Partial Delaunay triangulation and Bluetooth scatternet formation

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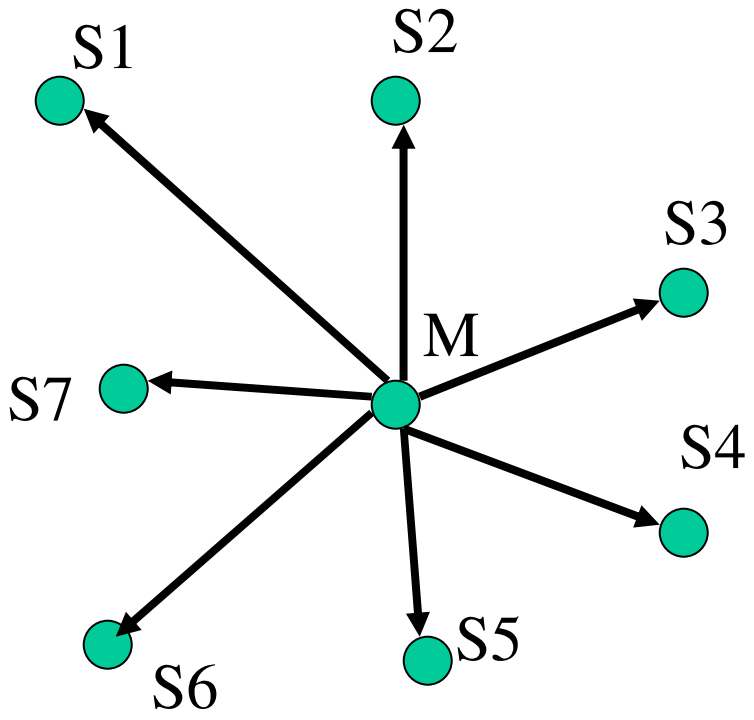
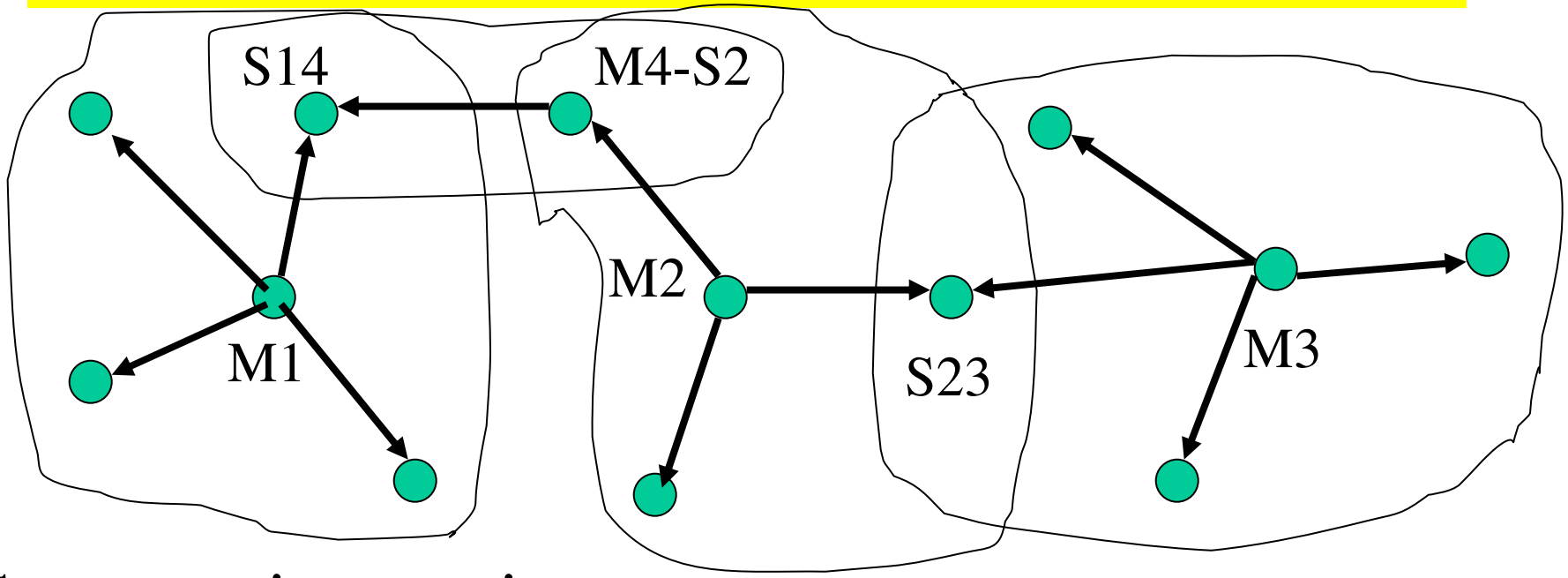
Bluetooth - piconet

- Short-range
- Master-slave
- Frequency hopping
- PICONET = master + K slaves, K≤7
- Additional slaves must be parked



Bluetooth - scatternet



Connect piconets into scatternet

Avoid master-slave bridges

Bridges participate in piconets on time division basis

Minimize number of slave roles

Scatternet by growing tree

- Ramachandran, Kapoor, Sarkar, Aggarwal 2000:
  grow tree from root, master not always directly connected to its slave
- Zaruba, Basagni, Chlamtac 2001:
  grow tree from root, at most 5 slaves per master;
  if >5, select two connected slaves, link them, and disconnect one;
  Multiple blueroots extension
- *Communication overhead and Scatternet maintenance?*
- Salonidis, Bhagwat, Tassiulas, LaMaire 2001:
  centralized, max 36 nodes
- Law, Mehta, Siu 2001:
  single-hop networks (complete graph)

Clustering based scatternet formation

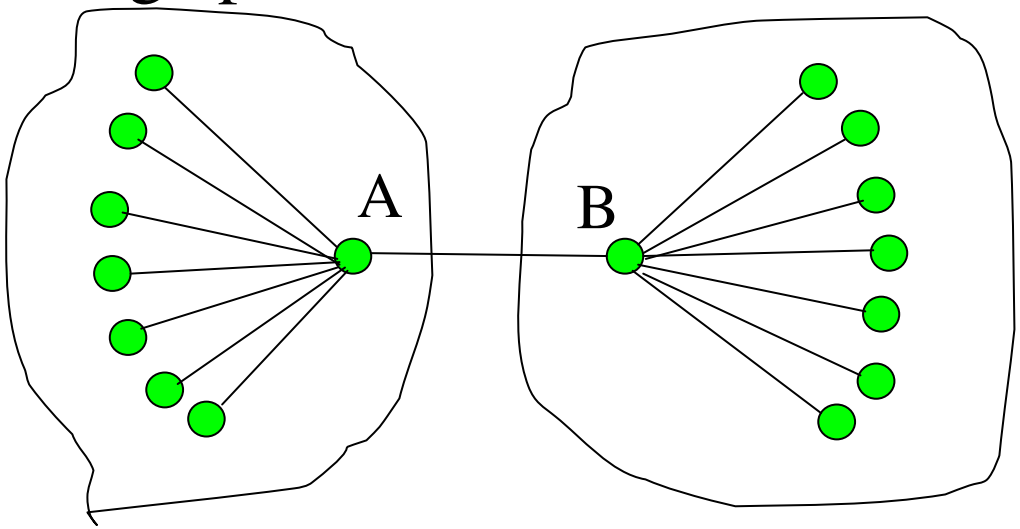
- Basagni, Chlamtac, Petrioli 2001
- Detect neighboring nodes by paging and scanning
- Apply clustering process
- Clusterheads = masters
- Nodes in a cluster = slaves
- Connect clusters = bridge piconets
- *degree (number of slaves) not limited to 7*
- parking and unparking process ?
- Maintenance is not localized – chain effect ?

Neighbor discovery in Bluetooth

- Each node decides with probability 0.5 between inquiry and inquiry-scan modes
- Senders and receivers change frequencies in mutually random pattern (? 32 frequencies)
- If sender and receiver are on the same frequency at some time, they discover each other, and establish master-slave relation
- In multi-hop networks, overall connectivity established quickly, but full awareness of all neighbors is slow

Scatternet by random key clustering

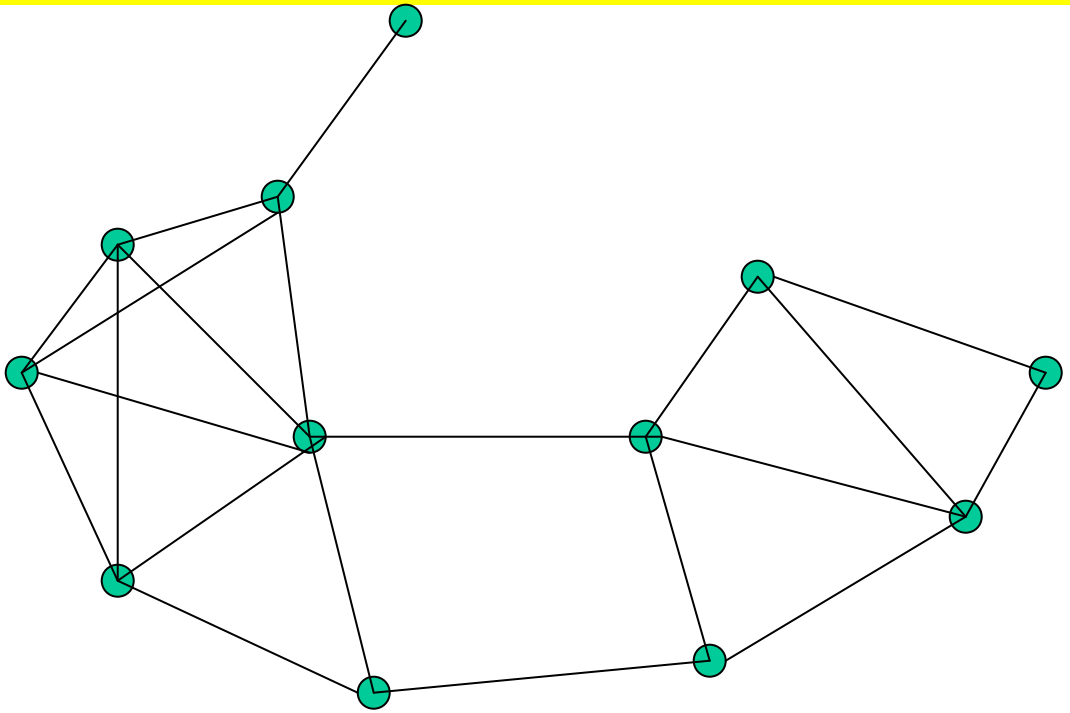
- Wang, Thomas, Haas 2002
- Guerin, Kim, Sarkar 2002
- Node decides to be master at random
- and then ‘slaves’ up to seven neighboring nodes
- Connect scatternet by bridge piconets
- No bridge piconet, disconnected scatternet ?



Degree limited connected scatternet formation

- Li, Stojmenovic 2001 – clustering based
- Stojmenovic 2002 – dominating set based
- *Phase I* = create unit graph and construct a planar connected structure in localized manner
- *Phase II* = eliminate some edges in the planar structure to limit the degree of each node to 7
- *Phase III* = decide master-slave roles between two nodes of each edge in the structure
- Only phase III differs in clustering vs. dominating set based formation; planar structure is optional

Scatternet formation – phase I



Unit graphs

radius

Create unit graph

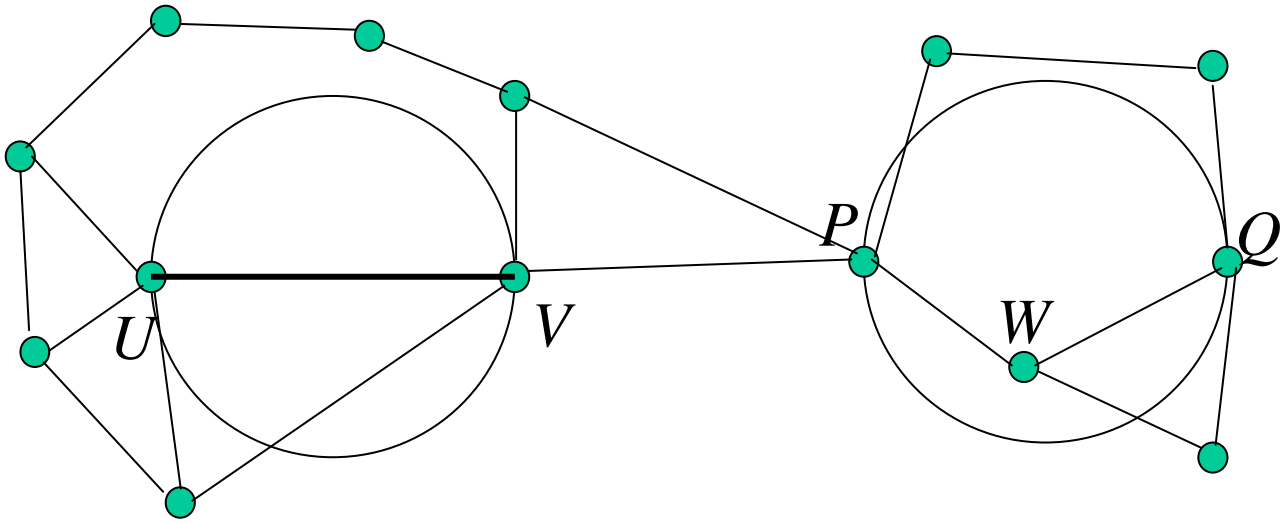
Assumption: Each node is aware of its position and learns position of all neighbors within transmission radius

Construct planar structure in localized manner:

Gabriel graph **GG**, Relative neighborhood graph **RNG**,

Partial Delaunay triangulation **PDT**

Gabriel graph



Gabriel graph GG(S) contains an edge (U,V)
iff the disk with diameter (U,V)
contains no other point from S

Computing GG from unit graph requires no message exchange

Gabriel graph properties

Planar – no two edges intersect

Connected - Contains MST (minimal spanning trees)

Unit graph contains MST

Planar graph with n nodes has at most 3n-6 edges

Average degree of a planar graph is < 6

RNG has average degree < 2.4 = too sparse

RNG is subset of GG

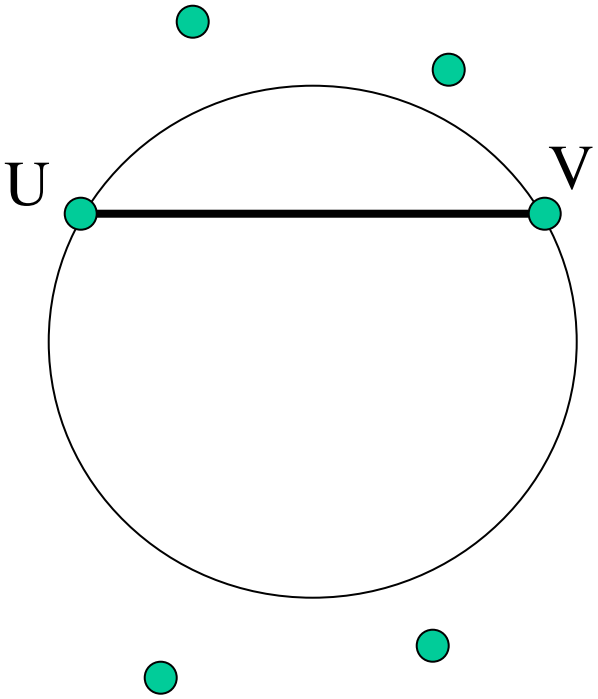
Intersection of GG and unit graph is connected and planar

Partial Delaunay Triangulation

Li, Stojmenovic 2001 RNG $\subseteq$ GG $\subseteq$ PDT $\subseteq$ DT

Delaunay Traingulation = dual Voronoi diagram

UV in DT iff there exist a circle with chord UV without other nodes inside it



Test disk with diameter UV:

If empty then UV in PDT

If nodes inside disk on both sides then not in PDT

Find smallest angle on both sides of UV

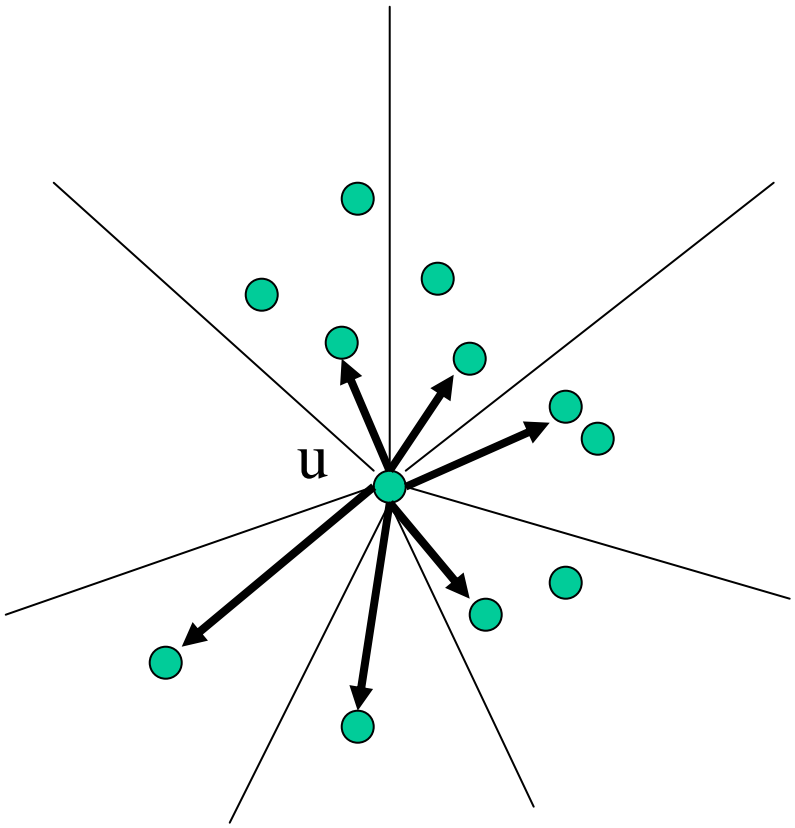
If together $\geq\pi$ then not in PDT

If together $<\pi$ then in PDT iff both are neighbors, using 1-hop or 2-hop info

PDT= portion of DT which can be decided locally

Yao graph

k=7

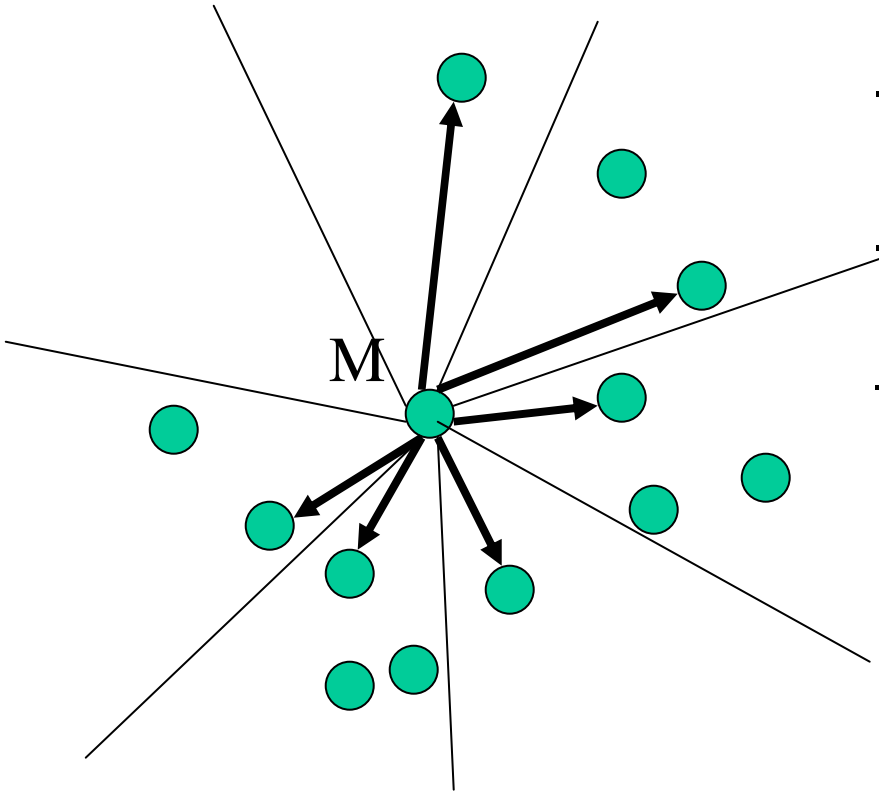


Divide into k equal cones around u

Find closest point in each cone, if any

Limiting degrees – cluster based

Phase 2: Applied on **active** nodes = nodes with highest keys among undecided neighbors



- apply Yao construct
- delete other edges
- undirectional graph remains

Deciding master-slave roles

-Key= Bluetooth ID (one-hop neighbor discovery)

-Key= (degree, ID) (two-hop neighbor information needed)

-Active node decides on roles on each undeleted edge:

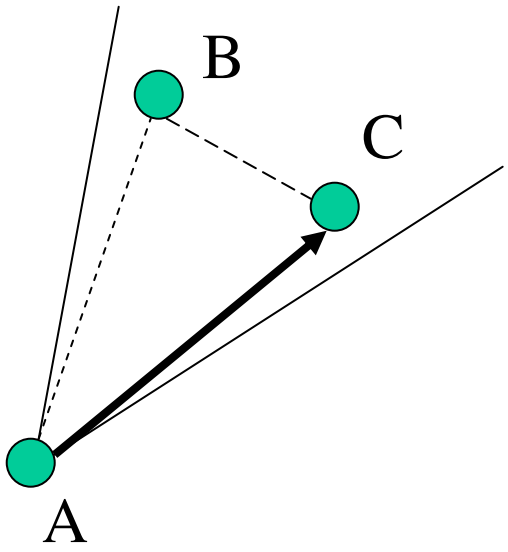
-Higher original key, or

-Clustering based: clusterhead= master, border node slave and master role given to other neighbor, which can be clusterhead or the second node for two-node gateway piconet

Yao construct preserves connectivity

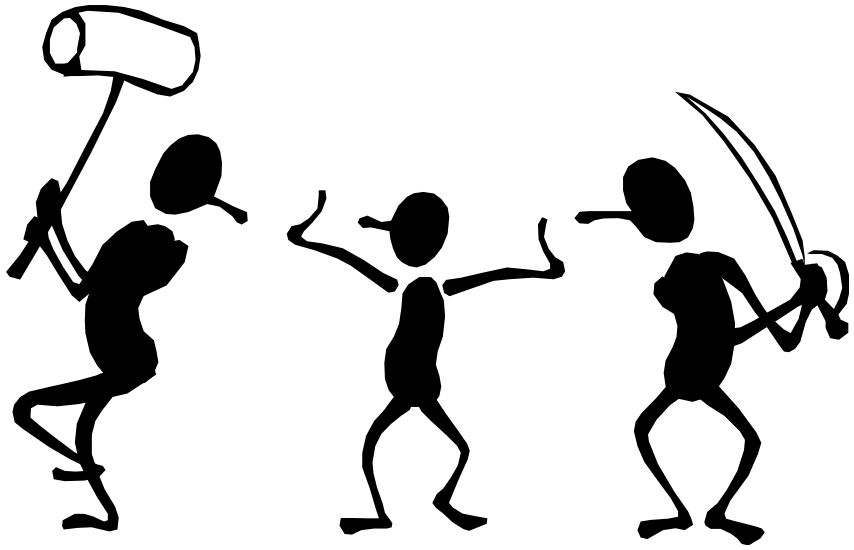
- SSort all edges of unit, GG or RNG by key=(length, survive), survive=0 if bi-directional in Yao, =1 if not
- CConstruct MST by considering edges in increasing order, include if no cycle created

If AB and BA not in Yao then $\exists$ C, AB $\leq$ AC, BC < AB $\Rightarrow$ BC, AC already considered for MST and connected, AB not needed in MST
IF AB is directional then $\exists$ path between them consisting of shorter edges and an edge of same length but bi-directional (proof involved) $\Rightarrow$ AB not needed in MST



Future work

- Experiments
- Bluetooth scatternet formation without position information
- Routing in scatternets
- Power efficient scatternets
- Denser planar graphs ?
- Neighbor discovery and non-unit graphs
- Scheduling, capacity, …
- Three-dimensional scatternets



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