Improving clustering techniques in Wireless Sensor Networks using thinning process

By

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Outline

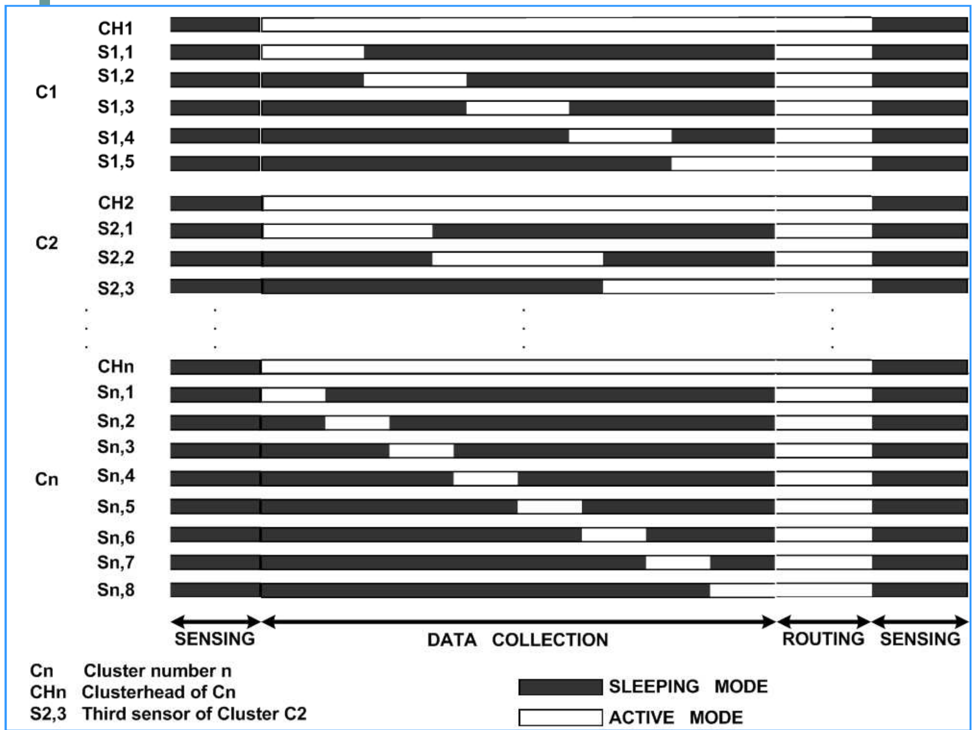
- Previous work
- Definition & Implementation
  - Max-Min d heuristic
  - Matérn Hardcore Process
- Experimental Results
  - Sparse and Dense Networks.
  - Large Networks

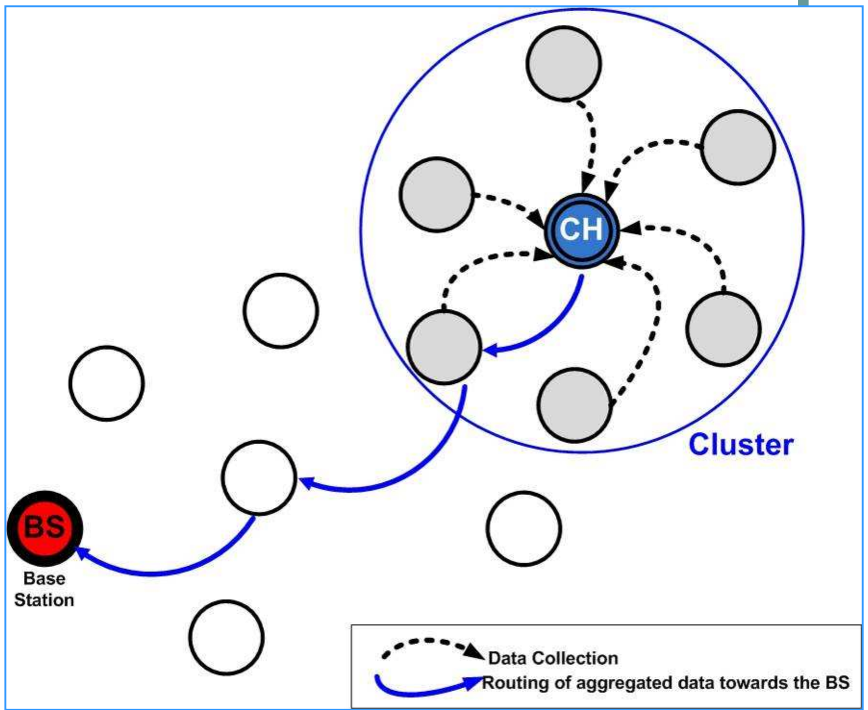
Why Clustering?

- Data aggregation and updates take place in CHs.
- Reduce network traffic and the contention for the channel.
- Limits data transmission (less energy).
- Facilitate the reusability of the resources.
- CHs and gateway nodes can form a virtual backbone for intercluster routing.
- Cluster structure gives the impression of a smaller and more stable network.

Why clustering?

- Each Clusterhead (CH) collects events, aggregates data and then forwards towards the BS.





Previous work: how to design clusters?

- Alan D. Amis, Ravi Prakash, Dung Huynh and Thai Vuong, "Max-Min D-Cluster Formation in Wireless Ad Hoc Networks", INFOCOM, pp. 32-41,2000.
- Algorithm is distributed and supports scalability.
- Rapid Cluster formation.

Previous Work from my team

- BUT
  - Never been validated.
  - Need for generalization.
  - We are First to validate it (to the best of our knowledge);
  - We have found conditions leading to a closed loop.
  - We have corrected it.
  - We have generalized the heuristic.

Previous work from my team

- Measurements on real sensor networks have shown that the quality of the link is a complex process:

  - Random events: interferences, environment

  - Synchronization (sleeping and active periods)

  - Not much room on a sensor for coding

Note

Earlier work with Günter and Gabi and Helmut

on measurement methodology

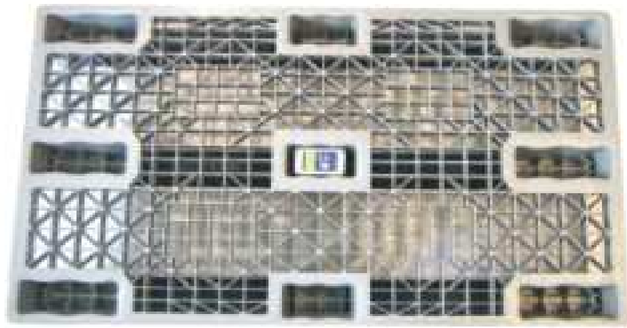
architecture models

and user models

But for WSN the measurement methodology is special and a lot of future work has to be done by the Performance Researchers

Previous work: Cold Chain Control

- A sensor in each pallet



- Costs less than 50 cents for actual deployments.
- Small number of sensors in a truck, direct view
- Large number of sensors in a warehouse, no direct view.

Cold Chain control

- Wireless Channel/Radio:
  - Susceptible to any change or orientation of physical medium.
  - Interference from competing technologies
- Random Deployment:
  - Physical distance between the nodes can vary significantly.
  - Obstacle rich environment causes sharper fading.
- Temporal Effects:
  - Random change in the quality of channel, causing variable packet loss in the channel.
  - Multi-path communication.

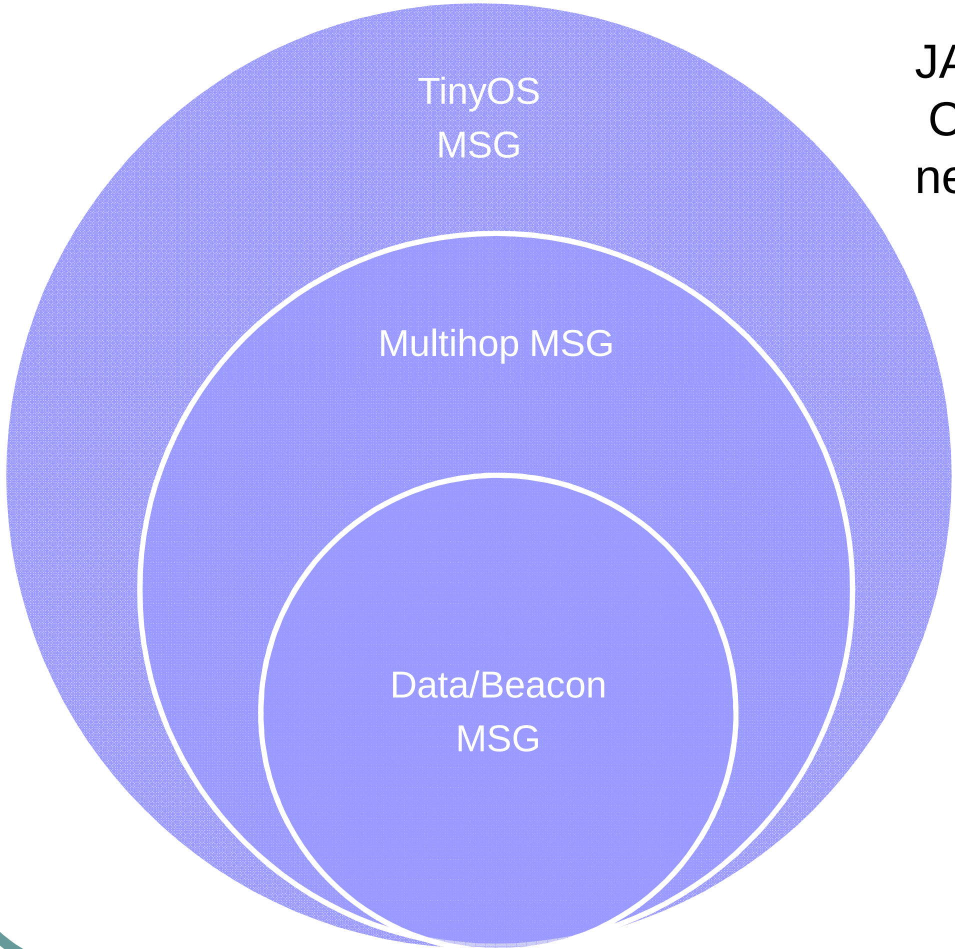
On progress work on clustering

- We are suggesting to use a thinning process to choose the cluster heads
- We first validate this idea by measurements on a set of real sensors.

Assumptions for empirical studies

- Not so powerful nodes.
- Low Cost.
- No GPS.
- No External Antenna.
- Nodes Rely on Beacons to construct topology.
- Max Transmission: 0 dBm, Min: -25 dBm

TinyOS- Open Source



JAVA- User Interface
C -Application Development
nesC – Embedded C, on sensors

Event **Receive** has priority over Event **Send**

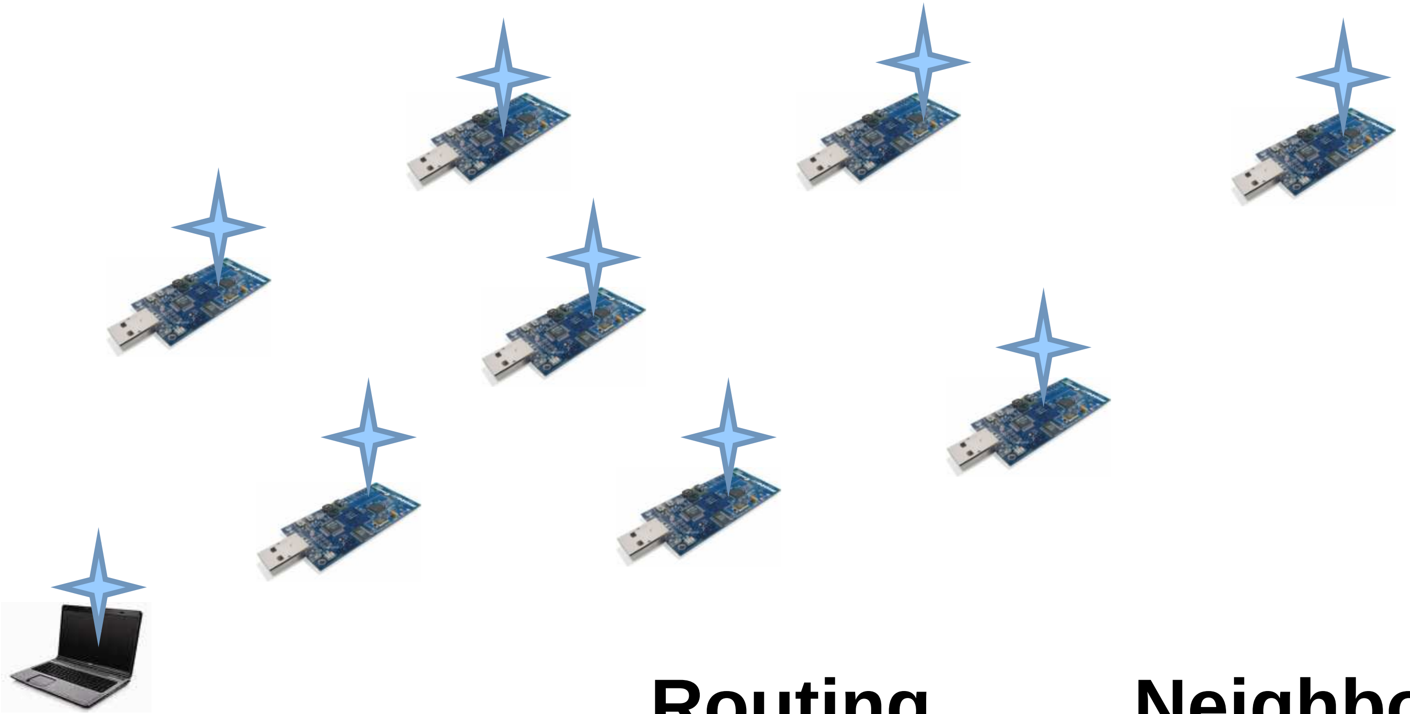
Quality Indicators

- RSSI: Received Signal Strength Indicator.
- LQI : "The link quality indication (LQI) measurement is a characterization of the strength and/or quality of a received packet."

  -- LQI is calculated from received packet.

  -- For CC2420 antenna value of 110 indicates a maximum quality frame while a value of 50 is lowest quality frames.

Beacon Message



Routing
- Cost
- Hopcount

Neighbor discovery
- LQI (Threshold)

Implementing Clustering in Real Wireless Sensor Networks

Motivation

- Huge literature, no real implementation of clustering on sensors.
- Max-Min cited over 2000 and distributive algorithm.
- Matérn Hardcore Process very simple to implement.

MaxMin Cluster Formation

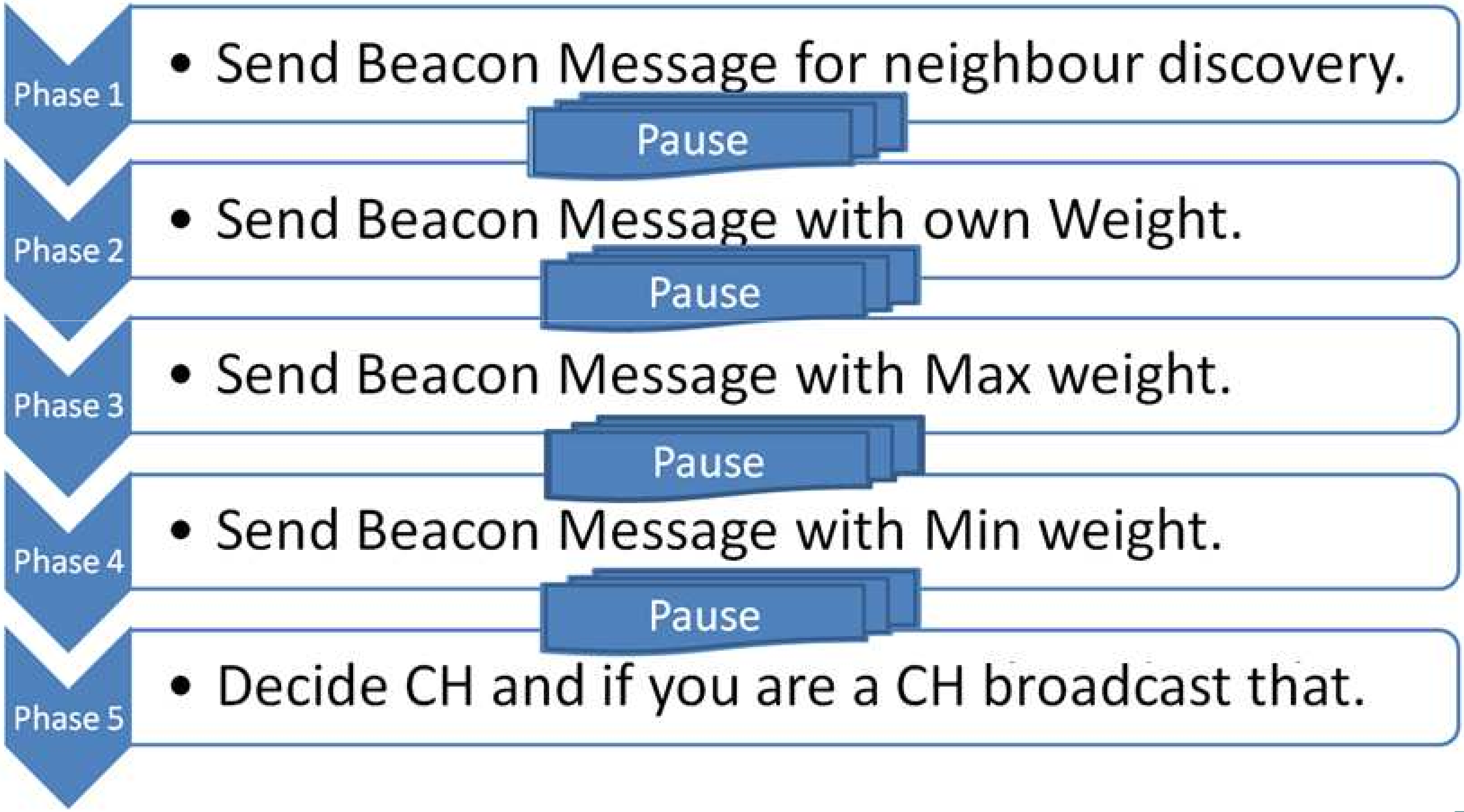
- Initial Phase:- Every node determines its initial weight. Also, neighbor table is formed.

- Max Flood Phase:- Each node finds the maximum weight neighbor from its neighbor list.

Each node updates its neighbor with weight chosen by them, which is used in next phase.

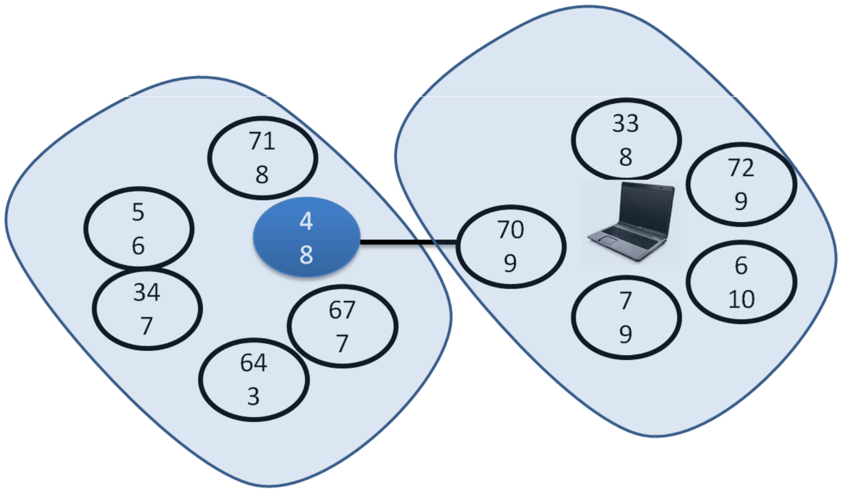
- Min Flood Phase:- Each node chooses min weight node among its neighbors.
- Decision:- Here, each node depending on calculation decides to be cluster head or not.

Implementation-MaxMin



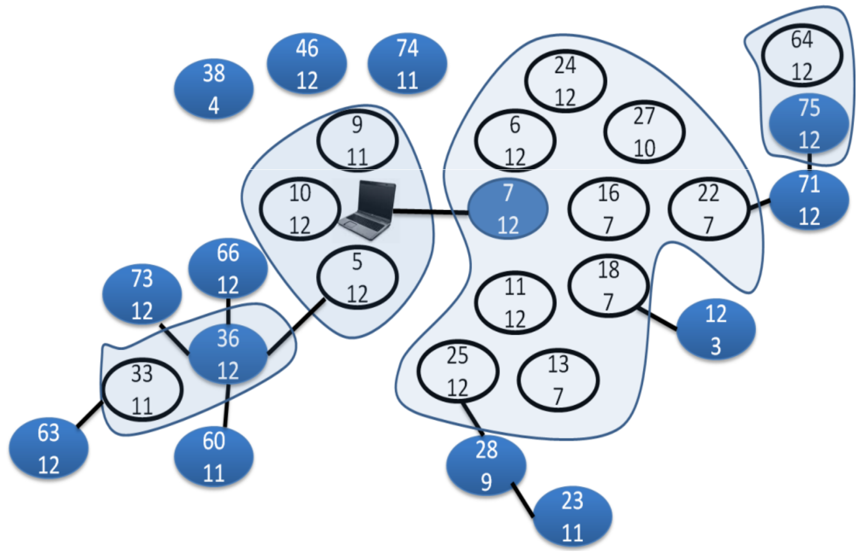
Analysis-Max-Min, Area = 4x5 m^2

Max-Min Sparse



Cluster Message- 200

Max-Min Dense



Cluster Message- 280

Matérn Hardcore Process

Thinning operation uses some definite rule to delete points of basic process

Matérn Hard core Process (MHP) , is essentially a dependent thinning applied to a stationary Poisson Point process Φ_b of intensity λ_b. The point of Φ_b are marked independently by random numbers uniformly distributed over (0,1). the dependent thinning retains the point x of Φ_b with mark $m(x)$ if the sphere $b(x, h)$ contains no points of Φ_b with marks smaller than $m(x)$. Formally, the thinning process Φ is given by:

$$\Phi = \{x \in \Phi_b : m(x) < m(y) \forall y \in \Phi_b \cap b(x,h) \setminus \{x\}\}$$

Node Id

Threshold LQI

Real Implementation on sensors

Implemention- Matérn

Step 1
- BS declares itself CH and sends beacons.

Step 2
- Nodes receiving beacons from clusterhead join it and form cluster.

Step 3
- Nodes not satisfying the conditions Matérn Hardcore Process (LQI), declare themselves as clusterheads. A conflict arises if more than one node declare themselves as CH.

Step 4
- This conflict is resolved using node-id. The node with higher Id will cease to be a CH.

Step 5
- Node which loses right to be a CH send a burst of special messages.

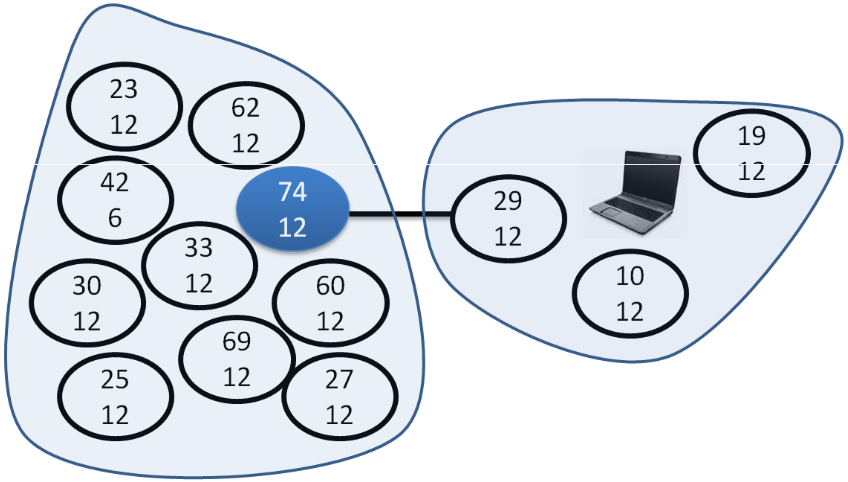
Pause

Step 6
- If node receives Special Message; node can become CH and then declares itself as CH.

Experimental Results- Dense and Sparse Networks

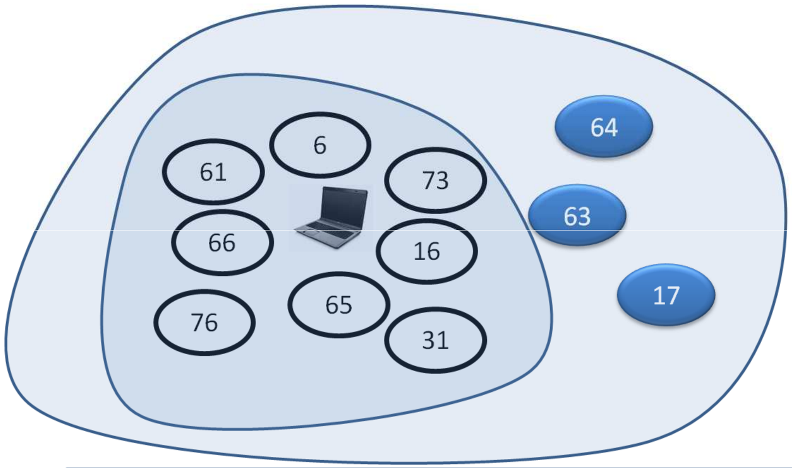
Max-Min vs Matérn Hardcore Point Process
Area = 4x5 m²

Max-Min



Cluster Messages- 190

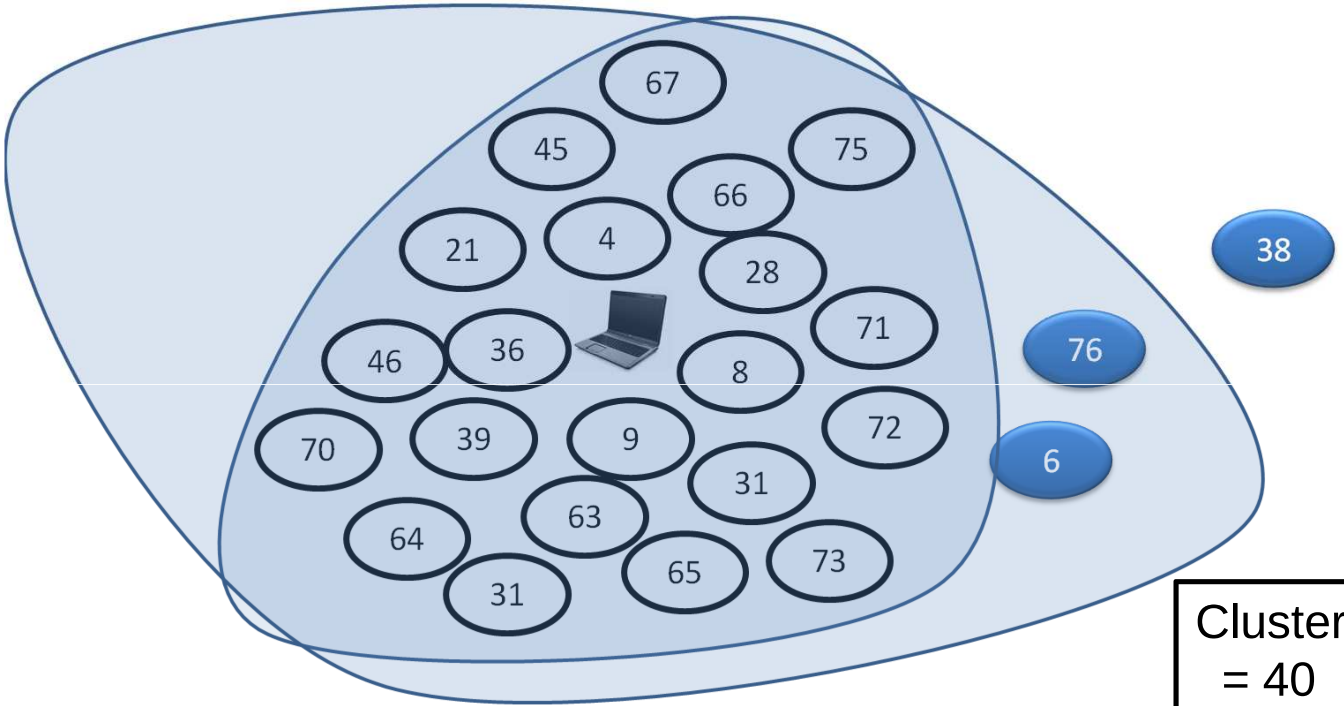
MHP



Node 17, 63, 64 some times declare themselves as CH when CH maintenace takes place and then connects directly with the BS to satisfy Matérn Hardcore conditions

Cluster Messages- 35

MHP in Dense- 4x5 m^2



Cluster Msg.
= 40

Node 6 and 76 sometimes declare themselves as CH when CH maintenace takes place and then connects directly with the BS to satisfy Matérn Hardcore conditions.

Max-Min Vs MHP, No maintenance

- Avg Data packets

Max-Min <350

MHP >4000

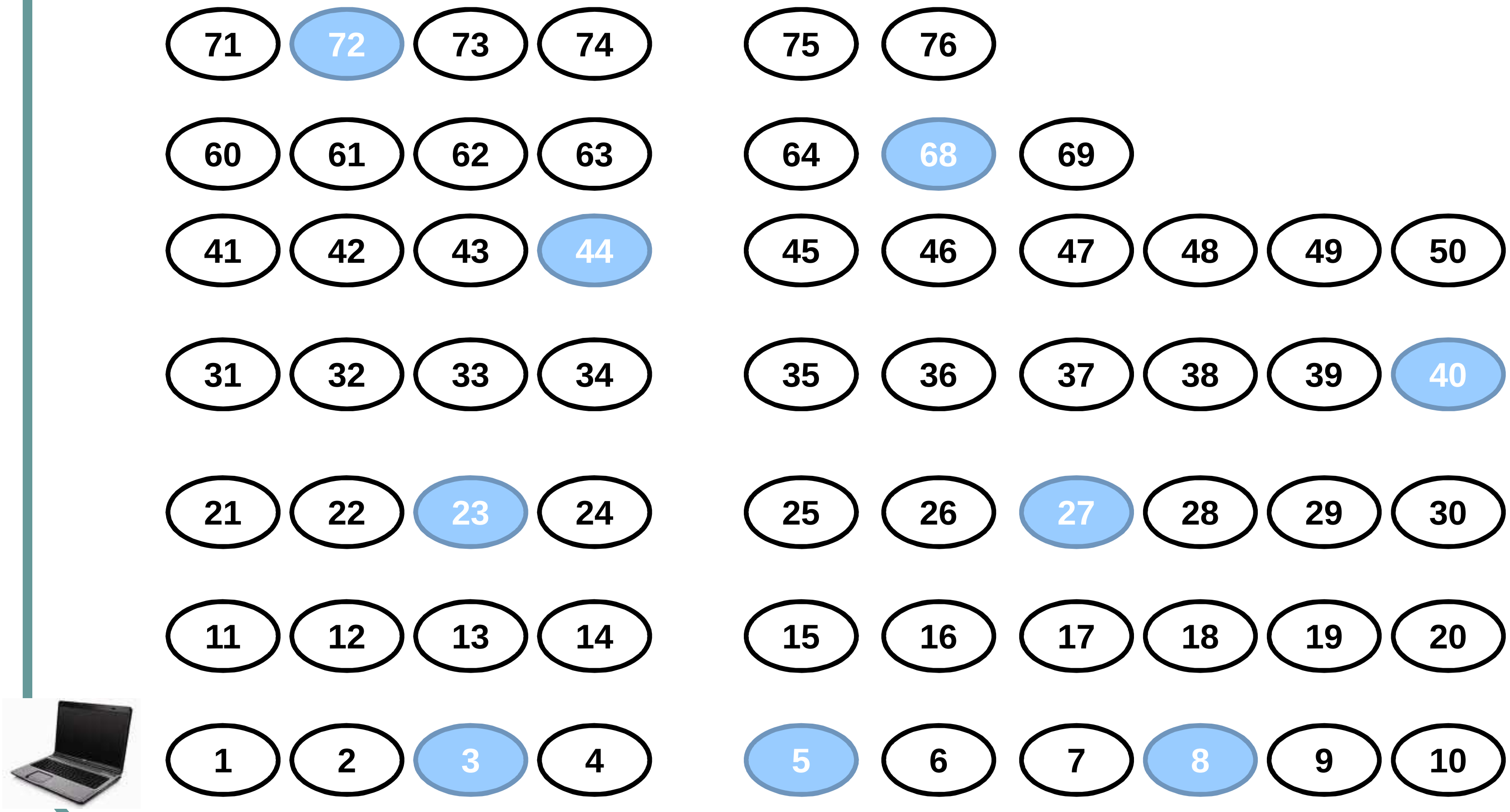
- Cluster Messages Sent 200

Max-Min 200

MHP <50

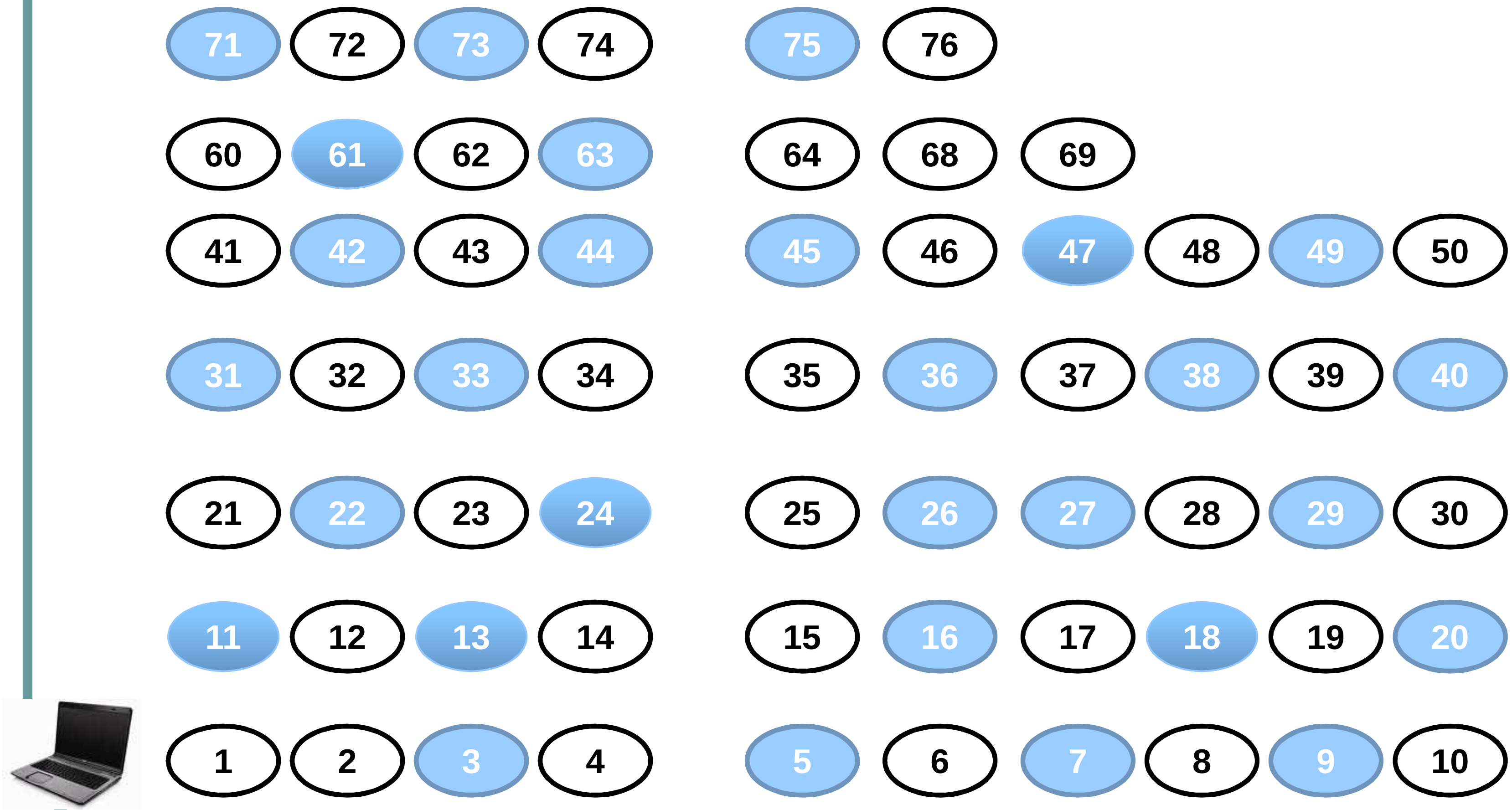
Experimental Results- Large Networks

Matérn Power level -20dBm, – ~450m²
35 special cluster messages over 8000 data packets per node



Tests run over whole night

Max-Min power level -20dBm, – ~450m²
Avg special cluster messages 130 per 250 packets per node



Conclusion

- Matérn Hard-Core Process is easier to implement.
- Relative Memory requirement is low.
- Clustering is faster and overhead is low.
- Compatible with CSMA and scalable.

- In MaxMin, the number of phase messages increases as number of neighbors increases.
- Matérn seems feasible even in denser network vis-à-vis MaxMin.

In theory, it seems that Max-Min is scalable and distributed and MHP is not. In practice, due to the high memory requirement, Max-Min is not scalable and MHP is scalable.

Thank you ☺!!

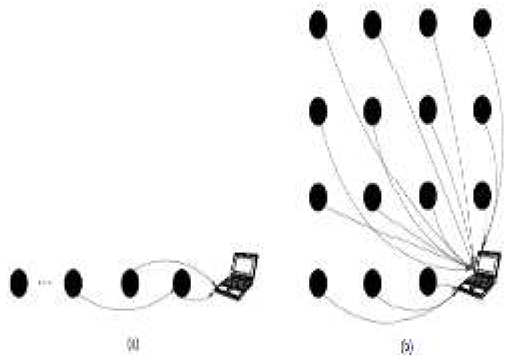
Experimental Set-up

- Topologies- MultihopLQI:
  - Straight line: Number of Sensors12,7,5 over 3,6 and 9 meters respectively.
  - Grid: 4*4, 3*6 over 3 meters
  - Grid: 5*5 over 6 meter each

Overall 55 Scenario And more than 1100 min of data

- Power Level:
  - From 31 pts to 3 on the scale of 31, where

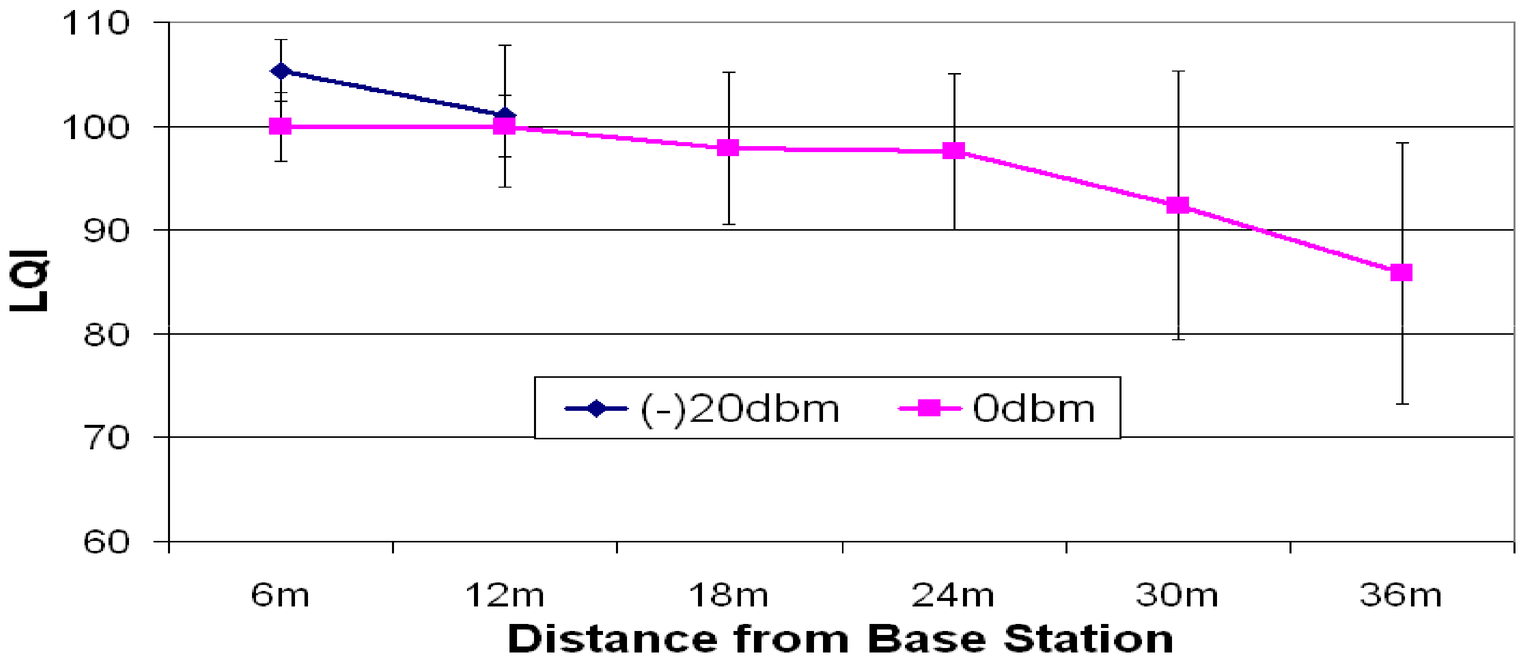
31 is 0dbm and 1 is -25 dBmm



Straight-line (a) and Grid (b) deployment.

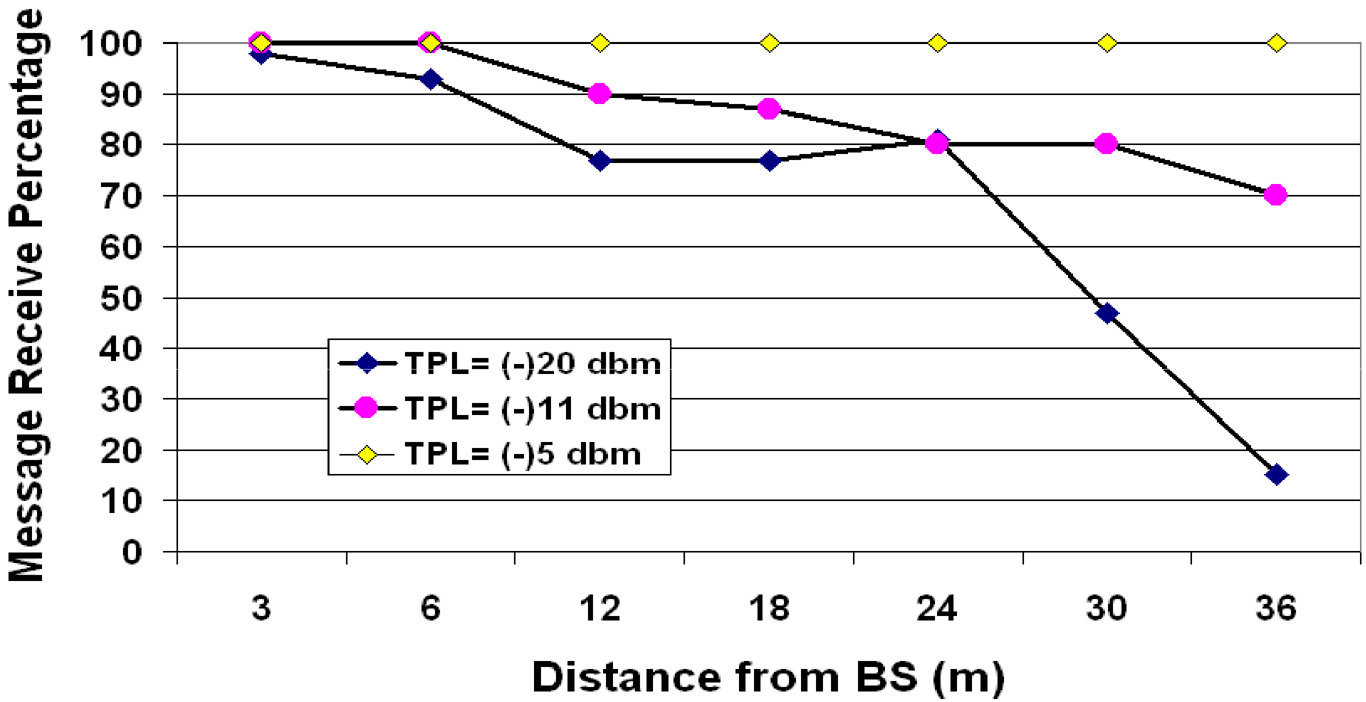
LQI-

Nodes placed in straight line, TPL= -20dbm



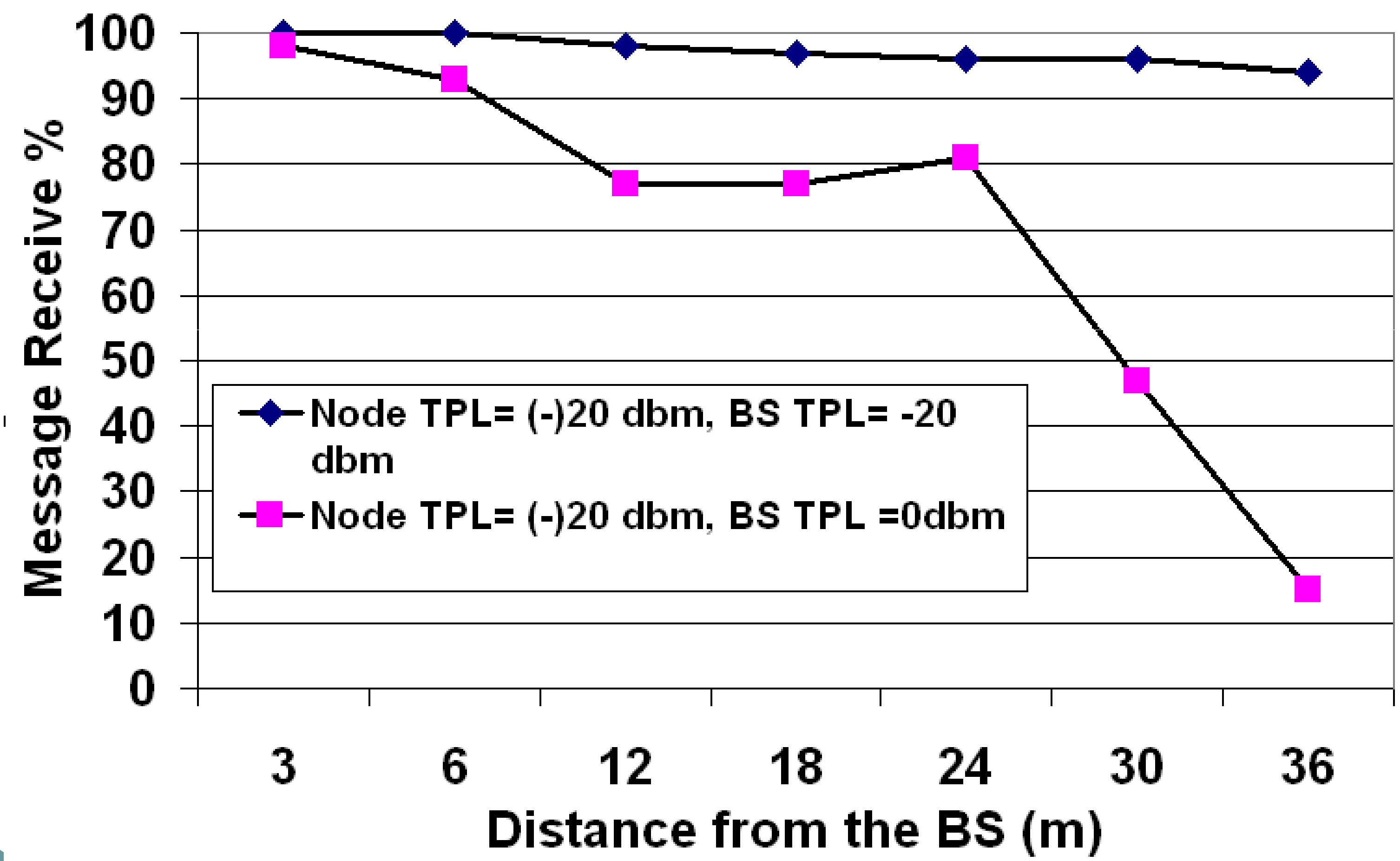
LQI of the BS received by the 6 different nodes,
Base Station TPL = 0dbm and -20 dbm.

Effect of High Power BS –
Nodes placed in straight line, BS TPL= 0dbm



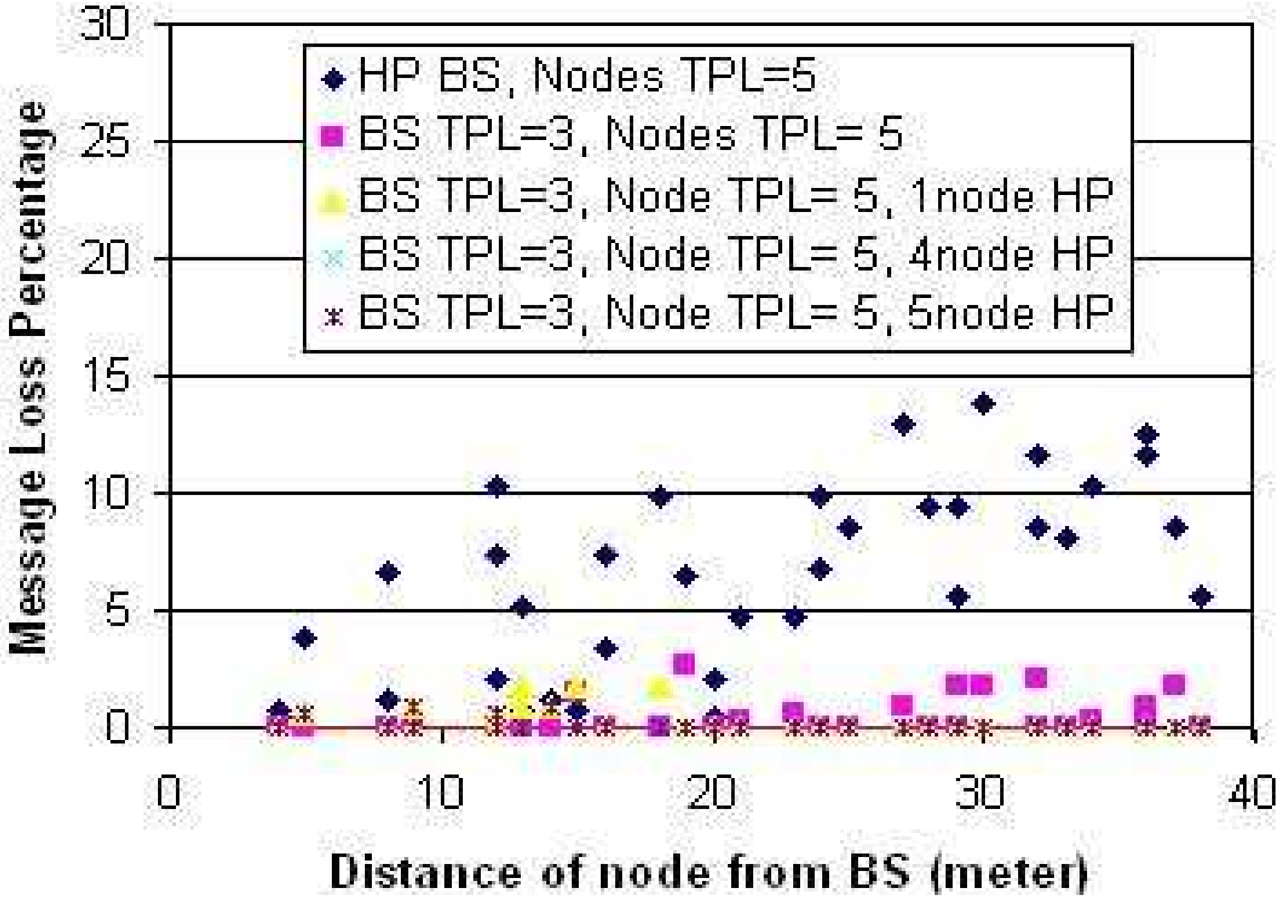
Nodes Placed in a 2 meter wide corridor open to public

Effect of High Power BS Topology- nodes in Straight Line



Effect of Heterogeneity-

Topology- 5x10 nodes in grid



Summary- Empirical Analysis

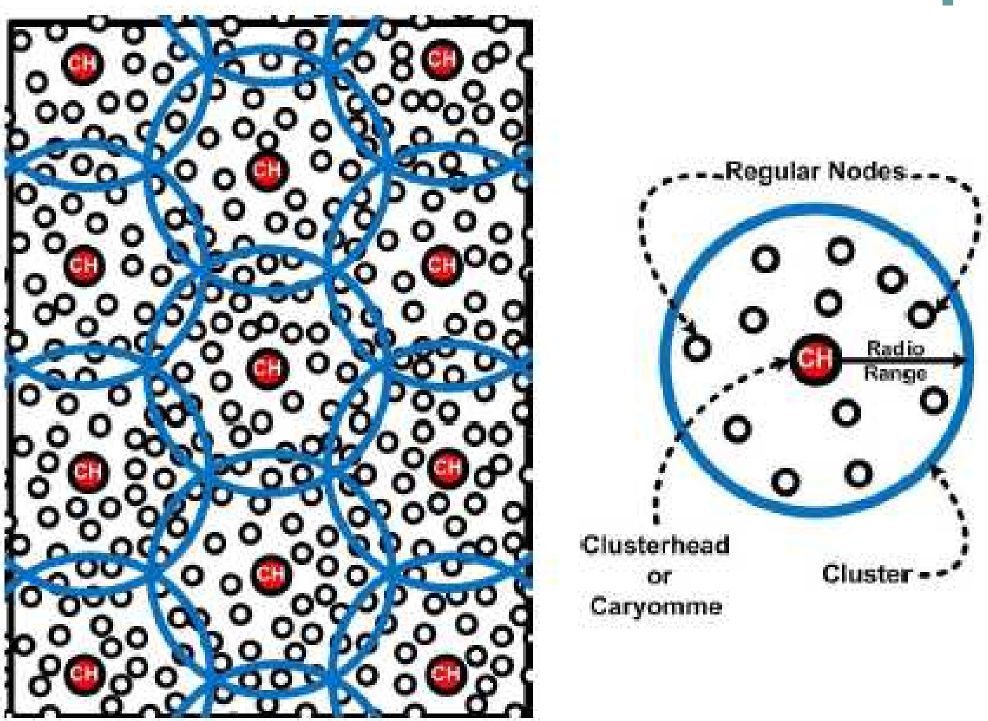
- Asymmetric Links may be present in the network.
- Exploiting this very feature to select cluster head and packet loses can be minimized.

Improvements on MaxMin

- MaxMin → Well known d-cluster formation for Ad Hoc Network (A.D. Amis, Infocom 2000).
- Initial form of MaxMin sometimes fails on constructing relationship between ClusterHeads and regular nodes.
- Corrected, Generalized and Validated in 2007 (A. Delye, Networking 2007).
- Performant in ClusterHead Selection, but needs improvement in order to fairly build relationship between clusterheads and regular nodes.
- It lacks studies on Single-Node Cluster phenomenon, on Criteria comparison and also on Energy-Efficiency : our objective is to address these issues.

The Generalized form of MaxMin

- MaxMin is a d-Cluster formation heuristic.
- Each node within the WSN is at most d-hops away from its Cluster Head.
- ClusterHeads selected by using criterion values.
- 3 phases (initial, floodmax, floodmin); 2d + 1 rounds



(a) WSN Clustering (b) Cluster

Fig. 1. WSN Clustering

The Generalized form of MaxMin

The WSN can be modeled as a graph $G = (V, E)$, where two nodes are connected by an edge if they can communicate with each other. Let $x \in V$ be a node in the WSN. $\mathcal{N}_1(x)$ is the neighbourhood of the node x. Let ν be a bijective function defined in V which is a totally ordered set.

$$\forall\, x \in V,\ \ \nu(x) = (f(x), id(x))$$

where $f(x)$ is the criteria function and $id(x)$ returns the address of the node x. The total ordering in V is defined as follows:

$$\begin{array}{l} \forall x \in V,\ \ \nu(x) > \nu(y) \Longleftrightarrow\ (f(x) > f(y)) \\ or\quad (f(x) = f(y)\quad and\quad id(x) > id(y)) \end{array}$$

The Generalized form of MaxMin

Initial phase: $k = 0$,

$$\forall\, x \in V,\ W_0 = \nu(x),\ S_0(x) = x \tag{1}$$

Floodmax phase: $k \in [|1, d|]$.
Assuming that $\forall x \in V$, $W_{k-1}(x)$ and $S_{k-1}(x)$ are known in a previous step. Let $y_k(x)$ be the unique node in $\mathcal{N}_1(x)$ defined by:

$$\forall\, y \in \mathcal{N}_1(x) \setminus \{y_k(x)\}\,,\ W_{k-1}(y_k(x)) > W_{k-1}(y) \tag{2}$$

W_k and S_k are calculated as follows:

$$\forall\, x \in V,\ W_k(x) = W_{k-1}(y_k(x)),\ S_k(x) = y_k(x) \tag{3}$$

The Generalized form of MaxMin

Floodmin phase: $k \in [|d+1, 2d|]$.
Assuming that $\forall x \in V$, $W_{k-1}(x)$ and $S_{k-1}(x)$ are known in a previous step. Let $y_k(x)$ be the unique node in $\mathcal{N}_1(x)$ defined by:

$$\forall\, y \in \mathcal{N}_1(x) \setminus \{y_k(x)\}\,,\ W_{k-1}(y_k(x)) < W_{k-1}(y) \qquad (4)$$

W_k and S_k are calculated as follows:

$$\forall\, x \in V,\ W_k(x) = W_{k-1}(y_k(x)),\ S_k(x) = y_k(x) \qquad (5)$$

The set S of clusterheads is defined by :

$$S = \{\, x \in V,\ W_{2d}(x) = \nu(x)\} \qquad (6)$$