# Energy and Coverage Aware Routing Algorithm in Self Organized Sensor Networks

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***Abstract*— This paper investigates the energy problem in sensor networks. After random deployment, nodes have to observe a region and transmit their sensor data to a central station. By checking redundancies in coverage and transmission with our XGAF algorithm presented here it is possible to shutdown the majority of nodes into sleep mode. Computation reduction in sleeping nodes and reduced communication results in increased network lifetime.**

**This paper presents a novel routing algorithm which takes into account information concerning coverage and energy and using the advantages of scale free networks. Additionally, the algorithm allows nodes to work self organized. Thence, communication with the central station is reduced.**

***Index Terms*— sensor network, self organization, coverage, energy awareness, scale free**

## I. Introduction

Environment surveillance is an important topic today. In many applications, e.g. forest fire detection or surveillance of volcanic activity, few single sensor are insufficient. A feasible surveillance system is a sensor network with hundreds of nodes, each equipped with sensor and communication systems. To be independent from their environment and to avoid influencing the observed region, nodes have to be self-sustaining and as small as possible. This results in limited energy, limited transmission range and limited sensor abilities. Current research tries to increase network lifetime by setting redundant nodes into a sleep mode. Most of them consider either transmission redundancy [8] or sensing redundancy [4], [5], not both. Another research topic is to find efficient routing paths in sensor networks [6], [7]. In [3], the authors describe the class of scale free networks as robust structure for growing networks. In the following, we focus on building up scale free networks as routing strategy for sensor networks. After applying our developed redundancy detection and controlled shutdown algorithm XGAF, we are able to exploit create a new energy aware scale free routing algorithm.

The remainder of this paper is organized as follows: Section II describes the scale free routing approach and its advantages, section III introduces our XGAF approach, section IV describes and analyzes abilities of our new routing algorithm. Finally, section V gives a conclusion and an outlook.

## II. Scale Free Networks

In growing networks, e.g. social networks or the internet, the nodes (humans, websites) are often linked in a scale free way. In contradiction to random networks the numbers of links per node are not all alike and they are not distributed normally. Rather, the growth of the network follows a preferred connection. The probability to become connected with a new node grows with the number of present connections. After evolving such a network, there exist lot of nodes with only few connections and few nodes with lot of connections. As explained in [1], the scale free behaviour is represented by (1).

$$P(k) \sim k^{-\gamma} \qquad (1)$$

$P$ is the probability for a node to have $k$ links, $\gamma$ is the degree exponent. The connection behaviour leads to a small average hop number from one node to any other, and is called "small world" phenomenon [2]. One advantage of this characteristic is a short average message way. But scale free networks are also advantageous in terms of robustness against random failures. Only failures of well connected nodes lead to a failure of the complete network [3]. Our goal was to create a routing algorithm in a sensor network, using advantages of scale free behaviour and avoiding the disadvantages. However, in sensor networks we have to reduce the computation for network joining to a minimum. In the best case every connection will be the result of simple local rules without transmission overhead. Therefore, we developed a novel connection strategy to build up a network with scale free properties.

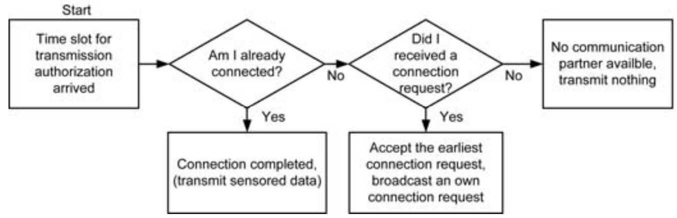


Fig. 1: Block diagram of the local algorithm on each node for scale free routing

Manuscript received October 15, 2006. This work was supported in part by the German Science Foundation (Keyword: Organic Computing).

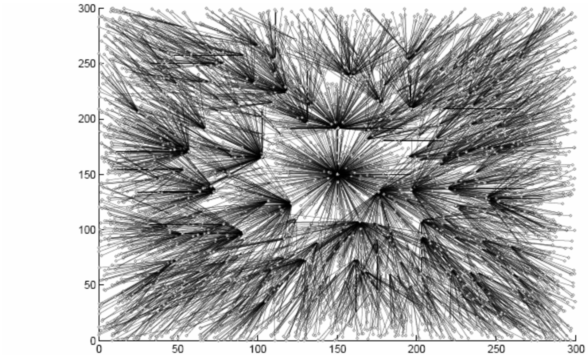

Fig. 2: Completed routing of a network. 5000 nodes were distributed randomly. Transmission range: 50m. Distribution area: 300m*300m

For a network with time division medium access [11] the strategy works as shown in Fig. 1. After having been integrated into a network, a node tries to connect with all unconnected nodes in range and integrates them into the network. If that happen using time slots, it is guaranteed that a node gets all possible connections, and this strategy results into a tree structure as shown in Fig. 2. The starting point for the algorithm is the central station, placed here in the middle of the observed area. As shown in Fig. 3, the result of this tree structure is a network with nearly scale free behaviour.

## III. Redundancy Detection and Controlled Shutdown

In this section we present our approach to detect and exploit redundancies in sensor networks. There are two kinds of possible redundancies, transmission and sensing redundancy. A sensor node is totally redundant, if its sensing and transmission function can be adopted by adjacent nodes. To check whether a node is redundant we have to consider transmission and sensing range. Transmission range is the maximal communication distance between two sensor nodes. Sensing range is the distance, in which a node can observe a phenomenon with its sensors. An example for a sensing redundant node is pictured in Fig. 4. The whole area which is covered by the sensor of node A is also covered by the sensing area of node B, C and D. Thus, node A is sensor-redundant.

To detect redundancy that way, a node has to check all positions of adjacent nodes, calculate their sensing areas and subtract the overlapping area from its own. This seems to be a very complex calculation for an energy limited sensor node.

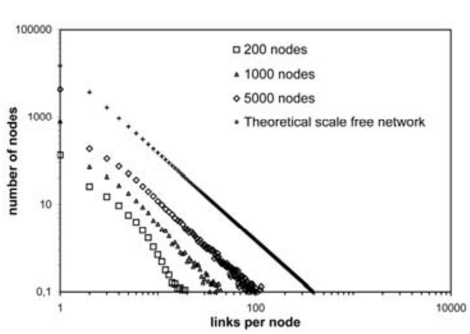


Fig. 3: Number of nodes versus number of links per node. Illustrated are our routing algorithm and a theoretical scale free network. Each result is averaged over 100 networks. Transmission range: 50m. Distribution area: 300m*300m

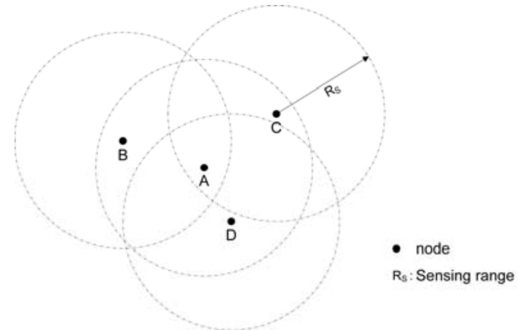


Fig. 4: Example for sensing redundancy of node A.

A more simple redundancy detection approach presented in [4] has still the problem to coordinate the shutdown of nodes and avoid "Blind Points". This leads to a communication overhead, which is infeasible in our vision of an energy aware node.

A really simple approach for detecting and coordinating communication redundancy is introduced in [8] and called Geography adaptive fidelity algorithm (GAF). Considering transmission range, GAF divides the region of autonomous communication partners into square cells thus forming a grid. Only one node in each cell has to be active to guarantee complete communication coverage. All other nodes are declared as redundant and can be set to a lower energized mode but still can adopt the function of the active node, if an error occurs. We extend this approach to work with coverage redundancy, as follows.

1.) Each node has to know its position in the network

2.) Transmission and sensing range are assumed as known values and equal for each node. Knowledge about them has to be available at each node.

3.) A virtual 2-dimensional grid is placed on the observed area. If the transmission range is at least twice the sensing range the size of a cell depends on the sensing range $R_S$, shown in Fig. 5 a). Otherwise, we use the transmission range $R_T$ to determine the cell maximum length L. Now, cell length is given in (2).

$$L = \frac{\min(R_S; R_T/2)}{\sqrt{2}} \qquad (2)$$

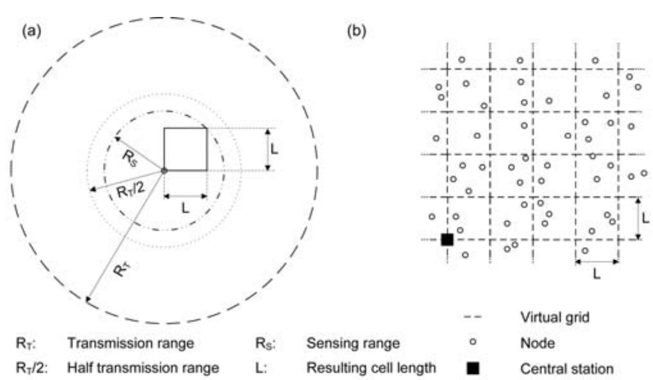


Fig. 5: (a) Cell size depends on sensing range (b) Visualization of resulting virtual grid

4.) Each node has to join a cell of the grid. The central station is the central point of 4 cells. With simple calculations, each node can decide which cell to join. The resulting virtual grid is shown in Fig. 5 b).

The resulting allocation of nodes, called extended GAF (XGAF), has same advantages as GAF with additional coverage awareness and guaranteed communication between diagonal adjacent cells. Disadvantageous is the need of at least one node in every cell for the algorithm to work. Unlike exact detection, we have to deploy nearly triple the number of nodes to obtain complete coverage with the same probability, as shown in Fig. 6 a), and active node ratio is nearly three times higher, too, illustrated in Fig. 6 b).

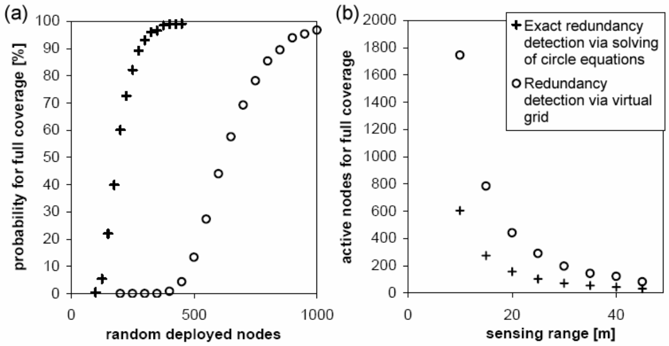


Fig. 6: Comparison of exact redundancy detection with our algorithm in a field of 300m*300m (a) probability for full coverage of the area, transmission range=100m, sensing range=40m (b) estimation of necessary active nodes, transmission range=100m, deployed nodes = 5000

After dividing network area into cells it is necessary that all nodes but one shut down and deactivate their sensors and transmission circuits for a specified time to save energy. The active node, termed clusterhead, has to swap from time to time, so that all nodes in the cell will loose nearly the same amount of energy and die almost at the same time. An energy aware role-changing protocol, e.g. in [10], can be adapted to this problem.

## IV. ENERGY AWARE ROUTING STRATEGY

Having found efficient approaches for building scale free networks and detecting redundancies it is now possible to combine both approaches for a new energy aware routing strategy. After applying our redundancy and shutdown algorithm we allow the remaining active nodes to connect as a net with scale free behaviour, similar to Section II.

As already shown, some nodes in a scale free network (with more links) have more importance than other nodes (with only one link). Nodes which have to maintain more links suffer from higher energy consumption. Additionally, their energy consumption for computation increases as they have to aggregate more data. Thus, key nodes die before others and the network breaks down.

But by applying our redundancy detection and controlled shutdown approach, a clusterhead now can decide how important it is for network's functionality. A highly redundant, nearly irrelevant node will connect with as many nodes as possible. If this one dies, another node of this well populated cluster is able to adopt its function and to maintain its connections. On the other hand, a non redundant, very important node will connect with as few further nodes as possible. To get such a big number of connections and to avoid lowly populated cells to become a network bottleneck we use three principles:

1.) Range Reduction

Clusterheads of lowly populated clusters have the possibility to decrease their transmission range to reach fewer nodes. They won't answer a connection request from a larger distance.

2.) Connectivity Limitation

Clusterheads of lowly populated cells are restricted to reach only one further connection. In fact, each clusterhead has the duty to try to connect with at least one further node to guarantee that all nodes become connected.

3.) Wait and See

Clusterheads of lowly populated clusters wait at least one time cycle before trying to establish further connections.

A network applying these three principles is shown in Fig. 7 (b) in contrast to a normal scale free network in Fig. 7 (a).

To achieve optimized number of connections we have to consider energy for transmission, sensing, aggregation, receiving and sleeping of each node in one cluster. To simplify the calculation we assume sensing cycle to be identical to the time slot cycle and the initial energy to be the same for all nodes.

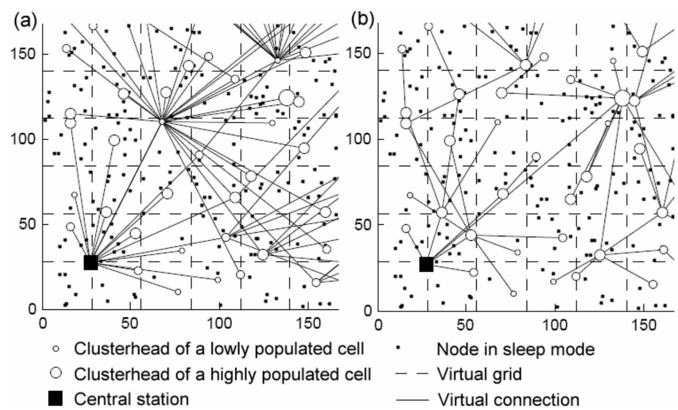


Fig. 7: Section of a large scale free network (a) without energy-awareness (b) with "Range Reduction", "Connectivity Limitation" and "Wait and See"

We further assume that a clusterhead has the task to transmit once per cycle and has to listen to connected nodes if they transmit. The cycle-energy of a clusterhead in a cell is estimated in (3).

$$E_{cy,chead}(c,n) = (c * P_R + P_T)t_{slot} + P_S(t_{cy} - (c+1)t_{slot}) + E_S \qquad (3)$$

$P_R$ means receiving power, $c$ number of connections outside the cell, $t_{slot}$ time of a time slot, $P_T$ transmission power, $P_S$ sleep mode power, and $t_{cy}$ cycle time, respectively.

Furthermore, we assume that a node in sleep mode has to receive commands each tenth cycle. The resulting energy is estimated as follows:

$$E_{cy,pas} = (P_R) * t_{slot} * 0.1 + P_S (t_{cy} - t_{slot} * 0.9) \qquad (4)$$

The next assumption is that in the normal case no node fails and no re-routing or role changing inside a cell is necessary. Hence, we can add these energy consumptions of each node in the cluster to estimate the resulting cell energy consumption (5) and the cell's lifetime (6).

$$E_{cy,cell}(c,n) = E_{cy,act} + (n-1) * E_{cy,pas} \qquad (5)$$

$$t_{life,cell}(c,n) = E_0 * n * t_{cy} / E_{cy,cell} \qquad (6)$$

$E_0$ represents the estimated energy remaining on a node after its self localization, detecting its cell and assessing its role.

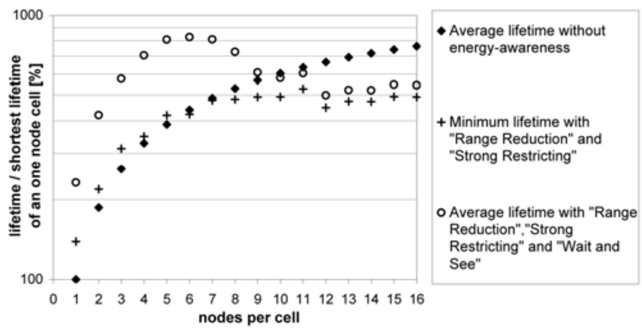


Fig. 8: Comparison of cell's lifetime with a simple scale free routing strategy with our energy-aware routing strategy. Average lifetime estimated over 5000 networks

TABLE 1
PARAMETERS FOR A CHIPCON NODE

(a)

| | |
|---|---|
| number of nodes | 700 |
| field size [m²] | 90000 |
| sensing range [m] | 40 |
| time cylce [s] | 1000 |
| time slot [s] | 1 |
| receiving power [mW] | 27,9 |
| sleep power [mW] | 0,002 |
| sensing energy [mJ] | 50 |
| intial energy [mJ] | 432000 |

(b)

| power for transmission [mW] | transmission range [cells] |
|---|---|
| 26,7 | 1 |
| 31,2 | 2 |
| 44,4 | 3 |
| 80,1 | 4 |

(c)

| | Strong Restricting | Range Reduction |
|---|---|---|
| nodes per cell | maximum connections | power for transmission [mW] |
| 1 | 2 | 26,7 |
| 2 | 3 | 26,7 |
| 3 | 3 | 26,7 |
| 4 | 4 | 26,7 |
| 5 | 4 | 26,7 |
| 6 | 5 | 31,2 |
| 7 | 5 | 31,2 |
| 8 | 6 | 31,2 |
| 9 | 6 | 44,4 |
| 10 | 7 | 44,4 |
| 11 | 7 | 44,4 |
| 12 | 8 | 80,1 |
| 13 | 8 | 80,1 |
| 14 | 9 | 80,1 |
| 15 | 9 | 80,1 |
| 16 | 10 | 80,1 |

(a) Fixed parameters, (b) Power for transmission depending on the transmission range, (c) Adjusted parameters for "Connectivity Limitation" and "Range Reduction"

We are now able to estimate the maximum number of connections for well populated cells to reach a specified lifetime. It is possible to increase the lifetime of low populated cells at the expense of the lifetime of higher populated cells. To get a realistic example we use the model of a Chipcon CC1000 transceiver [9]. Fixed and adjusted parameters of this transceiver are given in TABLE 1. The results with example parameters are shown in Fig. 8. As shown there, we are able to increase the lifetime of lowly populated cells (and therefore the network's lifetime with maximum coverage) by reducing the lifetime of highly populated cells.

## V. Conclusion and Outlook

In this paper we analyzed application of scale free networks in sensor networks. We developed a simple local algorithm on each node to build up a scale free network to improve network's robustness. Later, we extended an existing redundancy check algorithm to consider coverage and transmission redundancy in sensor networks and to shutdown redundant nodes. We merged the principle of scale free networking with benefits of redundancy exploitation of some nodes. Regions with higher node population have higher probabilities to spend more energy for connections than lowly populated regions. Thence, we neutralized the main disadvantage of scale free networks, the vulnerability of well connected nodes. The final result is a new energy-balanced scale-free network structure. In a first scenario with Chipcon nodes we increased network's lifetime by 130% with our algorithm. Our results were estimated using Matlab®. Currently, we implement the new network structure within a network simulator to implement real life energy models and deal with different medium access. Goals are to discover a simple scale free re-routing algorithm after an unexpected node failure and to prove our here presented optimized parameters scale free parameters.

Later, we want to extend the algorithm to more than one base station and to consider different sensing and transmission ranges.

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