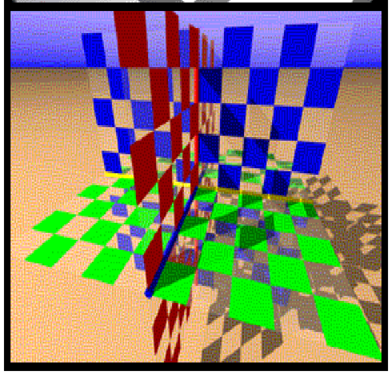

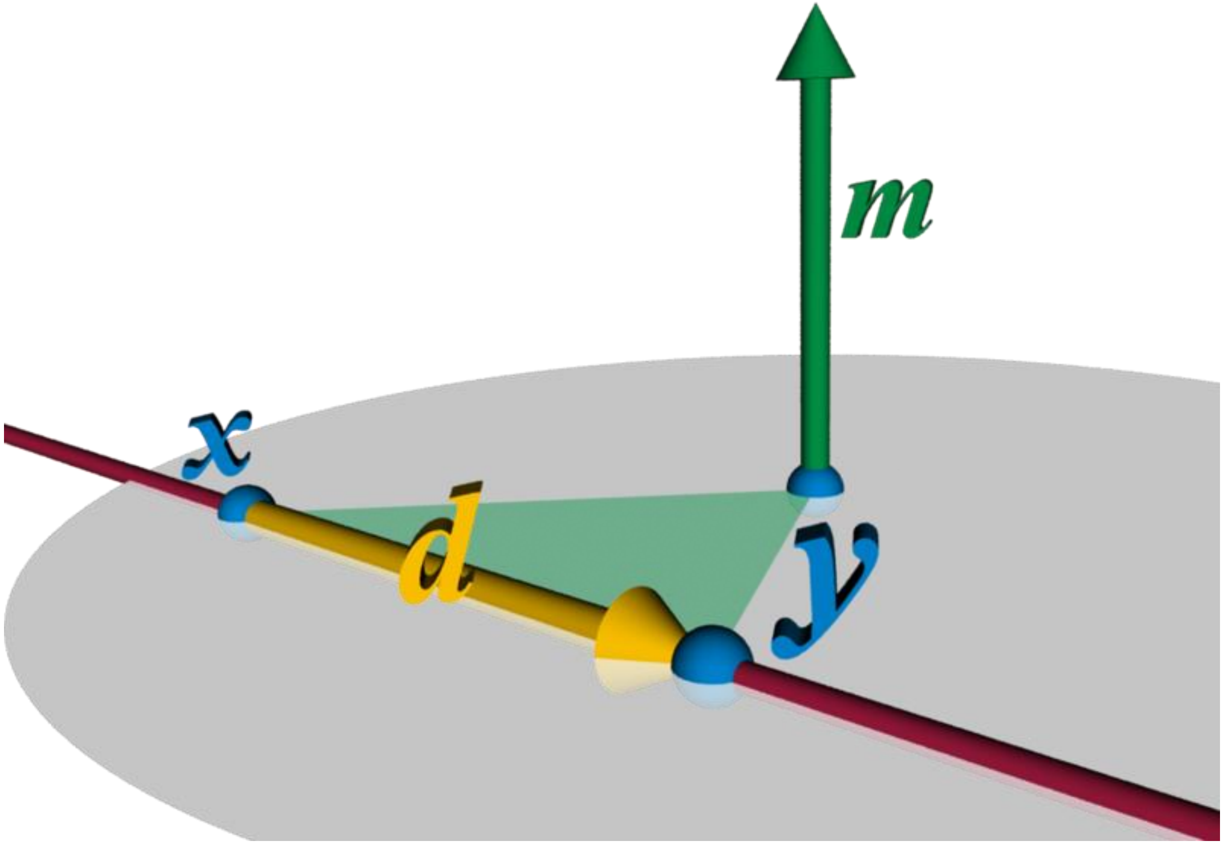

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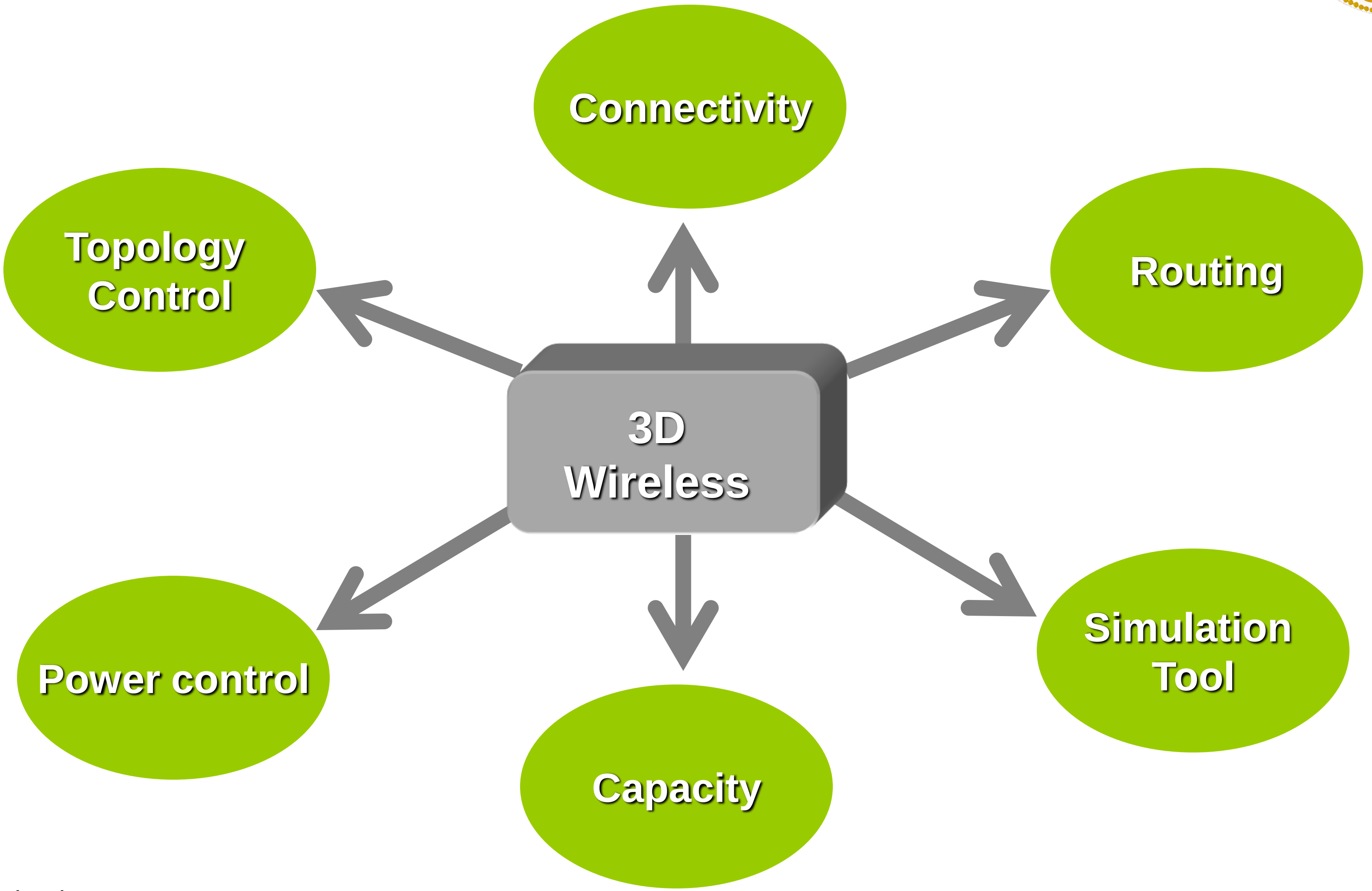
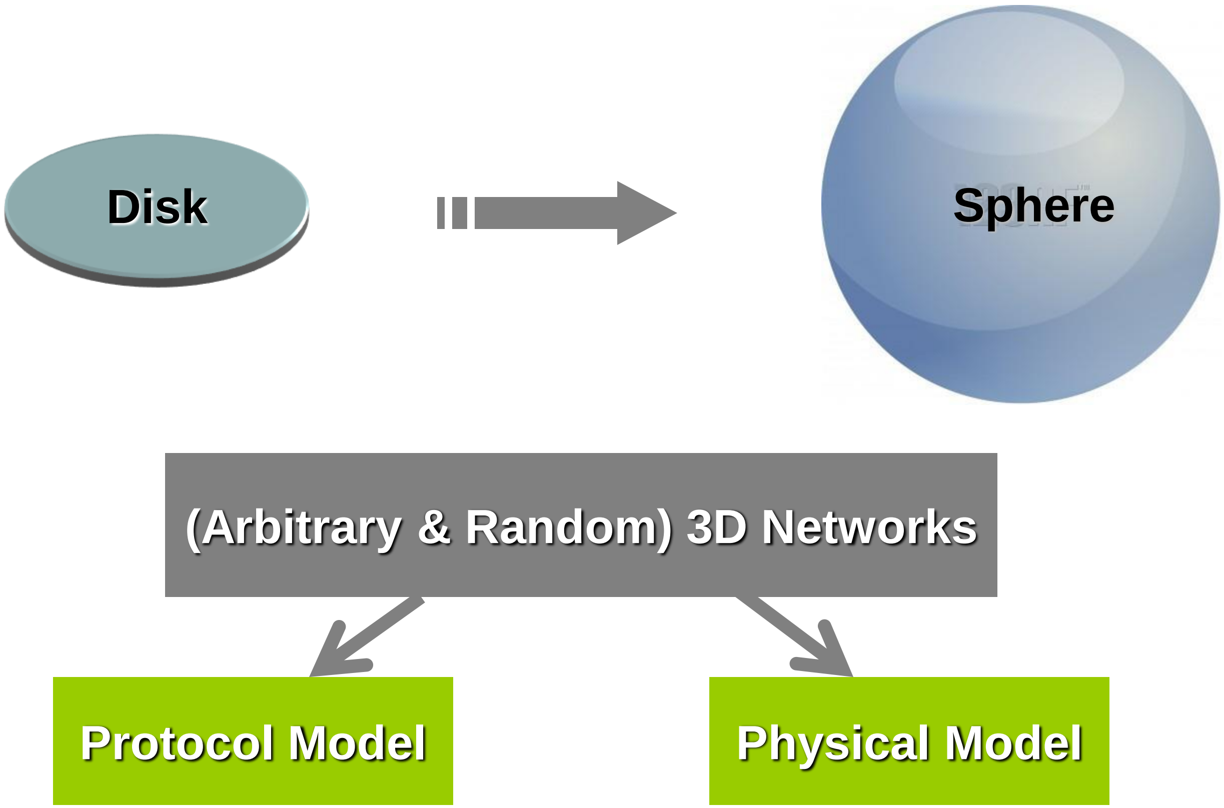


3D Wireless: Capacity (1)

- [Gupta & Kumar, 2000]



3D Wireless: Capacity (1)

- Main results:

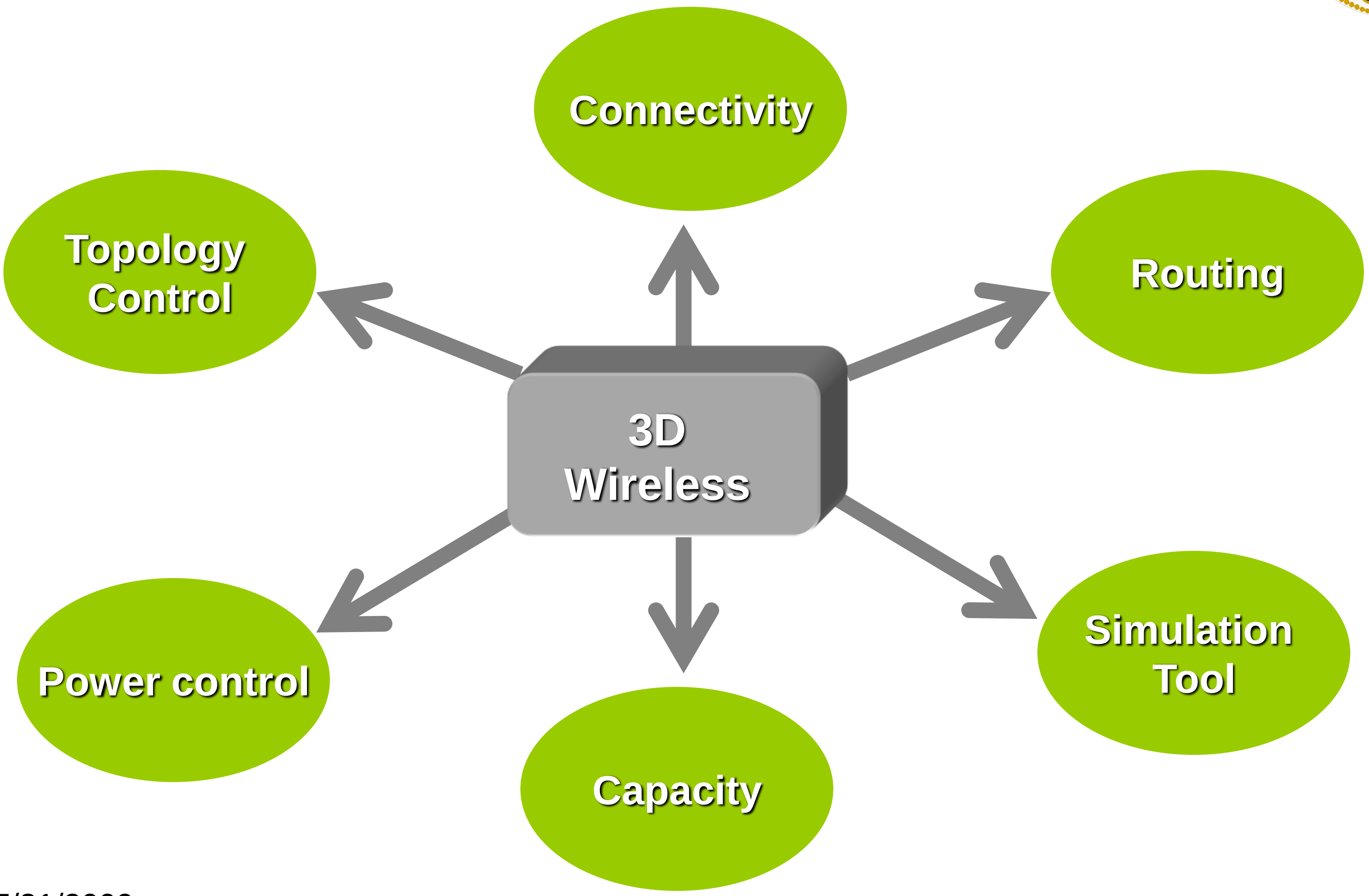
- Under a Protocol Model of noninterference, in a random 3-D network of n nodes randomly located in a sphere, with each node capable of transmitting at *W* bits/sec and using a common range, the throughput that each node can obtain for a randomly chosen destination is

$$\Theta\left(\frac{W}{(n \log^2 n)^{\frac{1}{3}}}\right)$$

- A 3D wireless network has higher capacity than a 2D wireless network.

3D Wireless: Capacity (2)

- [Lin et al, ChinaCom07]
- Derive the expected network throughput of a 3D wireless network, as a function of : ***number of flows*** sharing the space, ***path loss*** exponent, and background ***noise***
- Derive the CDF and PDF of the distance in 3D space
- Then find the threshold (r = radius) at which concurrent links can take place
- Network capacity will increase


Connectivity
Topology Control
Routing
3D Wireless
Power control
Capacity
Simulation Tool

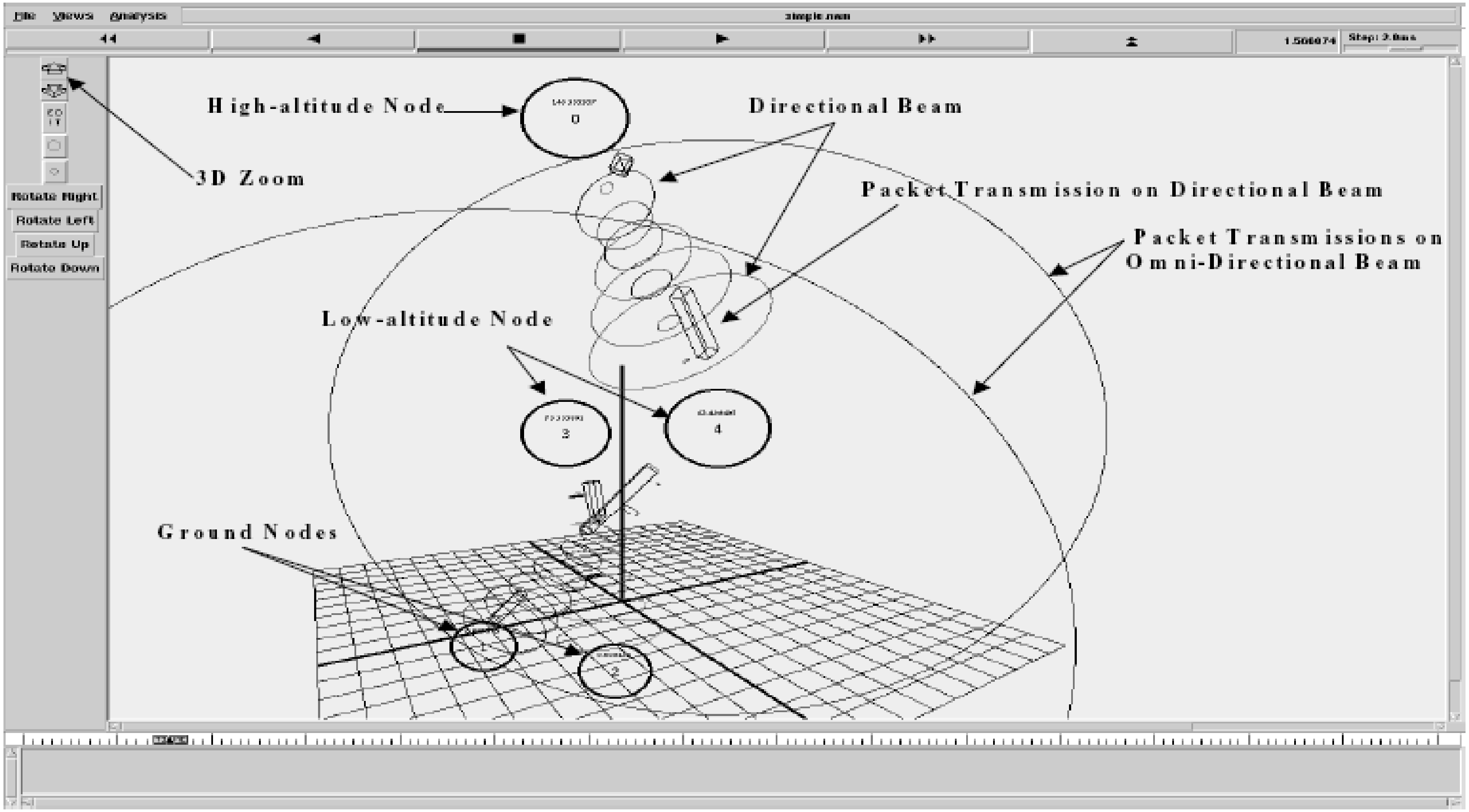
3D wireless: Simulation tool

- [HRL, 2002]

- Modify NS-2 and NAM to enable and support 3D wireless:

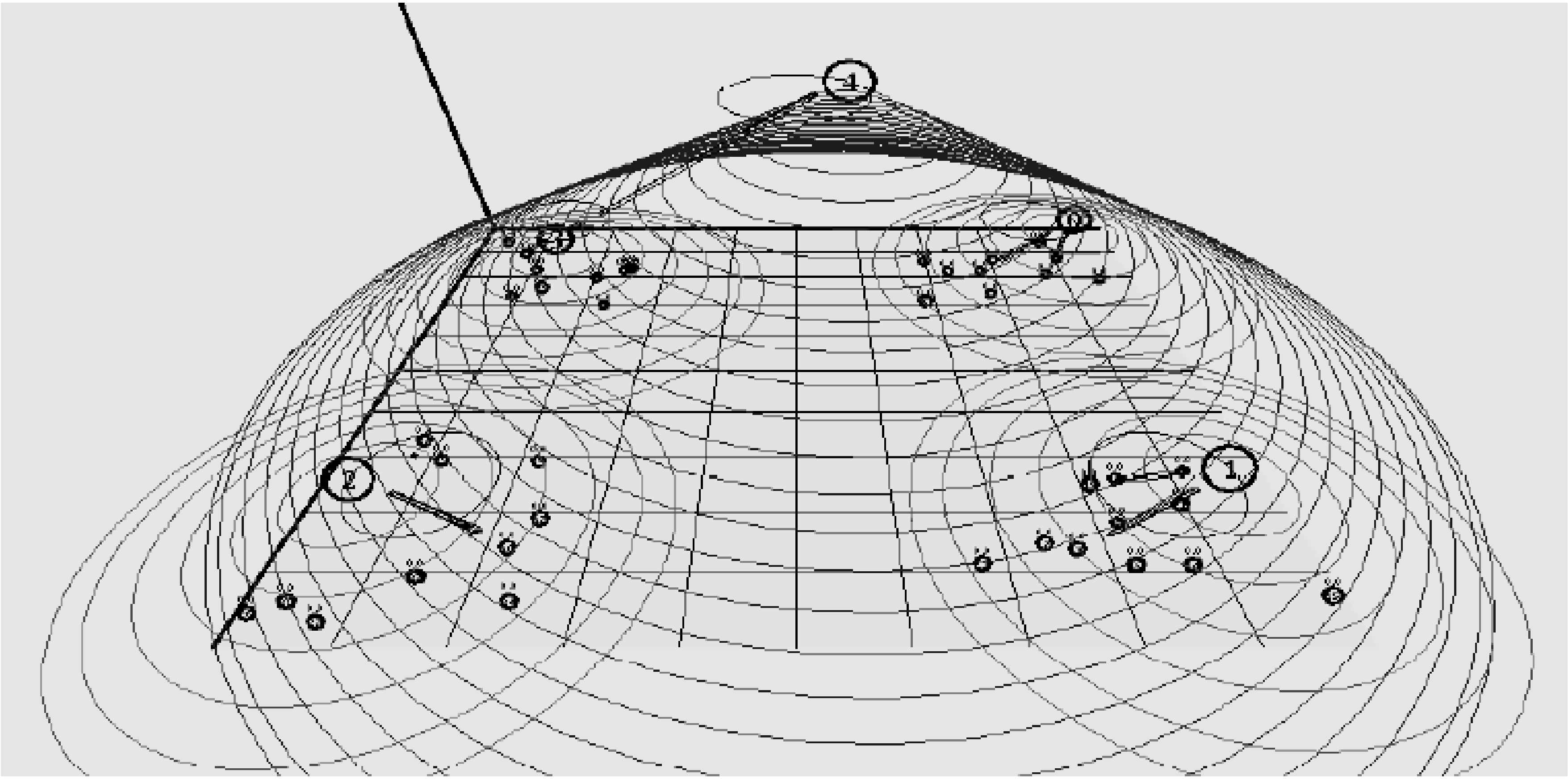
  - extending the boundary of the nodes' space to Z axis
  - specifying the nodes' mobility trajectories in 3D instead of 2D
  - modifying antenna and propagation objects to support directional beams

3D wireless: Simulation tool



Source: Bo Ryu, Tim Andersen, Mohin Ahmed, Tamer Elbatt, and Alon Peterson, "Research Tools for 3-D Mobile Ad-hoc Networking with Directional Antenna," HRL Lab 2002

3D wireless: Simulation tool



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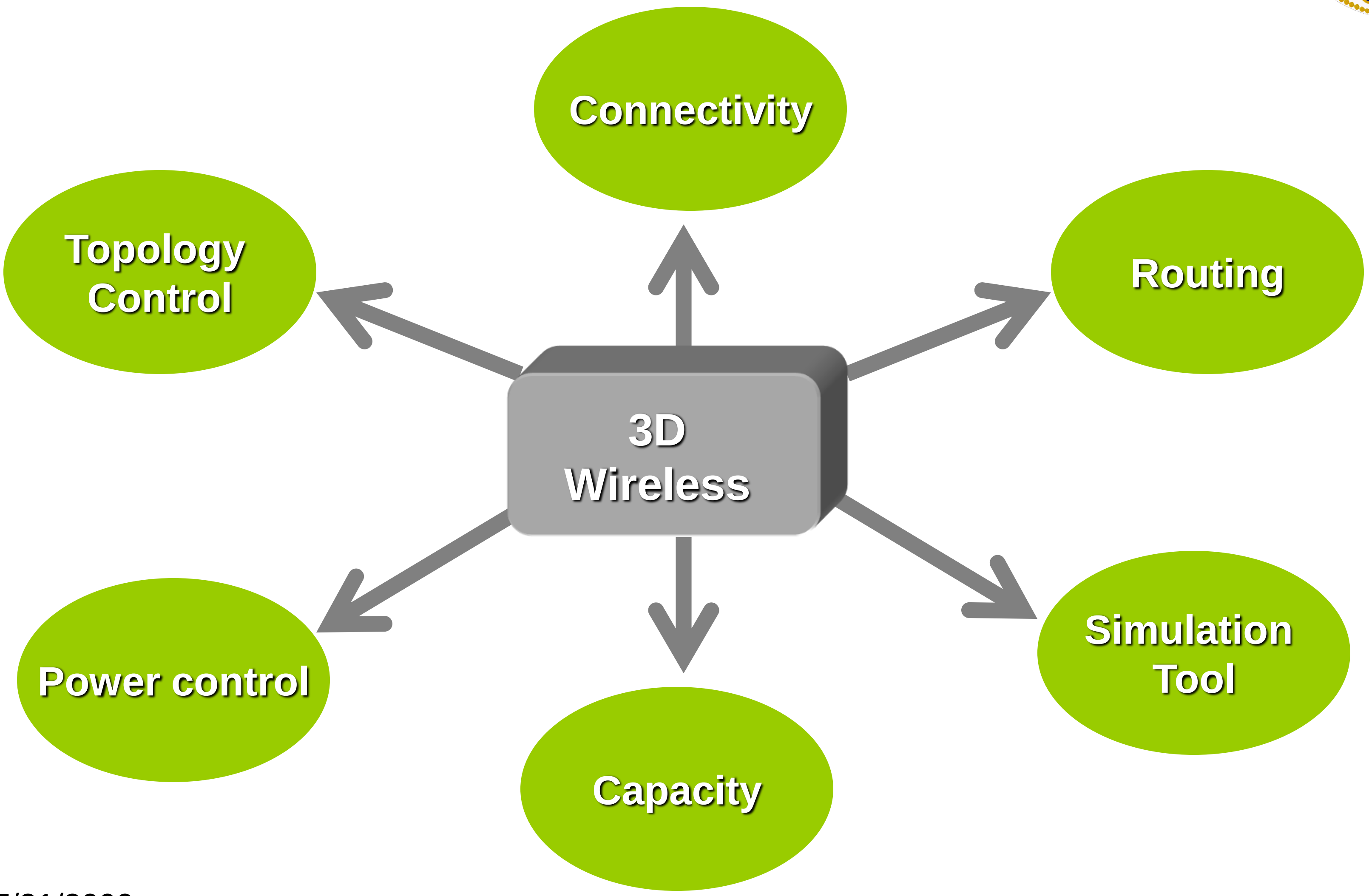
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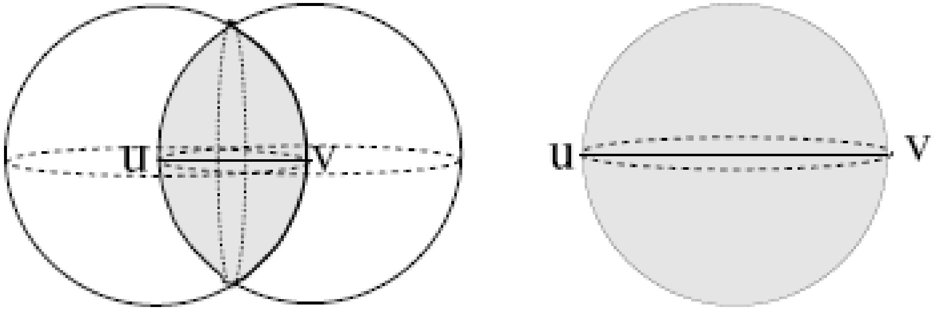
3D wireless: Connectivity, Topology and Power Control (1)

- [Bahramgiri et al, WiNet06]
- Control the topology of a multi-hop wireless network
- They extend the Cone-Based Topology Control (CBTC) algorithm (which is in 2D) to the third dimension
- Varying the transmission power at each node
- The main idea here is that each node increases its power until there is no 3D-cone of degree α in which there is no other node.

3D wireless: Connectivity, Topology and Power Control (2)

- [Wang et al, Globecom06]
- Investigate power efficient topology control protocols for 3D wireless networks
- Extend several 2D geometric topologies (GG, RNG, Yao-based graph) to 3D case

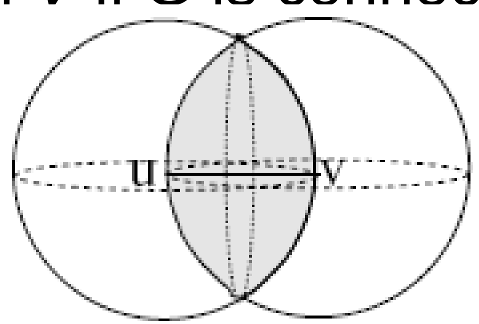


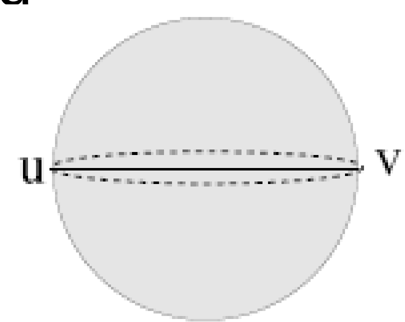
GG & RNG

- The *Gabriel graph* (GG) contains edge *uv* ∈ G iff *disk*(*u*, *v*) contains no other node of *V* , where *disk*(*u*, *v*) is the disk with edge *uv* as a diameter

- The *relative neighborhood graph* (RNG), consists of all edges *uv* ∈ G such that the intersection of two circles centered at *u* and *v* with radius *uv* does not contain any node from the set *V*

- Both GG and RNG are connected, planar, and contain the Euclidean MST of *V* if G is connected





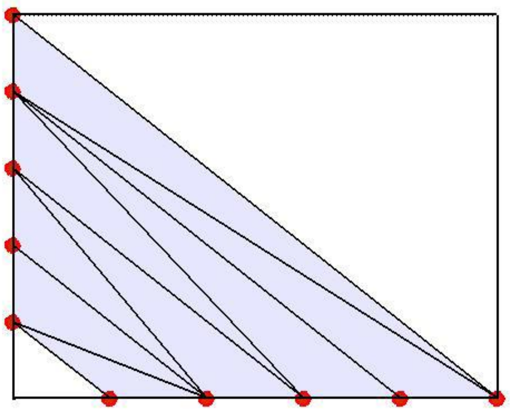
3D wireless: Connectivity, Topology and Power Control (3)

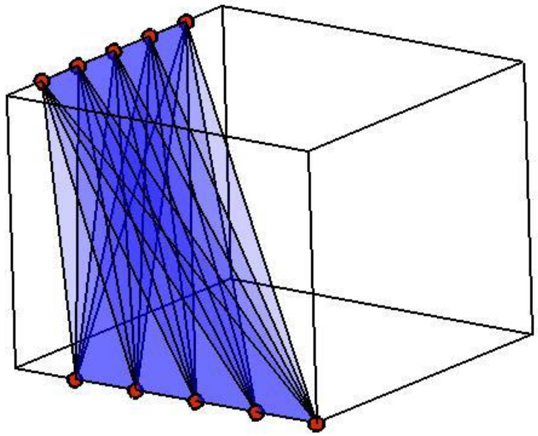
- [Wang et al, ICCCN08]
- Is an extension work for [Wang et al, Globecom06]
- Topology control considering fault tolerant

Delaunay Triangulation

- Delaunay Triangulation can be extended to n-dimensions

- **Definition** (Wiki) **:** For a set P of points in the (*n*-dimensional) Euclidean space, a Delaunay triangulation is a triangulation DT(P) such that no point in P is inside the circum-hypersphere of any simplex in DT(P)

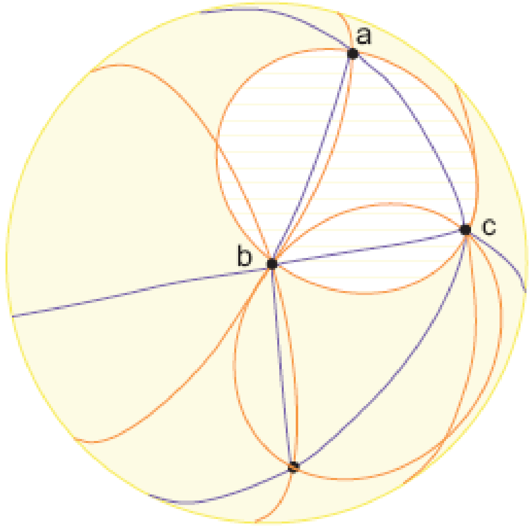


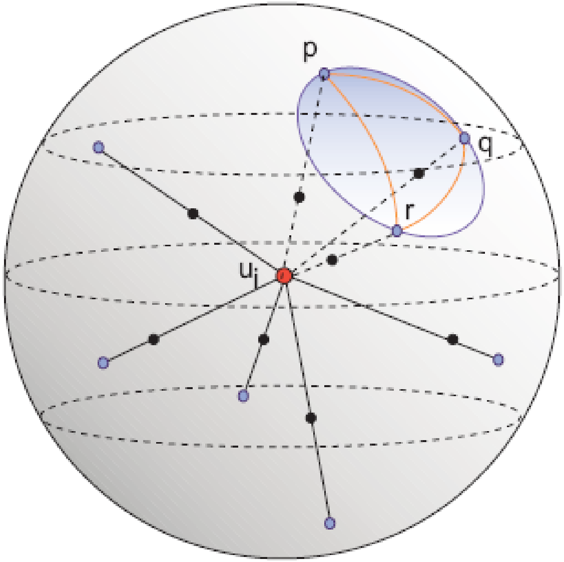


- **Delaunay Triangulation** of n points in 2-D will have at most O(n) triangles while in 3-D it can have $O(n^2)$ tetrahedra

3D wireless: Connectivity, Topology and Power Control (4)

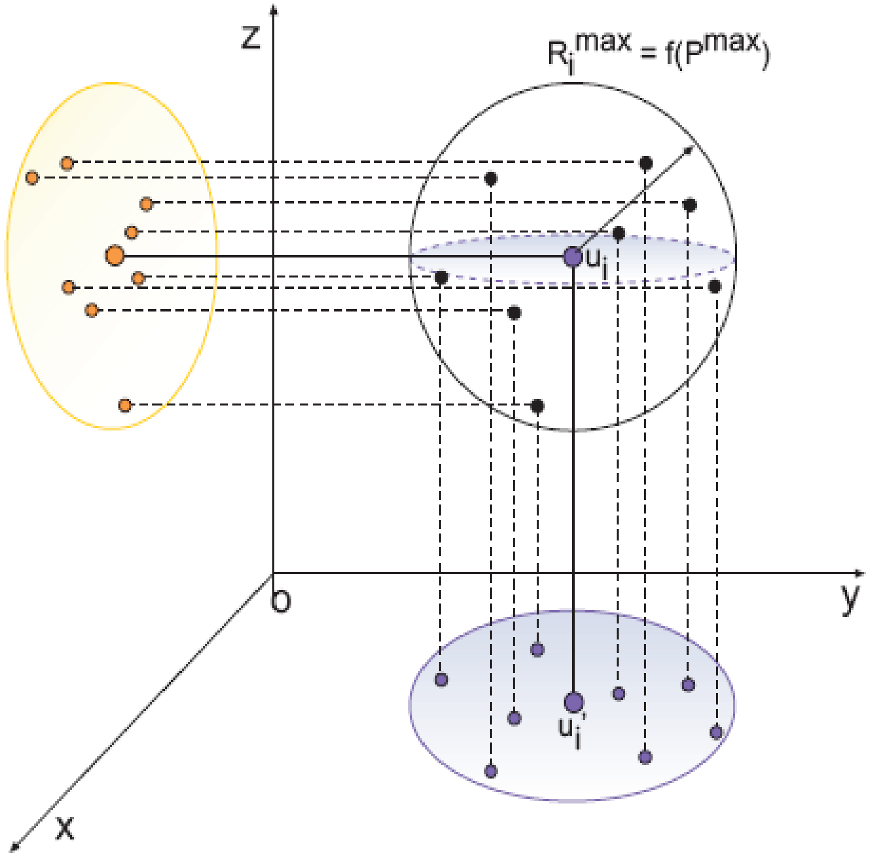
- [Ghosh et al, Secon07]
- Spherical Delaunay Triangulation (SDT)
- Theorem: let each node u_i construct SDT of its projected neighbor locations on the spherical surface for some power level P_i, If the largest surface area Ω_i^{max} of the spherical cap for node u_i satisfies $\Omega_i^{max} \leq 2.72\ R_i^2$ ($\forall\ u_i$) then network topology is connected

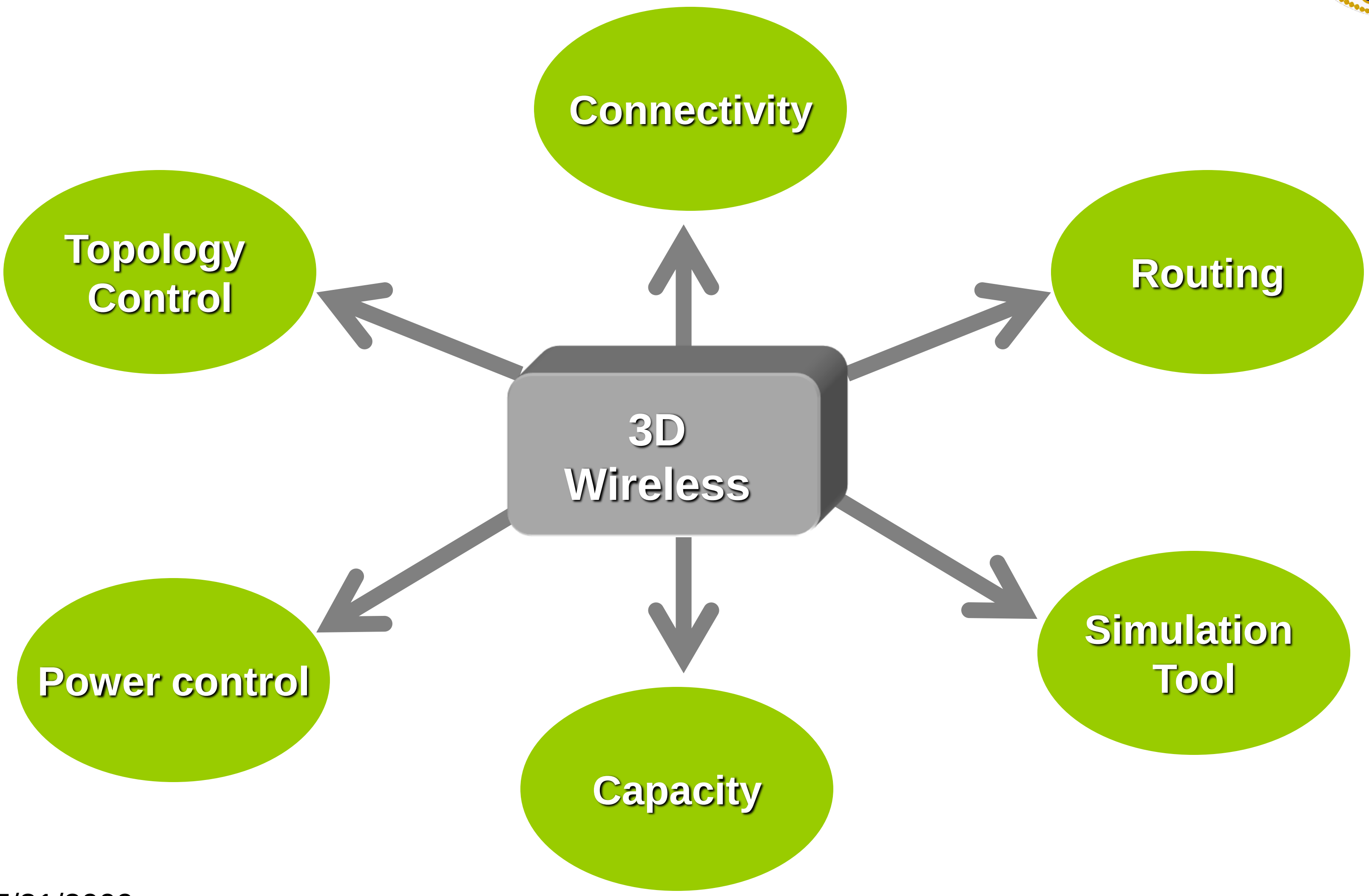




3D wireless: Connectivity, Topology and Power Control (4)

- Heuristic Extension to CBTC

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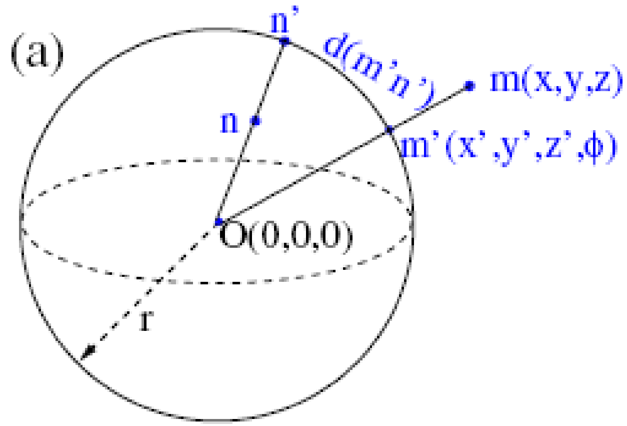
3D Wireless: Routing (1)

- [Li et al., ICC08]
- Investigate how to design *load balancing routing* for 3D networks
- Propose a 3D load-balancing routing method, called *3D Circular Sailing Routing* (CSR)
- CSR maps the 3D network onto a sphere and routes the packets based on the spherical distance on the sphere

3D Wireless: Routing (1)

- Projection on 3D Sphere

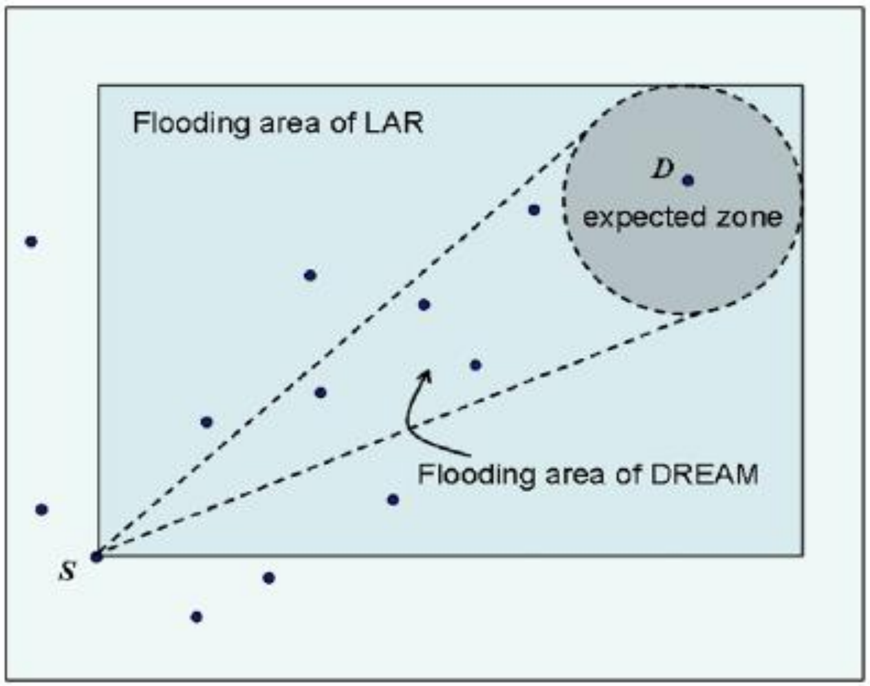
- Any point *m*(*x, y, z*) in R maps to *m*(*x, y, z, φ*) on the 3D sphere, *φ* is the Euclidean distance from *m* to the center of the sphere
- The projection gives each node a position on the surface of the sphere
- For routing: the distance between any two nodes is measured by the shortest arc of the great circle passing through the nodes' projections

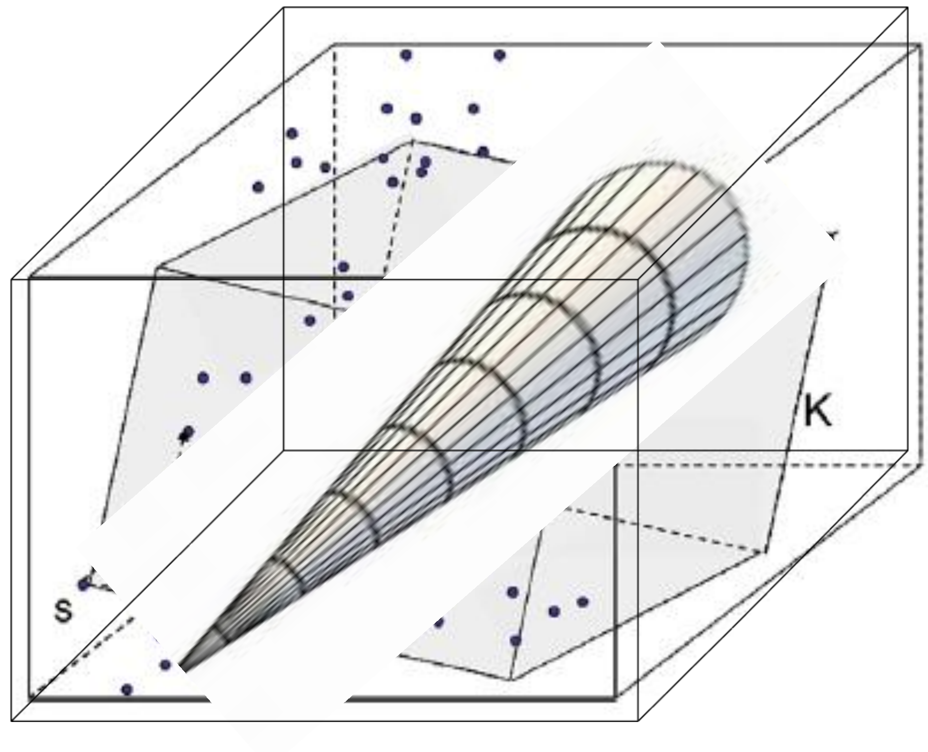


3D Wireless: Routing (2)

- [Abdallah et al., ComCom08]
- Extend the position-based wireless routing algorithms from 2D to 3D
- Examples: LAR, DREAM, GPRS, etc
- The 3D technique improves the delivery rate of the wireless network

3D Wireless: Routing (2)





Conclusion

- 3D wireless early studies focused mainly on network connectivity
- Recently, Routing, Channel Assignment, and Topology Control are more considered in 3D
- Extending algorithms from 2D to 3D is not always easy and efficient

References

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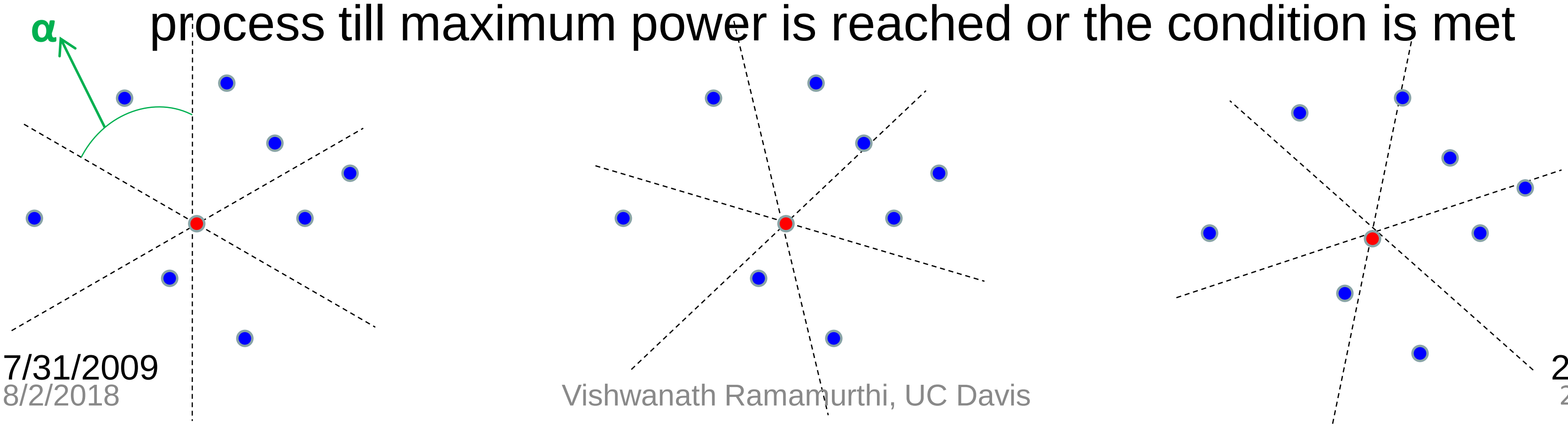
Backup Slides

CBTC(α) - Phase 1

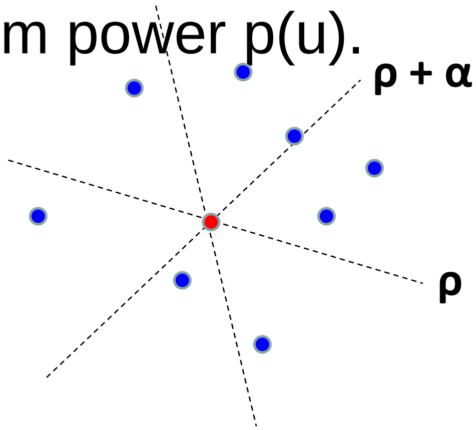
- Phase 1:
  - Each node starts with minimum power $p = p_0$
  - Each node u broadcasts neighbor discovery message using power p
  - Nodes which receive a neighbor discover message send back an acknowledgement
  - On receiving acks node u records all acks and the directions they come from
  - Determine whether there is one neighbor in every cone of α-degrees centered at u. Increase power level p and continue process till maximum power is reached or the condition is met



CBTC(α) - Phase 1

- $p(u) < P_{max}$ is the minimum power to find a neighbor in every cone with angle α

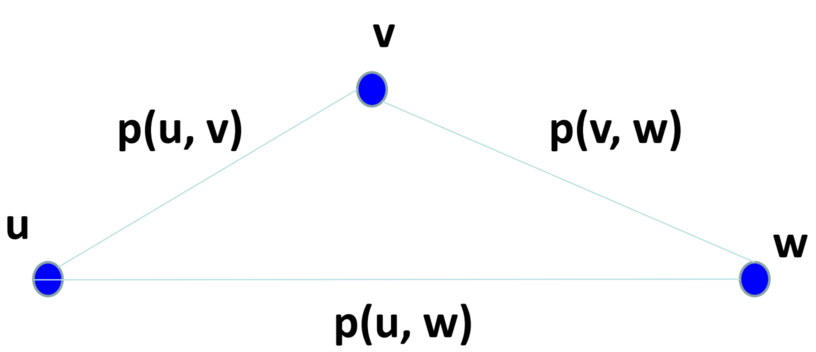
- Property: For each node u and for each angle ρ ($0 \le \rho \le 2\pi$), if there is a node in the cone C = [ρ, ρ+α] when sending with maximum power P_{max}, then there is a node v' in cone C when sending with minimum power p(u).



- This property implies that CBTC achieves the same connectivity as that with scheme where all nodes use maximum power

CBTC – Phase 2

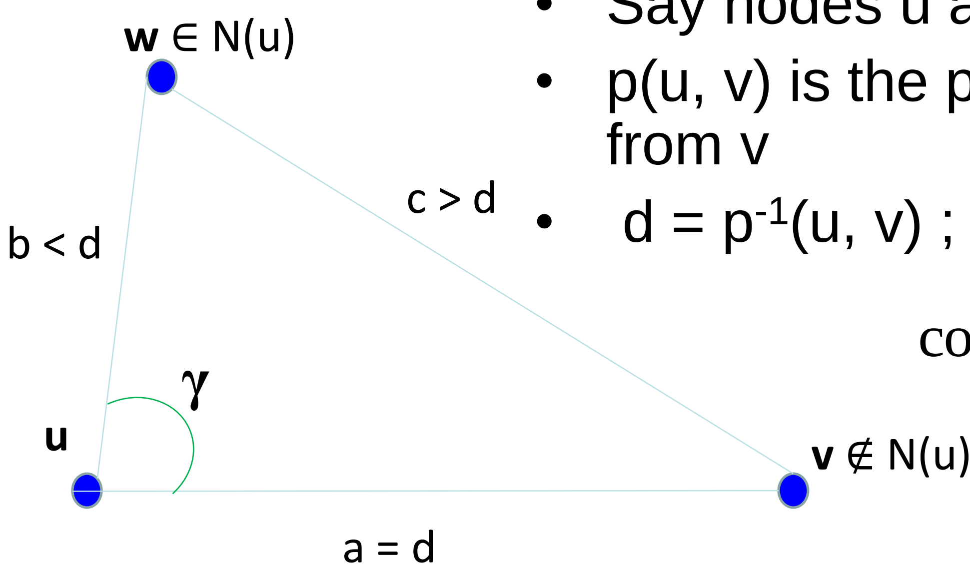
- This phase removes redundant edges without impacting the connectivity
- This phase reduces the node degrees and hence reduces interference
- If there are two nodes v, w ∈ N(u) and w ∈ N(v) such that
  - $p(u,v) \leq p(u,w)$
  - $p(u,v) + p(v,w) \leq q.\ p(u,w)$
- Remove w from N(u)



- With q = 1, node w is removed from N(u) if an indirect path consumes less power than a direct path

Value of α for CBTC

- Let G be the topological graph formed by the CTBC algorithm and let H be the graph formed using P_{max} at all nodes
- Theorem: Suppose we use **$\alpha \leq 2\pi/3$** and H is connected. Then graph G obtained by CTBC is also connected



- Say nodes u and v are not connected
- p(u, v) is the power required to reach v from v
- $d = p^{-1}(u, v)$; **$p^{-1}(u) < d$**

$$\cos\gamma = \frac{a^2 + b^2 - c^2}{2ab} \leq \frac{b^2}{2db} < \frac{1}{2}$$

$$\gamma > \pi/3 \geq \alpha/2$$

- There is a cone C = [-α/2, α/2] with no node v' ∈ N(u)