國 立 交 通 大 學

電信工程研究所

碩 士 論 文

A Comprehensive Survey and Analysis of Routing Technologies for Green Computing in WSNs

無線感測網路綠能運算之繞徑技術研究分析

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Abstract (English)

Green technologies in wireless sensor networks that were introduced in the past years have excitingly changed the design of the sensor networks and their communication. This had enabled the sensor network applications to become unprecedentedly wide. Yet with the constrains of the resources in the sensor network, looking for even better green technologies have become vital. My research objective is to study these technologies as a whole and then do a more focused analysis on some prominent energy efficient routing strategies. With a comprehensive analysis of these techniques, we have attempted to get a more clear idea of the energy goals and the performance parameters of the routing strategies. Here we present the significance of “node death rate” in sensor networks and propose its usage as a performance parameter to validate a routing strategy. We also developed a new routing technique that can improve the life time of the network in its full performance and also give a more desirable node death rate. Most importantly this strategy retains the distributiveness of the algorithm, thus reducing the cost of location awareness.

Abstract (Chinese)

摘要

過去幾年裡，無線感測網路引進了綠色科技的想法大大的改變了無線感測網路的設計和通訊方式，這也使感測網路的應用範圍更加的廣泛。然而，由於感測網路諸多 的能源限制，尋找更好的綠色科技就變的極為重要。我的研究包括對於現有的科技進行了解，並針對一些知名的能源效率路由策略做更深入的比較分析。經過更全面 的分析之後，我們試著了解對路由策略影響比較大的參數以及我們欲達到的能源目標。對此，我們展示了”端點死亡速率”在感測網路裡的重要性，並提出它如何驗 證路由策略。我們也開發了一個可以增長網路存活期限的新技術，且得到一個比較理想的端點死亡速率。更重要的是，這個策略保留了分佈式演算法原有的架構，也因此減少為了獲取位置資訊所需消耗的資源。

Acknowledgement

I would like to start thanking Professor Lin, Ting-Yu. She had been my mentor, wonderful advisor and a constant inspiration throughout the last two years of my studies. Not only in academics, she had been supporting me every other aspect, from guiding me with the career options to providing me with every resource I wanted for my studies in NCTU.

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1. Chapter 1: Background

1.1. Introduction to Wireless Sensor Networks

Recent advances in micro-electromechanical systems (MEMS) technology, wireless communications, and digital electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate in short distances. These advances in sensor technology and usage of the sensor networks have made it possible for the sensor networks to be used in many applications. Also this widespread of sensor network usage have made it necessary for the sensor networks to be improved tremendously. As of for the last few years the technology related to sensor networks have phenomenally improved. But there is still a large scope for the network performance to be improved. Many of the research challenges remain the same. For the most part, the most of the research on WSN have been dedicated to the energy efficiency of the network. But there is an undying need to improve the energy efficiency of the network. In the next part of the chapter we are going to introduce the basics of WSN and then emphasis on the need of better energy efficiency for WSN.

1.2. Basic Network architecture of Wireless Sensor Network

A simple network architecture of a sensor network can be presented as in the Figure 1.The network mainly consists of nodes, base station and a main network.

The node has the actual sensor (Transducer) that gives analog output. This is fetched to A/D converter then the digital data can be processed with a processor inside the sensor node. Nowadays it is quite reasonable to assume that each node consists of a processor that can run a simple algorithm. All the distributed communication protocols used for the network assume the ability of the sensor nodes' computation. But please note that this computation power is usually less. This is due to the cost reduction as well as to save the energy of the nodes.

Base station is connected to the nodes wireless, this connection may not be as direct as given in the Figure 1.How the nodes communicate with the base station is defined by the communication protocol. Most part of the thesis is dedicated to discuss about the communication. The reason why this communication becomes more important is because, a base station usually consists of a large number of nodes and the wireless communication is more energy consuming.

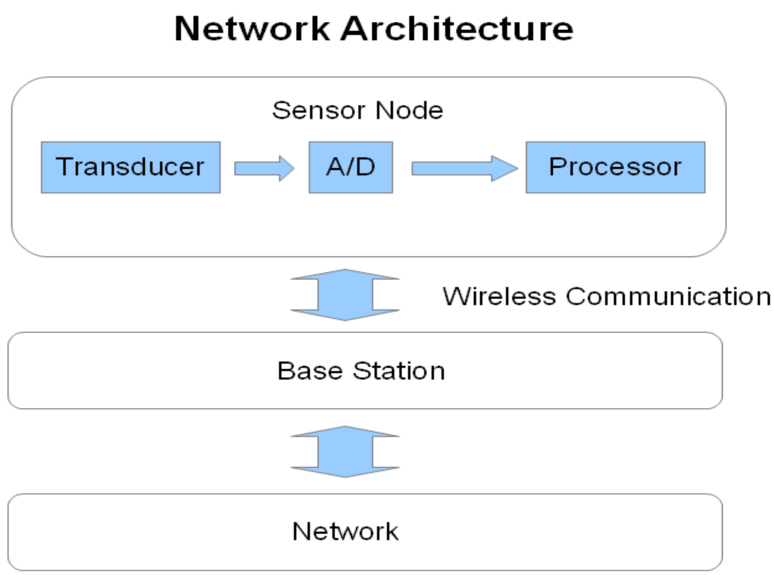

Figure 1: Sensor Network architecture

1.3.Green Technologies in Wireless Sensor Networks

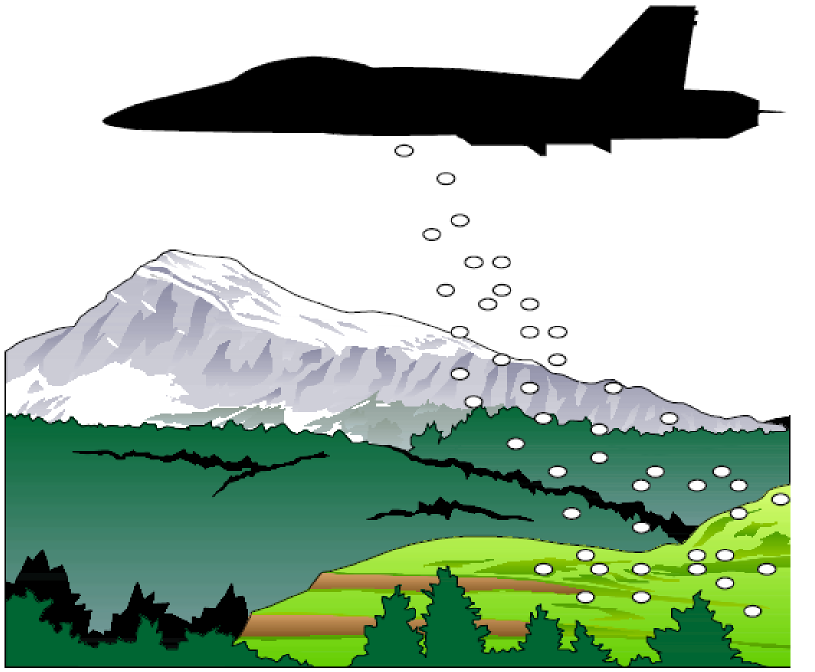

Figure 2: A random deployment of the sensors, it is difficult to make targeted deployments in most cases

1.3.1. Why energy efficiency is so important?

Wireless Sensor networks are battery enabled networks. Each node consists of limited power source. Sensing and data transmission done collectively. So a death of a node effects the performance of the network. So it is important the "whole network" would survive longer time. Even if some nodes die, at least there should be sufficient nodes to perform a collective data sensing effectively. Therefore need for green technologies in wireless sensor network have been essential.

1.3.2. How does a Sensor Network spend energy?

Data acquisition (Acquisition model)

Sensors spend energy in data acquisition. But this energy dissipation is to be managed by the sensor manufacturers.

Data transfer (Radio Model/Routing protocols)

Data transmission is the communication between sensor nodes and the base station or sensor nodes themselves. What times what order what data and how they communicate is dictated in the routing algorithms. So it is important to focus on routing algorithms to improve the energy efficiency of the data transmission.

Data processing (Computing model)

Data can be transmitted without much categorization or processing. But smart processing of the data can improve the energy efficiency tremendously. Majorly data compression techniques that makes the data transmission much efficient.

1.3.3. Our Focus: Data transfer

In this research we were focusing on how to improve the energy of the network by reducing the energy dissipation at data transfer phase. In a sensor network whole data transfer can be merely briefed in to the routing protocol of the network, we will here onwards concentrate on the routing protocols of the sensor networks. In general both scheduling and routing is defined by the routing protocol we employ for the sensor network. Our objective is to figure out the weak points of the existing dominant protocols and improve them.

2. Chapter 2: Routing Protocols : Survey

There are numerous categorizations of the routing protocols we can find in the past literature. But We would like to give a few categorizations of the communication protocols here. These categorizations can be helpful for the network designer to design a network that can fit the user's requirements. So that she could decide what protocols could be used for the WSN.

Here we would like to give two categorizations. One based on the Network structure and the other based on the functionality of the network.

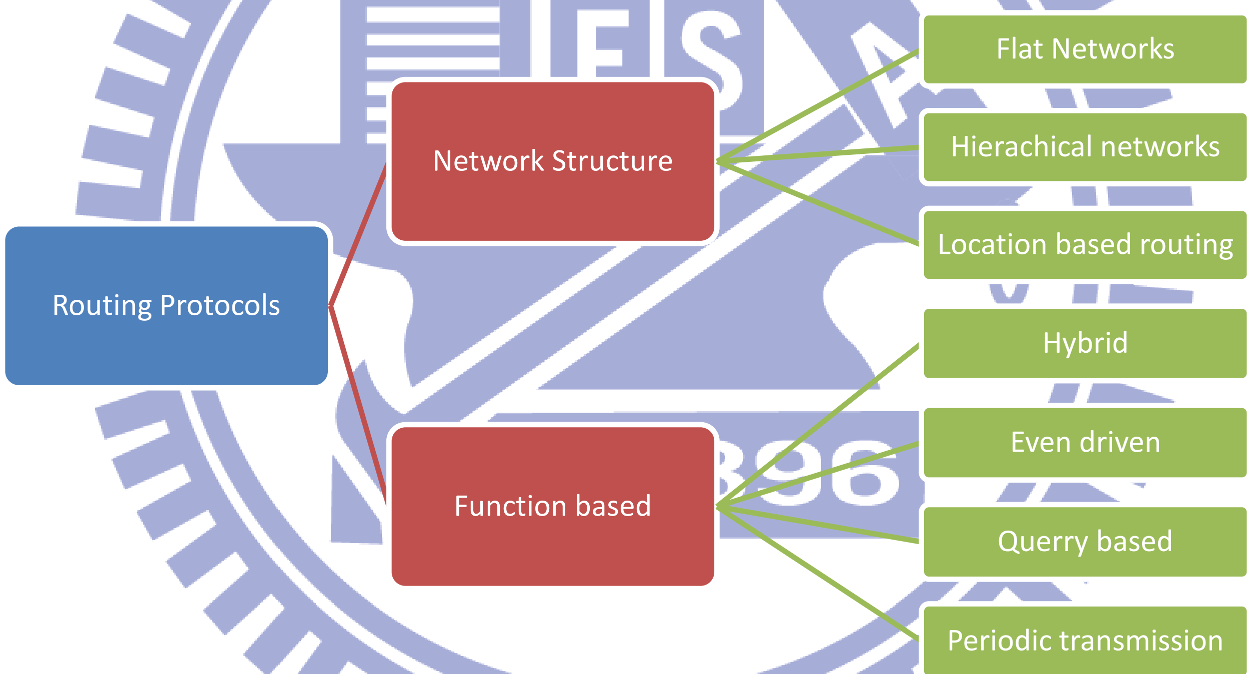

Figure 3: Categorization of routing protocols

2.1. Flat routing

Since the large number of nodes, the base station does not identify the nodes with a unique ID, rather sends the query of the data it needs to the region or the whole networking the nodes in the region act together to perform a task. Flat routing is data centric.

In these protocols, they utilize the negotiations and elimination of the redundant data as a means to save energy. The most prominent routing protocol in this category is SPIN. Besides we would introduce a few more protocols briefly.

2.1.1. Sensor Protocols for Information via Negotiation (SPIN)

SPIN is a data centric routing protocol. The basic concept in SPIN using descriptors called meta-data. During the communication, these meta data is exchanged by the nodes in order to do the negotiation. This exchange is done using an advertising mechanism. Each node upon receiving new data, advertises it to its neighbors and interested neighbors, ire. those who do not have the data, retrieve the data by sending a request message. SPIN's meta-data negotiation solves the classic problems of flooding such as redundant information passing, overlapping of sensing areas and resource blindness thus, achieving a lot of energy efficiency. There is no standard meta-data format and it is assumed to be application specific, e.g. using an application level framing. There are three messages defined in SPIN to exchange data between nodes. These are: ADV message to allow a sensor to advertise a particular meta-data, REQ message to request the specific data and DATA message that carry the actual data. Fig., redrawn from summarizes the steps of the SPIN protocol.

One of the advantages of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbors. SPIN gives a factor of 3.5 less than flooding in terms of energy dissipation and meta-data negotiation almost halves the redundant data. However, SPIN’s data advertisement mechanism cannot guarantee the delivery of data. For instance, if the nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all. Therefore, SPIN is not a good choice for applications such as intrusion detection, which require reliable delivery of data packets over regular intervals.

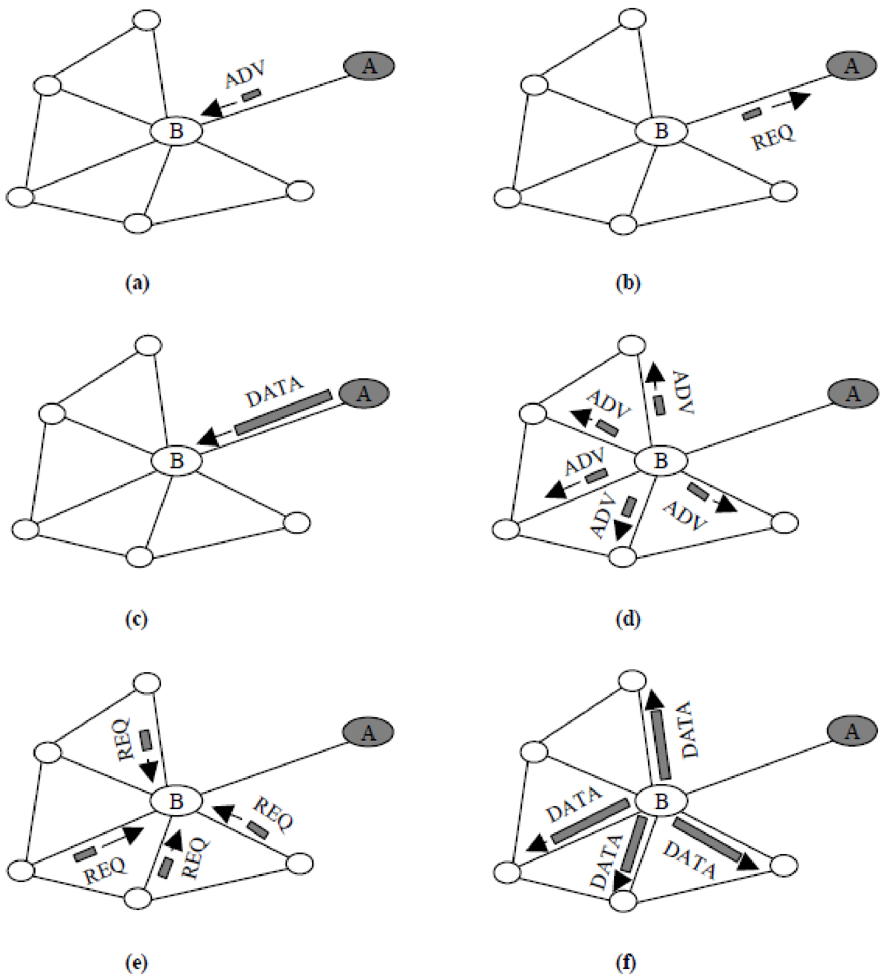

Figure 4 How spin works

The SPIN-1 Protocol. Node A starts by advertising its data to node B

(a). Node B responds by sending a request to node A

(b). After receiving the requested data

(c), node B then sends out advertisements to its neighbors

(d), who in turn send requests back to B (e,f).

2.2. Hierarchical routing

In hierarchical routing the network is divided into a hierarchical clustering structure. This makes the network look multi-tier instead of single tire. The most prominent advantage of the clustering is that it can do the data aggregation and use data compression for the aggregated data. This can tremendously reduce the amount of transmitted messages thus improving the energy efficiency. Also this also allows the network to cover a larger geographical area. This cluster formation could be done many ways. But it is important that the clustering and the cluster head to be dynamic so that the energy dissipation of all the nodes will be similar over time.
LEACH, PEGASIS, TEEN, APTEEN are the prominent protocols in this category. Since we are going to elaborate these protocols in the coming chapter, we do not discuss about them in details. But in the coming chapter not only there will be a discussion, we implement these protocols do a comparison and give some directions in to enhance them.

The Table 1 gives an abbreviated comparison of the main two groups of routing protocols. Hierarchical routing and Flat routing. Since the flat routing involves multi hop routing there is not much scope for data aggregation. Though there can be a small scale data infusion on the path. Nevertheless it looks for more optimum paths for the data communication. Due to the clustered structure, data communication is always done through the cluster head in hierarchical networks. So there is little opportunity to look for the optimum path. In hierarchical routing, the cluster heads spend more energy than the others. But with the dynamic cluster head rotation techniques, most protocols balance the energy dissipation of the network. In fact it is crucial for the sensor networks to have balance energy dissipation but unfortunately many flat routing techniques do not guarantee this.

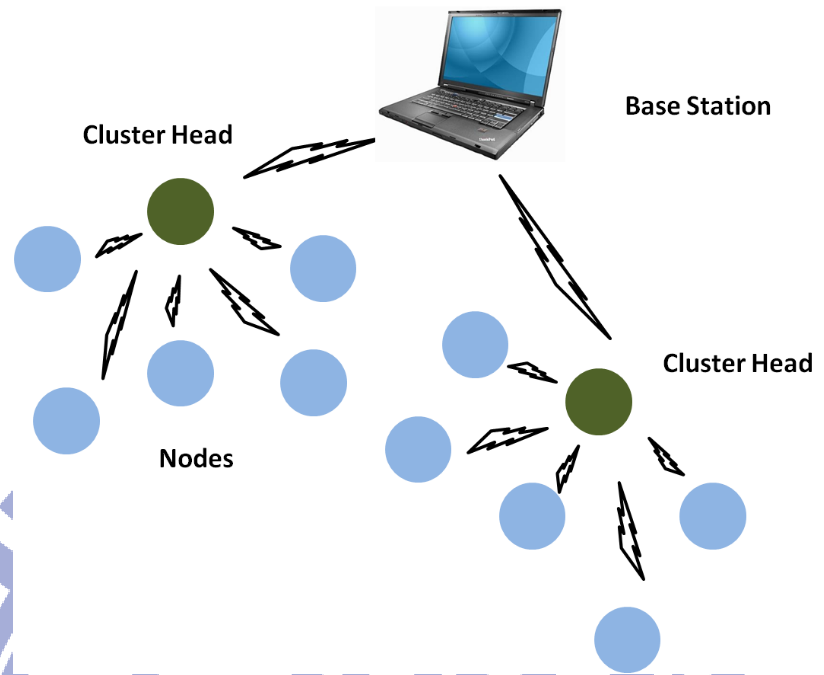

Figure 5: Clustering/ tire networks

Hierarchical routing	Flat routing
Reservation based scheduling	Contention based
Collision avoided	Collision can occur
Data aggregation is done in Cluster head	Data aggregation is done a node in the multichip path
Simple	More complex
Routing paths are non-optimal	Routing paths are optimal
Balanced energy dissipation	Traffic pattern dependent energy cost
Fair channel allocation	Channel allocation fairness is not guaranteed

Table 1: Comparison between hierarchical and flat routing topologies

2.3. **Location based routing**

It is true that many wireless nodes nowadays have the ability to know its location. Location based routing protocols utilize this information in the protocol in order to find the distances between different nodes and the distance between the nodes and the base station etc. Since in a large number of nodes are there, the addressing is not done well. When Base station wants to know information from one specific location, it can send the query only to one or a few nodes and get the information from those nodes. This will effectively improve the energy awareness of the network.

2.4. Categorization of routing protocols: Function based

Query based

In these protocols the base station need to ask the network when it needs data from some region or from the whole network. This could be done by sending a request to the sensor network. This query is either broadcasted in the whole network or the desired region; nodes listen to this query and transmit the data. Otherwise sensor nodes do not transmit any data.

Periodic data communication

In these routing algorithms data is sensed periodically. Network does not make any decisions. It transmits the data to the base station. Data is processed there in order to make use of the information.

Event driven.

Data sensing is done periodically but the some of the decision making is done with in the network. So it determines at which point the data to be transmitted and which point it should not.

So only when the sensed data meets criteria it transmits the data. This strategy itself can be used to reduce the number of data transmitted thus the energy spending.

Hybrid (Event driven and periodic)

This version is much similar to the event driven situation, but there is a periodic data transmission in large periods. Because in a scenario in which some nodes dysfunction. In that case, they stop sending data to the BS. But if they are meant to be 'event driven' the base station might understand this normal. With an additional inclusion of a condition that all nodes should transmit after a large period, the nodes which do not transmit can be identified as malfunctioning nodes by the base station.

3. Chapter 3: Hierarchical routing implementation and comparison

In this chapter we would like to introduce more routing protocols in hierarchical networks. There are number of reasons that a hierarchical routing is discussed more. In fact not only mere description, we implement them compare the results and also further analyze them to look for the relative drawbacks and benefits.

Clustered tier network has advantages when it comes to energy conservation of the network. Unlike normal ad-hoc networks micro sensor networks are designed for specific application. All the sensors collect similar data and the data transmission is from micro sensor nodes to a central location (base station).Since all the nodes do a similar data sensing, there is a huge correlation between the sensed data in all the nodes. So if there were a data aggregation of the nodes in the same region, more likely the data could be enormously reduced. By clustering the network with respect to the geographical proximity, this benefit could be leveraged. So every cluster in that way needs to have a cluster head [1]. In reality this cluster head does the most energy dissipation. Because even with data infusion this cluster head will have to do the maximum transmission. Thus it is clear that the cluster head must be a high energy node. Unfortunately we cannot make sure that the network has some high energy nodes in each region. Because sensor network deployment usually a random one.(Figure 2) In most networks it is quite difficult to make a targeted sensor deployment. So it is impossible to have targeted high energy node deployment to each region of the network. To overcome this challenge [2] comes up with a protocol called Low Energy Adaptive Clustering Hierarchy – LEACH, that dynamically changes the cluster heads of the clusters so that there will not be an issue of the evenness of the energy dissipation of the network.

3.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

3.1.1. Introduction [2]

As we mentioned in the previous section, LEACH is a groundbreaking communication protocol based on hierarchical clustering. It is a distributed algorithm. Each node runs the algorithm inside; instead it is run in a central location.

Operation of LEACH is broken into rounds. Each round consists of following phases. Set-up phase, when the clusters are organized, followed by a steady-state phase, when data transfers to the base station occur. In order to minimize overhead, the steady-state phase is long compared to the set-up phase.

3.1.2. Advertisement Phase

Initially, when clusters are being created, each node decides whether or not to become a cluster-head for the current round. This decision is based on the suggested percentage of cluster heads for the network (determined a prior) and the number of times the node has been a cluster-head so far. This decision is made by the node *n* choosing a random number between *0* and *1*. If the number is less than a threshold *T (n)*, the node becomes a cluster-head for the current round. The threshold is set as:

Equation 1

$$T(n) = \begin{cases} \frac{P}{1-P*(r \bmod \frac{1}{P})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

Where *P* = the desired percentage of cluster heads (e.g., *P = 0.05*), *r* = the current round, and G is the set of nodes that have not been cluster-heads in the last 1/P rounds. Using this threshold, each node will be a cluster-head at some point within *1/P* rounds. During round *0 (r = 0)*, each node has a probability *P* of becoming a cluster-head. The nodes that are cluster-heads in round *0* cannot be cluster-heads for the next *1/P* rounds. Thus the probability that the remaining nodes are cluster-heads must be increased, since there are fewer nodes that are eligible to become cluster-heads. After *1/P -1* rounds, *T=1* for any nodes that have not yet been cluster-heads, and after 1/P rounds, all nodes are once again eligible to become cluster-heads. Future versions of this work will include an energy-based threshold to account for non-uniform energy nodes. In this case, it is assumed that all nodes begin with the same amount of energy and being a cluster-head removes approximately the same amount of energy for each node. Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. For this "cluster-head-advertisement" phase, the cluster-heads use a CSMA MAC protocol, and all cluster-heads transmit their advertisement using the same transmit energy. The non-cluster-head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement. Assuming symmetric propagation channels, the cluster-head advertisement heard with the largest signal strength is the cluster-head to whom the minimum amount of transmitted energy is needed for communication. In the case of ties, a random cluster-head is chosen.

3.1.3. Cluster Setup Phase

After each node has decided to which cluster it belongs, it must inform the cluster-head node that it will be a member of the cluster. Each node transmits this information back to the cluster-head again using a CSMA MAC protocol. During this phase, all cluster-head nodes must keep their receivers on.

3.1.4. Schedule Creation

The cluster-head node receives all the messages for nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the cluster head node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster.

3.1.5. Performance of LEACH

There are many performance parameters they use to evaluate and compare the protocols. Authors of LEACH and many others protocol designers have used the following metrics to determine the energy efficiency capabilities of a sensor network.

1. The time (the round) of the first node dies.
2. The number of nodes alive with respect to time (number of nodes)

In the following section we analysis the performance metrics of the sensor networks in detail. But here we give the performance of LEACH as given by [2]

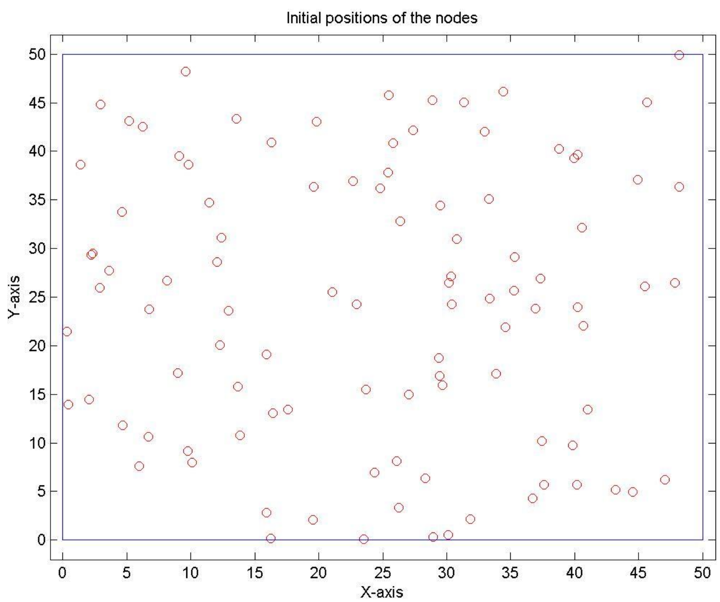

Figure 6: Initial positions of the nodes

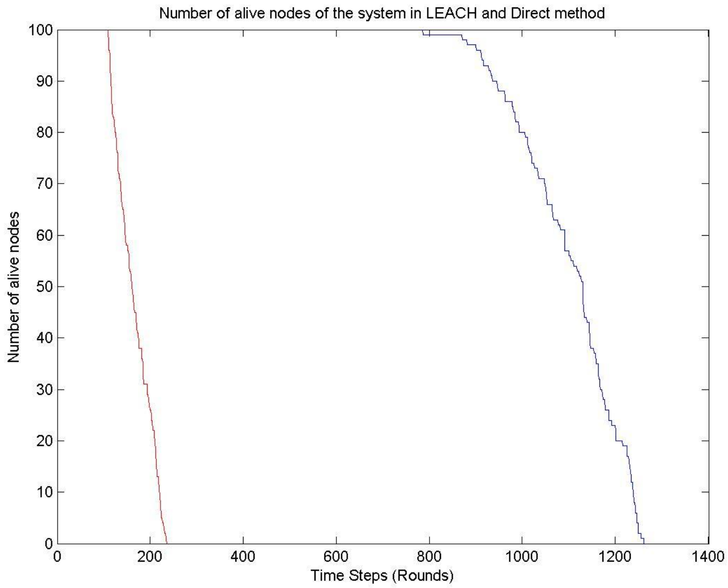

Figure 7: No of alive nodes Vs. rounds (time) curve

	***0.5J* battery per node**		***1J* battery per node**	
	Direct method	LEACH	Direct method	LEACH
First node dying round	101	940	223	1853
Last node dying round	235	1325	472	2602

Table 2: Comparison : LEACH and direct method

3.1.6 Discussion on LEACH performance

As you can see, LEACH tremendously improves the lifetime of the network while keeping the network distributed. Undoubtedly it is a very good protocol, because it maintains the distributiveness of the network (So that the central base station does not need to know the locations of each node).

3.2. LEACH-C (LEACH-Centralized)

While there are advantageous to using LEACH's distributed cluster formation algorithm, where each node makes autonomous decisions that result in all the nodes being placed into clusters. this protocol renders no guarantee about the placement and or number of cluster head nodes. Since the clusters are adaptive obtaining a poor clustering set up during a given round will not greatly affect overall performance of LEACH. However using a central control algorithm to form the clusters may produce better clusters by dispersing the cluster head nodes throughout the network. This is the basis for LEACH-C LEACH Centralized a protocol that uses a centralized clustering algorithm and the same steady state protocol as LEACH.

In addition to determining good clusters the base station needs to ensure that the energy load is evenly distributed among all the nodes To do this the base station computes the average node energy and whichever nodes have energy below this average cannot be Cluster-heads for the current round. Using the remaining nodes as possible Cluster-heads the base station runs a simulated annealing algorithm [3] to determine the best *k* nodes to be Cluster-heads for the next round and the associated clusters This algorithm minimizes the amount of energy the non-Cluster-head nodes will have to use to transmit their data to the Cluster head by minimizing the total sum of squared distances between all the non-Cluster-head nodes and the closest Cluster-head. At each iteration the next state which consists of a set of nodes in *C'* is determined from the current state the set of nodes in *C* by randomly and independently perturbing the *x* and *y* coordinates of the nodes *c* in *C* to get new coordinates *x'* and *y'*. The nodes that have location closest to *(x',y')* become the new set of Cluster-head nodes *c* that makes up set *C*. Given the current state at iteration *k* represented by the set of Cluster-head nodes *C* with cost *f(C)* the new state represented by the set of *Cluster*-head nodes *C'* with cost *f(C)* will become the current state with probability, *Equation 2*

$$p_k = \begin{cases} e^{-(f(C\prime)-f(C))/\alpha_k} & : \quad f(C\prime) \geq f(C) \\ 1 & : \quad f(C\prime) < f(C) \end{cases}$$

where α_k is the control parameter equivalent to the temperature parameter in the thermodynamic model and *f()* represents the cost function defined by,

Equation 3

$$f(C) = \sum_{i=1}^{N} \min_{c \in C} d^2(i, c)$$

where *d(i,c)* is the distance between node *i* and node *c.* The parameter α_k must be chosen to be increasing with increasing α_k to ensure that the algorithm converges. However, if α_k increases too quickly, the system will get stuck in local minima. On the other hand, if α_k increases too slowly, the system will take a very long time to converge.

3.3. TEEN *(T**hreshold sensitive** E**nergy** E**fficient sensor** N**etwork protocol)*** [4]

3.3.1. Functioning

In this scheme, at every cluster change time, in addition to the attributes, the cluster-head broadcasts to its members, *Hard Threshold (*HT): This is a threshold value for the sensed attribute. It is the absolute value of the attribute beyond which, the node sensing this value must switch on its transmitter and report to its cluster head.

*Soft Threshold (*ST): This is a small change in the value of the sensed attribute which triggers the node to switch on its transmitter and transmit. The nodes sense their environment continuously. The first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends the sensed data. The sensed value is stored in an internal variable in the node, called the *sensed value (SV)*. The nodes will next transmit data in the current cluster period, only when *both* the following conditions are true:
1. The current value of the sensed attribute is greater than the hard threshold.
2. The current value of the sensed attribute differs from *SV* by an amount equal to or greater than the soft threshold.
Whenever a node transmits data, *SV* is set equal to the current value of the sensed attribute. Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions by eliminating all the transmissions which might have otherwise occurred when there is little or no change in the sensed attribute once the hard threshold.

3.3.2. Important Features

The main features of this scheme are as follows:

1. Time critical data reaches the user almost instantaneously. So, this scheme is eminently suited for time critical data sensing applications.
2. Message transmission consumes much more energy than data sensing. So, even though the nodes sense continuously, the energy consumption in this scheme can potentially be much less than in the proactive network, because data transmission is done less frequently.
3. The soft threshold can be varied, depending on the criticality of the sensed attribute and the target application.

4. A smaller value of the soft threshold gives a more accurate picture of the network, at the expense of increased energy consumption. Thus, the user can control the trade-off between energy efficiency and accuracy.
5. At every cluster change time, the attributes are broadcast afresh and so, the user can change them as required.

The main drawback of this scheme is that, if the thresholds are not reached, the nodes will never communicate; the user will not get any data from the network at all and will not come to know even if all the nodes die. Thus, this scheme is not well suited for applications where the user needs to get data on a regular basis. Another possible problem with this scheme is that a practical implementation would have to ensure that there are no collisions in the cluster. TDMA scheduling of the nodes can be used to avoid this problem. This will however introduce a delay in the reporting of the time-critical data. CDMA is another possible solution to this problem.

This protocol is best suited for time critical applications such as intrusion detection, explosion detection etc.

3.4. *APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol)* [5]

In APTEEN once the CHs are decided, in each cluster period, the cluster head first broadcasts the following parameters:

Attributes(A): This is a set of physical parameters which the user is interested in obtaining data about.

Thresholds: This parameter consists of a hard threshold (HT) and a soft threshold (ST). HT is a particular value of an attribute beyond which a node can be triggered to transmit data. ST is a small change in the value of an attribute which can trigger a node to transmit data again.

Schedule: This is a TDMA schedule similar to the one used in [APTEEN PAPER 8], assigning a slot to each node.

*Count Time(*TC*)*: It is the maximum time period between two successive reports sent by a node. It can be a multiple of the TDMA schedule length and it accounts for the proactive component. In a sensor network, close-by nodes fall in the same cluster, sense similar data and try to send their data simultaneously, causing possible collisions.
In the following section, data values exceeding the threshold value are referred as critical data.

The main features of our scheme are :

1. By sending periodic data, it gives the user a complete picture of the network. It also responds immediately. to drastic changes, thus making it responsive to time critical situations. Thus, It combines both proactive and reactive policies.
2. It offers a flexibility of allowing the user to set the time interval (TC) and the threshold values for the attributes.
3. Energy consumption can be controlled by the count time and the threshold values.
4. The hybrid network can emulate a proactive network or a reactive network, by suitably setting the count time and the threshold values.

The main drawback of this scheme is the additional complexity required to implement the threshold functions and the count time. However, this is a reasonable trade-off and provides additional flexibility and versatility.

Implementation

In order to do a fair comparison we implemented all the algorithms above in MATLAB and then used randomly generated 100 node network with some properties given.Not only we used the same network, we also employed the same network energy model as described in the following.

3.5. The simulation network

We assumed a network with 100 nodes.Nodes are deployed randomly in a 50mx50m area.The deployment is done with a random selection of *x* and *y* coordinates of each node's location with a uniform probability.All the nodes in the network are identical in all aspects.They all are tasked with the same , have same properties related to energy. All are equipped with a battery power of *0.5J* (otherwise specified), where this battery has a linear battery discharge charactersitics.Through out the network and the through out the whole duration, the environmental conditions related to energy dissipation (such has humidity and temperature) remain same.Nodes are static and do not move from the initial location (due to wind, water etc.) through out the time of the experiment.Nodes have some computational ability to run a distributed algorithms like LEACH.

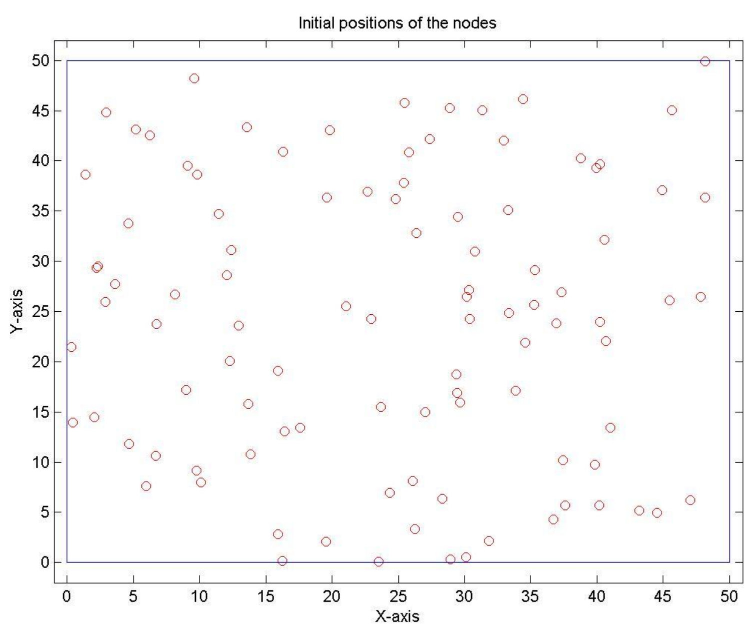

Figure 8: Randomly deployed network in a 50mX50m area.

3.5.1. First order Radio Model

There are different research on the energy efficient radios on the table.Also there are different assumption on how energy is spent while transmitting and receiving a chunk of data by the radio transmitter and the reciever.These depends not only the channel conditions, the radio characteristics and the Tx and Rx modes. But here we stick to a simple model which is given in [2],where the radio dissipates $E_{elec} = 50\ nJ/bit$ to run the transmitter or receiver circuitry and $\epsilon_{amp} = 100\ pJ/bit/m^2$ for the transmit amplifier with an acceptable SNR.

No

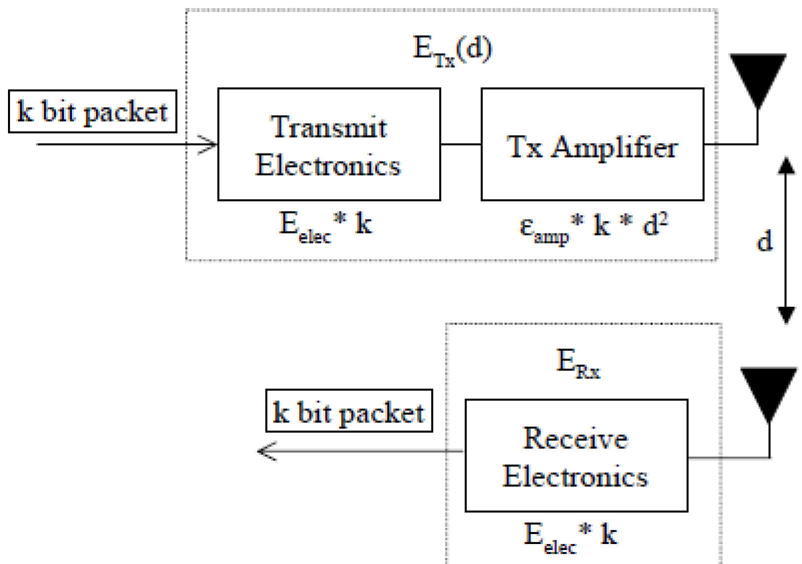

Figure 9: First order radio model

Thus, to transmit a *k-bit* message a distance *d* using our radio model, the radio expends,

Equation 4

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2$$

And to receive this amount of *k-bit* message, it expends.

Equation 5

$$E_{Rx}(k) = E_{Rx-elec}(k)$$
$$E_{Rx}(k) = E_{elec} * k$$

We make the assumption that the radio channel is symmetric such that the energy required to transmit a message from node A to node B is the same as the energy required to transmit a message from node B to node A for a given SNR. For our experiments, we also assume that all sensors are sensing the environment at a fixed rate and thus always have data to send to the end-user.

3.6.Results

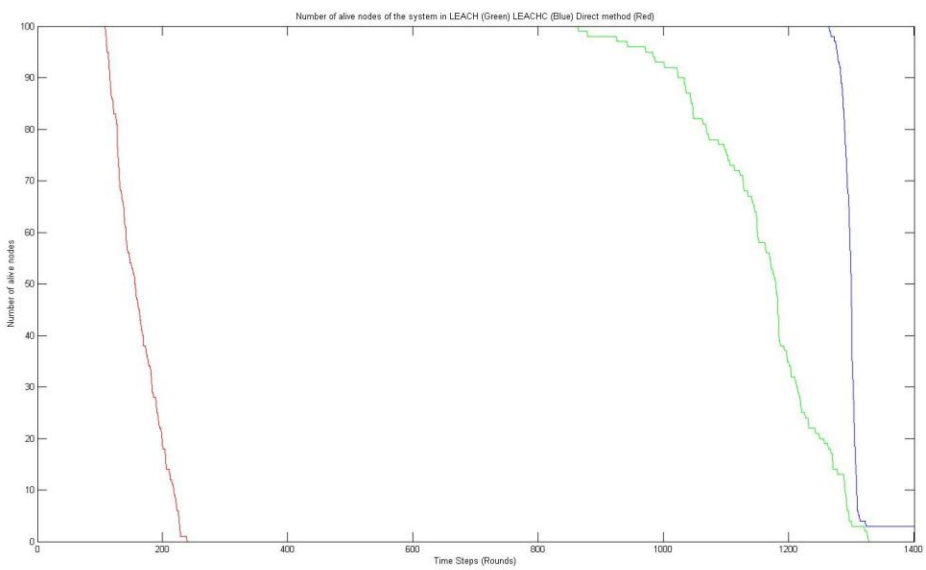

Figure 10: Direct transmission (red), LEACH-C (blue)and LEACH(green) comparison no of

nodes alive vs. rounds

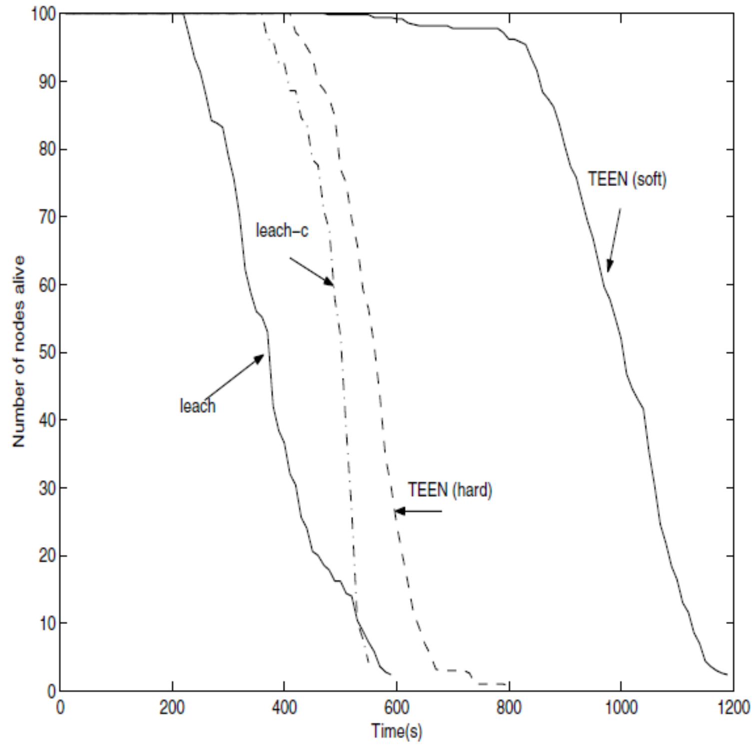

Figure 11: no of alive nodes vs. rounds TEEN

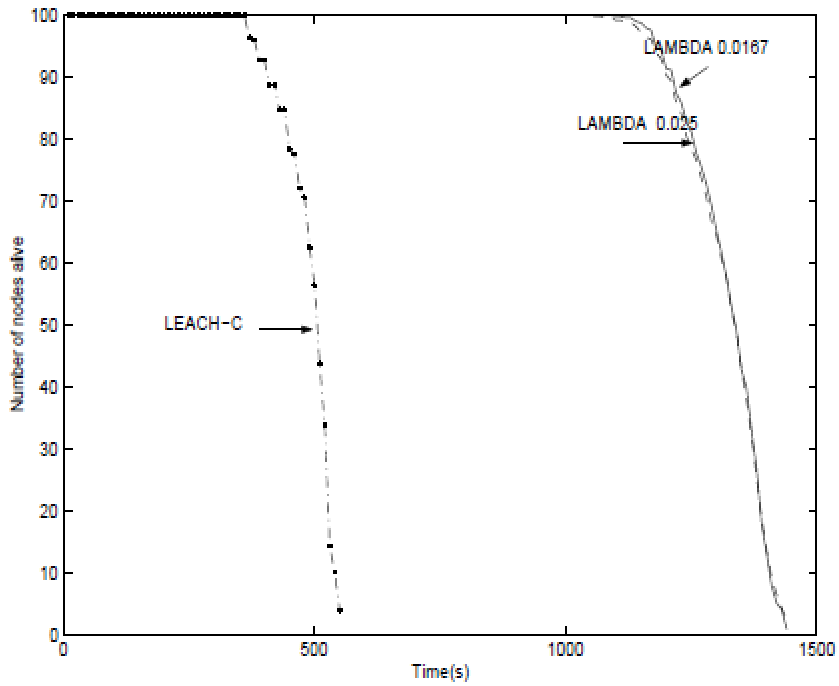

Figure 12: No of nodes alive vs. Rounds APTEEN

4. Chapter 4: Performance Metrics of WSN communication protocols

In this chapter we introduce the energy goals of the sensor networks and the parameters to measure them.

As we discussed in the first chapter, the sensor networks are energy constrained networks. Therefore the success of a communication protocol is measured by the energy efficiency it can render to the network. So it is important to define the energy goals of the network we need to achieve and realize the metrics that measure them clearly.

First of all it is clear that the network lasting longer is desirable and must be attained. As we can understand the network capacity could be measured by the no. of alive nodes in the network. So we consider the lifetime of the network in its full capacity as an energy goal. This could mean we can take as the time of the first node dies as a metric .The similar manner we think network lifetime at any capacity is also an energy goal. Similar fashion time of the last node dies would be a performance metric. Therefore a graph of No of alive nodes Vs. Time (rounds) could give accurate picture of the protocols' energy performance.

Since the wireless networks perform the functions collectively, it is important that all the nodes to be functioning well. When the network performs in its full capacity, service quality will be maximum. When the number of live nodes decreases the service it renders also decreases. When the service quality decreases to a some amount, the network becomes disposable even when there are nodes alive in the network.

So first node dying is more important than the last node dying. And also it is desirable that the whole network dies at the same time. That way the network will be in its fully functioning capacity for the most of the time.

Based on these facts what we need is a network works at its full performance longest time possible and then dies together so that it could be replaced by another.

In order to determine if the network dies fast or not, we need to devise a metric. We take the slope of the No of alive nodes Vs. Time graph for this as it essentially reflects the network's performance degradation rate. So what needed to be achieved is a high steepness in the graph.

Proposed performance parameter,

So after first node dies,

Equation 6

Death rate of the nodes = d (Number of nodes alive)/dt

= constant d(number of nodes alive)/d(rounds)*

= number of nodes / (Round in which last node dies - Round in which first node dies)

We also observe that in most of the improved versions of LEACH [6] [7] (though they are centralized) they use the energy balancing which would eventually achieve the same as we discussed before.(See Figure 10) Even though they do not explicitly discuss about this.

4.1. The advantages of the high steep summarized

1. Since there is a high steep all the nodes die together. So the network will be fully functioning till the first node dies, and soon after that 'the whole network' can be replaced instead of replacing nodes.

2. if the slope is less steep that means, at one point there will be coverage holes in the network. So the network function is not good. The only way you can fix it would be to deploy "more nodes" at the initial deployment.

But if we know the characteristics would have a steep slope that means the coverage holes will not be there for more time. (only for few rounds). So we can deploy the exact amount of nodes needed for the coverage. This is economical and makes the task easier for the network designer.

But besides, we also have another energy goal. As described in the [2],It is desirable that the network die geographically evenly. For an example five nodes dying in a close proximity to each other can reduce the network performance more than an if those five nodes were spread in a large area evenly.

5. Chapter 5 :Keeping the nodes alive

As we implied we propose a new protocol to address the energy goals we discussed above. Main goal is our algorithm is to keep all the nodes alive as much times as possible. It perform most of the communication like LEACH.LEACH is taken here not only because of its energy awareness also it is the most efficient distributed algorithm we think exists as a data gathering hierarchical protocol.

The reason why the first node dies very fast in a LEACH network is because the nodes are not aware of the energy levels of its own, and of course relative energy level w.r.t the network. Most centralized algorithms solve this problem by base station requesting the energy levels of all the nodes and then processing this data to find better clusters Cluster heads in order to optimize the energy balance of the network.

Since our objective is to retain the distributiveness of the network, we do not employ such a centralized clustering algorithm. But the nodes can send its own battery (energy) level to the base station as it sends the other information periodically. If the node represent its energy level with a 6 bit number *(64 levels)*, the energy cost of this transmission could be considered nominal, as it is sent every 10k bit data transmission. The node also finds out its closest node (the neighbor) and it's ID. Note that it does not need to know the location (even the relative coordinates or distance) of the neighbor. Also during the setup phase the node finds out the energy level of the neighbor. Also the base station sends a broadcast of the 'average energy level of the network'. Since all the nodes send its energy level at the setup phase, BS can easily calculate this and send to all the nodes with a nominal energy cost reception.

Equipped with the information such as its own energy level, it is neighbor and its energy, the nodes go to the advertisement phase of the protocol in which it elect itself as a cluster head as in LEACH with a probability. But in our case the nodes with energy level below the average energy level, choose not to become a CH (So the $P=0$ for those nodes). This eliminates the risk of a low energy node becoming a CH (Which is the most probable reason of the first node to die fast.)Later the clustering of the network done in a way similar to that of the LEACH.

5.1.Data transmission phase

By this time the nodes are assigned of their work already, either to act as a CH or a normal node. But if the node is a low energy node (i.e. energy level is below the average energy level) and the neighboring node is a high energy node, instead of data being transmitted directly to the CH it will be routed to the CH through the neighbor. If the node is a high energy node, data is transmitted directly to the CH.(Note that a low energy node cannot become a CH)

5.2. In pseudo codes

Setup phase

1. Each node finds out what is its neighbor (nearest node).
2. It finds out its own energy level. (This could be a discrete level represented with 6bits)
3. send the energy level to the BS.
4. it finds out neighbors energy too.
5. Receives the average energy level of the network from the BS. (This is calculated in the base station using the information sent by all the nodes.)

Advertisement phase

5.Node determines its relative energy level.

If (the nodes energy > average energy) then Node is a 'High energy node'

else Node is a "Low energy node".

6.If the node is a low energy node it becomes ineligible to become a CH.

if it has high energy level, it becomes eligible. (but still randomly elects itself as in original LEACH)

7. if the node is a non CH node, it finds out which CH it belongs to using the strengths of the advertisements.

Data transmission phase

8. if the node is a “low energy node”, and the neighbor is ”high energy node”. it sends the message via the neighbor to neighbor CH.

9. if it is a high energy node, it does its duty. (as a normal node or a CH)

10. After considerable rounds of data transmission. go to 1.

5.3. Simulations and analysis

In order to make the validation of our strategy we simulated the algorithm with the network setup given in the last chapter. The network is a random 100 node network in which the nodes are distributed in random locations in a square area of 50mX50m.The radio model used is the same model we used in before. Simulation is done using MATLAB. Besides the new routing mechanism we also simulated LEACH and Direct method to get the comparison of the routing strategies. As we have suggested, we have included the “Node death rate” as a performance parameter. So this value was calculated for each simulation.

The results for the simulation is given in Figure 13 and Table 3

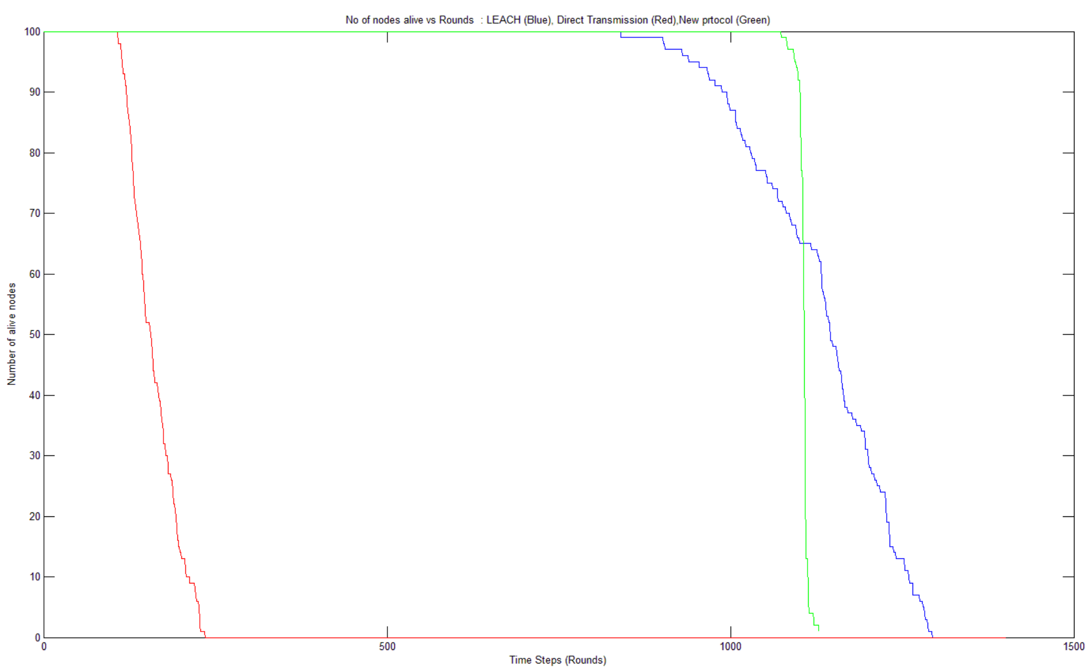

Figure 13: NO of alive nodes vs rounds LEACH(blue), Direct(red), new (green)

	LEACH	Direct method	New
First node dying	855	178	1102
Node death rate	0.2150	1.7857	3.8461

Table 3 :First node dying round and the node death rate for the given techniques

LEACH-Centralized largely out perform all the other routing protocols in terms of energy parameters. But since this is a centralized algorithm it is involved with the cost of having location measuring equipment (like GPS) in every node. While all the other three algorithms do not require a such. Comparing the new strategy with LEACH, we can derive that the proposed technique does delay the first node dying significantly. Thus allowing the network to be functioning in its full capacity for a longer time. Also it has a very high node death rate much higher than LEACH , which makes it superior to LEACH (and direct transmission). So the new strategy reduces the time it has to be working in a partial capacity and improve the first node dying round.

5.4. Summery and future work

Based on the performance matric evaluation we have done, we have found the importance of the higher steep in the 'no of nodes alive Vs. rounds' curve. After discussing the significance of the new performance matric and the importance reducing the time the network functions in the partial capacity, we have presented a new routing strategy that can achieve these goals while maintaining the distributiveness of the algorithm. The TDMA scheduling for this protocol we have not explicitly mentioned here. But it could be derived from the TDMA scheduling in LEACH, though there should be some alterations to allow the nodes to know their neighbors and its energy, also to do the neighbor routing, when dictated by the algorithm. We suggest the node death rate can be used to evaluate the energy efficiency of a routing protocol. But note that it is a complementary parameter that can be used along with network life time. It must be an interesting endeavor, trying to combine these two to formulate a steady metric that determines a energy efficiency of a routing protocol.

6. Chapter 6 : Conclusion

During the research our main objective was to study and analyze the green technologies related to wireless sensor network communication. We have presented the importance of the energy efficiency of the sensor networks and briefly discussed the architecture and the function of the WSN in the beginning. Then we narrowed down our interest in to the routing strategies of the sensor networks in order to do a effective analysis. Following the discussion of many protocols and their categories, we have implemented some of the prominent protocols in MATLAB simulations. These results we have used to identify the advantages and drawbacks of the protocols in a relative fashion.

In the latter part we have introduced and reevaluated the energy goals and the energy performance parameters of the routing protocols of the WSN. Importance of the "Death rate of the nodes" and how to calculate this value is presented. Final section of the thesis is dedicated to developing a new routing strategy that allows the network to last longer in its full performance and also improve the steepness of the "number of alive nodes vs. time curve" (node death rate) more desirably, while maintaining the distributiveness of the algorithm. The performance of the proposed technique is compared with other protocols to verify the relative advantages.

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