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Energy savings in wireless sensor networks

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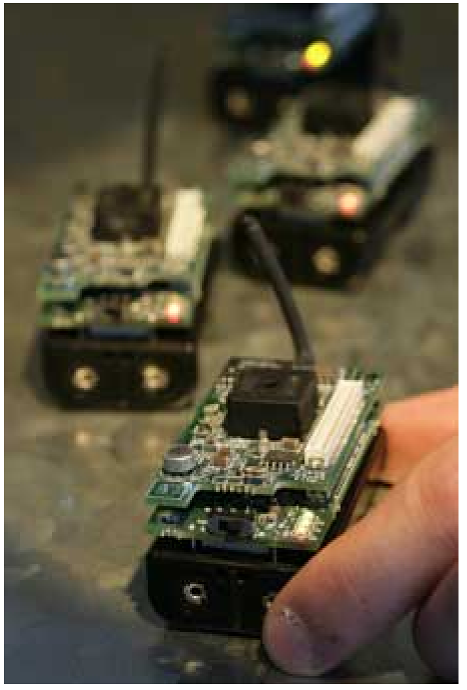
Outlines

I. Wireless Sensor Networks

II. Activity scheduling and coverage problem

III. Routing with guaranteed delivery



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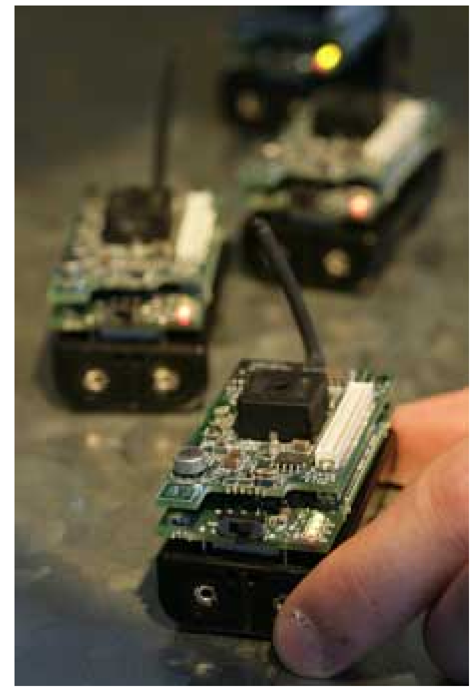
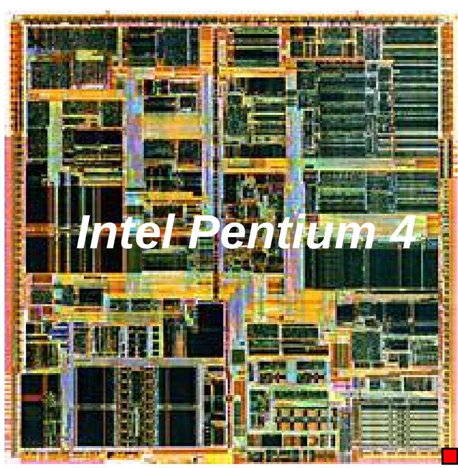
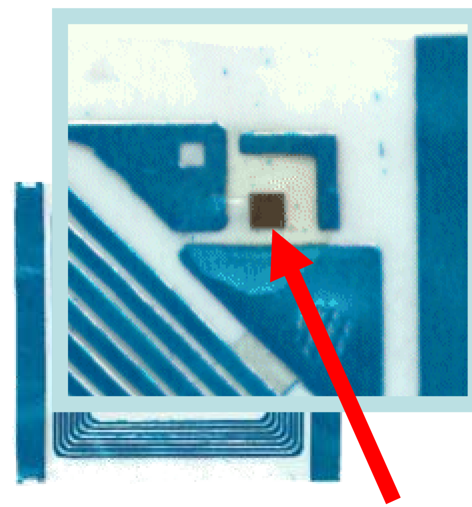


RFID Tags

- **Smart labels**
  - Radio Frequency Identification Tag
  - By opposition to **bar code** which use **optical** principles
- **A stronly limited component:**
  - 500 times smaller than a classical microprocessor





EAS Application

- **Electronic Article Surveillance**
  - Once powered, the tag emits
  - The reader listen channel and activate alarm as early as transmission is detected
  - During checkout, the tag is burned out
  - Problem: power and hear the tag whatever the tag orientation

Applications

- **Batch identification**
  - It is the capability to collect information from a set of tags
  - In opposition to optical identification

Marathon
Automatic clocking in

Automatic luggage sorting

Automatic inventory
50 items in less than one second

More POPS, smaller POPS...

Courtesy, Alien Technology

POPS = Portable Objects Proved to be Safe

POPS = Petits Objets Portables et Sécurisés

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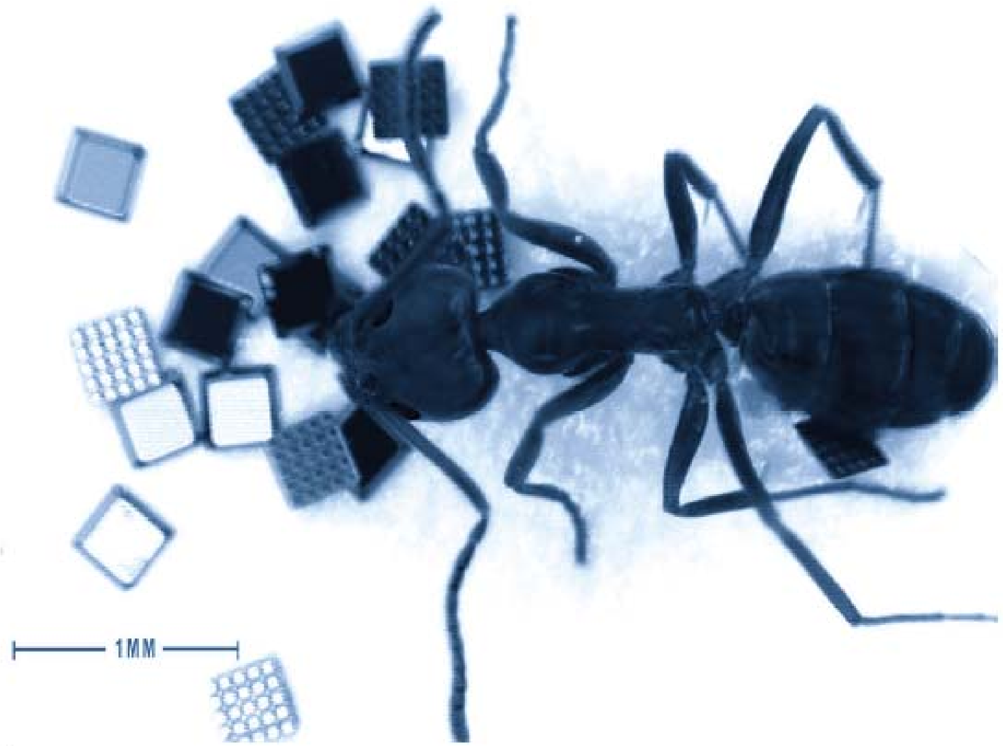

Courtesy, Auto-ID Center

The MIT Auto-ID Center Vision of "the internet of things"

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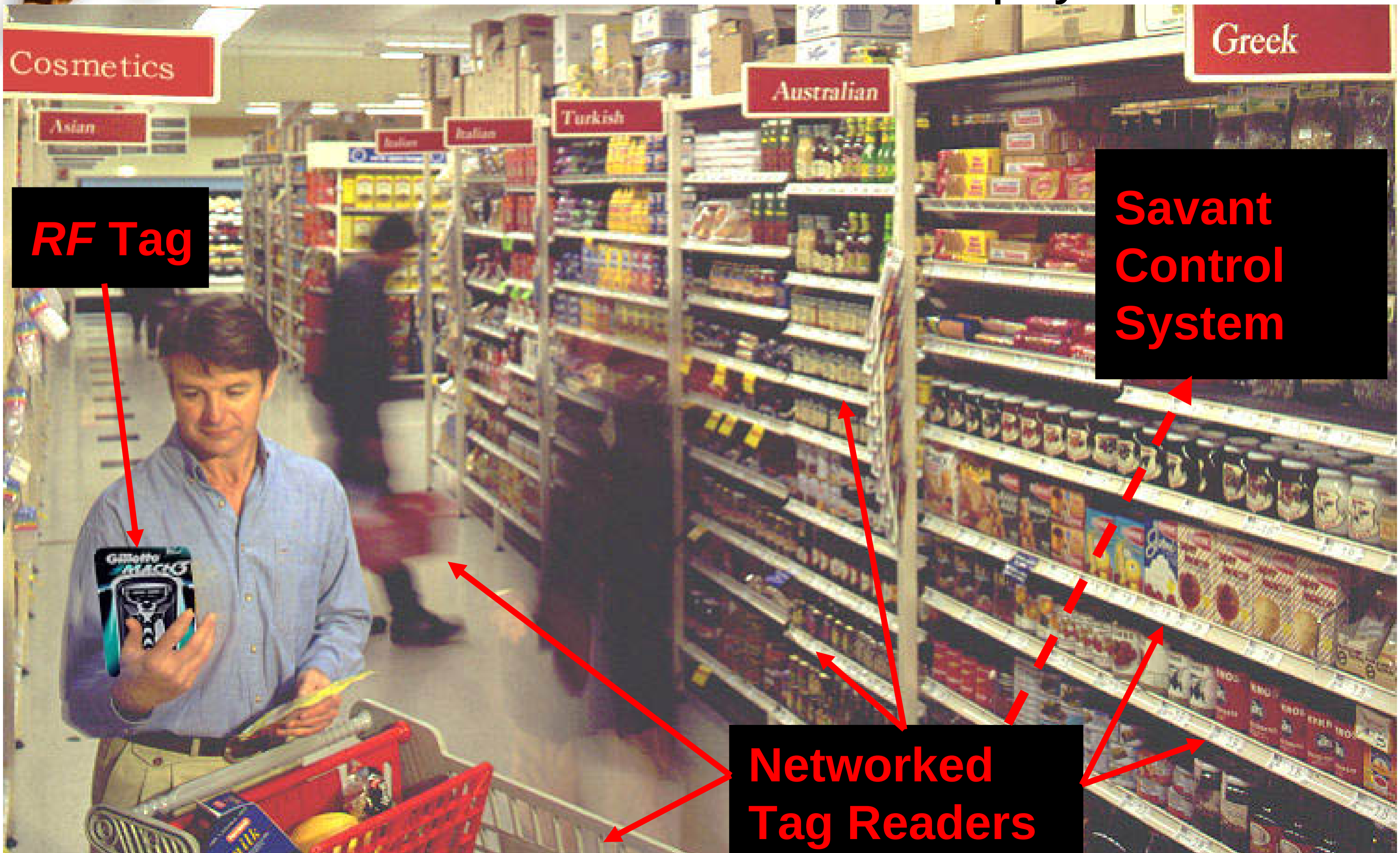
Networking the physical world



Auto-ID Center classification

Class V tags
Readers. Can power other Class I, II and III tags;
Communicate with Classes IV and V.

Class IV tags:
Active tags with
broad-band peer-to-peer communication

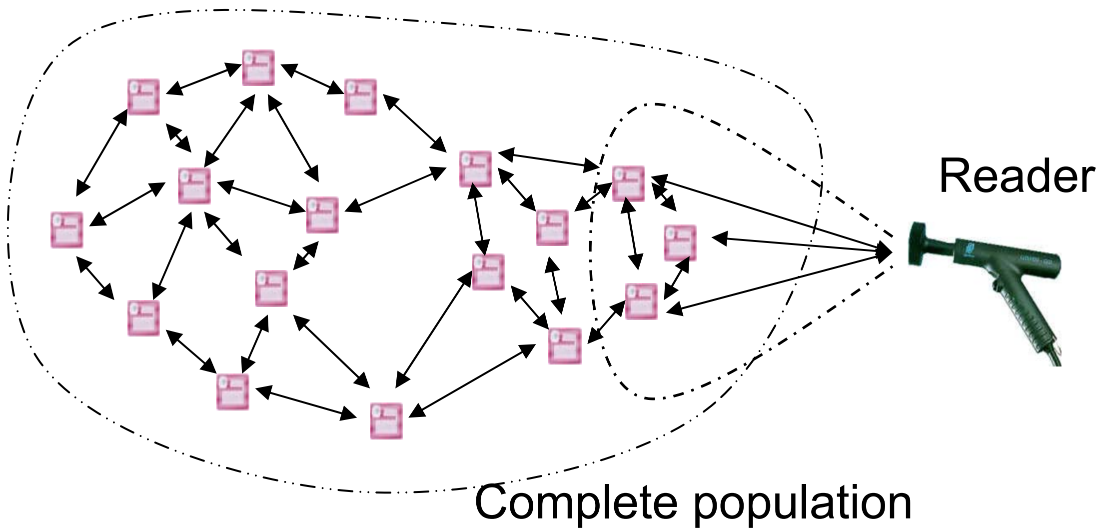
Class III tags:
semi-passive RFID tags

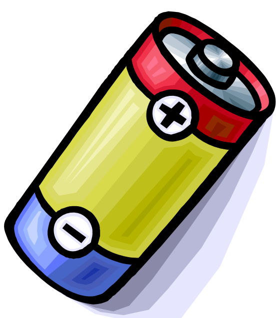
Class II tags:
passive tags with additional
functionality

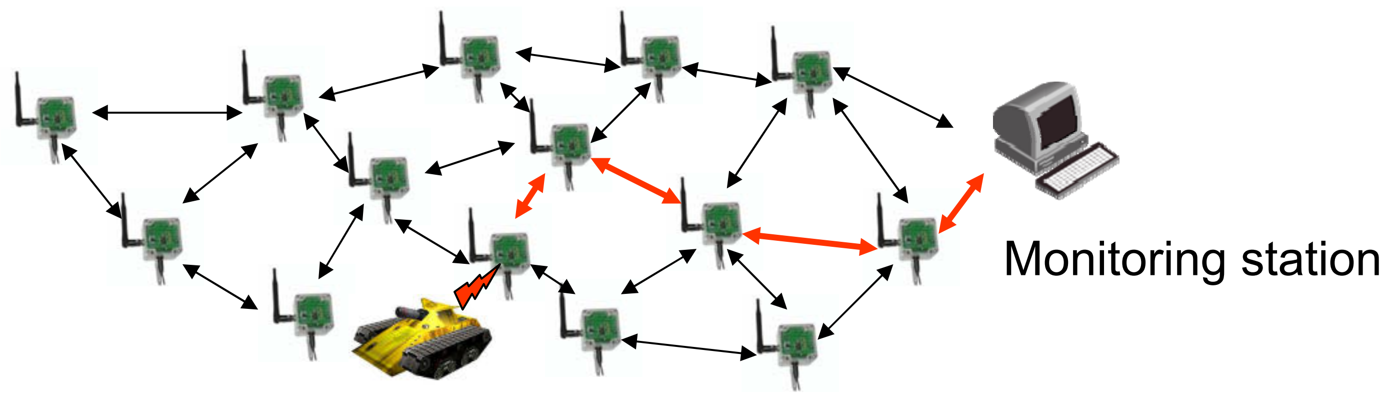
Class 0/Class I:
read-only passive tags

Benefits of class IV tags

- **Decentralized behavior**
  - The request is broadcasted in the whole network by using multi-hop method
- **Similar to sensor networks**





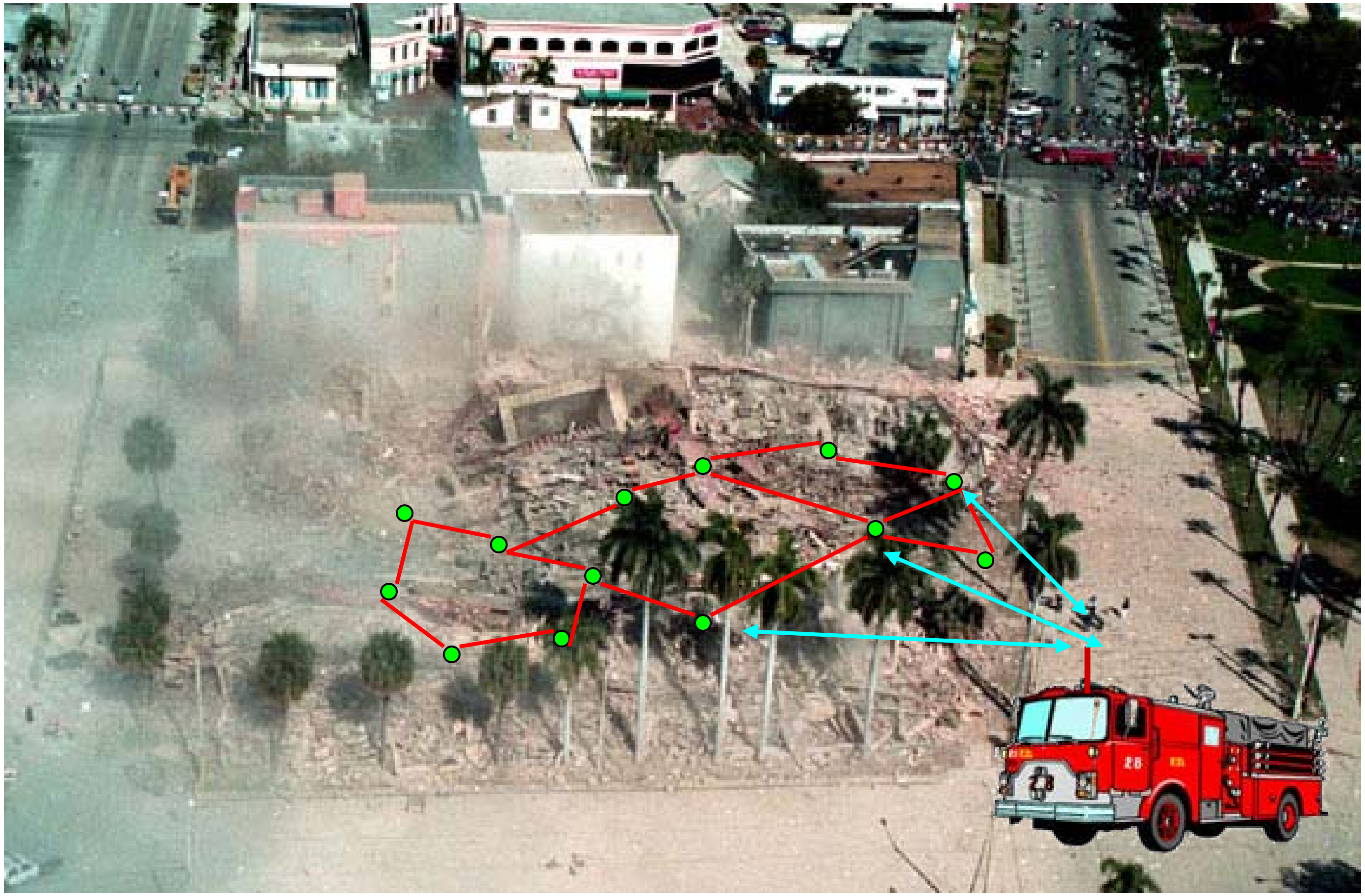


Sensor Nets for Search and Rescue

● **Inactive Sensor**

Sensor Nets for Search and Rescue

Sensor Nets for Search and Rescue

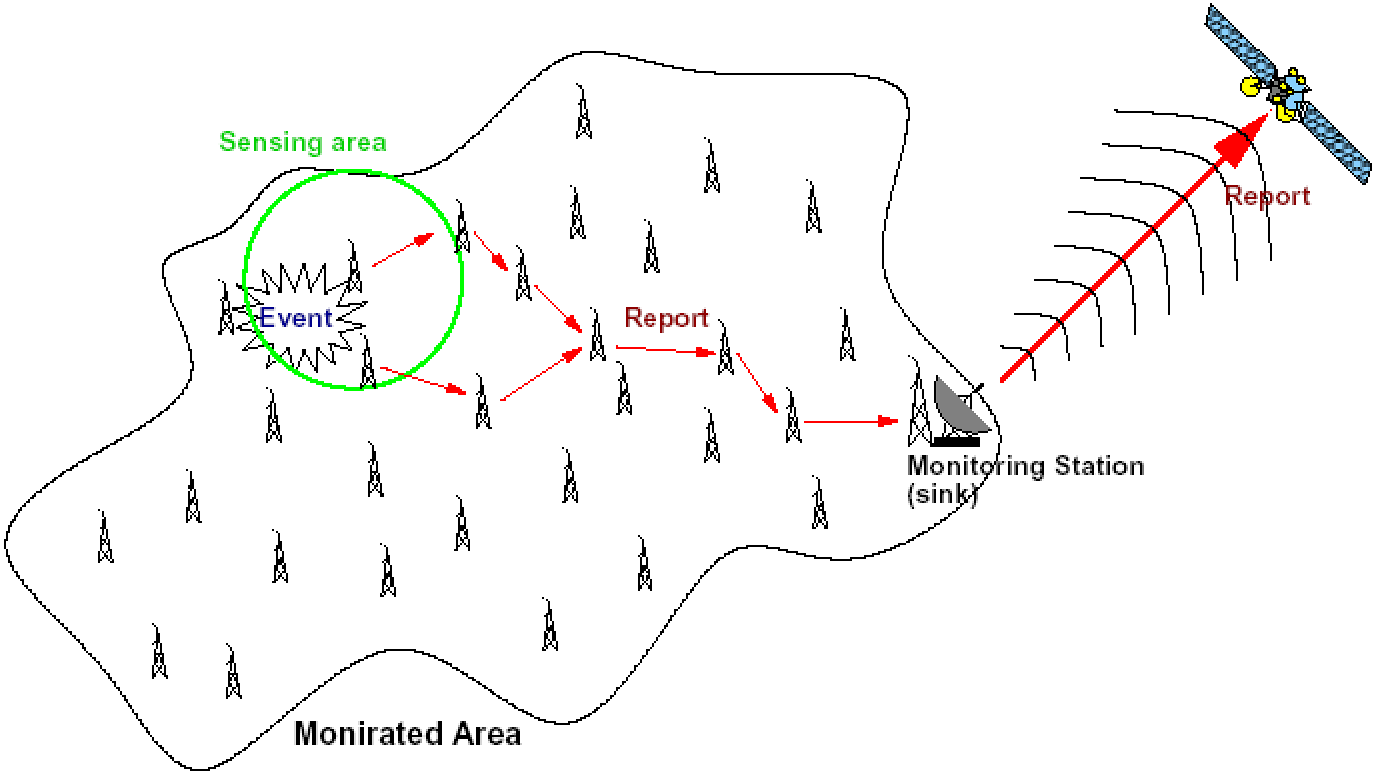


● **Active Sensor**

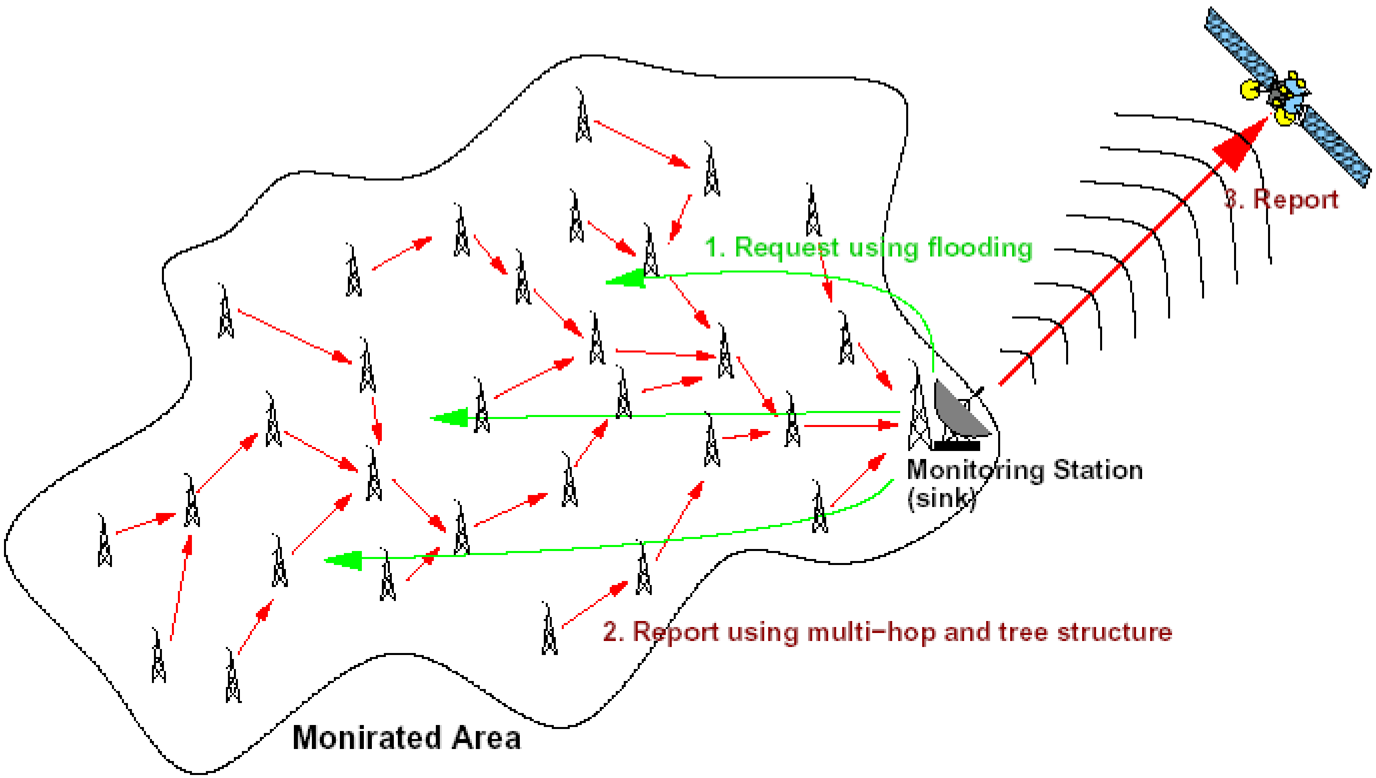
Application

- **In the UC Berkeley Botanical Garden, 50 "micromotes" sensors are dangled like earrings from the branches of 3 redwood trees to monitor their growth.**

Event-driven model

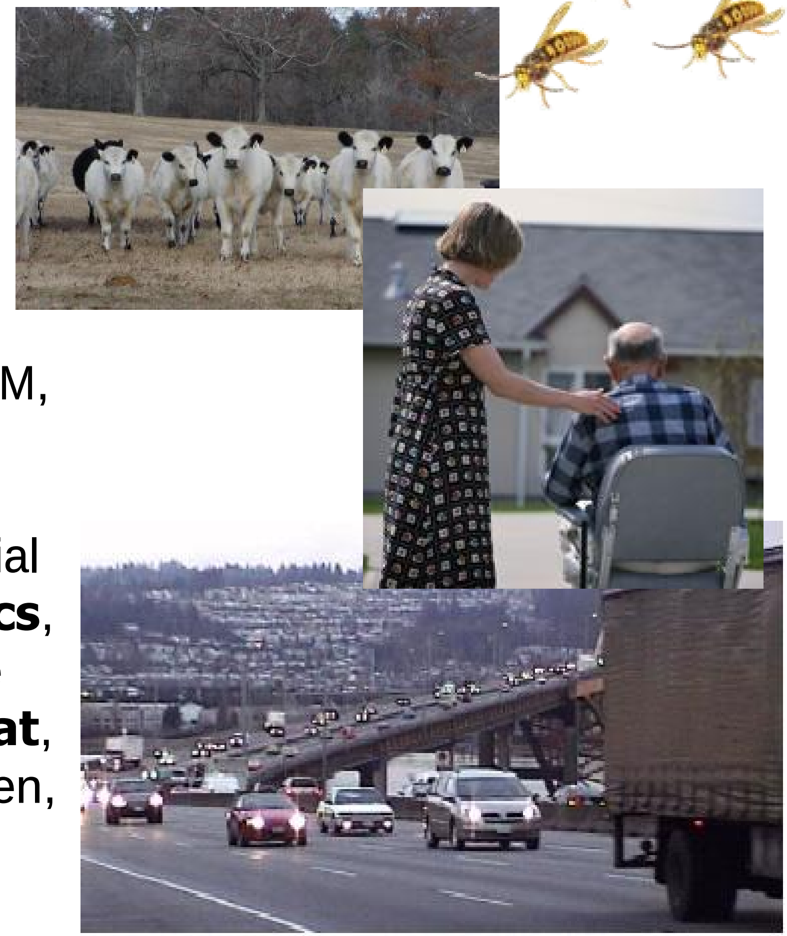


On-demand model



WASP Project

Wireless Accessible Sensor Populations

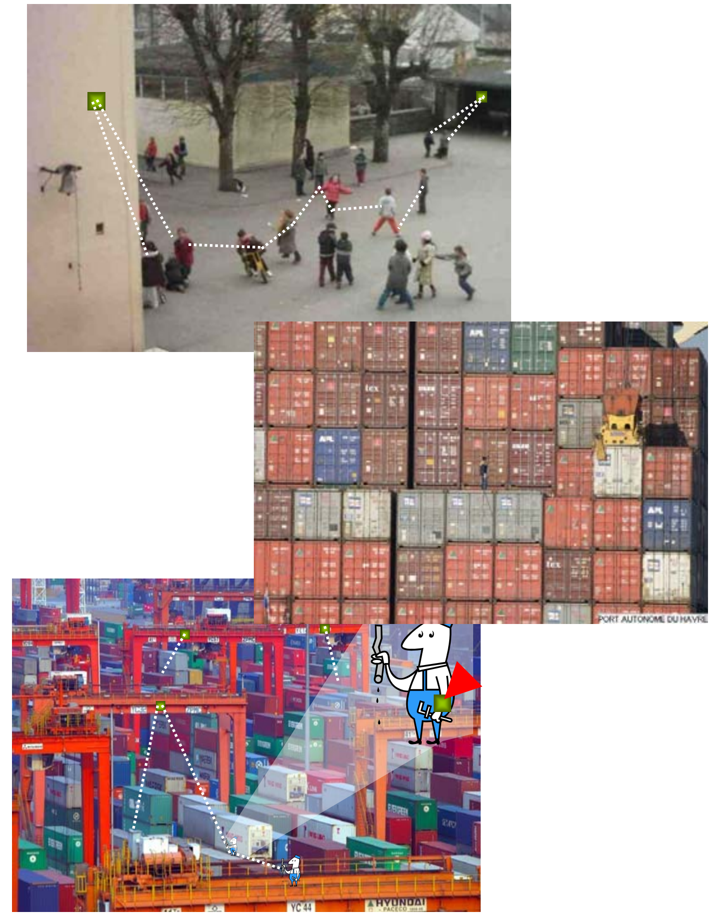


Philips Research Eindhoven, Philips Forschung Laboratorium, IMEC, CSEM, TU/e, **Microsoft** Aachen, Health Telematic Network, Fraunhofer IIS, Fokus, IGD, Wageningen UR, Imperial College London, **STMicroelectronics**, INRIA, Ecole Polytechnique Federale Lausanne, Cefriel, Centro Ricerce **Fiat**, Malaerdalen University, RWTH Aachen, **SAP**, Univ of Paderborn

SVP Project

Surveiller et Prévenir

CEA, INRIA, Institut Maupertuis, Aphycare, LIP6, M2S, Thales, ANACT



Dispositif expérimental

Un Anthony motivé par la recherche !

Ceinture POLAR pour la mesure ambulatoire de la FC

VO2000 : Mesure ambulatoire des échanges gazeux

5 capteurs Séréo'Z sans fil

Tapis déroulant
Vélo à effort paramétrable
Sac à dos chargé

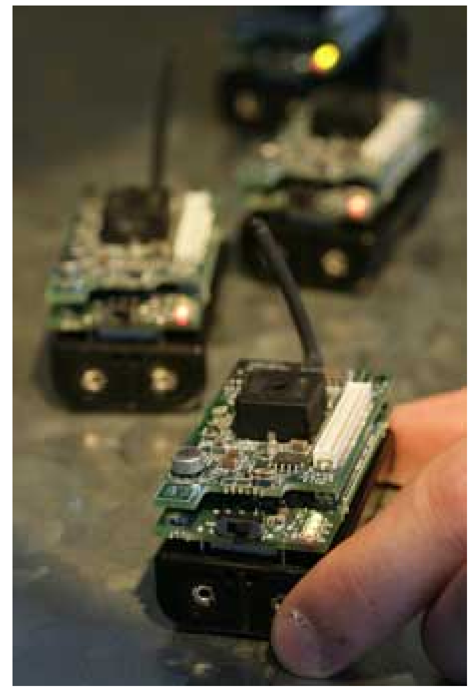
Outlines

I. Wireless Sensor Networks

II. Activity scheduling and coverage problem

III. Key distribution in wireless sensor networks

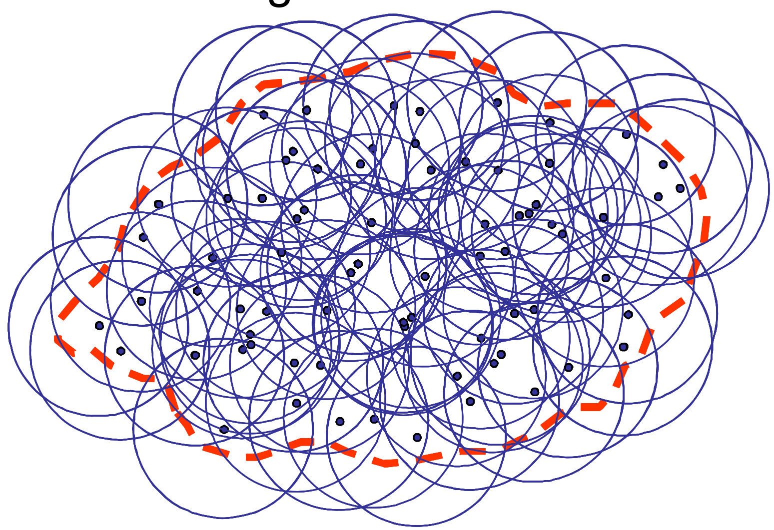
IV. Routing with guaranteed delivery



Sensor Networks

Heavy energetical constraints

- Unable to change or reload batteries



Idea: "Turn redundant sensor nodes to sleep"

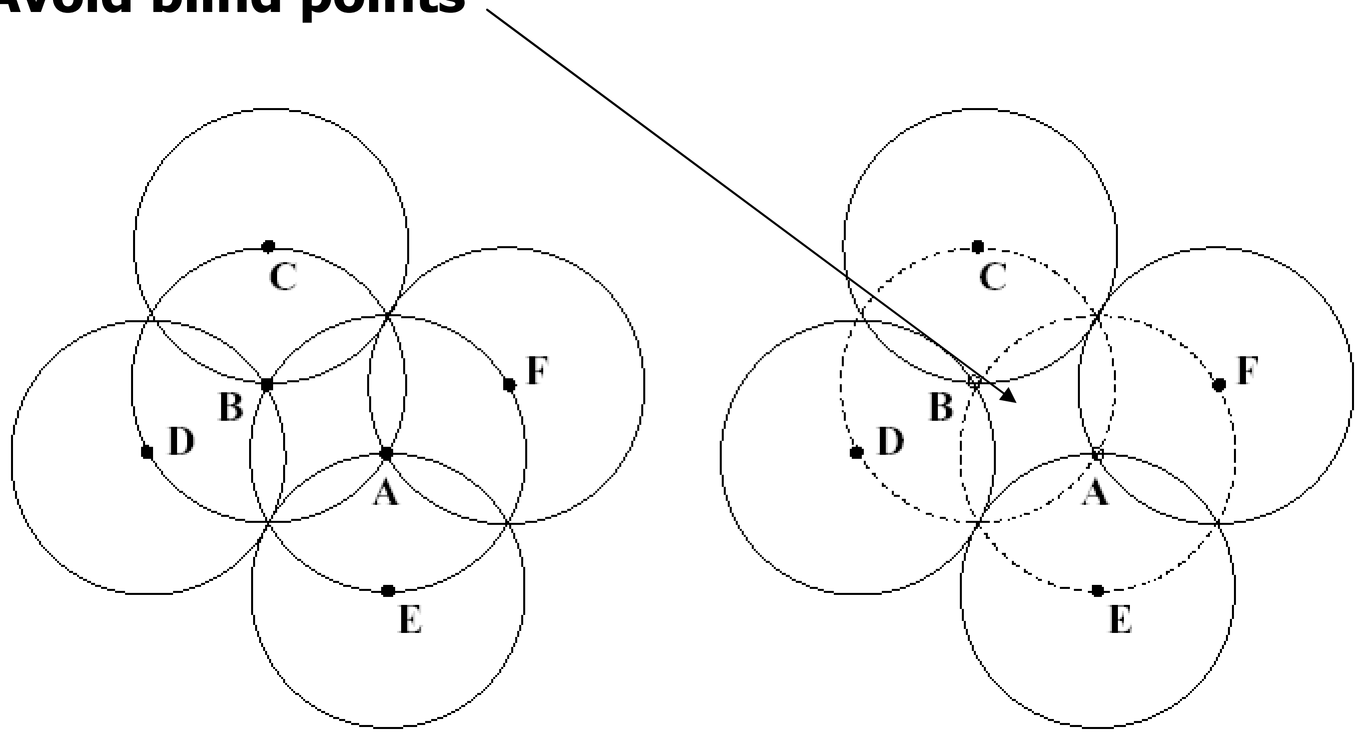
=> Nodes periodically turn into sleep or active mode
=> Need for **activity scheduling** and **self-organization**
=> ***Connectivity*** and ***area coverage*** must be preserved

Sensor Coverage

- **How well do the sensors observe the physical space**
  - Sensor deployment: random vs. deterministic
  - Sensor coverage: point vs. area
  - Coverage algorithms: centralized, distributed, or localized
  - Sensing & communication range
  - Additional requirements: energy-efficiency and connectivity
  - Objective: maximum network lifetime or minimum number of sensors
- **Area (point)-dominating set**
  - A small subset of sensor nodes that covers the monitored area (targets)
  - Nodes not belonging to this set do not participate in the monitoring – they sleep
- **Localized solutions**
  - With and without neighborhood information

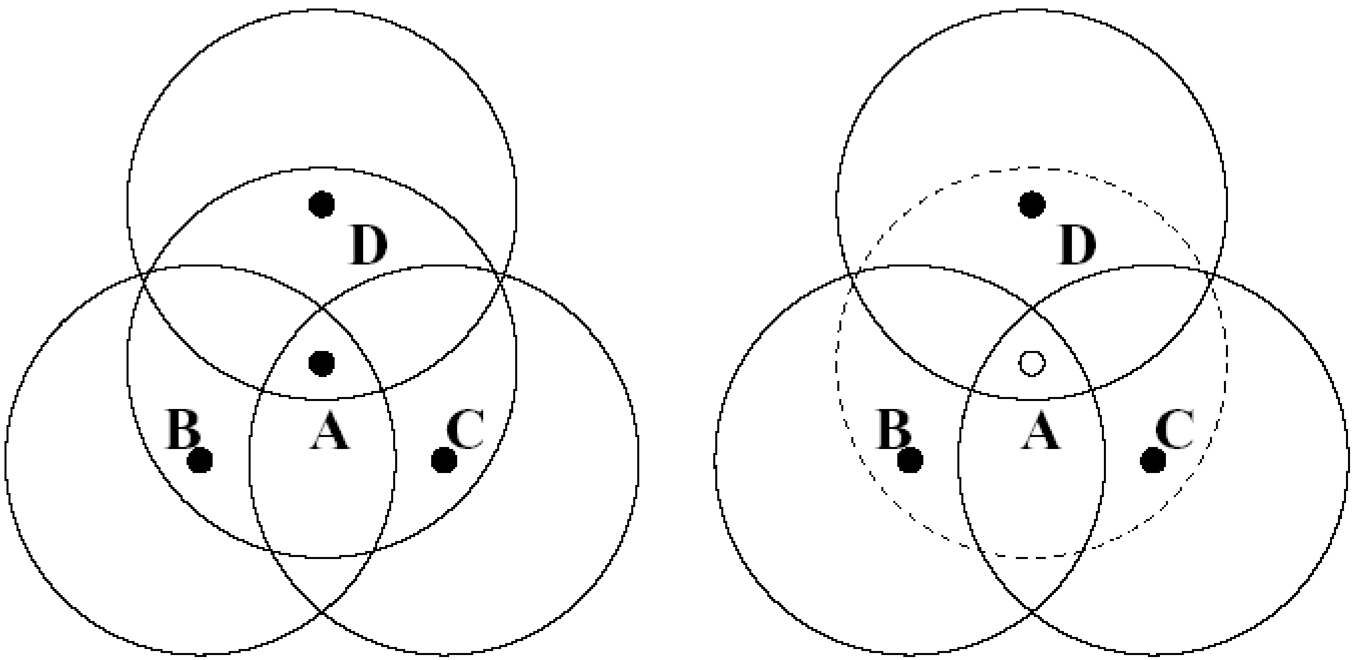
Sensor coverage (2)

- **Avoid blind points**



Sensor coverage (3)

- **Avoid lost of connectivity**



Area-dominating set

- **With neighborhood info [Tian and Geoganas, 2002]**
  - Each node knows all its neighbors' positions.
  - Each node selects a random timeout interval.
  - At timeout, if a node sees that neighbors who have not yet sent any messages together cover its area, it transmits a "withdrawal" and goes to sleep
  - Otherwise, the node remains active but does not transmit any message

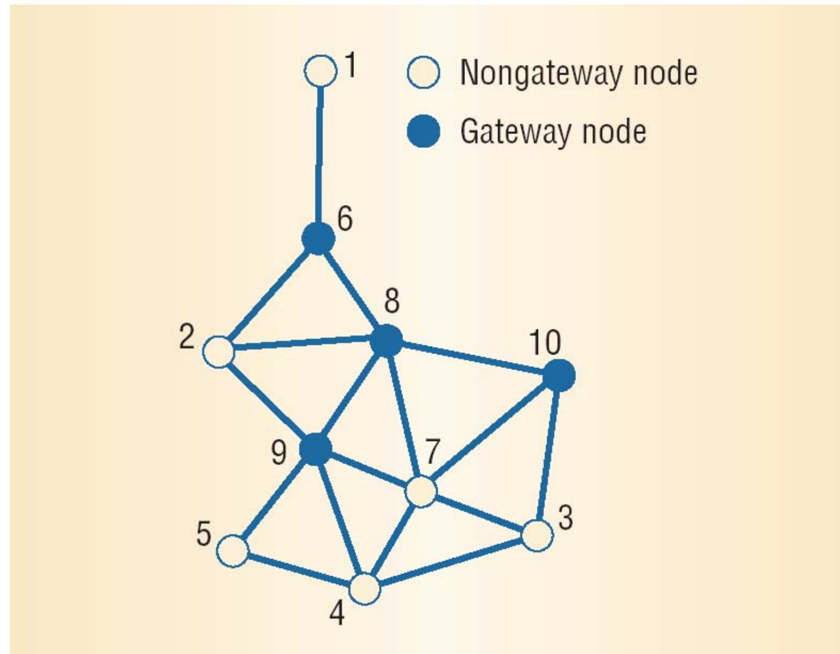
- **With neighborhood info based on Dai and Wu's Rule k [Carle and Simplot-Ryl, 2004]**
  - Each node knows either 2- or 3-hop neighborhood topology information
  - A node u is fully covered by a subset S of its neighbors iff three conditions hold
    - ✓ The subset S is connected.
    - ✓ Any neighbor of u is a neighbor of S.
    - ✓ All nodes in S have higher priority than u.

Wu & Dai dominating sets

- (Simplified version [Carle and Simplot-Ryl 2004])

- **Each node has a priority (*e.g.* its ID)**
  - Variations:
    <degree, ID>
    <battery, degree, ID>
    <random, battery, degree, ID>
    …

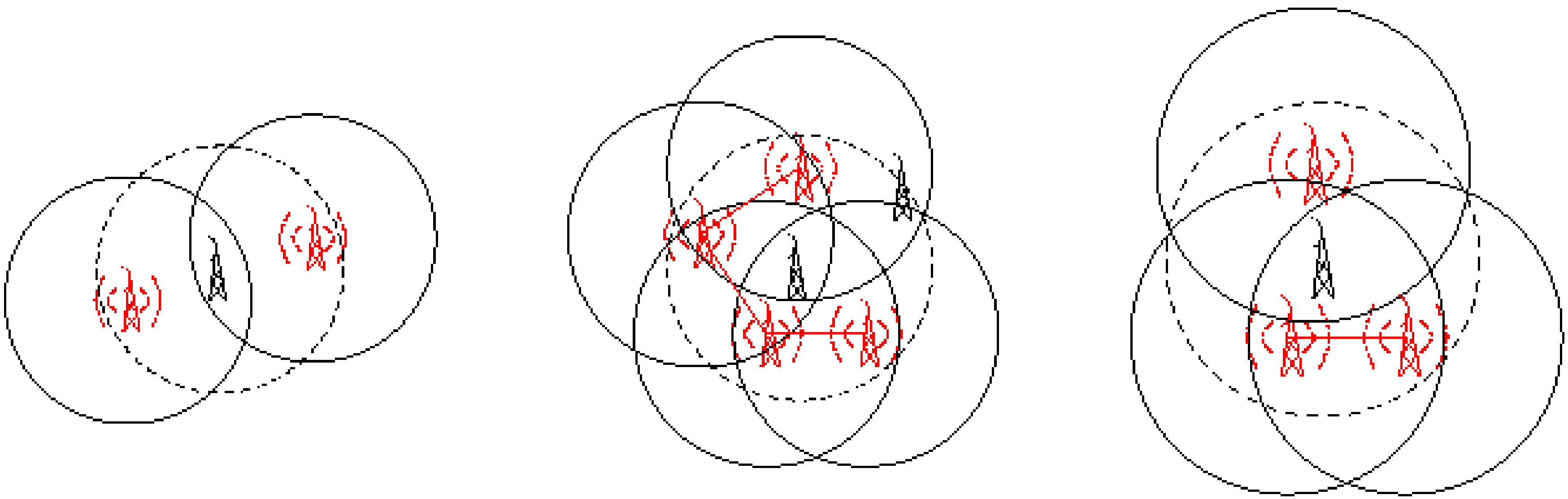
- **A node is not dominant iff**
  - The set of neighbors with higher priority is connected and covers the neighborhood



Connected area dominating sets

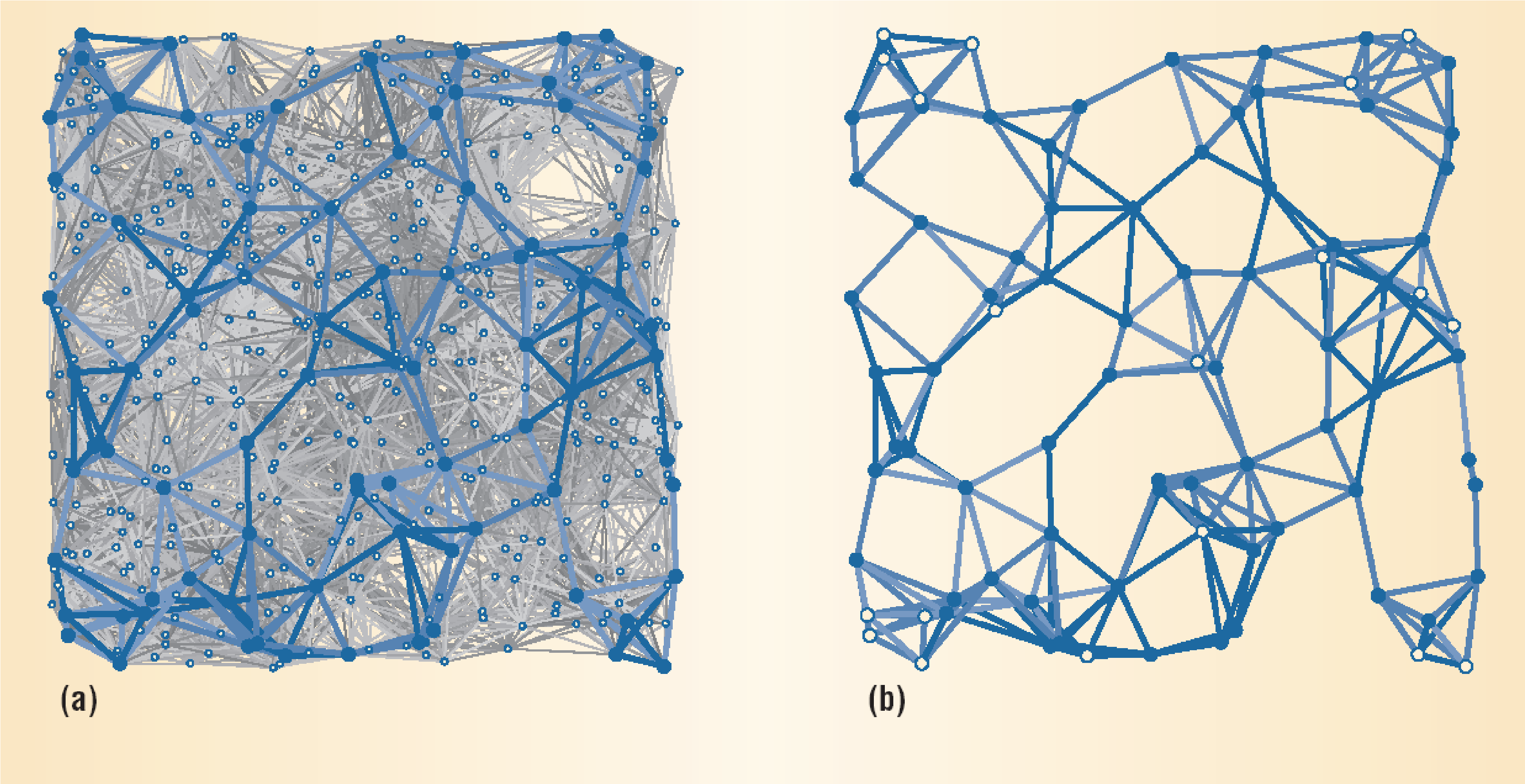
[Carle, Simplot-Ryl 2004][Gallais et al. 2006]

- **We change notion of coverage**
  - A node u is covered by a subset A of its neighborhood if the monitoring area of u is covered by nodes of A
- **Remaining battery is used as priority**
- **Timeout is used to inform transmit priority**
- **Examples:**



Connected area dominating sets (2)

- **We obtain a Connected** Area **Dominating Set**



Coverage without neighborhood info

- **PEAS: probabilistic approach [F. Ye et al, 2003]**
  - A node sleeps for a while (the period is adjustable) and decides to be active iff there are no active nodes closer than r'.
  - When a node is active, it remain active until it fails or runs out of battery.
  - The probability of full coverage is close to 1 if

$$r' < (1+\sqrt{5}) \times r$$

where r is the sensing (transmission) range

- **No guarantee of coverage or connectivity!**

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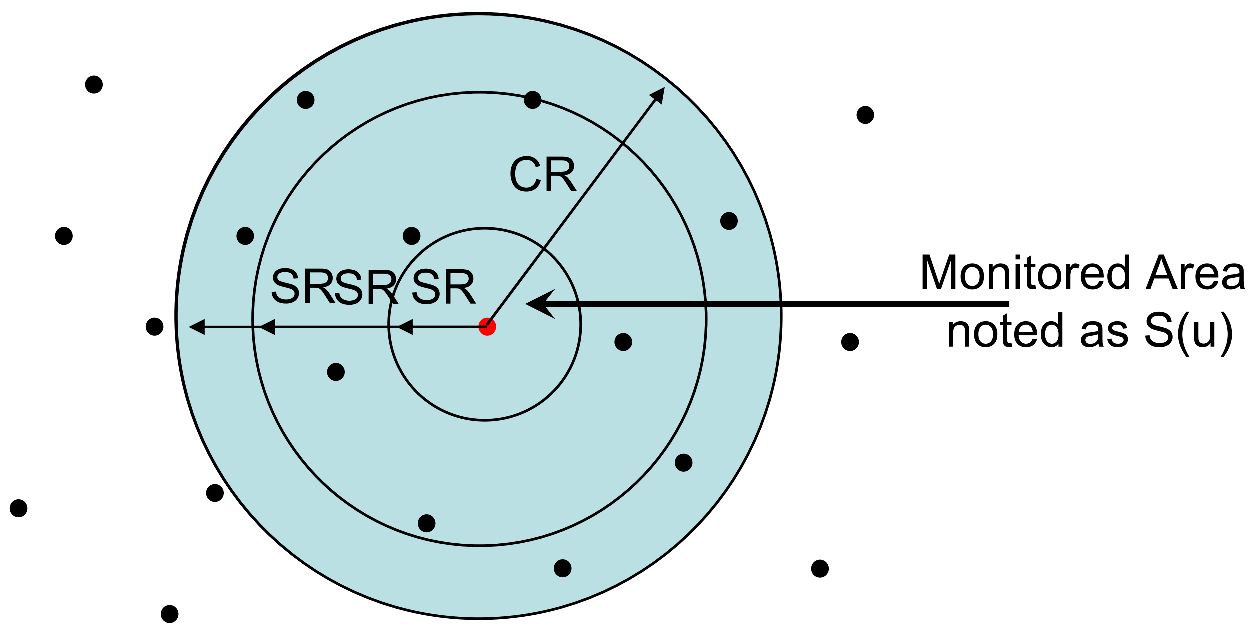
Ranges

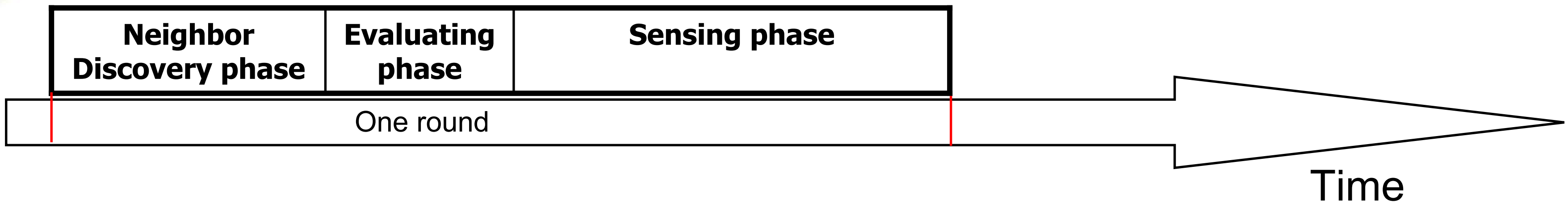
Communication Range, noted as CR

Sensing Range, noted as SR

SR2SR=CR2SR



Overview TGJD

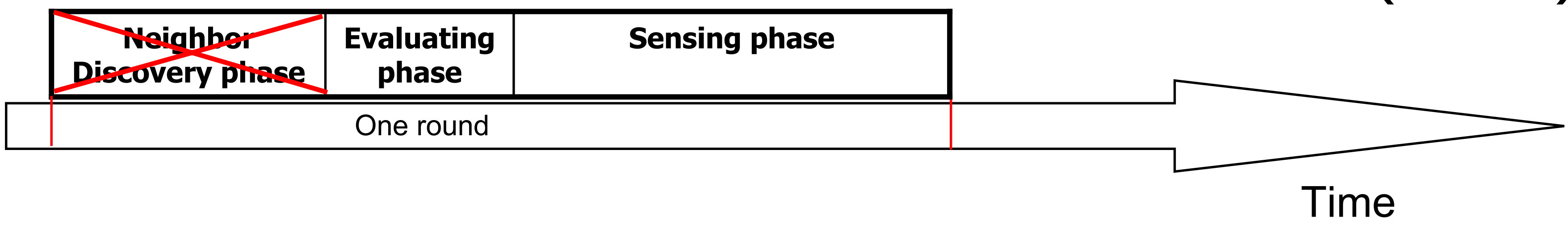


- **Neighbor discovery phase**

- **Evaluating phase**
  - ✓ Back-off scheme: avoid *blind point* (no neighboring nodes can simultaneously decide to withdraw)
  - ✓ A node decides to sleep: OFF message sent to one-hop neighbours
  - ✓ Receiving OFF messages during the timeout: corresponding neighbors are removed from the neighbor table
    - ⇒ At the end of the timeout, decision is made considering **only non-turned-off neighbors**

- **Connectivity is ensured as long as 2SR ≤ CR**

Carle, Gallais, Simplot-Ryl and Stojmenovic, 2005 (CGSS)



Evaluating phase

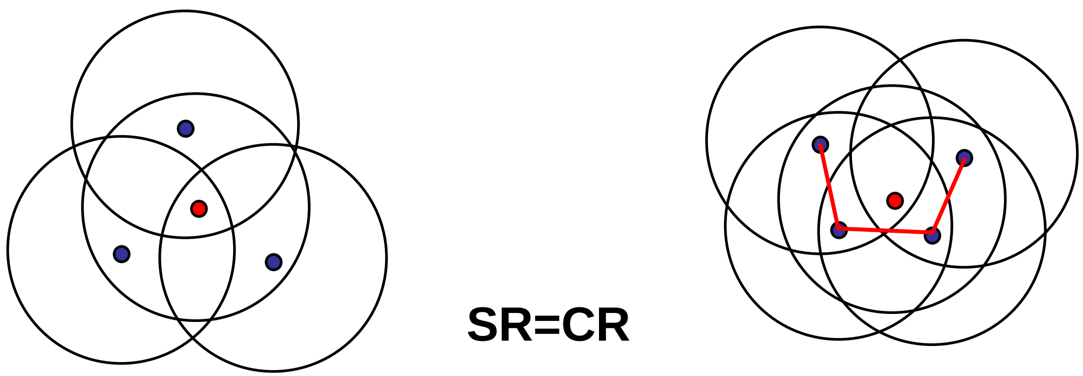
- Each node waits during a random timeout
- Once timeout ends, a node evaluates its **coverage** and decides
- **Advertisement** is then sent to one-hop neighbors
  - ✓ It only contains the position (x,y)

- Any message received during the timeout stands for a **new neighbor to be considered**

CGSS: Connectivity and Advertisements

- **Connectivity is ensured for any SR/CR ratio since full coverage must be provided by a connected set**

  (cf. Dai and Wu)



SR=CR

- **Which information must be broadcasted?**
  - ✓ Positive-only, **PO**: *u* broadcasts its position iff it remains active
  - ✓ Positive and **negative, PN**: *u* emits whatever the decision is.

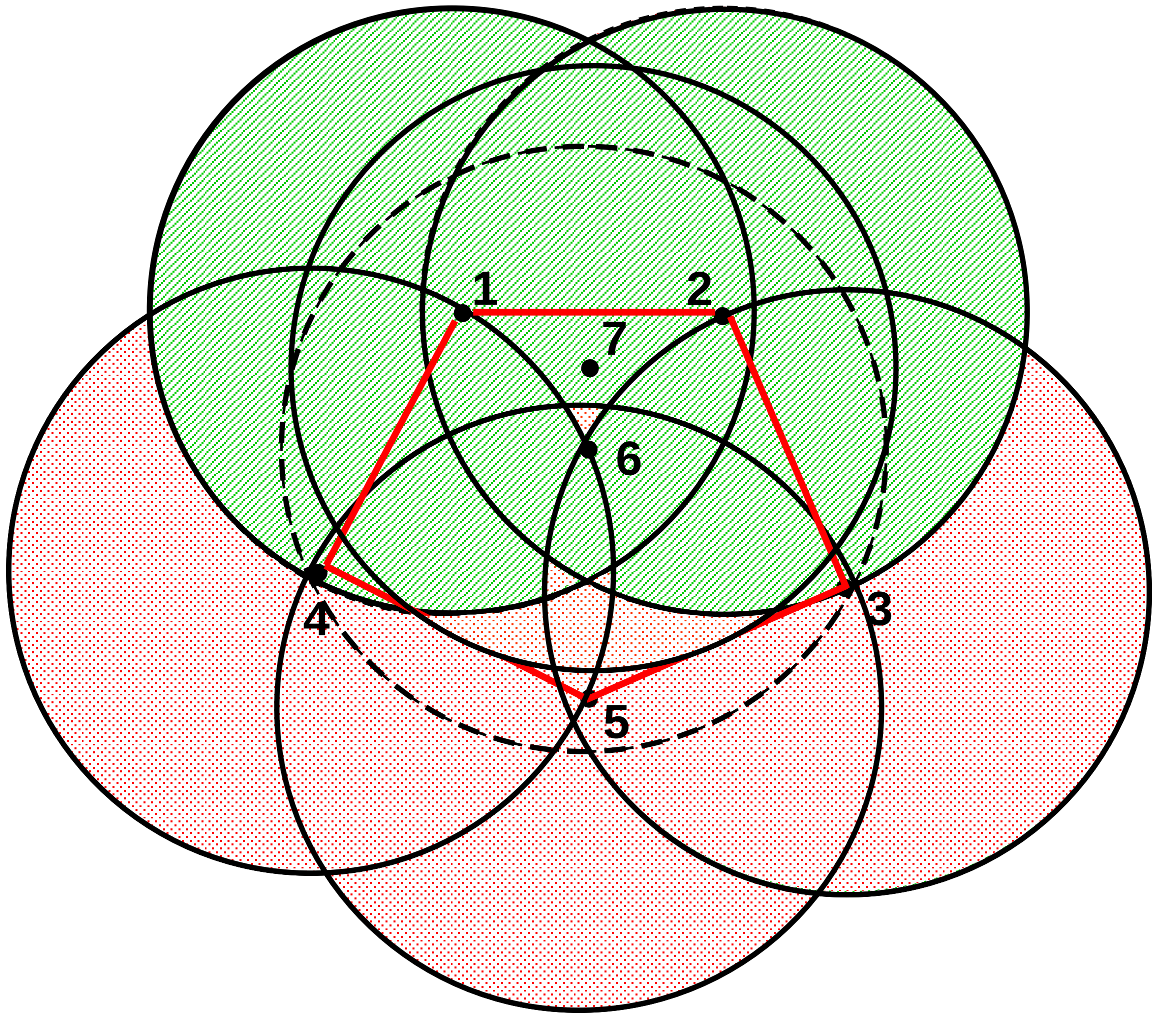
CGSS: Positive-only **(SR=CR)**

1 ?
empty
→ active

2 ?
1
→ active

3 ?
2
→ active

4 ?
1
→ active



5 ?
3 | 4
→ active

6 ?
1 | 2 | 3
4 | 5
→ sleep

7 ?
1 | 2
→ active

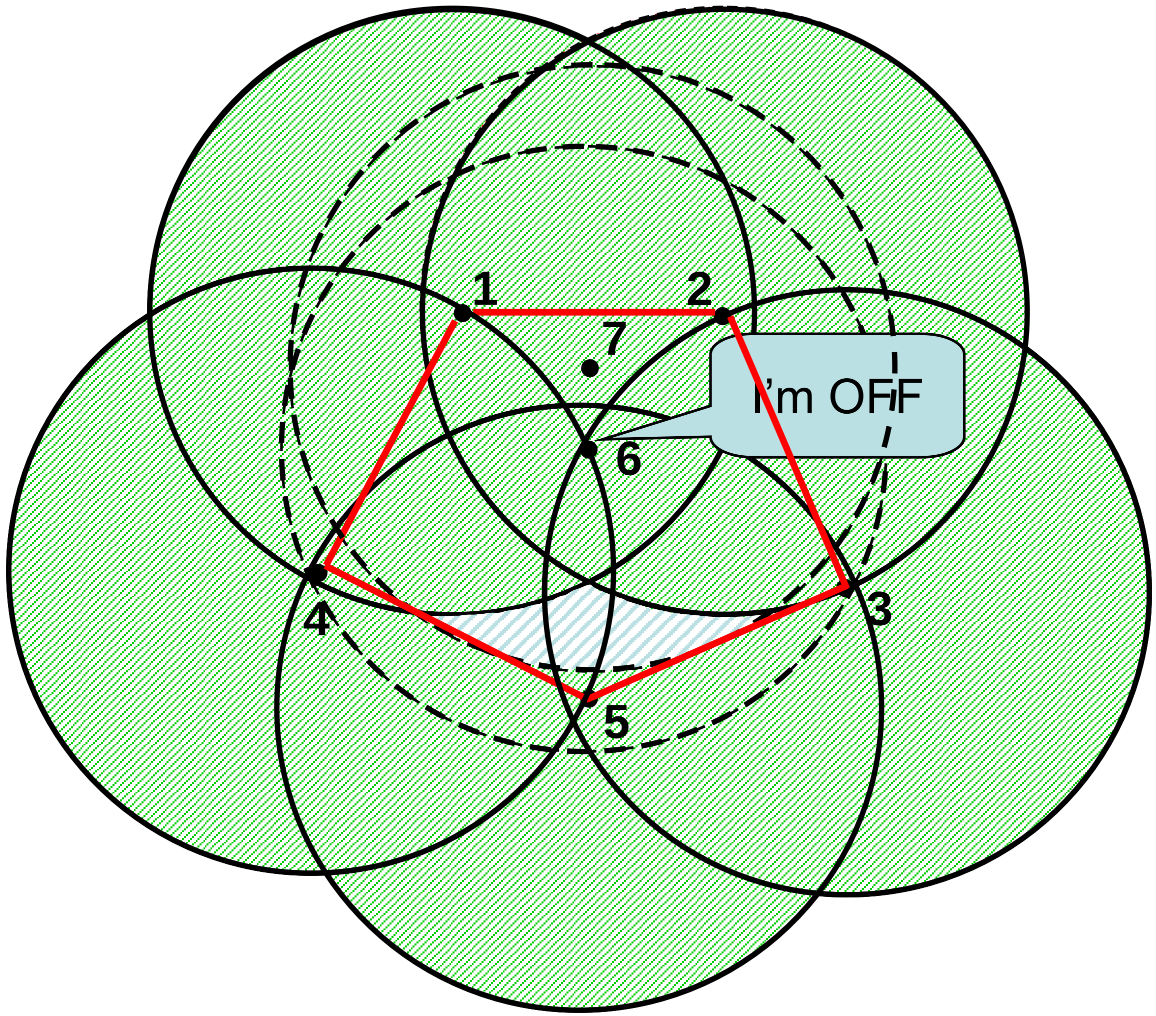
CGSS: Positive and Negative **(SR=CR)**

1
empty
→ **active**

2
1
→ **active**

3
2
→ **active**

4
1
→ **active**



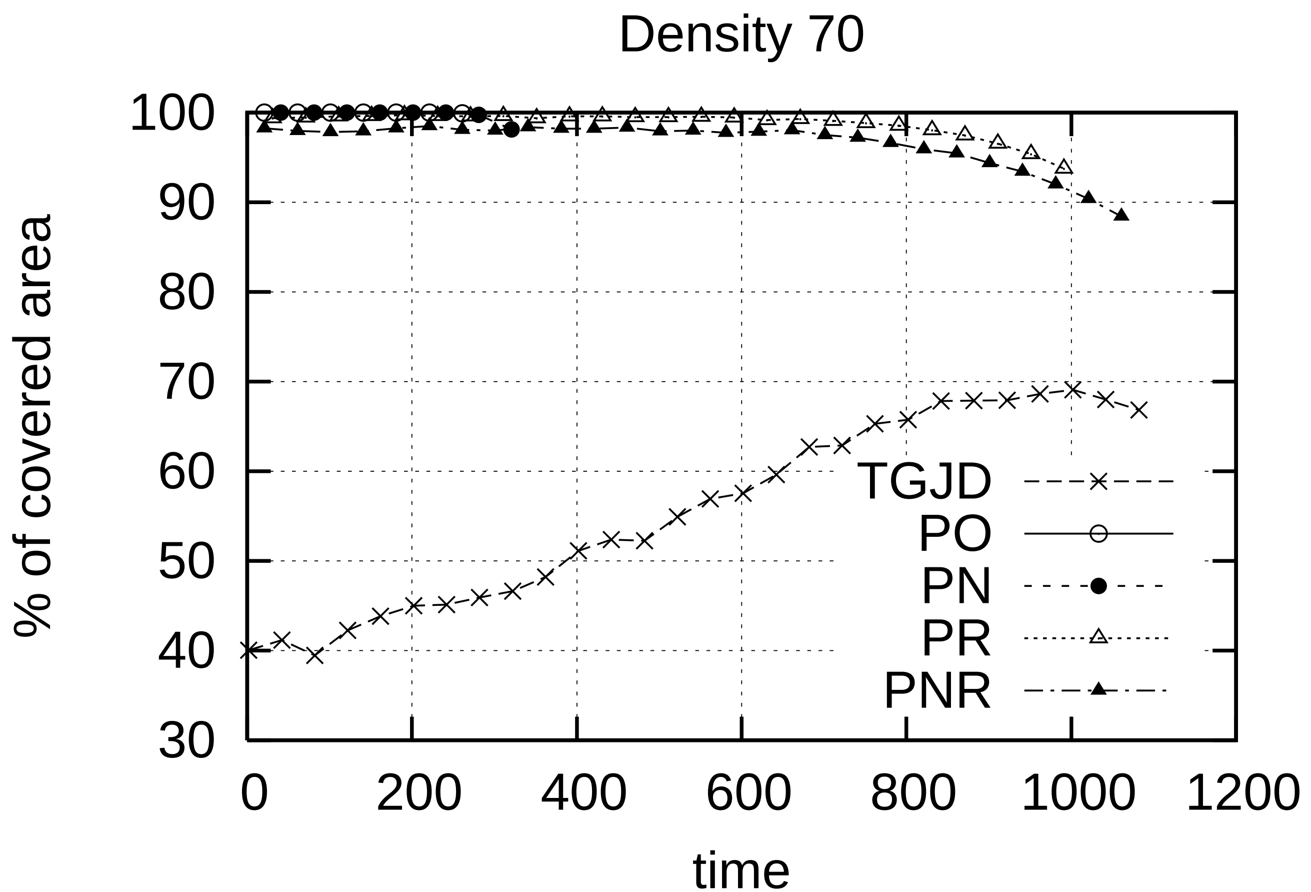
5
3 4
→ **active**

6 ?
1 2 3
4 5
→ **sleep**

7 ?
1 2 6
→ **sleep**

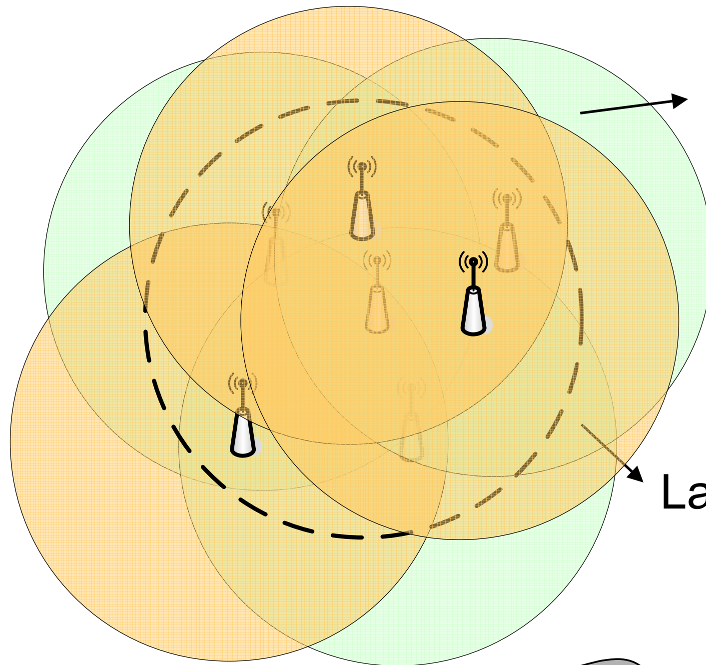
Experimental results

impact on protocol performances once messages get lost



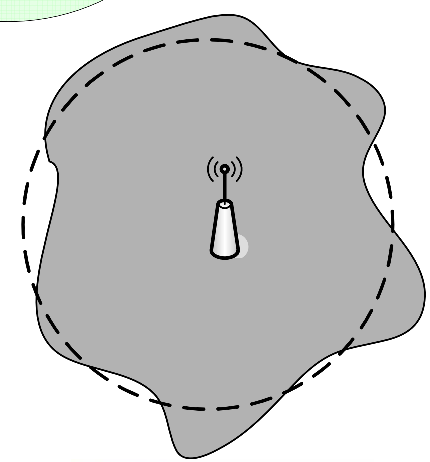
=> Loss of messages induce coverage loss for TGJD

Work in progress



- **Extend CGSS to k-coverage**
  - Insert a parameter (layer k) in activity messages
  - While i<k and covered at layer i, evaluate coverage at layer i+1
  - Each node looks at its k-coverage
  - Decides to be active or not

- **Non-ideal physical layer for sensing**
  - Unit disk may not be always valid ;-)
  - Would it really impact existing protocols?
  - Coverage evaluation scheme would be modified
  - Or shorter sensing radii could be announced



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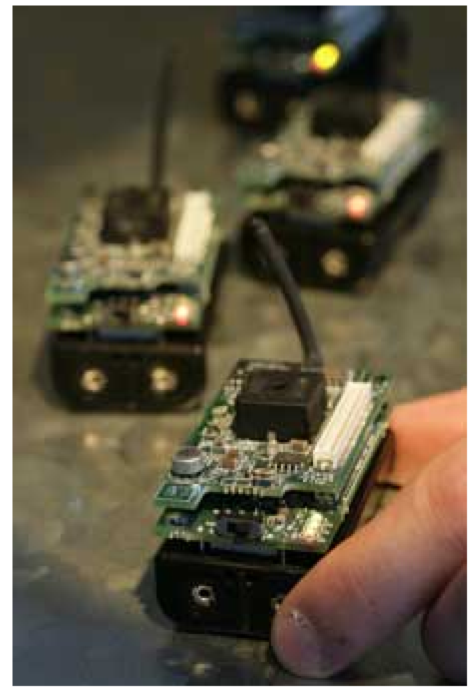
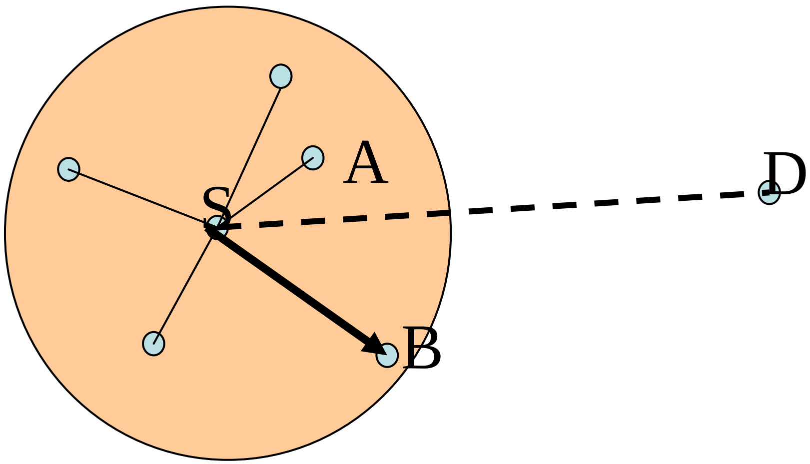


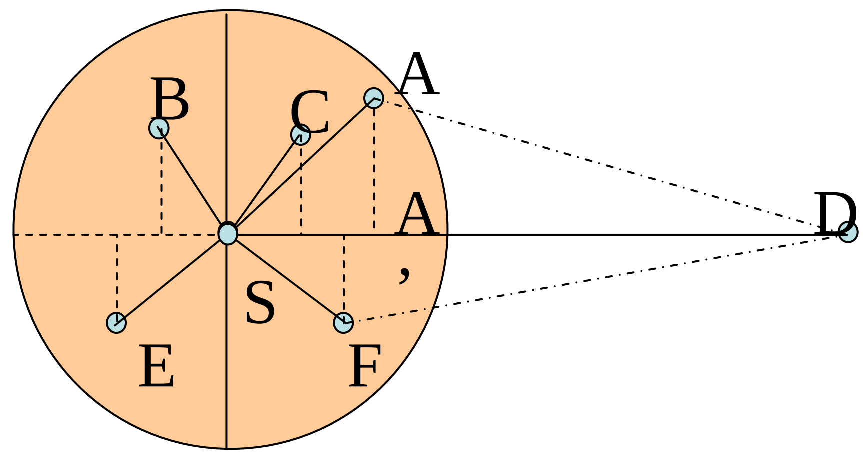
Basic principles

- **Nodes know their own geographical position and positions of their neighbors**
  - → localized
- **When a node has a packet for a given destination (knowing its position), it decides which neighbor is the next hop**
  - → memory-less
- **Example:**
  - S forwards to neighbor B closest to D
  - [Finn 1987]

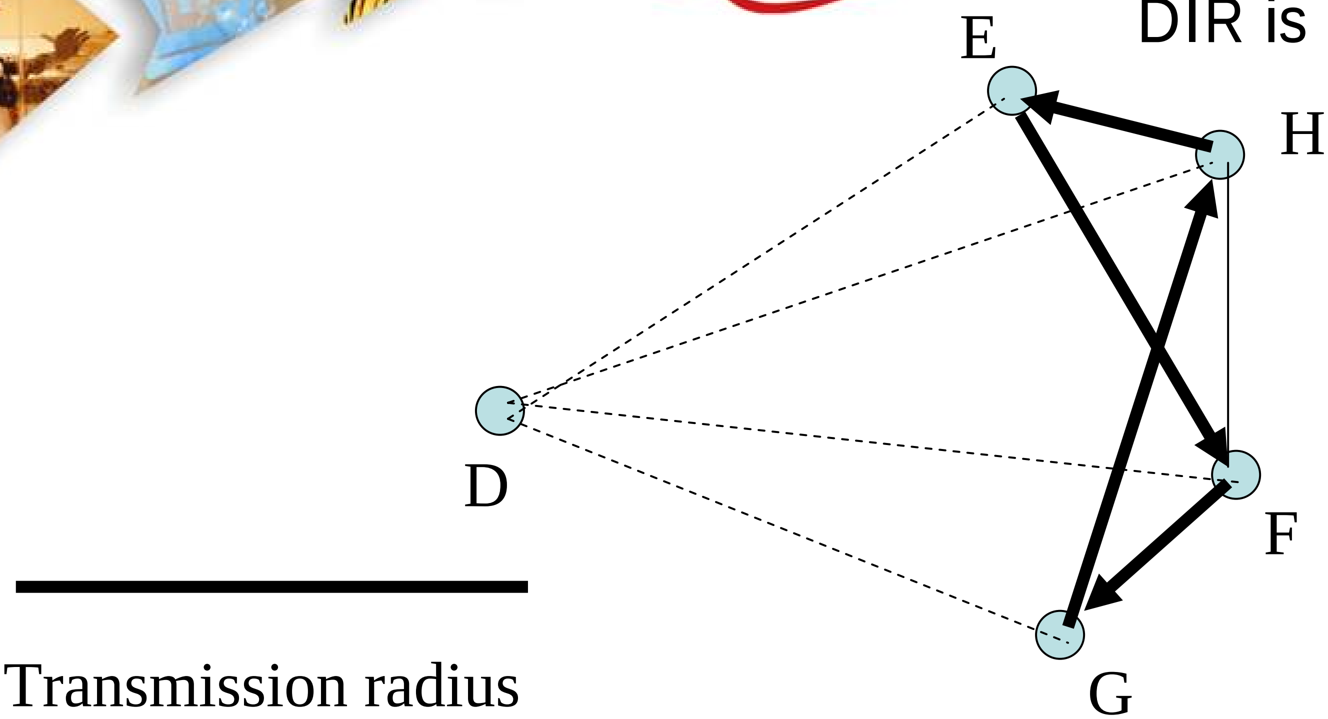


Some variations

- **Nearest forward progress [Hou]**
  - → small steps
- **More forward progress [Kleinrock]**
  - → big steps
- **Random progress [Nelson, Kleinrock]**
  - → ???
- **...**
- **Most close to SD with progress [Elhafsi, Simplot-Ryl]**
  - Variation of DIR [Basagni et al.] which is not loop free [Stojmenovic]

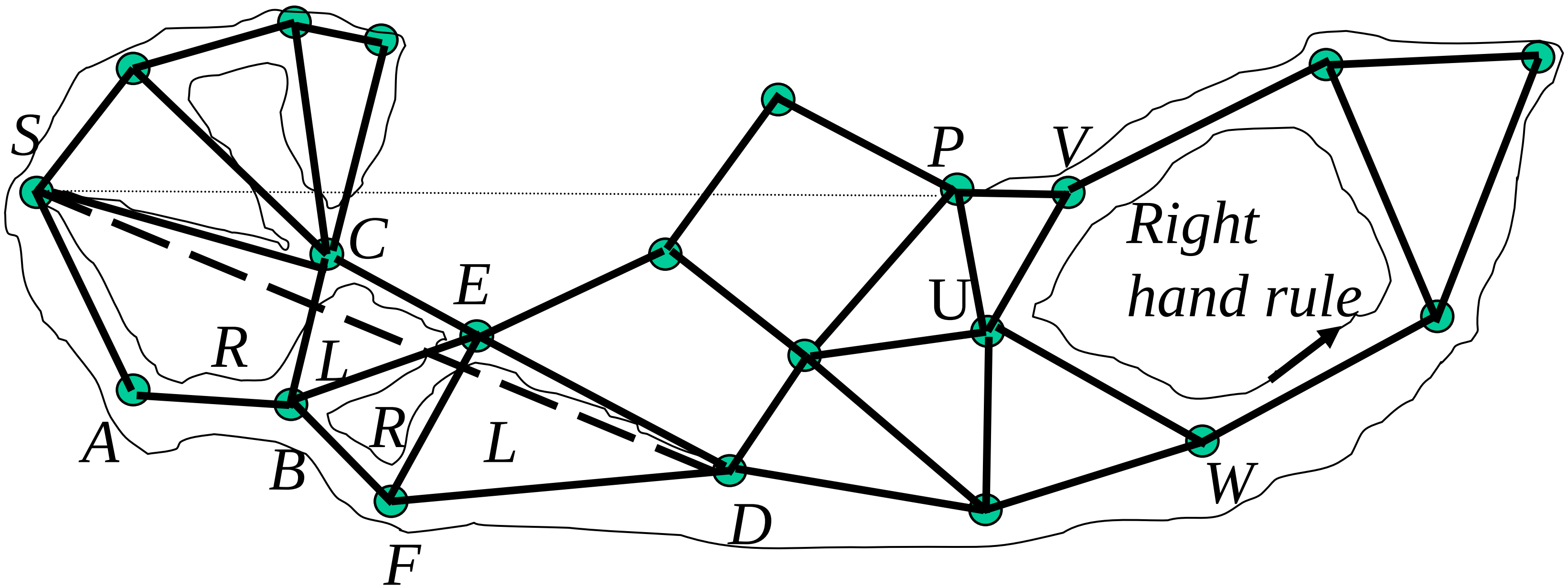


DIR is not loop-free !



- **Greedy and MFR are loop free**
- **If we include constraints on positive progress, the protocol is loop-free**
- **What if there is no neighbor with (strictly) positive progress?**
  - → Dead-end → Recovery process

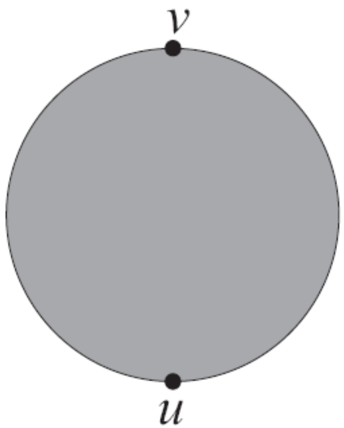
Face routing – guaranteed delivery

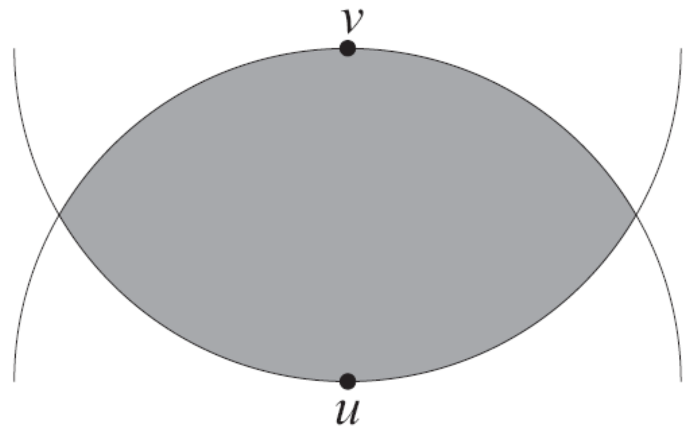


[Bose et al. 1999]

- **Construct planar subgraph**
- **Route in planar subgraph:**
  - SABCEBFED
  - SC…ABFD…W…VP

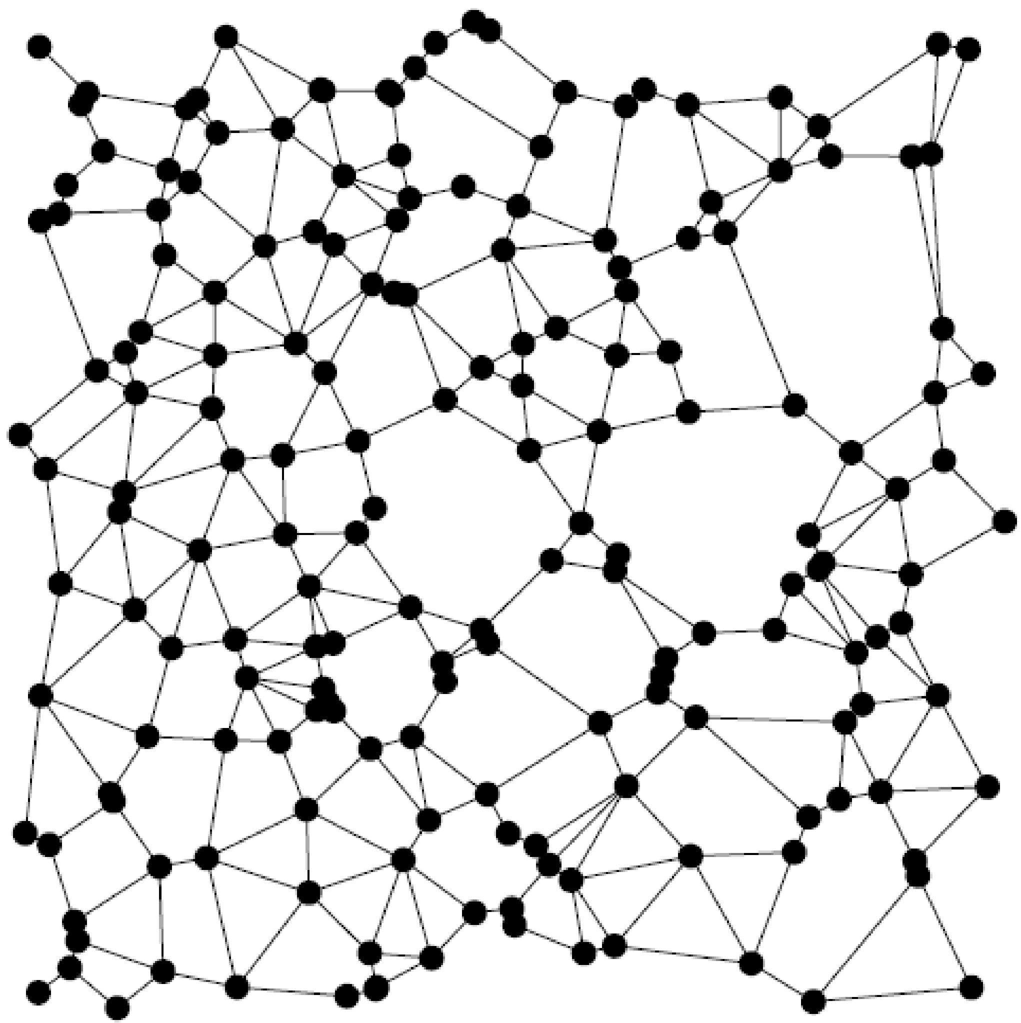
Planarization





- GG = Gabriel Graph
- RNG = Relative Neighborhood Graph
- GG contains RNG
- They are both planar (if the initial graph is the UDG)

Example of GG

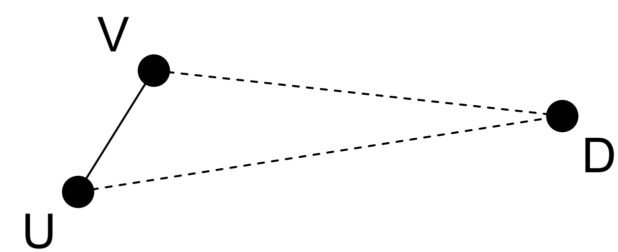


FACE is not energy efficient

- **For two reasons:**
  - The path itself can be long
  - Because of GG, edges are short → can be inefficient
- **Two counter-measures:**
  - Stop the recovery as soon as possible
    - ✓ When in dead-end: note the distance to the destination
    - ✓ Apply FACE until reaching a node which is closer than this distance
    - ✓ Frey and Stojmenovic have shown that only one face is used for each recovery
    - ✓ This scheme is called GFG Greedy-FACE-Greedy [Data et al.] where greedy part can be energy efficient (see later)
  - Apply Shortest path over FACE
    - ✓ → inefficient since edges maintained in GG are the shortest ones
    - ✓ Other solutions exist (see later)

Cost-over-progress scheme

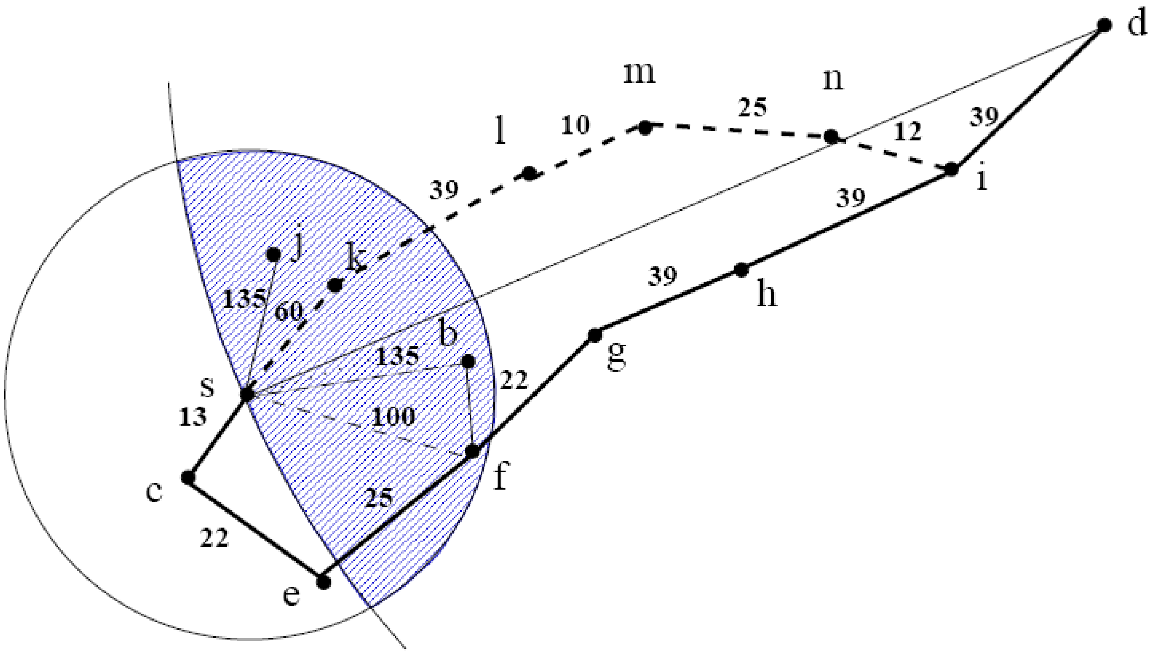
- **[Data, Stojmenovic]**
- **The principle is to consider each neighbor with positive progress and to evaluate the cost of the complete path**
  - Current node = U
  - Considered neighbor = V
  - Destination = D



  - Cost of one step = cost(U,V)
  - Number of steps = |UD| / progress
    - ✓ Progress = |UD|-|VD|
  - Evaluation of the cost of the path under homogeneous hypothesis: cost(U,V)*|UD|/progress
- **When minimizing this total cost |UD| is constant, so it is equivalent to minimize cost/progress**

Introducing shortest path in greedy part

- **After choosing the next neighbor, SP can be apply**
  - Ruiz et al. proposed to apply this after MFR
  - Problem: SP can include nodes which are farther to the destination
  - → the path has to be embedded in the message
  - → or at least the "truncated SP"



Removing memorization of the SP

- **In order to prevent the insertion of SP (or truncated SP) in message, we can use positive path**
  - A path is said to be positive is the distance to the destination is strictly decreasing

- **Summary:**
  1. the current node choose the target neighbor (e.g. MFR)
     If there is no target, go to 5 (recovery)
  2. It computes the shortest positive path to this node
  3. It sends the packet to the next node in this path
  4. Go to 1

  (Steps 1–4: Greedy)

  5. Note the distance from the current node to the destination
  6. Apply FACE until reaching a node which is closer, then go to 1

  (Steps 5–6: Recovery)

Selecting the target neighbor

- **Ruiz et al. proposed to apply MFR**
- **Cost-over-progress can also be applied**
- **More accurate: we can replace the cost by the cost of the shortest positive path…**
- **Summary:**

1. the current node choose the target neighbor

   which is the neighbor with strictly positive progress which minimizes cost-over-progress where the cost is the cost of the shortest positive path

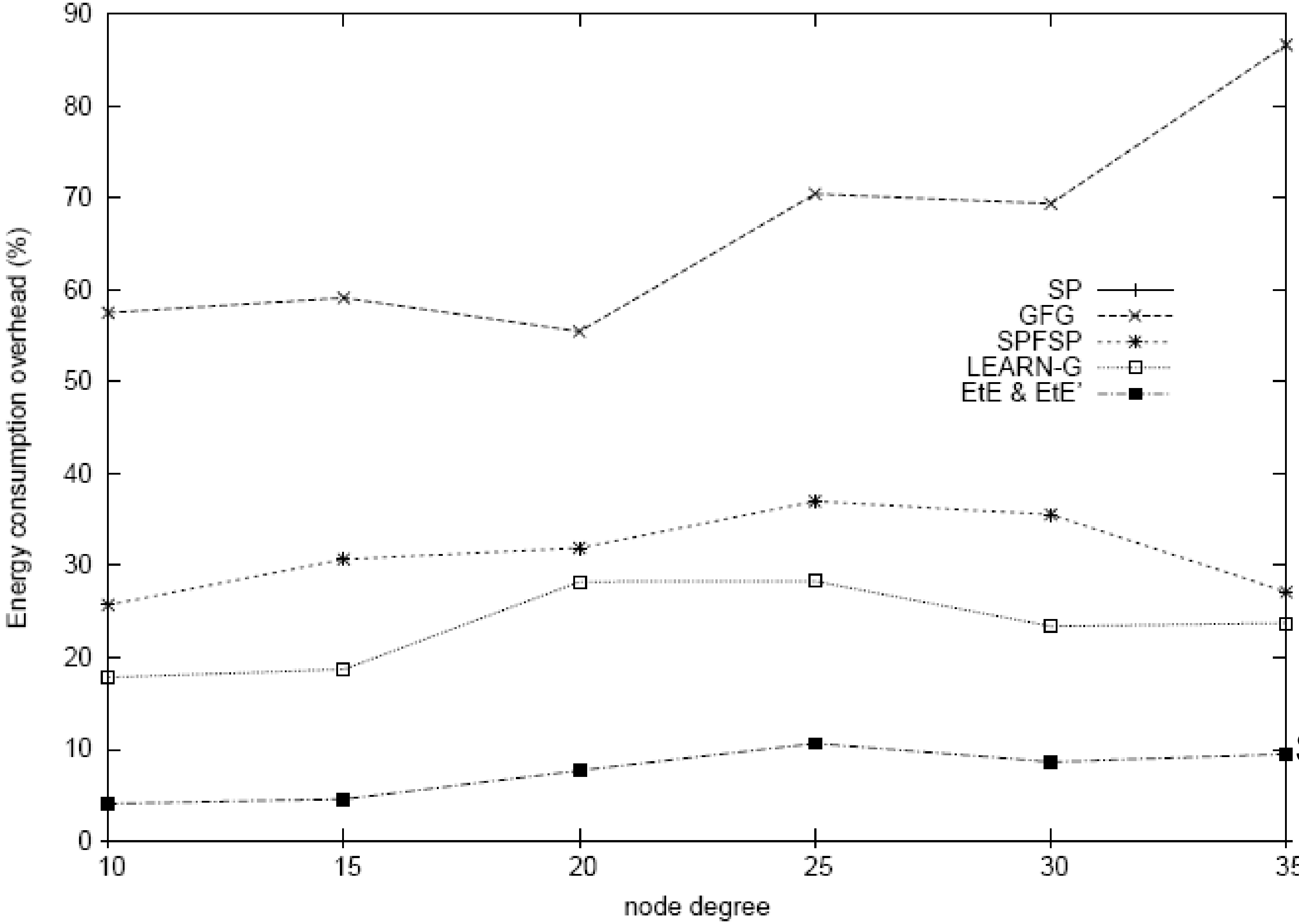
   If there is no target, go to 5 (recovery)
2. It computes the shortest positive path to this node
3. It sends the packet to the next node in this path
4. Go to 1

(Steps 1–4: Greedy)

5. Note the distance from the current node to the destination
6. Apply FACE until reaching a node which is closer, then go to 1

(Steps 5–6: Recovery)

Performances



Cost/progres

SP after MFR

SPP after C/P

Energy-efficient recovery

- **The main problem is length of the edges in GG**
- **→ idea:**
  - before applying GG:
  - apply a connected dominating set algorithm which minimizes the number of dominant nodes

- **A set of nodes is said to be dominant iff each node of the network is in this set of a neighbor of one node in this set**

Wu & Dai dominating sets

- (Simplified version [Carle and Simplot-Ryl 2004])

- **Each node has a priority (*e.g.* its ID)**
  - Variations:

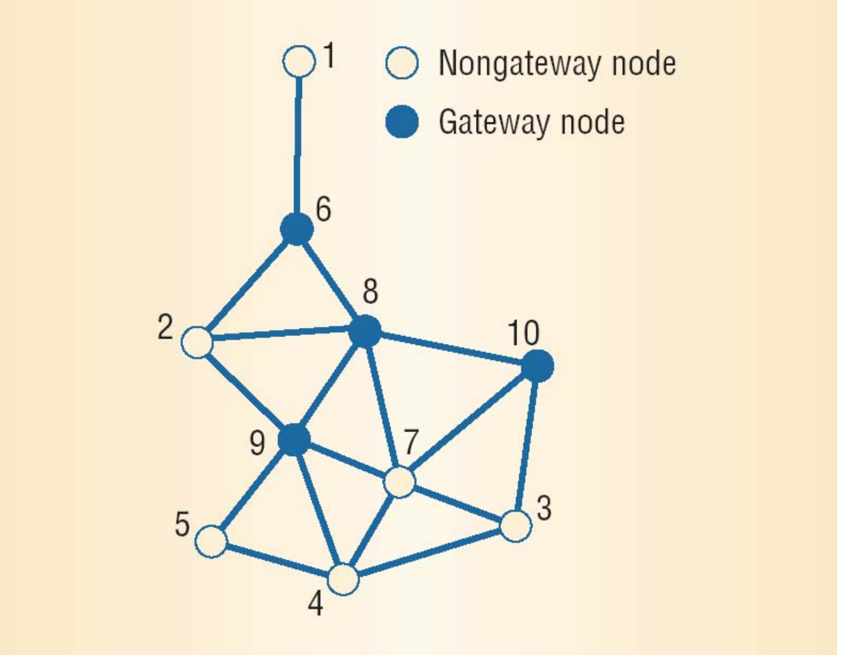
    <degree, ID>

    <battery, degree, ID>

    <random, battery, degree, ID>

    …

- **A node is not dominant iff**
  - The set of neighbors with higher priority is connected and covers the neighborhood



Energy-efficient recovery

- **The main problem is length of the edges in GG**
- **→ idea:**
  - before applying GG:
  - apply a connected dominating set algorithm which minimises the number of dominant nodes

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- **Then, apply FACE over the dominating set where routing along an edge uses shortest positive path**

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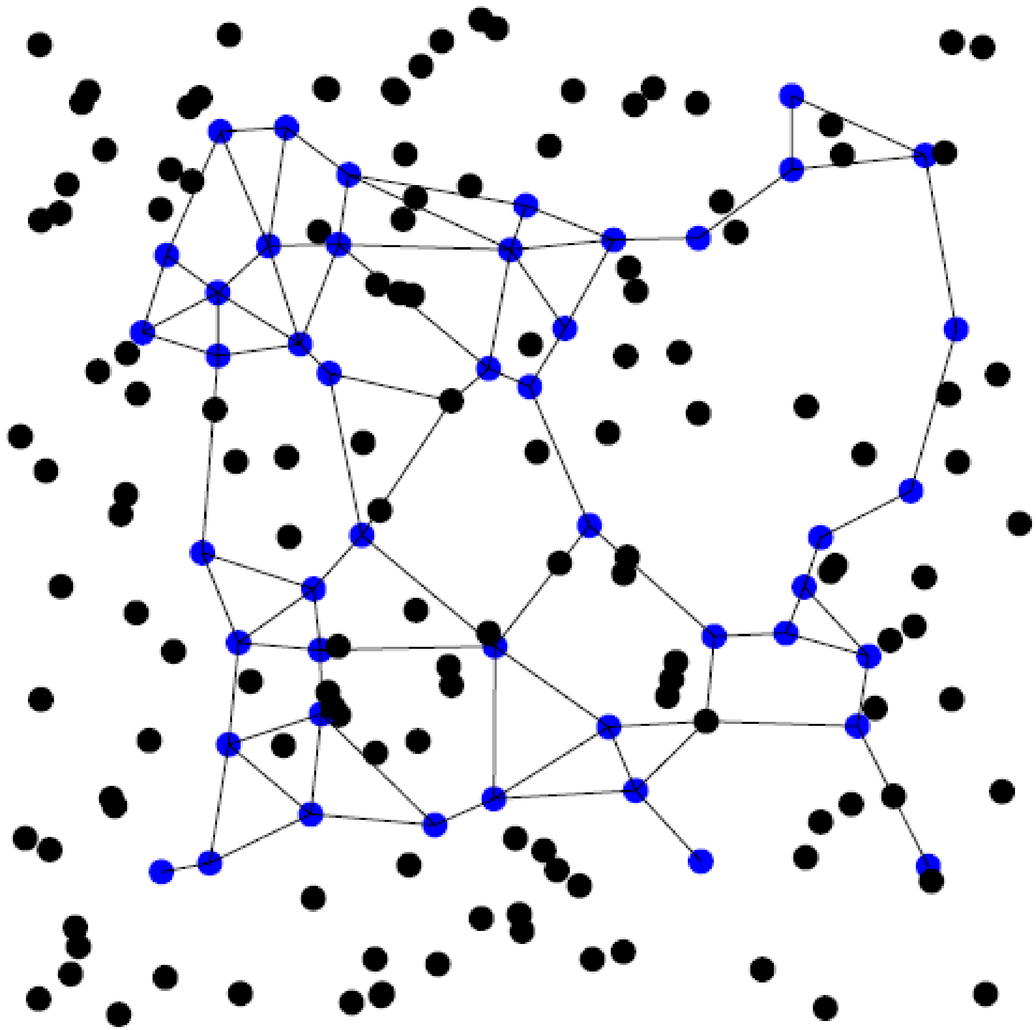
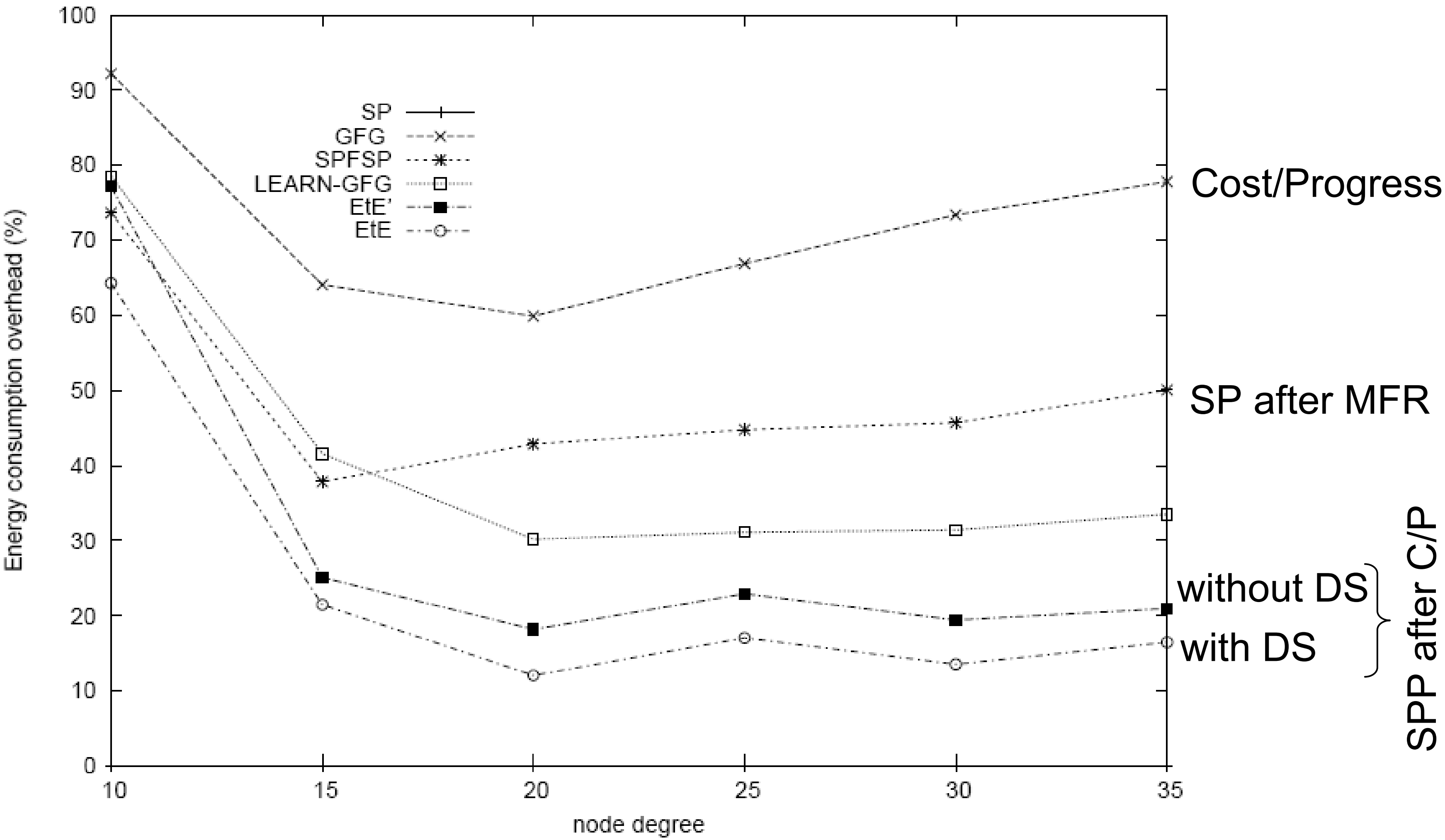
GG over CDS



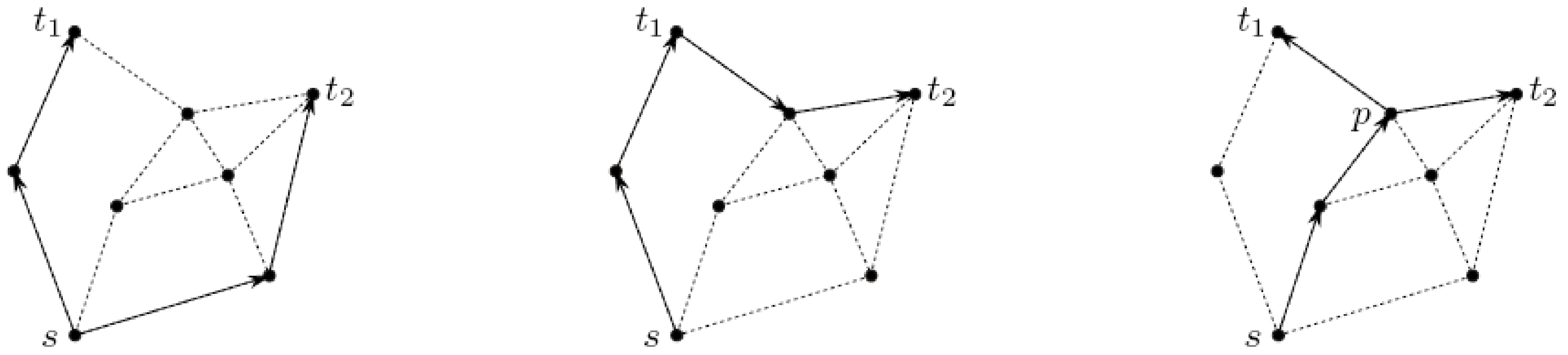
Performances



What else?

Multicasting

- **Same problem but the message as to be sent to several targets**



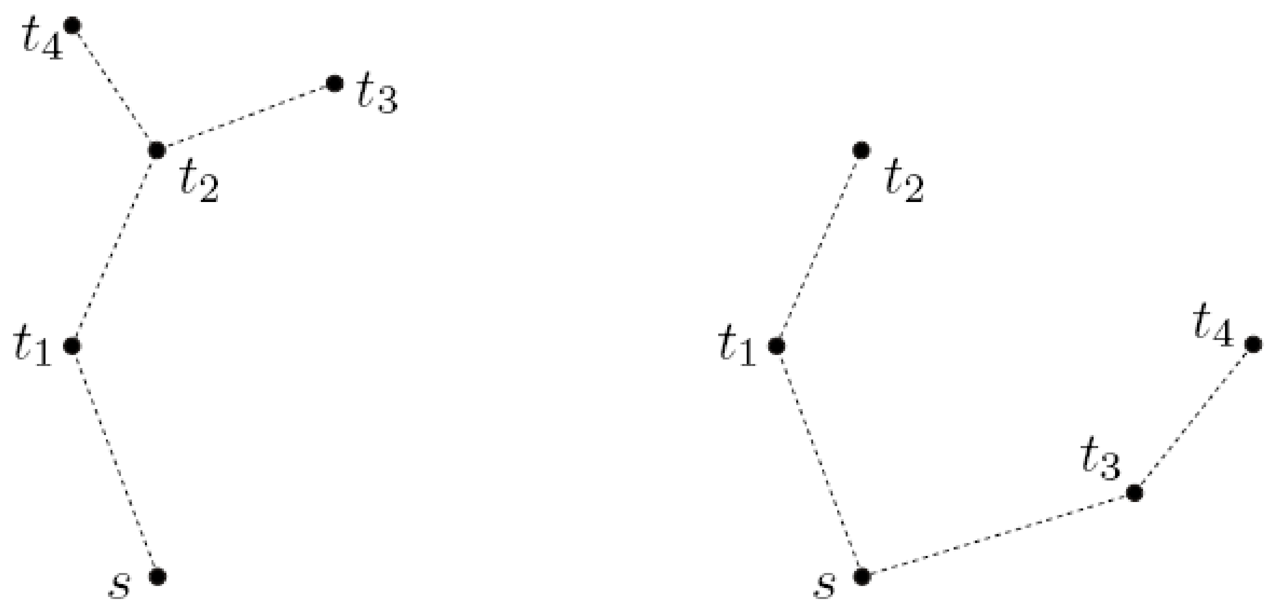
(a) The message is split at the source node.

(b) The message is never split.

(c) The message is split at the end of a common path.

MST-based splitting decision

- **Ingelrest et al. have shown that MST is a good approximation of the Steiner tree and propose to use it for splitting decision:**

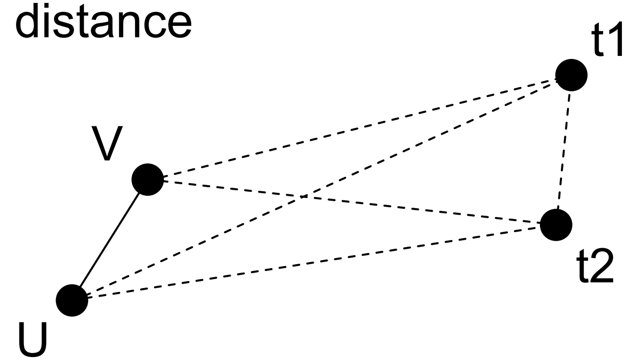


(a) All destinations are kept in the same set.

(b) Two subsets $\{t_1, t_2\}$ and $\{t_3, t_4\}$ are created.

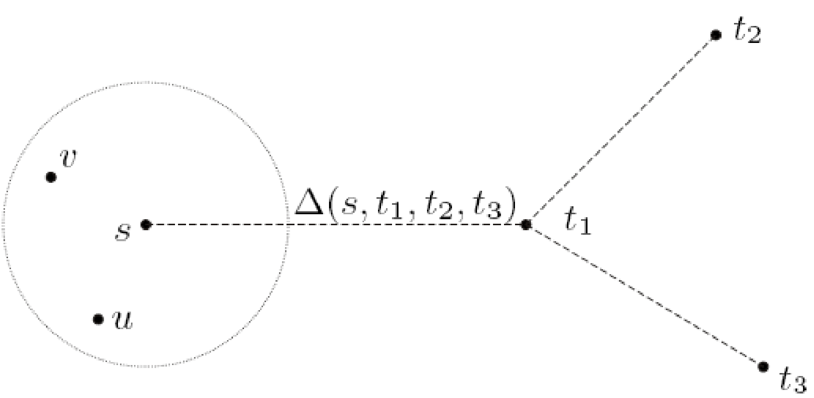
Greedy part

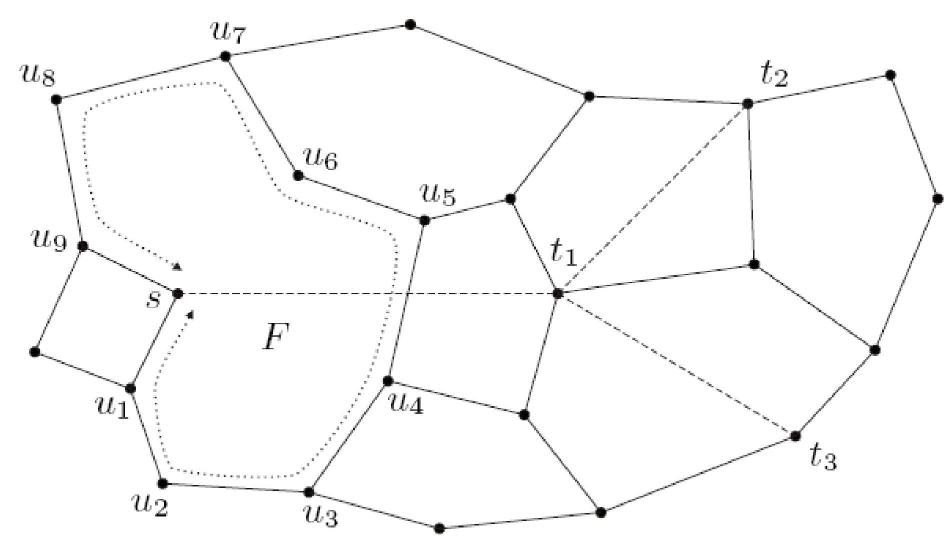
- **For each group, apply a variation of cost-over-progress**
  - The cost is as usual (techniques presented in the first part apply)
  - But what progress???
  - Again, we use MST in order to estimate to distance
  - If U is the current node,
    the progress when considering V is
    |MST(U,t1,…,tN)|-|MST(V,t1,…,tN)|



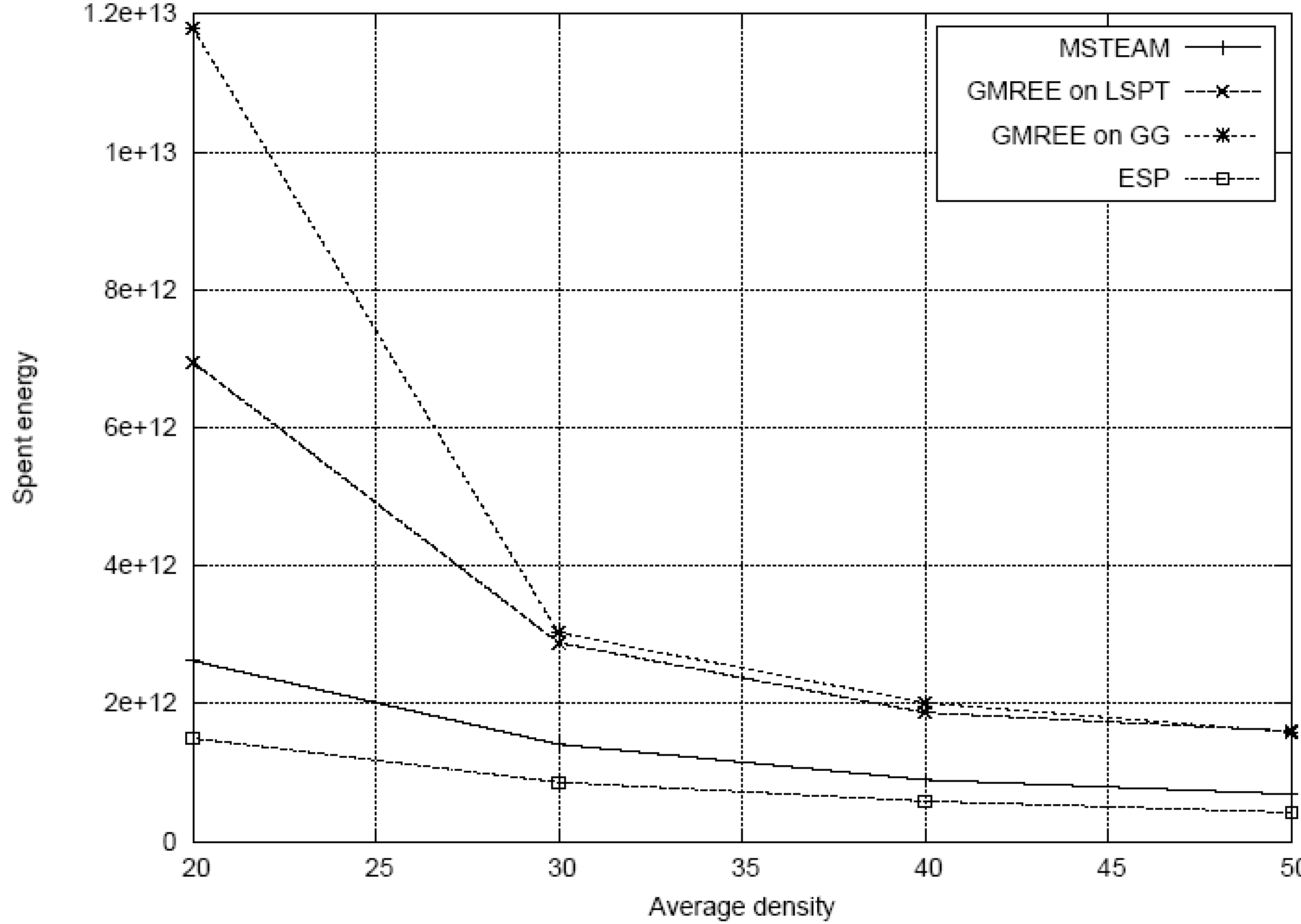
Recovery part

- **We can apply a variation of FACE:**
  - When a dead-end is detected we note the distance to the closest target/destination and we apply FACE to this destination until we reach a node for whom there exists a target closer than this distance.
  - Other possibility: replace the line to the destination by the MST edge





Performances



Ruiz et al. 2007

MSTEAM

Centralized Algorithm

Next?

Conclusion & perspectives

- **Best-known position-based routing (unicast and multicast) have been presented**

- **With geographical information**
  - Basic algorithm: YES (MFR)
  - Energy efficient (EE): YES (cost/progress, ETE…)
  - Guaranteed delivery (GD): YES (FACE, GFG)
  - EE+GD: **YES** **(ETE)**

- **Without geographical information**
  - Basic algorithm: YES (VCap)
  - Energy efficient (EE): **YES** **(VCost…)**
  - Guaranteed delivery (GD): **YES** **(LTP)**
  - EE+GD: **YES** **(HECTOR)**

Conclusion & perspectives

- **Are these protocols efficient in real world?**
- **Big problem: the guaranteed delivery part requires planarization of the connection graph…**
- **Planarization of an arbitrary graph cannot be done in a localized way**
- **Challenge: which properties are needed for the physical layer in order to find a localized algorithm for the planarization**

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Energy savings in wireless sensor networks

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