Broadcasting (flooding) algorithms in wireless (ad hoc) networks

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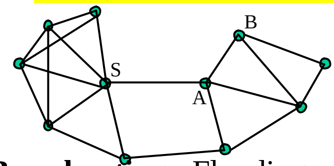
Multi-hop wireless networks



Unit graphs
radius
Sensor networks
Mobile ad hoc networks
Rooftop networks

Broadcasting = Flooding =

sending message from one node S to all other nodes

One-to-all and **one-to-one** networks

Blind flooding = message retransmitted once by each node **one-to-all** / each edge **one-to-one**

Power efficiency ? Retransmission by A and B suffices

Broadcasting - applications

- Alarm signal
- Route discovery in non-GPS routing
- Paging
- Destination search in GPS routing:
  - Source S *broadcasts* short message that will search for destination D
  - Destination D will *route* back to S with a short message location report
  - S will *route* full message to D
- Location updates for routing, geocasting, …

Broadcasting in one-to-all model

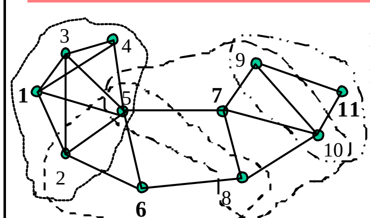
- Centralized vs. **localized** decisions ?
- **Average** or worst case performance analysis ?
- **Localized maintenance** or chain effect ?
- **Deterministic** or stochastic decisions ?
- Guaranteed delivery **yes= reliable** (if MAC ideal) or no ?
- Set of transmitting nodes depends on source?

  yes / **no** (stable sets allow scheduling active periods = scheduling node activity problem)
- **Assumptions** about local knowledge:
  - 1-hop neighbors,
  - 1-hop neighbors + degree of neighbors,
  - location of 1-hop neighbors,
  - 2-hop neighbors

Dominating set = transmitting nodes

- Each node is either in dominating set or is a neighbor of a node from dominating set
- Broadcasting by retransmiting from nodes in a *connected dominating set*
- Each node receives the message if retransmissions are collision-free
- Finding (connected) dominating sets of minimal size is NP-complete problem (centralized)
- Find connected dominating set of small size by a localized algorithm
- Deterministic: Clustering, covering, forwarding neighbors

Broadcasting via clustering one-to-all



Lauer 1988

Pagani, Rosi 1999

Lowest ID clustering

Lin, Gerla 1997

Clusterheads: 1,6,7,11

Borders: 2,5,8,9,10

Maintenance overhead

Broadcasting:

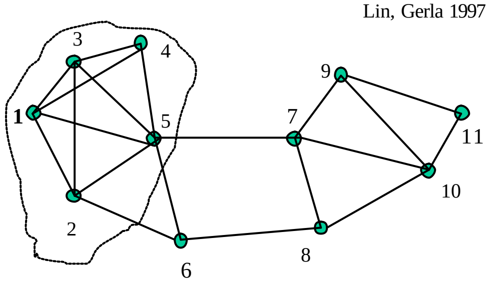
clusterheads and borders retransmit:

9 out of 11 nodes (one-to-all)

Experiments: ~65% for any number of nodes and any average degree

Lowest ID clustering – first cluster

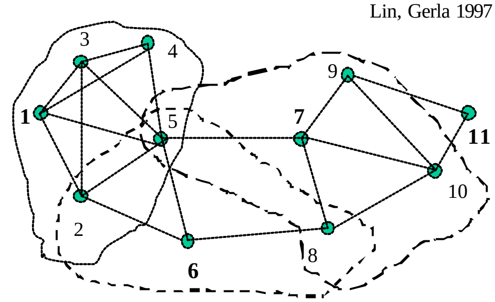
Lin, Gerla 1997



Clusterhead = lowest ID among undecided neighbors next?

Lowest ID clustering – second and third clusters

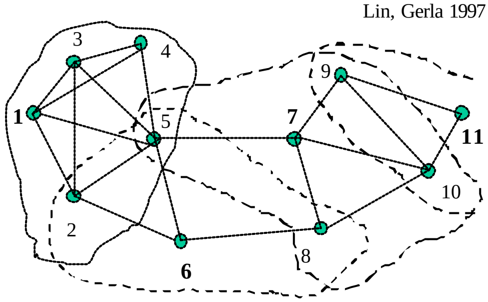
Lin, Gerla 1997



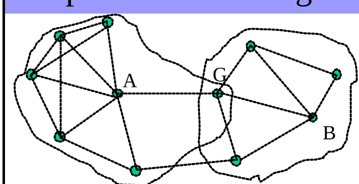
next ?

Lowest ID clustering – fourth cluster

Lin, Gerla 1997



Improved clustering for broadcasting



ConID=(*degree*, *id*) Clusterheads=

higher *degree* nodes, lower *id* if degrees same

Clusterheads: A, B; border: G - Retransmission by 3 out of 11 nodes

Experiments: ~52% for any number of nodes and any degree

ConID/LowestID ~80%

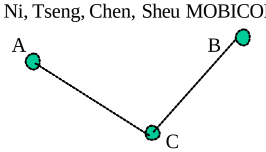
Chain effect with clustering

- Mobility or change in the activity status of a single node may trigger global update of cluster structure
- Localized algorithm but not localized maintenance
- Localized maintenance is preferred
- Set of border nodes in cluster structure can be reduced (with some overhead)

Broadcast storm problem

Redundancy, collision, contention:

Ni, Tseng, Chen, Sheu MOBICOM 1999



Hidden terminal problem: collision at C

RE: ratio of connected nodes receiving message

SRB: ratio of nodes that do not retransmit the message

REachability and **S**aved **R**e**B**roadcasts

Probabilistic, counter, distance, location and cluster based broadcasting

Ni, Tseng, Chen, Sheu MOBICOM 1999

(delivery not guaranteed even for collision free broadcasting!)

Probabilistic: retransmit with fixed probability p

Counter-based: retransmit if <C copies received

Distance-based: retransmit if distance to each transmitting neighbor >D

Location-based: retransmit if additional area ratio > A best (GPS advantage) but SRB low for RE>80%

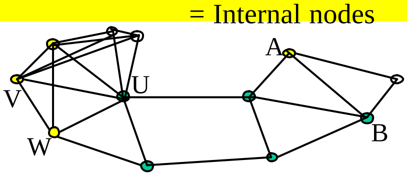
Cluster based: reduce above methods to clusterheads and borders

Stochastic flooding broadcast

- Cartigny, Simplot and Carle 2002, 4 schemes:
- Probability *p* for retransmitting is inversely proportional to local density
- Distance between two nodes is evaluated by comparing their neighbor lists; *p* increases with the distance, in favor of nodes at the border of senders
- *p* depends on both local density and distance
- Plus neighbor elimination is applied: no retransmission if no neighbor exists that did not hear the same message already

Connected dominating sets by covering

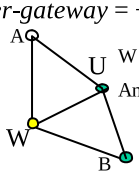
= Internal nodes



Wu, Li '99

Intermediate node = has two unconnected neighbors

inter-gateway = + not covered by any neighbor



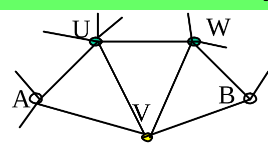
W covered by U= AWB replaced by AUB ∀ A,B

Any neighbor of W is neighbor of U & id(w)<id(u)

Replace *id* by (*degree*, *x*, *y*)

Stojmenovic, Seddigh and Zunic 2000

Gateway nodes



Wu, Li '99

Gateway= inter-gateway + not covered by 2 nodes

V covered by U and W iff

Any neighbor of V→ neighbor of U or W &

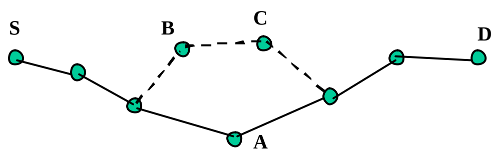
V(degree, x, y) < min (U(degree, x, y), V(degree, x, y))

Internal nodes maintenance:

non-GPS (update list of neighbors of each neighbor)

GPS: update location of all neighbors

Internal nodes are connected



Nodes on shortest path between S and D are all *intermediate*

If A on the shortest path is not gateway then A is covered by two *gateway* nodes B and C – S and D remain connected

Intergateway nodes – coverage by one other node

Dominating set: S and D linked to internal nodes

Generalized covering rule

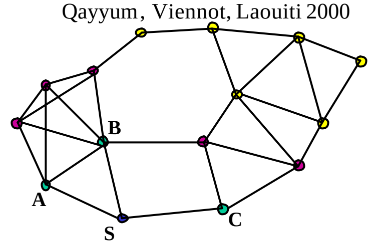
- Dai and Wu 2002
- Each node finds connected components of the subgraph induced by its neighboring nodes
- Node A is not internal if there exist one component so that every neighbor of A is a neighbor of at least one node from the component, and the *key* of A is lower than the *key* of any node in the component
- *Id* used as *key* by Dai and Wu, can be replaced by *degree*, attached to any message from given node
- Localized maintenance, stable selection

Power-aware connected dominating set

- Wu, Dai, Gao, Stojmenovic, Wu 2001-2
- *Key=(energy, degree, x, y, id)*
- Nodes with more energy are preferred in dominating set, which may change in time
- Routes through nodes in dominating set only
- Broadcasting by nodes in dominating set
- Nodes in dominating set are active = scheduling node activity

Multipoint relaying

Qayyum, Viennot, Laouiti 2000



S: source or relay point of retransmitting node

Find minimal set of 1-hop neighbors that *covers* all 2-hop neighbors of **S**: **B** and **C** (relays of S)

Heuristics: B: 4, A: 2, C:2, choose *B*; A:0, C: 1, choose *C*

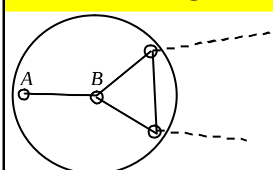
internal -clustering-multipoint relay

Percentage of retransmitting nodes for 100 nodes

Degree= average number of node's neighbors

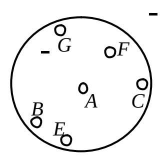
Method/degree	4	6	8	10
lowestID	67	61	67	64
ConID	**50**	**51**	**51**	**54**
intermediate	80	88	92	95
Inter-gateway	65	67	69	70
gateway	**60**	**54**	**50**	**45**
Multipoint relay	60	60	61	63

Neighbor elimination



Problem in [NTCS]:

Node A retransmits in all methods but has no neighbor in need of message



Node A eliminates neighbors E and F from its neighboring list;

A retransmits because of G

August 2000: independently

Peng,Lu and Stojmenovic,Seddigh

Simulation with MAC IEEE 802.11

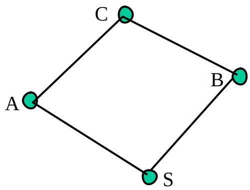
- 100 nodes in $[0,m]^2$ R=500meters m=sR, s=1,3,5,7,9,10,11 [NTCS] d ~ 97,25,10,6, 3.5, 3, 2.4
- Bit rate 1M/sec, slot time 20us(microsec), packet size 280bits or **p**~127 slots; no ack [NTCS]
- A receives packet, waits DIFS (~2) slots, chooses random backoff counter BC in [0,31]
- BC= # of transmission free slots as sensed by A
- BC=0 → A transmits continuously for **p** slots
- One broadcast message in the network
- Network static while broadcasting is in progress

Internal nodes + neighbor elimination

All methods: **RE> 94%**

	dense		medium		sparse	
SRB	1x1	3x3	5x5	7x7	9x9	11x11
Inter-gatew.	97	32	29	34	37	43
gateway	98	76	54	45	41	45
Neigh.Elim.	57	11	14	22	30	45
Int.gat+NE	99	39	36	40	43	54
Gatew.+NE	99	81	60	49	47	55

Broadcasting with 100% delivery ?



Problem with low delay ≤ 31 slots
and long message length p=127 slots:
S transmits to A and B simultaneously
Retransmissions from A and B
collide at C

Toward guaranteed delivery RE=100%

RANA: Retransmissions After Negative Acknowledgements
from nodes that experienced collisions but recognized sender

Experiments: over 98% delivery in all cases, SRB –10% or <

Ongoing work

- Stojmenovic 2000: Forward message to nodes that are further than itself from source, and to closer neighbors that did not transmit within time limits
- Rogers 2001: A forward message received from B to neigbhors C for which the angle BAC is > T (threshold value) – not reliable
- Lou and Wu 2002: forward node set based broadcast in clustered mobile ad hoc networks
- Multipoint relaying = selecting forwarding neighbors variants: Lim and Kim 2000, Calinescu, Mandoiu, Wan and Zelikovsky 2001, Sun and Lai 2001, Lou, Wu 2002
- Covering for unidirectional links: Wu 2002

Relevant problems

- Broadcasting with multi-channels Basagni 2000
- Choose transmission radius at each node so that network is connected and sum of transmission powers is minimized:
  Wieselthier, Nguyen and Epremides 2000,
  Wan, Calinescu, Li, Frieder 2001, Clementi,
  Penna, Silvestri, Crescenzi 2001
- Select minimal set of sensors so that every point in a given area is monitored by at least one sensor
  Tian and Georganas , 2002

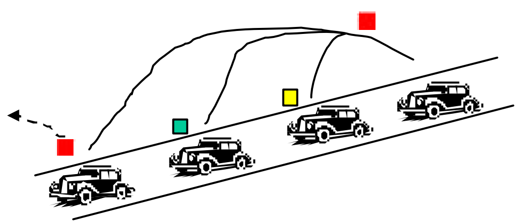
Inter-vehicle communication

Sun, Feng, Lai, Yamada, Okada 2000

-Learn neighboring cars on the same highway and direction

-include ID of furthest neighbor in the transmitted message

-furthest neighbor retransmits



Inter-vehicle communication with GPS

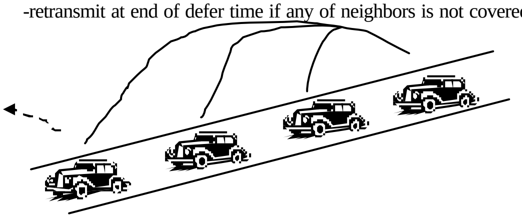
Sun, Feng, Lai, Yamada, Okada 2000

-Include LOCATION with the message

-defer time inversely proportional to distance from vehicle

- discard neighbors covered by any of transmissions

-retransmit at end of defer time if any of neighbors is not covered



Broadcasting in one-to-one networks

Heinzelman, Kulik, Balakrishnan MOBICOM 1999:

Each node sends *short* message to **all** its neighbors

Long messages are sent to neighbors that request it

Subramanian, Katz 2000:

Construct and maintain a spanning tree

No short messages but maintenance overhead

Reducing broadcast search

Reduce number of short messages by using

internal nodes and **planar subgraphs**

I-broadcast: edges between internal nodes + # non-internal

P-broadcast: edges of planar subgraph (e.g. RNG)

IP-broadcast: internal nodes, planar subgraph on it

PI-broadcast: planar subgraph, internal nodes on it

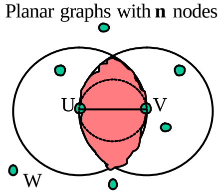
Relative Neighborhood Graph

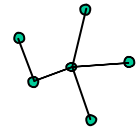
Minimize # of edges in connected subgraph

Planar graphs: no two edges intersect

Planar graphs with **n** nodes have at most **3n-6** edges

UV ∈ RNG iff lune has no nodes





Ð **UWV** < p/**2 for any W**   **P inside lune® PU<UV and PV<UV**

Experiments: average degree of a node is < 2.4 for n=100 nodes

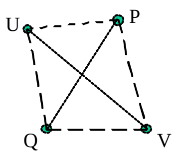
RNG is planar and connected subgraph   Toussaint 1980

RNG is planar graph

Planar graph = no two edges intersect

Proof by contradiction: Assume

UV, PQ ∈ RNG(S), UV ∩ PQ

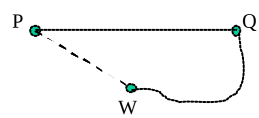


→∠ PUQ < π /2, ∠ PVQ < π /2,

∠ UPV < π /2, ∠ UQV < π /2,

→ Sum of angles in UPVQ < 2π

RNG contains Minimal Spanning Tree



By contradiction: Assume

PQ ∈ MST, PQ ∉ RNG;

→ ∃W, PW<PQ and QW<PQ, PW ∉ MST

Replace PQ by PW in MST

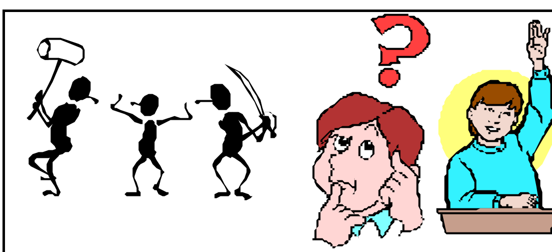
→ new MST has smaller sum of edge lengths. contradiction

→ **RNG is connected**

Performance in one-to-one networks

Percentage of edges for re-transmitting short messages for **n**=100 nodes P=RNG I=gateway

Method/degree	4	5	7	9	15	40
P-broadcast	53	45	33	26	16	6
PI-broadcast	53	45	33	26	16	6
IP-broadcast	**52**	**44**	**32**	**25**	**15**	**5**
I-broadcast	61	52	41	35	21	6



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