Broadcast analysis in Multi-hop Wireless Networks

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SPASWIN 2005 - Riva del Garda - Italy
April, 7nd 2005

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Talk Outline

- Introduction of multi-hop wireless networks
- Our clustering metric
- Broadcast: Related works and motivations
- Our proposition
- Analysis and simulations
- Conclusion

Wireless multi-hop networks

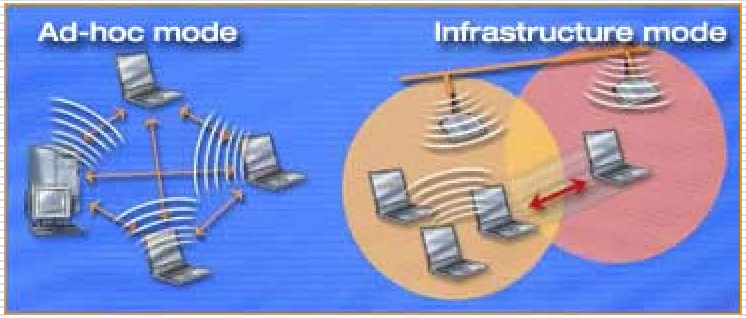
Introduction and Generalities

Wireless Multi-hop Networks

- Formed by wireless hosts which may be mobile and may appear/disappear at any time.
- Without (necessarily) using a pre-existing infrastructure.
- Routes between nodes may potentially contain multiple hops (if nodes are not in transmission range of each other).

Why WMN ?

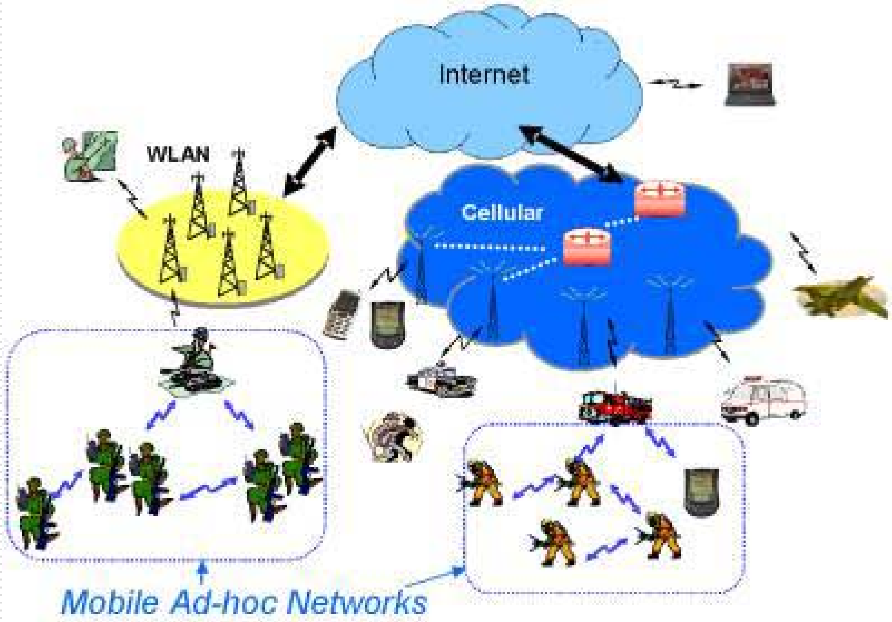
- Ease of deployment
- Speed of deployment
- Decreased dependency on infrastructure



Either everyone with everyone or all via one: Communication in wireless LAN

Many Applications

- Personal area networking
  - cell phone, laptop, ear phone, wrist watch
- Military environments
  - soldiers, tanks, planes
- Civilian environments
  - taxi cab network
  - buildings, meeting rooms
  - extend Internet connectivity
  - boats, small aircraft
- Emergency operations
  - search-and-rescue
  - policing and fire fighting

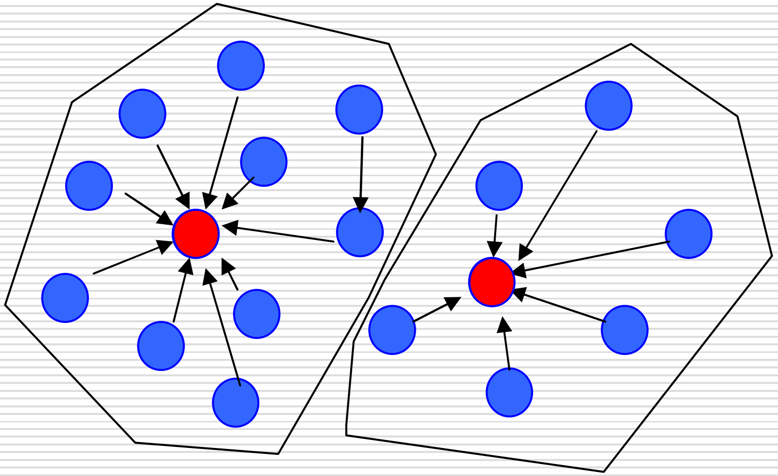


What we need in such networks

- To allow any pair of nodes to communicate (one to one).
- To spread some information to every nodes (one to all).
- To allow scalability, we also need to organize the network (for monitoring, routing, localization, services, etc).

Organizing a multi-hop wireless network

- Flat structures do not scale well
  - Flooding
    - bandwidth, storage, computations, latency, losses of messages
- Hierarchy
  - Well known
- → cluster the network
- → clusters (groups of nodes) identified by their cluster-head
- Distributed, stable…



Modeling

- The network is modeled by a non-directed graph G(V, E)
  - V is the set of nodes
  - E is the set of the edges.
    - If R is the range radius and dist(u,v) the Euclidean distance between u and v:

$$\exists e = (u,v) \in E \Leftrightarrow dist(u,v) \leq R$$

- We note $\Gamma_k(u)$ the k-neighborhood of node u:
  - if d(u,v) is the distance in the graph between u and v:

$$\Gamma_k(u) = \left\{ v \in V \middle| v \neq u, d(u,v) \leq k \right\}$$

Our clustering metric

Motivations

- In most past solutions :
  - Cluster-heads selection based on various criterion : highest degree, lowest mobility, lowest ID, etc.
  - Homogeneous clusters, bounded by « absolute » criterion as number of nodes by cluster, cluster radius or diameter, etc.

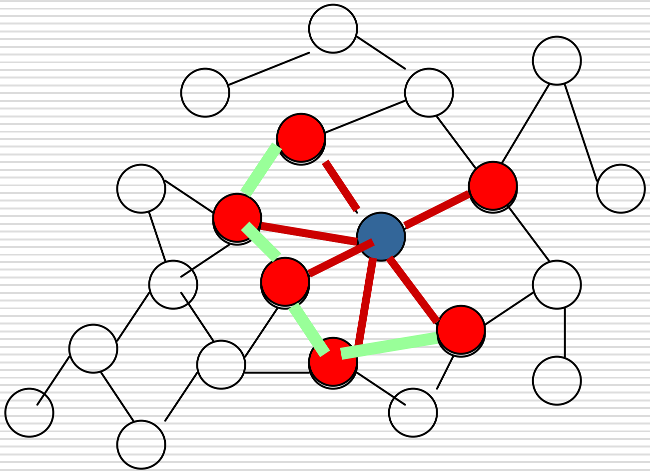
But in large scale networks:

  - May lead to a whole clusters reconstruction for small changes (as a node motion).

- We thus propose a clustering algorithm:
  - Non-based on « absolute » criterion
  - Which adapts to topology modifications
  - Which provides a clusters organization robust against nodes mobility

Our metric: the density

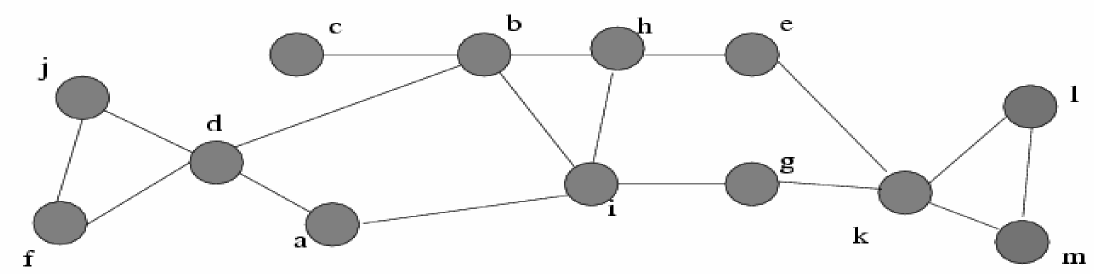
$$\rho(u) = \frac{\left|\left\{e=(v,w)\in E \,\middle|\, w \in \{u\} \cup \Gamma_1(u) \text{ and } v \in \Gamma_1(u)\right\}\right|}{\left|\Gamma_1(u)\right|}$$



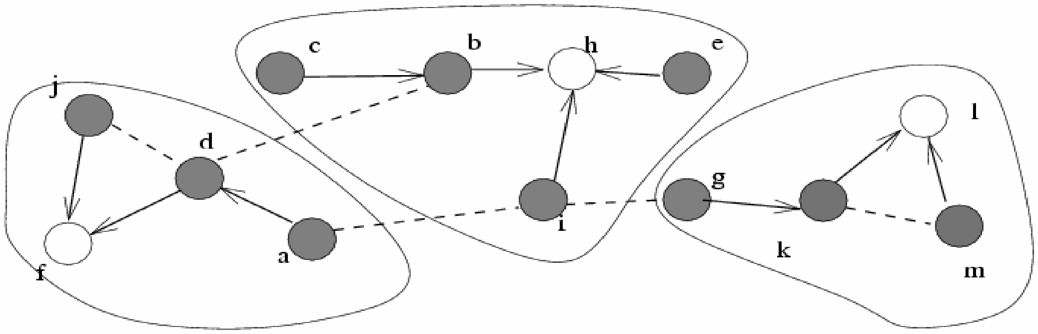
$\text{Density}(u) = \rho\ (u) =$

= (6 + 4)/6 = 10/6

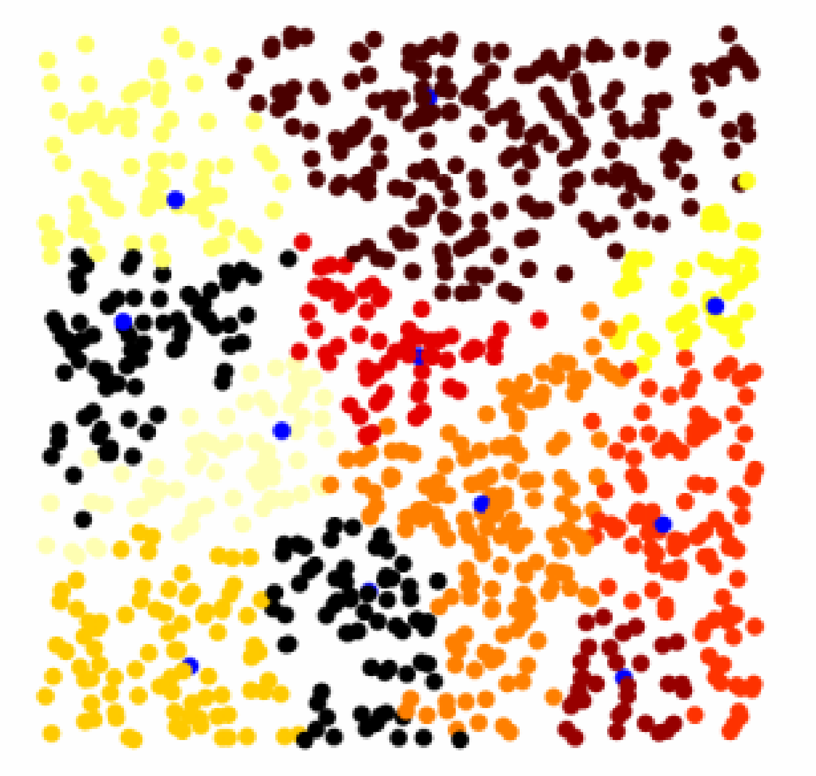
Clusters and trees formation



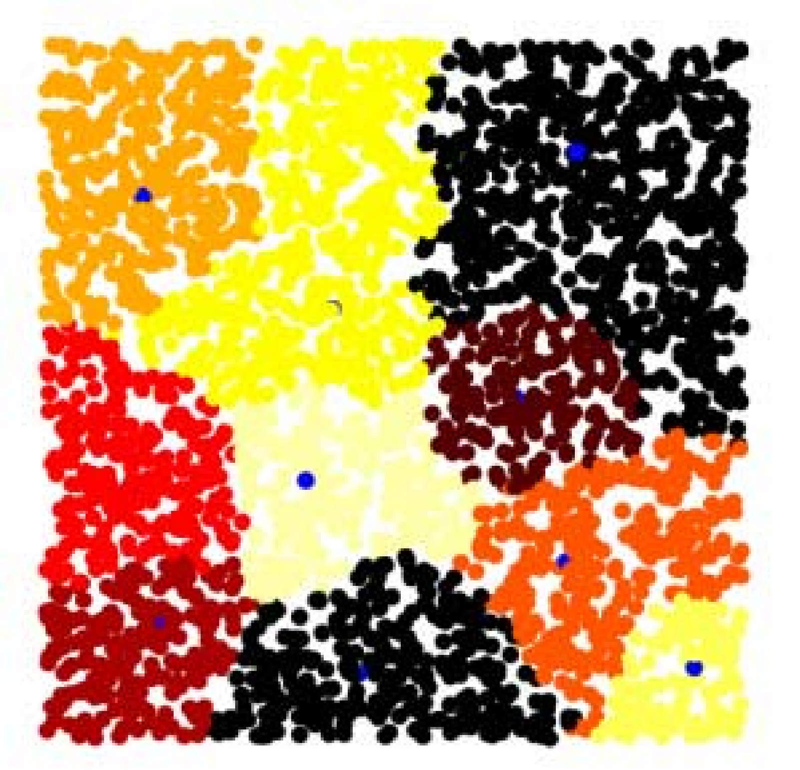
Nodes	a	b	c	d	e	f	g	h	i	j	k	l	m
Degree	2	4	1	4	2	2	2	3	4	2	4	2	2
#Links	2	5	1	5	2	3	2	4	5	3	5	3	3
Density	1	1.25	1	1.25	1	1.5	1	1.33	1.25	1.5	1.25	1.5	1.5



Clusters



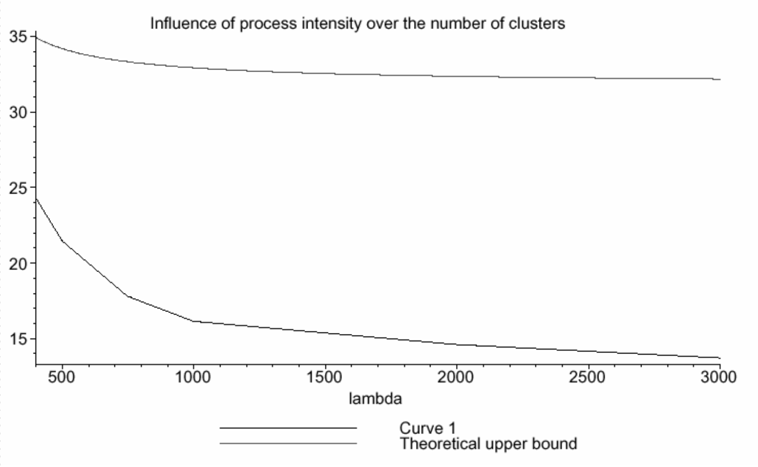
1000 nodes – radius 0.1



3000 nodes – radius 0.1

Organization characteristics

- Theoretical Analysis using a Poisson Point Process of constant spatial intensity λ and Palm Calculus provided:
  - The mean density value : $\tilde{\rho}(u) = E^0[\rho(0)] = 1 + \frac{1}{2}(\pi - \frac{3\sqrt{3}}{4}) \times (\lambda R^2 - \frac{1-e^{-\lambda\pi R^2}}{\pi})$
  - An upper bound of the mean number of clusters built:



- Simulations provided:
  - Clusters characteristics (number of nodes, shapes, node eccentricity, heads eccentricity, etc)
  - Trees characteristics (depth, number of leaves, distances and density distribution, etc)

Analysis of the density value

- Poisson point process Φ of constant spatial intensity λ.
- Density of a node located at the origin point:
  - Under Palm probability, there exists almost certainly a point in 0

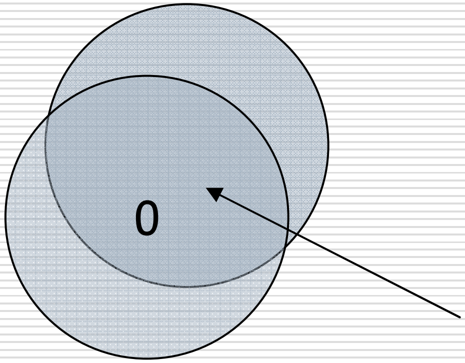
If the $(Y_i)_{i=1,2,\ldots,|\Phi(B_0^{'})|}$ are the points of the process Φ lying in B'_0:

$$\tilde{\rho}(u) = E^0[\rho(0)]$$

$$= 1 + E^0\left[\sum_{i=1}^{\Phi(B_{Y_i}^{'})} \frac{\Phi(B_0^{'} \cap B_{Y_i}^{'})}{\Phi(B_0^{'})}\right]$$

$$= 1 + \frac{1}{2}\left(\pi - \frac{3\sqrt{3}}{4}\right) \times \left(\lambda R^2 - \frac{1 - e^{-\lambda\pi R^2}}{\pi}\right)$$

  - Idea: to count the mean number of nodes and links in node 0's neighborhood



Area of the 2 circle intersection

Average number of clusters

The mean number of clusters is given by the mean number of cluster-heads :

$$\mathbb{E}\left[\text{Number of heads in a Borel subset } C\right] = \lambda\nu(C)\mathbb{P}^o_\Phi\left(0 \text{ is head }\right)$$

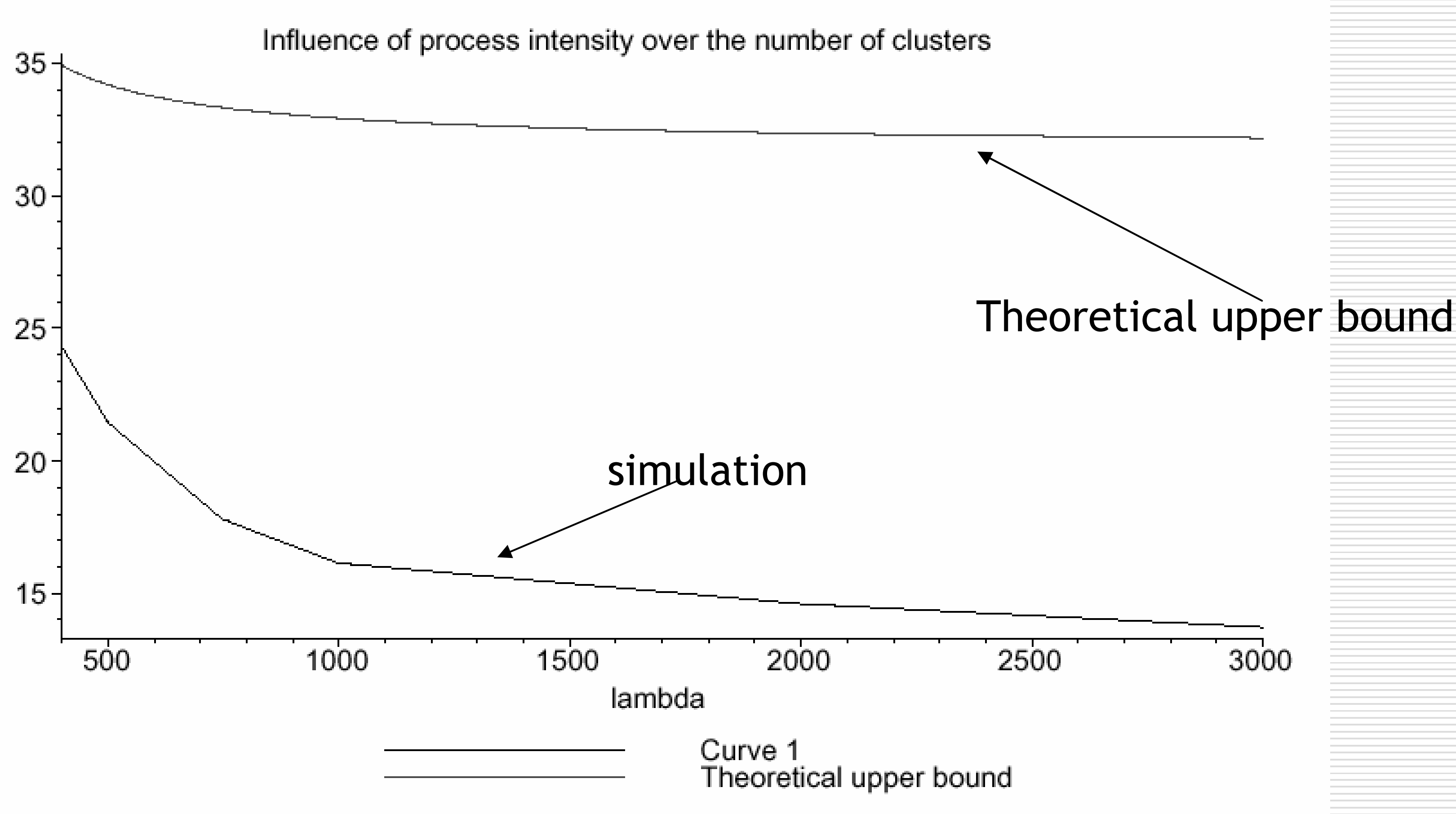
To be a cluster-head, a node must have the highest density in its neighborhood:

$$\mathbb{P}^o_\Phi\left(0 \text{ is head}\right) = \mathbb{P}^o_\Phi\left(\rho(0) > \max_{k=1,..,\Phi(B_0)} \rho(Y_k)\right)$$

We bound this probability :

$$\mathbb{P}^o_\Phi\left(\rho(0) > \max_{k=1,..,\Phi(B_0)} \rho(Y_k)\right) \leq \left(1 + \sum_{n=1}^{+\infty} \frac{1}{n} \frac{\left(\lambda\pi R^2\right)^n}{n!}\right) \exp\left\{-\lambda\pi R^2\right\}$$

Comparison theory-simulation



Broadcast
Related works and motivations

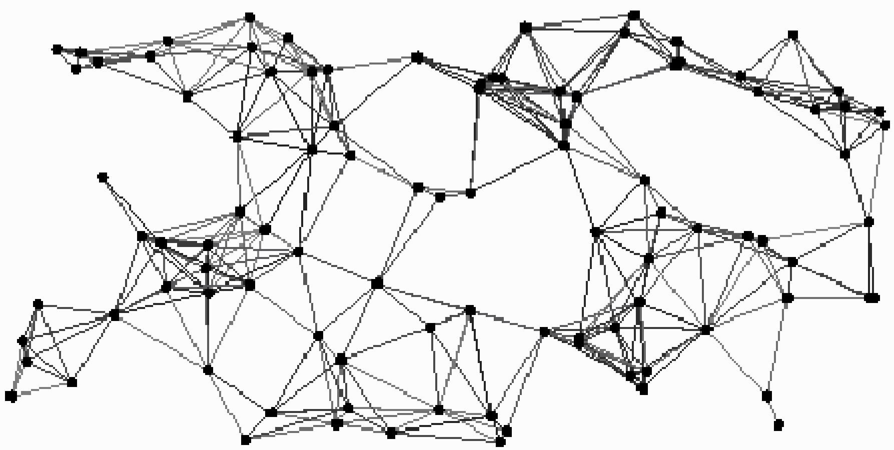
Motivations

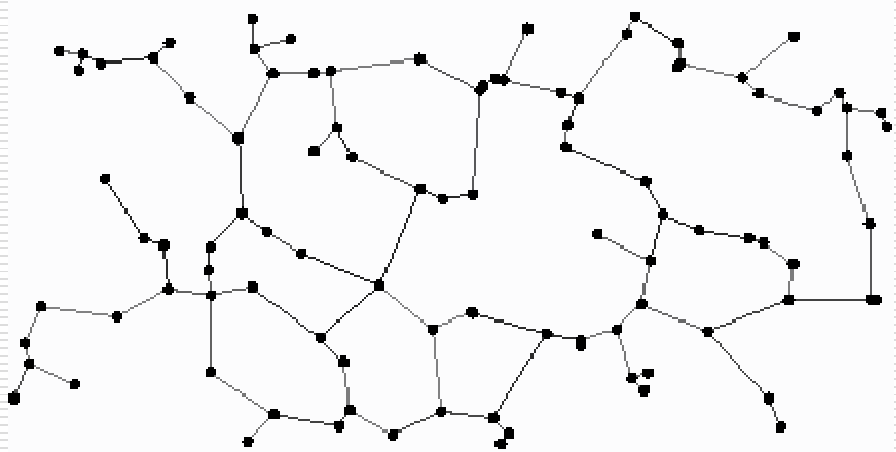
- In large scale multi-hop wireless networks, we need in the same time:
  - to organize the network
  - to perform a broadcast over the whole network without generating too many messages and receptions
- But:
  - None clustering algorithm has been studied for broadcast.
  - None broadcast algorithm uses existing structures.

Broadcast - Relative works

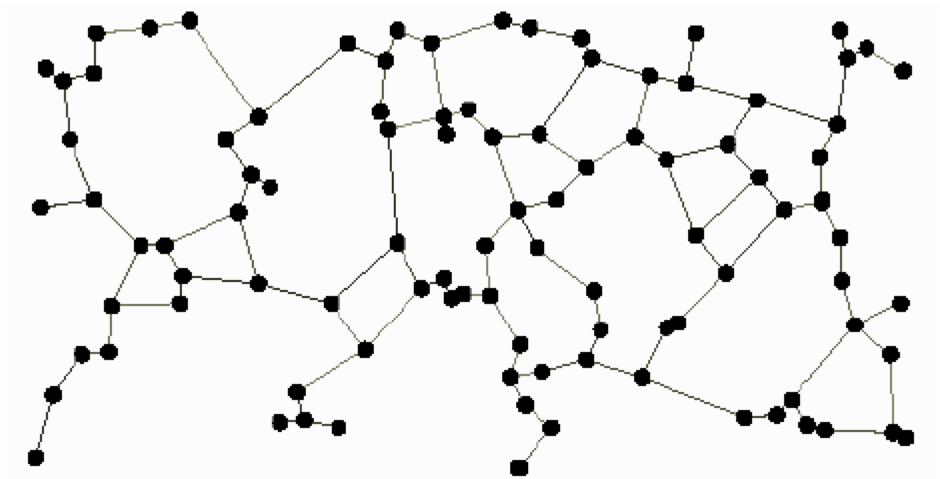
- Blind flooding:
  - Each node reemits the message upon first reception
    - Easy to implant
    - Many collisions, bandwidth occupation, spending of energy
- Dominating set
  - A dominating set is a subset of the nodes of the network.
  - When a broadcast is performed, only nodes in the dominating set retransmit.
  - Selecting the dominating set:
    - Based on metric (degree, ID…)
    - Neighbors-Elimination Scheme
      - Each node waits for a random time to see if its neighbors elect them and then decides whether it should belong to the dominating set.

Broadcast

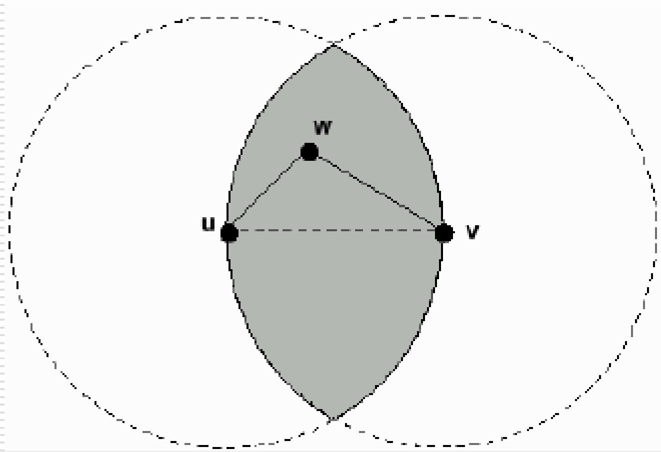




LMST

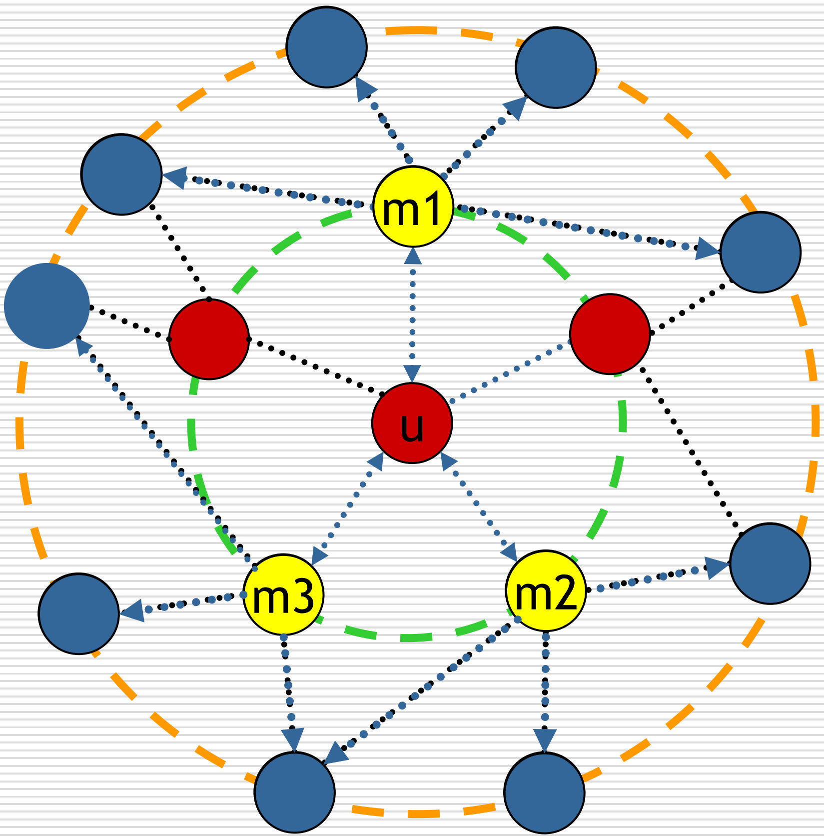


Relative Neighborhood Graph



Broadcast - Relative works

- MPR of OLSR protocol
  - Each node u selects a set of nodes within its neighbors as its MPR.
  - MPR of u such that if u transmit a message relayed by all its MPR, every node at two hops of u receives the message.
  - When a broadcast is performed, v transmits a message coming from u and that it receives for the first time iff v is a MPR of u.



Why using our clusters structure

- Self-organization provides
  - Clusters
  - Cluster-heads
  - Spanning forest of the network
  - Good properties for broadcast:
    - Great number of leaves:

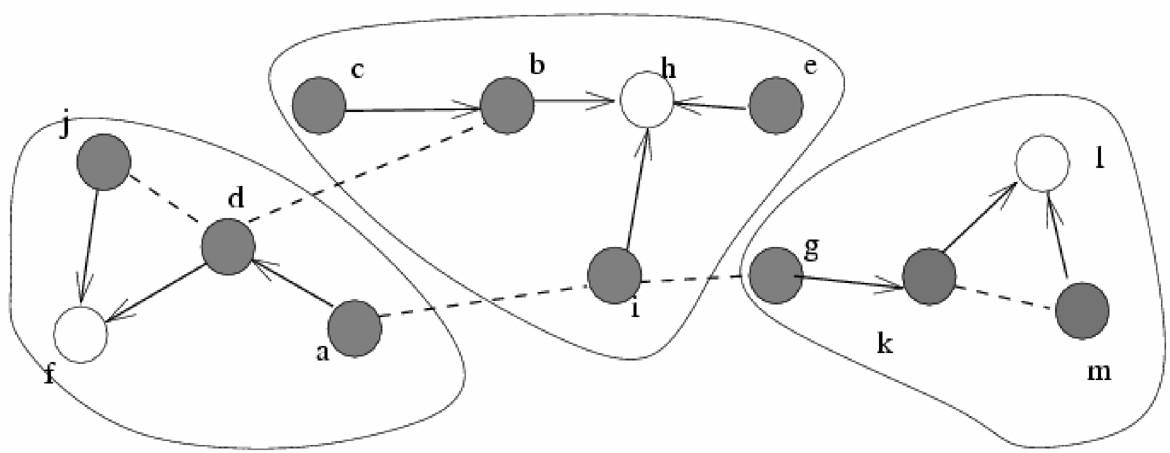
	500nodes	600nodes	700nodes	800nodes	900nodes	1000nodes
% leaves	73,48%	74,96%	76,14%	76,81%	77,71%	78,23%

- A priori can be used for broadcast

- Dominating sets created by the clusters formation:
  - For broadcasts within a cluster
    - Internal nodes (non-leaf nodes)
  - For broadcasts in the whole network
    - Internal nodes + gateways between trees

GW selection

- Before broadcasting, we need to connect our trees.
- GW = (u,v)
  - *u* and *v* neighbors
  - *u* and *v* not in the same cluster
- Information is gathered to the root
  - Internal nodes are preferred
- Only internal nodes + GW forward broadcast packets



Broadcast analysis and simulations

General analysis

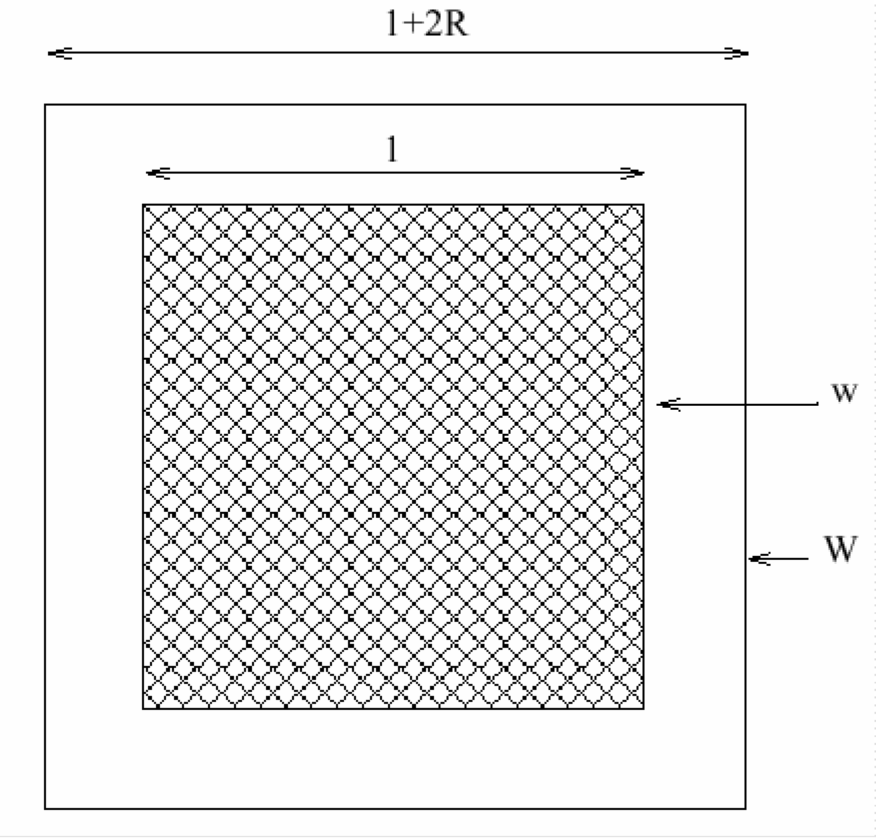
- We consider a Poisson Point Process Φ of intensity λ in a ball of radius R centered in node O: B(O, R).
- Φ_{Relay} a thinning of Φ representing the relay nodes, of intensity λ_{Relay}.
- The mean number of receptions ~r by a node 0 is thus the mean number of relays in node 0's neighborhood.

$$\bar{r} = \mathrm{E}^0_{\Phi}[\Phi_{Relay}(B_0^{'})] = \frac{\lambda_{Relay}}{\lambda}\mathrm{E}^0_{\Phi_{Relay}}[\Phi(B_0^{'})]$$

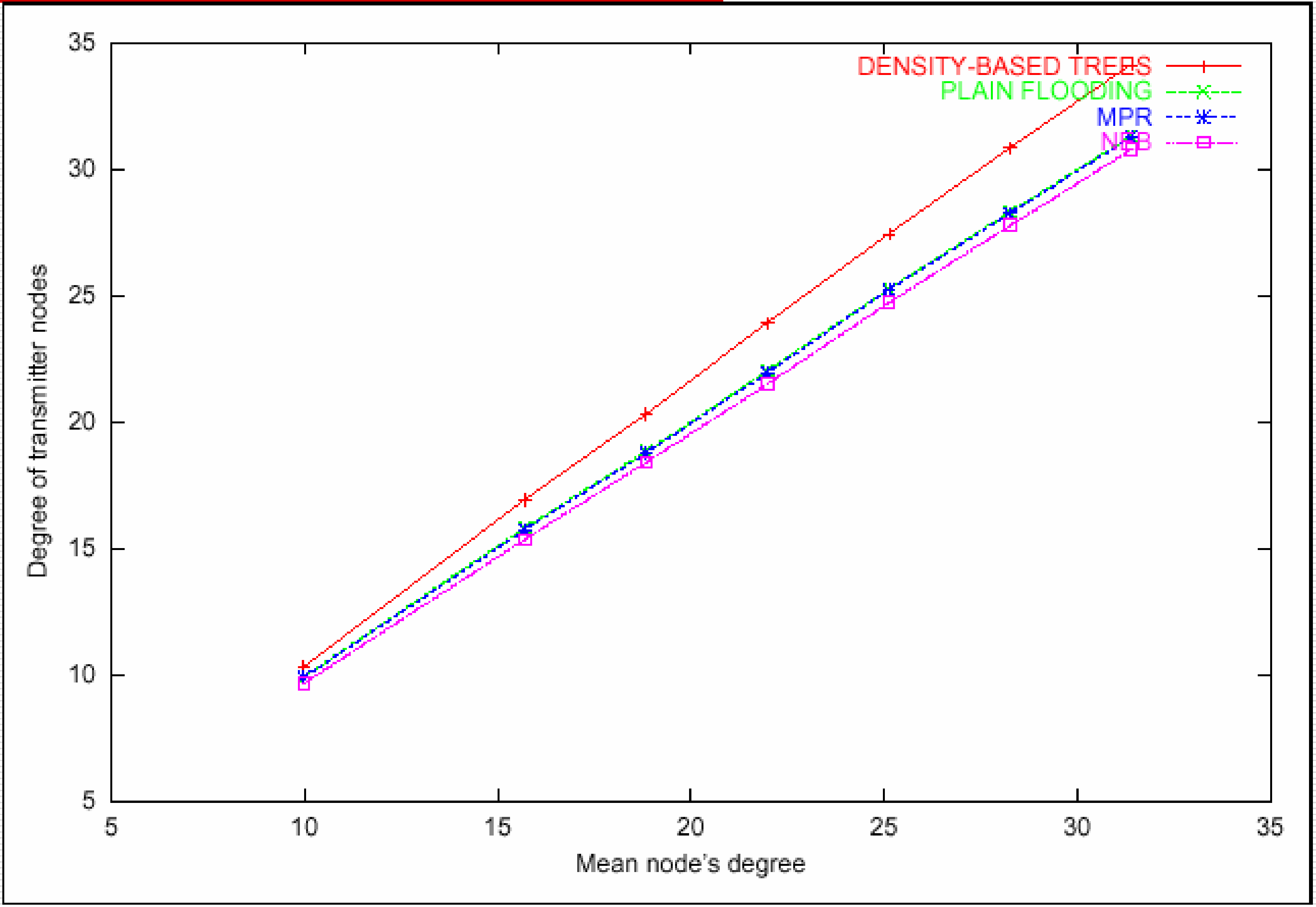
- Mean number of receptions == product of
  - Degree of relay points
  - Probability to be a relay
- How to minimize it ?

Simulation model

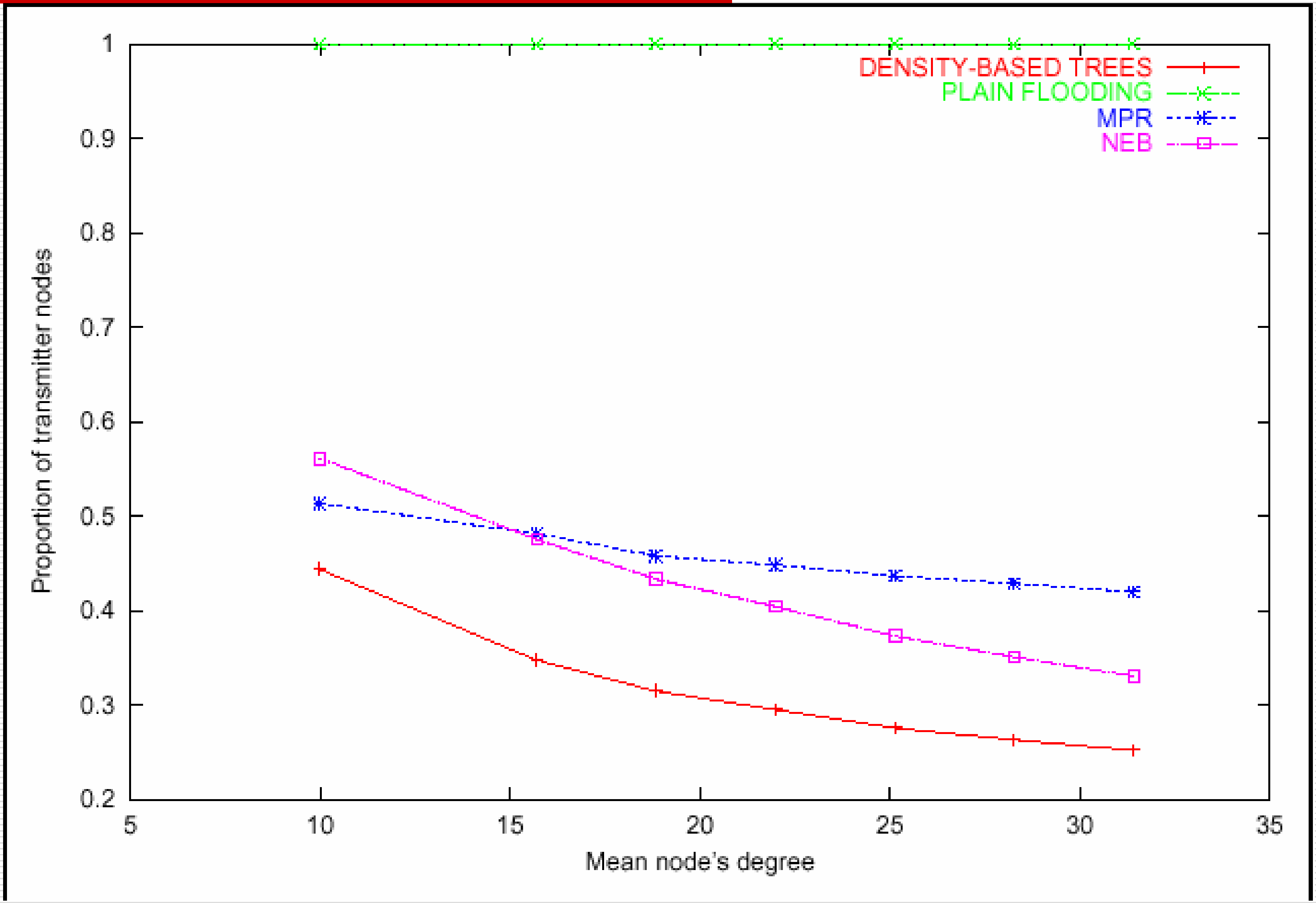
- Nodes deployed with a Poisson point Process of intensity λ in W.
- Statistics computed for nodes in w only to avoid edge effects.
- Nodes in w may receive messages from nodes in W\w.



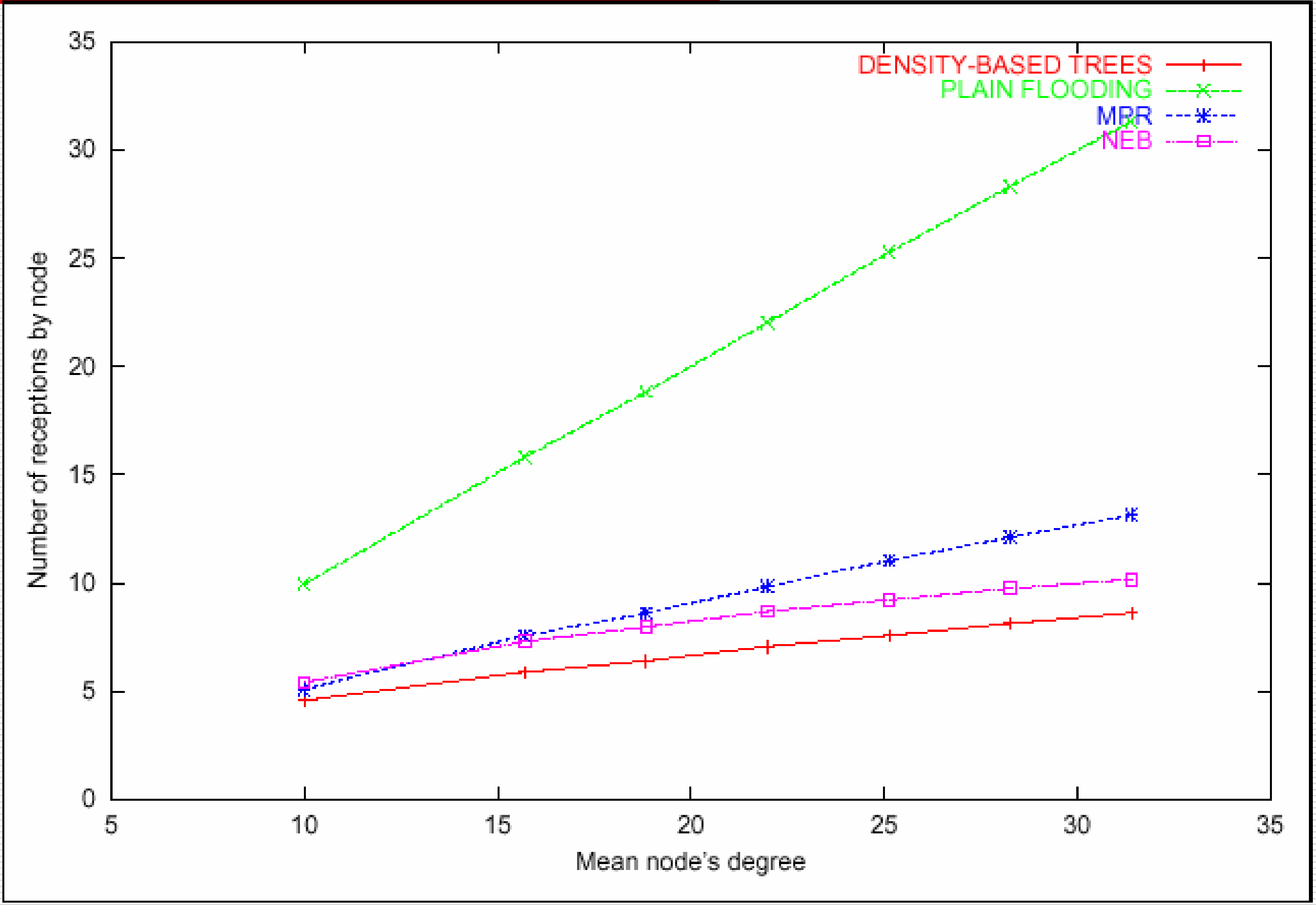
Degree of relays



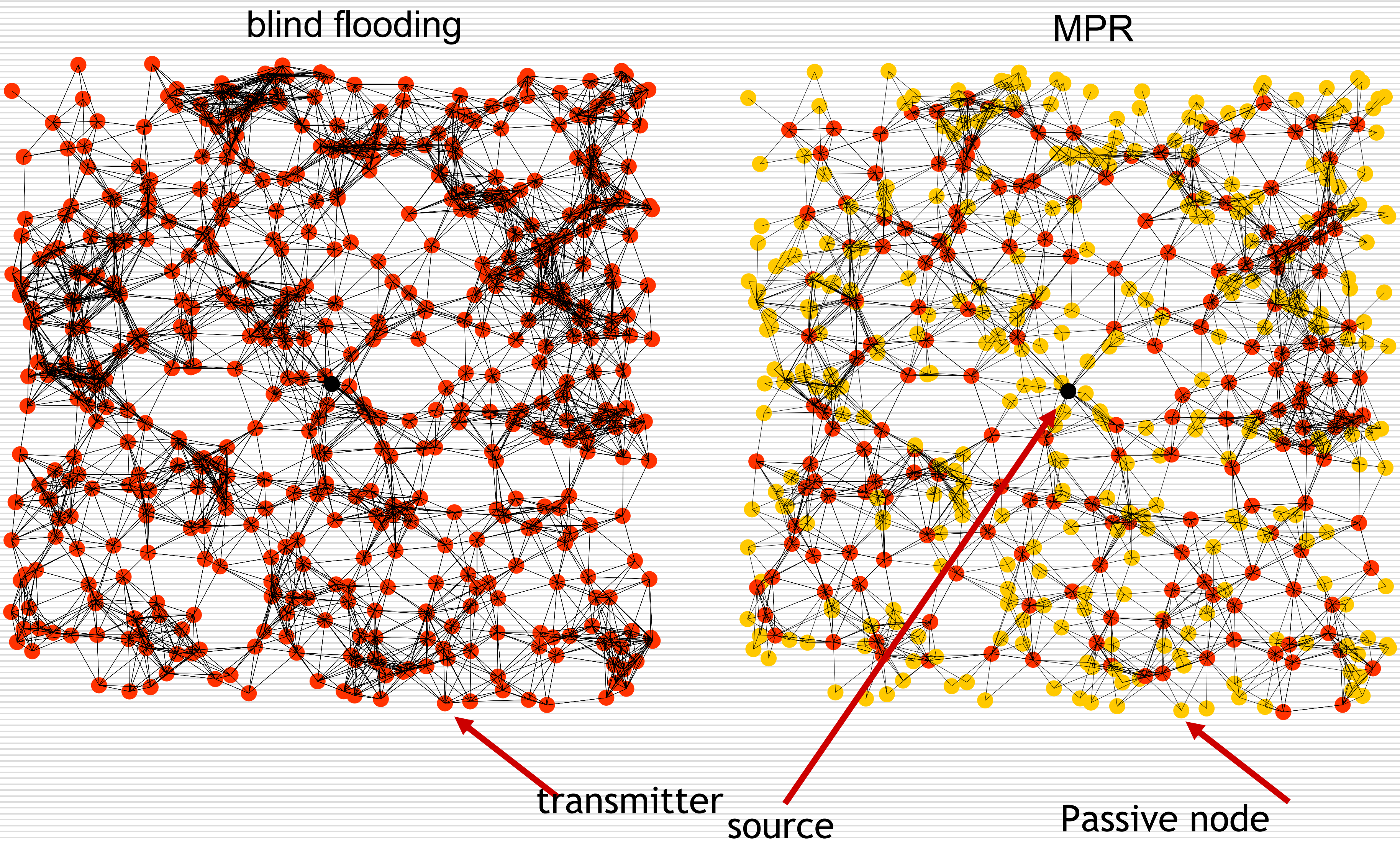
Ratio of transmitters



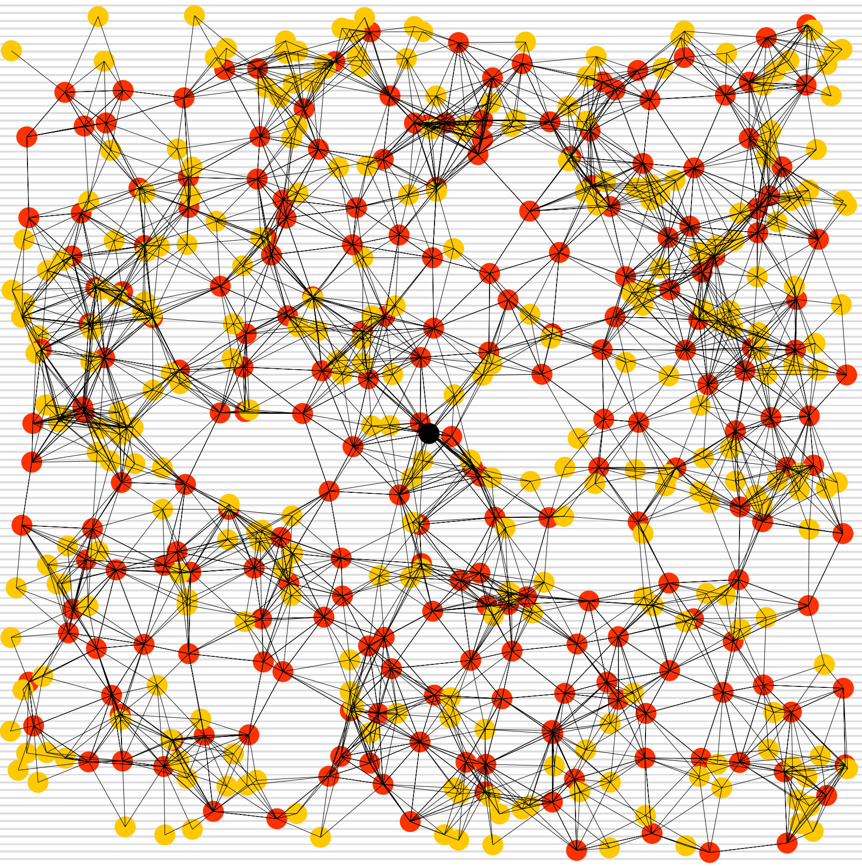
of receptions by node



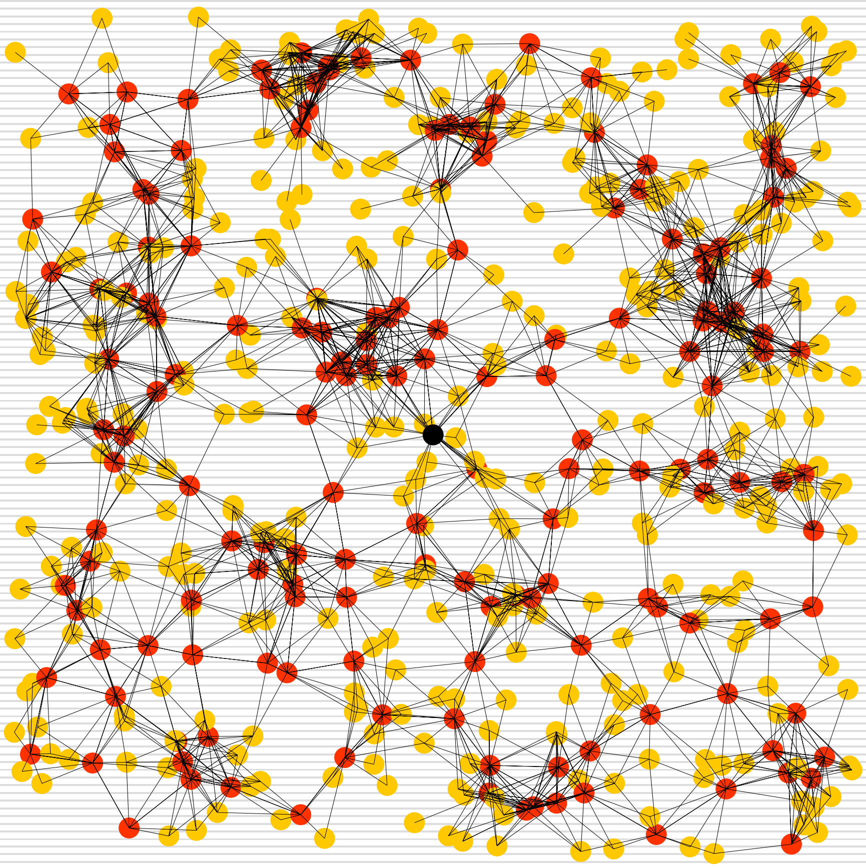
Flooding / MPR



NES / Density

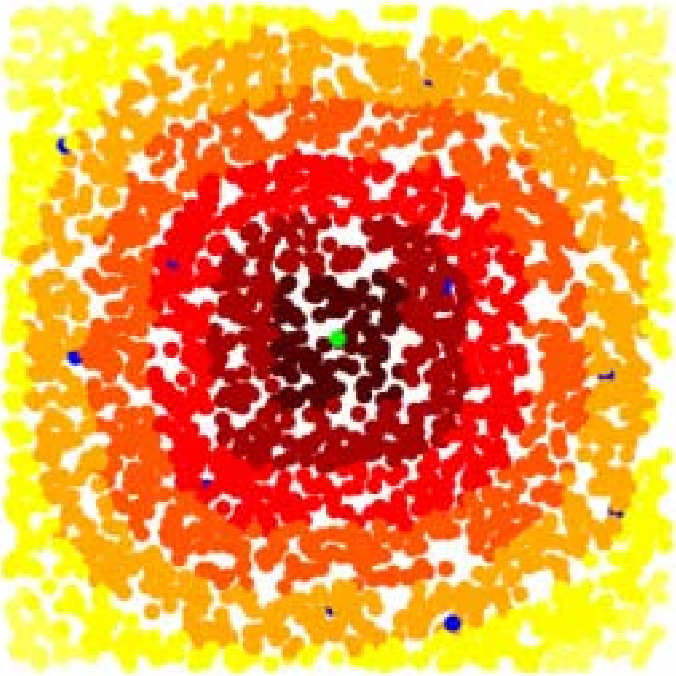


Neighbors-elimination scheme

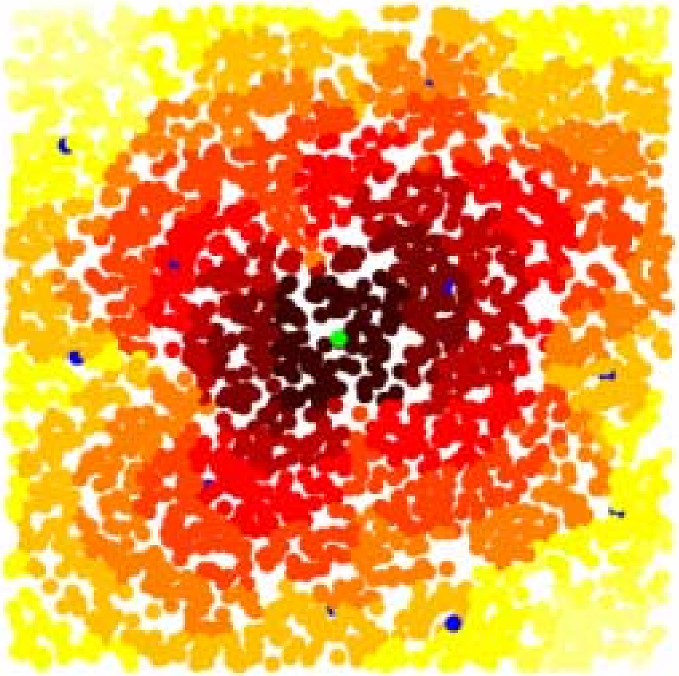


Density

Latency



With MPR (optimal)



Density

Self-organization

Conclusion

Conclusions and perspectives

- We proposed
  - a distributed clustering algorithm:
    - suitable for large scale networks
    - stable
  - which offers an useful underlying structure (forest decomposition)
  - which allows an efficient broadcast

- We intend to:
  - deeper study broadcast trees
  - study broadcast robustness and reliability

Thank you for your attention