Bluetooth scatternet formation

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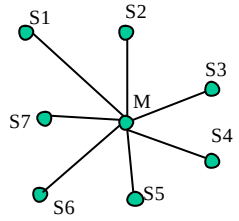
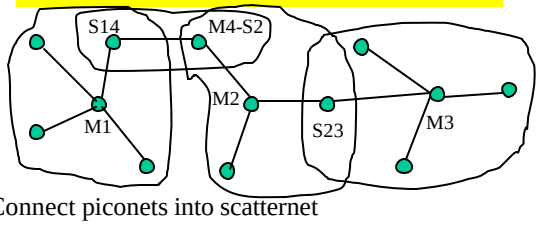
Bluetooth - piconet

- 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

Scattenet by growing tree

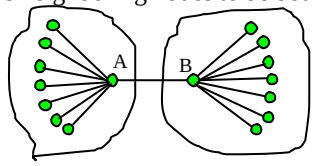
- Ramachandran, Kapoor, Sarkar, Aggarwal 2000:
  grow tree from root, master not always directly connected to its slave
- Zaruba, Basagni, Chlamtac 2001:
  grow tree from root, at most 5 slaves per master; if >5, select two connected slaves, link them, and disconnect one;
  Multiple blueroots extension
- *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 ?

Degree limited clustering based

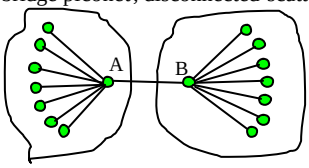
- Balaji, Kapoor, Nanavati, Ramachandran 2001
- Master = Highest degree node (degree for undecided neighbors only), up to seven neighbors with smallest degree are slaves
- Allows neighboring nodes to be both masters



No bridge piconet, disconnected scatternet ?

Scatternet by random key clustering

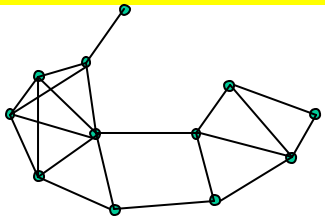
- Wang, Thomas, Haas 2002
- Guerin, Kim, Sarkar 2002
- Node decides to be master at random
- and then 'slaves' up to seven neighboring nodes
- Connect scatternet by bridge piconets
- No bridge piconet, disconnected scatternet ?



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

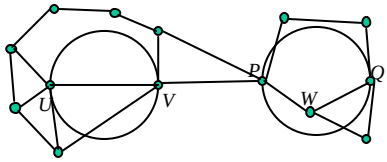
Assumption: Each node is aware of its position and learns position of all neighbors within transmission radius

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

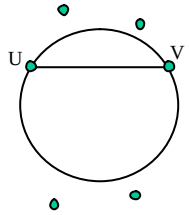
RNG is subset of GG

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

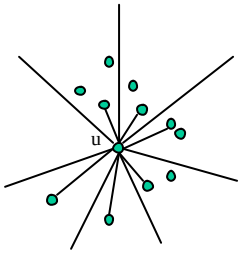
If together $\geq\pi$ then not in PDT

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

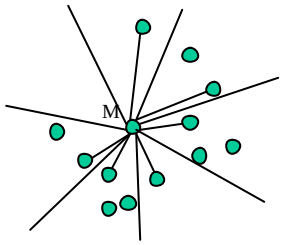


Divide into k equal cones around u

Find closest point in each cone, if any

Limiting degrees - Yao structure

Phase 2: Applied simultaneousy on nodes of unit graph, GG, RNG or PDT with degree >7 = out-degree limited



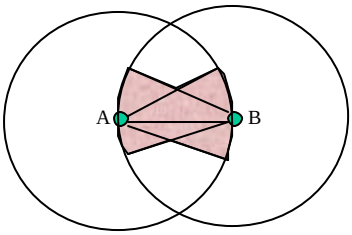
Limit in-degrees:

1) Keep only bi-directional edges: Y, YG, YR, YP
2) Apply reverse Yao construct: YY, YYG, YYR, YYP

1) is subset of 2)

Yao bidirectional edges is connected

- Contains RNG as subgraph (Wang, Li 2002)



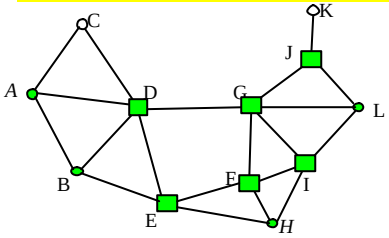
Assigning master-slave roles

- Phase 3: assigning roles to endpoints of each edge
- Solution 1:
  key=(degree, id),
  higher key node on each edge is master
  problems:
  master node may have many slave roles,
  too many piconets
- Solution 2:
  cluster the nodes in the structure
  create piconet from slave-slave edge iff
  the edge belongs to RNG
  problem: chain effect, no localized maintenance

Dominating set based master-slave roles

- Phase 3: assigning roles to endpoints of each edge
- Localized maintenance
- Solution 3:
  find a dominating set,
  key=(dominating, degree, id)
  higher key node on each edge is master
  Two non-dominating nodes may not be connected
  Nodes in dominating set only can be masters

Dominating sets



Wu, Li '99

Higher degree priority: [SSZ]

Localized maintenance;

No communication overhead

C,K not intermediate = any two neighbors connected

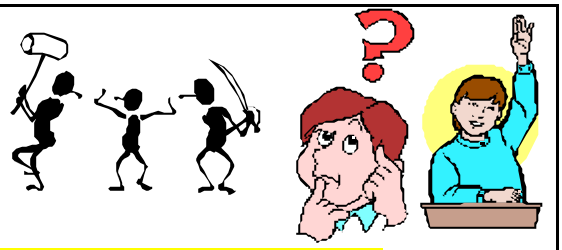
A,B,H,L not inter-gateway = covered by a neighbor

Any path via H can be replaced by a path via F (EHI → EFI)

Gateway nodes = not covered by two connected neighbors

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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