EFFECIENT ROUTING TECHNIQUE THAT MAXIMIZE THE LIFETIME AND COVERAGE OF WIRELESS SENSOR NETWORKS

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This Thesis was submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Computer Science

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DEDICATION

This thesis is sincerely dedicated To My loving Parents who help me along the way to make this accomplishment possible, and to my fiancé and my sisters for their kind help, moral supports, and encouragement that was indispensable to the accomplishment of this work.

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LIST OF ABBREVIATIONS OR SYMBOLS

Symbol or Abbreviation	**Meaning**
WSN	Wireless Sensor Network
OML	Online Maximum Lifetime Heuristic
CMAX	Capacity Maximization
ERPMT	Efficient Routing Power Management Technique
ERPMT_O	Efficient Routing Power Management Technique Based on OML
ERPMT_C	Efficient Routing Power Management Technique Based on CMAX
DAG	Directed Acyclic Graph
α	the ratio of total node energy dedicated for data originated from the node itself
β	the ratio of total node energy dedicated for data relays from other nodes

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ABSTRACT

Wireless sensor networks (WSN) have become very popular in the last few years. One key issue about WSN is that sensor nodes have a limited battery capacity, so it is important to develop energy efficient solutions to keep these networks functioning for the longest possible time.

Most of the nodes energy is spent on data transmission; for that many routing techniques have been proposed to expand the network lifetime in the literature such as the Online Maximum Lifetime heuristics (OML) and capacity maximization (CMAX). The OML has obtained the best lifetime in the literature.

The main problem in most of the proposed heuristics is that they find the lowest energy route and use it for every communication, and this leads to energy depletion of the nodes along that path; especially the nodes closer to the sink that will carry more traffic, and as a result lead to network partition and blind areas (areas that can not be sensed by any node) becomes too large, as a result the data retrieved becomes unreliable.

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In this thesis, we introduce an efficient routing power management heuristic to gain higher lifetime and increased coverage by managing the power at the node level by dividing the node energy into two ratios; one for the sensor node originated data (α) and the other is for data relays from other sensors (β). This heuristic, which called ERPMT (Efficient Routing Power Management Technique), has been applied to OML and CMAX to get the modified versions of them, which are ERPMT_O and ERPMT_C respectively in order to study the effect of that on the network lifetime, energy expenditure, and coverage.

Furthermore, we took into consideration the terrain heterogeneity and study its effect on the existing routing techniques (e.g. OML) as well as ERPMT_O and ERPMT_C. To simulate the terrain heterogeneity, we use two statistical distributions (Uniform and Poisson) to generate a Directed Acyclic Graph (DAG).

Results from running extensive simulation runs revealed the superiority of both ERPMT over existing heuristics. ERPMT increases the lifetime up to 56.7% in the best case which is achieved when α = 50% of total energy. Also, the formation of blind areas has been prevented and the coverage of the network is increased as a result of the fair power expenditure management; that we still have the same power expenditure as OML, but in our case the expenditure is more organized and fairly distributed; energy levels of the nodes deviate only by 8.43% from the energy levels mean of the whole network. Which is not the case when we do not use ERPMT; the deviation in this case is 24.85%. For that, by combining a successful existing routing technique with our new power management technique we come up with an Efficient Routing Power Management Technique that maximizes the lifetime and coverage of Wireless Sensor Networks (WSN).

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1. Introduction

1.1. Overview, Challenges, and Power Aware Routing in WSN

Wireless sensor networks have received increasing attention over the few recent years (Akyildiz, et al., 2002). A sensor network consists of small-size nodes with sensing, computation, and wireless communication capability. These nodes collaborate together by performing desired measurements, process measured data, and transmitting it to some special nodes, commonly referred to as sink nodes, these nodes collect data from all other nodes to analyze it and make conclusions about the activity in the sensed area. In addition they can act as gateways to other networks.

There are many applications of these networks, some of them are:

(a) Military communication applications between soldiers in a battlefield.

(b) Data acquisition in an unfriendly terrain that can not be monitored by humans.

(c) Exploration of natural resources.

(d) Meetings, conventions, and electronic class rooms etc, where people can share information quickly.

In many sensor networking environments, the sensor nodes have limited battery capacity (Al-karaki and Kamal, 2004; Lewis, 2004). Moreover, they may be situated in areas where it is not possible to re-charge and thus have limited lifetimes as in case of sensors which are deployed in hostile (e.g., battlefield) or otherwise hard to reach (e.g., the bottom of the ocean) environments. Hence, it is vital to develop solutions that are energy efficient and maximizing the network lifetime (Akkaya and Younis, 2003; Akyildiz, et al.,

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2002). The network lifetime in this work is defined as the number of successful messages routed until the first fail request.

Data can be propagated to the destination in different methods: single-hop transmission, multi-hop transmission and cluster-based transmission. Single-hop transmission is the simplest transmission method which tries to communicate directly with the sink node but this consumes higher power rates, multi-hop transmission delivers data by forwarding it to one of its adjacent nodes which are closer to the sink node, the data propagate from the source node to the sink by hop from one node to another until it reaches the sink node, but because nodes closer to the sink must forward data coming from other nodes as well as sending their own data to the sink their batteries drain quickly more than others and results on blind areas and network partitions. In cluster transmission, nodes are grouped into clusters and one node which is the cluster head is responsible of sending other nodes data to the sink. In our work, we are concerned with the first two methods and we try to balance between them when necessary to gain higher lifetimes and coverage as we will see later in the discussion.

Since most of the sensor energy spent on data transmission, which includes data generated by the sensor itself and data relayed by other sensors, the main focus was to develop energy-aware routing heuristics which try to optimize network lifetime by managing routes in a way that will save power as much as possible so that the lifetime of the network is maximized.

Another important challenge, it worth pay attention to other than lifetime in sensor networks is coverage; each sensor node obtains a certain view of the environment, this view

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is limited and can only cover a limited physical area of the environment(Al-karaki and Kamal, 2004; Lewis, 2004). One of our purposes was to keep all or most of the network nodes alive most of the network lifetime.

The main problem in most of energy-aware routing heuristics is that they find the lowest energy route and use it for every communication (Al-karaki and Kamal, 2004; Chen and Varshney, 2004). But using a low energy path frequently leads to energy depletion of the nodes along that path especially the nodes closer to the sink that will carry more traffic and as a result lead to network partition, blind areas (areas that can not be sensed by any node) becomes too large, the data retrieved is unreliable and the usefulness of the sensor network will be greatly reduced. Some heuristics have been proposed to solve this problem by taking into account the residual energy at nodes and delay the depletion of nodes that are already low in energy. In our work we seek to prevent, but not to delay the depletion, at the same time increases the network lifetime.

In our study, we will consider two of these routing heuristics which try to delay the early depletion of sensors energy: The first heuristic we have used is OML (Online Maximum Lifetime), which employs two shortest path computations to route each message. To maximize lifetime, it is recommended to delay as much as possible the depletion of a sensor's energy to a level below that needed to transmit to its closest neighbor. The second heuristic is CMAX (Capacity Maximization) heuristic which makes admission control. That is, it rejects some routes that are possible.OML was chosen because it achieves the best lifetime in the literature. And because it was built as a modification for CMAX, we also consider CMAX to study the effects of applying the proposed technique on it.

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In this thesis, we introduced a new technique which maximize the lifetime of the network as well as preserve coverage as much as possible. What distinguishes our work from previous researches is that in order to maximize the lifetime, we perform a battery power management at the node level, such that the total power of the sensor battery is divided into two parts; the first is dedicated for sending data generated by the sensor itself, while the other is for data relays from other sensors, the division is done in different ways to test each combination effect. By doing this we gained an increased network lifetime and coverage.

Our approach can be used along with the existing routing heuristics to gain the advantages from these routing techniques while doing our power management to gain higher lifetimes and preserve coverage. For that, we compared ERPMT (ERPMT_O and ERPMT_C) against two well known routing heuristics: OML and CMAX. Also, we studied the dimension effects (1D and 3D) on the lifetime performance metric. We also took into consideration the heterogeneity of the deployment environment. For example, Uniform and Poisson distributions imitate flat and uneven terrains respectively (Al-Sharaeh, et al., 2008). This is done as follows; the sensor network is represented by an adjacency matrix that was generated depending on the Euclidian dimensions of the network nodes, such that they were compared to a threshold in order to determine if there is connectivity (edge) or not between every two nodes. As a result we show the effects of applying ERPMT on the network lifetime, energy expenditure, and coverage which is increasing the lifetime and coverage while keeping the energy expenditure the same as OML which gains the highest lifetime in the literature (Park and Sahni, 2006).

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1.2. Research Objectives

Our study has number of objectives which are done and discussed through the thesis, they are:

(a) Implementing and evaluating the existing heuristics using random Distribution.

(b) Implementing and evaluating the existing heuristics using Poisson distribution and study the effect of changing the distribution on routing protocols.

(c) Implementing and evaluating our proposed power management technique using Uniform and Poisson distribution.

(d) Implementing and evaluating our proposed power management technique using 3D Uniform and Poisson distribution and study the effect of changing from 1D to 3D.

(e) Comparing the results of different combinations of implementations and study their effect on average lifetime, network coverage, and energy expenditure.

This thesis is organized as follows:

In this chapter, we presented an overview on wireless sensor networks and its applications, a problem overview, main challenges, power aware routing methods, and finally the objectives of the proposed system were discussed. In the second chapter, other existing studies in the literature for maximizing network lifetime were introduced. In the third chapter, a description of details of sensor network deployment and system implementation is provided. Also, our proposed routing heuristics are presented. Experiments and the evaluation of the results for the proposed technique using different types of distributions and different power division and management ways are given in the fourth chapter. Finally, the thesis is concluded and the future work is mentioned in the fifth chapter.

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2. LITRATURE REVIEW

Several energy-aware heuristics have been proposed in the literature. They all have a common objective of extending the lifetime of the Wireless Sensor Network (WSN), such as:

Singh (1998), proposed a way to select routing paths based on five metrics that may be used in the selection of the routing path for energy efficient routing. The first is to use a minimum-energy path that can be computed using Dijkstra's shortest path heuristic. But using a minimum-energy path for the current route request may prevent the successful routing of future messages. The second is maximizing time to network partition. The third is to minimize variance in node energy levels. The last two metrics are to minimize the node cost of each transmission (the cost of a node is some function of the amount of energy used so far by that node), and minimize maximum node cost. Of the proposed five metrics, only the minimum-energy path and minimizing node cost have been implemented by Singh because of difficulty of implementing the others in a routing protocol.

Rodoplu and Meng (1999), introduced the Minimum Energy Communication Network (MECN), which is a protocol that computes an energy-efficient subnetwork. The main idea of MECN is to find a subnetwork that will have fewer nodes and require less power for transmission between any two particular nodes. In this way, global minimum power paths are found without considering all the nodes in the network. This is performed using a localized search for each node considering its relay region.

A hierarchical clustering heuristic for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH) was proposed by Heinzelman (2000). LEACH is

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a cluster-based protocol, which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as Cluster Heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network. In LEACH, the CH nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the Base Station (BS) in order to reduce the amount of information that must be transmitted to the BS. LEACH is able to distribute energy consumption evenly throughout the sensors, doubling the useful system lifetime for the networks.

Manjeshwar and Agarwal (2001), developed the Threshold-Sensitive Energy Efficient Sensor Network Protocol (TEEN) for time-critical applications. In TEEN, sensor nodes sense the medium continuously, but data transmission is done less frequently. A cluster head sensor sends its members a hard threshold, which is the threshold value of the sensed attribute, and a soft threshold, which is a small change in the value of the sensed attribute that triggers the node to switch on its transmitter and transmit. 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 that might otherwise occur when there is little or no change in the sensed attribute. 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 tradeoff between energy efficiency and data accuracy. Simulation of TEEN has shown that this protocol outperforms LEACH in terms of energy dissipation and network lifetime.

The Small MECN (SMECN) is an extension to MECN and it was proposed by Li and Halpern (2001). In MECN, it is assumed that every node can transmit to every other node, which is not possible every time. In SMECN possible obstacles between any pair of

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nodes are considered. However, the network is still assumed to be fully connected as in the case of MECN. The subnetwork constructed by SMECN for minimum energy relaying is provably smaller (in terms of number of edges) than the one constructed in MECN. The subnetwork computed by SMECN helps in sending messages on minimum-energy paths.

Li, et al. (2001), proposed the Hierarchical Power-Aware Routing in Sensor Networks, The protocol divides the network into groups of sensors. Each group of sensors in geographic proximity is clustered together as a zone, and each zone is treated as an entity. To perform routing, each zone is allowed to decide how it will route a message hierarchically across the other zones such that the battery lives of the nodes in the system are maximized. Messages are routed along the path that has the maximum over all the minimum of the remaining power, called the max-min path.

Toh (2001), introduced the MMBCR (Min-Max Battery Cost Routing) and CMMBCR (conditional MMBCR). The MMBCR heuristic aims to achieve a balance between the energy consumption and the minimum residual energy at the node along the selected route. In CMMBCR, the sensors along the chosen route must have residual energy above a threshold γ. If there is no source to destination route with this property, then the MMBCR route is used.

An enhancement over the LEACH protocol was proposed by Lindsey and Raghavendra (2002). The protocol, called Power-Efficient Gathering in Sensor Information Systems (PEGASIS), is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need only communicate with their closest neighbors, and they take turns in communicating with the BS (Base Station). When the

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round of all nodes communicating with the BS ends, a new round starts, and so on. This reduces the power required to transmit data per round as the power draining is spread Uniformly over all nodes. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS instead of multiple nodes. Simulation results showed that PEGASIS achieves better lifetime than the LEACH protocol.

Manjeshwar and Agarwal (2002), introduced Adaptive Periodic TEEN (APTEEN) which is a hybrid protocol that changes the periodicity or threshold values used in the TEEN protocol according to user needs and the application type. Simulation of APTEEN demonstrated that APTEEN's performance is somewhere between LEACH and TEEN in terms of energy dissipation and network lifetime.

Misra and Banerjee (2002), proposed the MRPC (Maximum Residual Packet Capacity) lifetime-maximization, which depends not only on the residual battery energy on a node, but also on the expected energy spent in reliably forwarding a packet over a specific link. MRPC selects the path that has the largest packet capacity at the 'critical' node (the one with the smallest residual packet transmission capacity). They also present CMRPC, a conditional variant of MRPC that switches from minimum energy routing to MRPC only when the packet forwarding capacity of nodes falls below a predefined threshold.

Kar (2003), proposed the CMAX (Capacity Maximization), the capacity is the number of messages routed over some time period, heuristic which provides a single path for each message (no multiple paths) chosen with respect to the link weights. The heuristic makes admission control. That is, it rejects some routes that are possible In order to increase lifetime.

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Stojmenovic and Lin (2004), introduced localized heuristics to maximize lifetime in which they define a new power cost metric based on both nodes life time and distance-based power metrics. They also show that the required transmission power can be reduced if additional nodes placed at desired locations between two nodes at distance d.

Park and Sahni (2006), proposed the OML (Online Maximum Lifetime) heuristic where two shortest path computations are done to route each message. In order to maximize lifetime, it is recommended to delay as much as possible the depletion of a sensor's energy to a level below that needed to transmit to its closest neighbor.

Al-Sharaeh, et al. (2008), introduced a Multi-Dimensional Poisson Distribution Heuristic to better evaluate the routing heuristics; by taking into account earth's terrain and the multi-dimensional concept and this is done by the way we generate the placement of the sensor nodes as well as the interconnection between the sensors. A major effect on the performance of different routing heuristics was gained.

Al-Sharaeh, et al. (2009), introduced a study of the deployment strategy effect on maximizing the lifetime of the wireless sensor networks; it shows that changing the statistical techniques of distribution -such as Poisson Distribution- that meet real environment requirements affect the performance of maximizing lifetime routing heuristics in many aspects, such as average lifetime and network capacity.

From the above we believe that increasing the lifetime in a different way is still an important requirement, in our work we seek to get higher lifetimes as well as preserving coverage of the network in a different way, which is controlling the energy expenditure at the node level, that has not been applied before and test its effect on some existing heuristics.

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3. Theory and Implementation

3.1. Sensor Network Model

A wireless sensor network is described by a directed graph **G= (V, E)**, where **V** is the set of nodes, and **E** is the set of edges between these nodes, there will be a directed edge from node **v** to node **u** (i.e. $(v, u) \in E$) if a single-hop transmission form node **v** to node **u** is possible. Such modeling can be used to represent Wireless Sensor Networks (WSN). for each **(u, v)** $\in$ **E**, in case of single hop transmission from sensor **u** to sensor **v**, the current energy in sensor u, **c_e(u)** is represented by Formula 3.1 (Park and Sahni, 2006).

$$c_e(u) = c_e(u) - w(u,v) \tag{3.1}$$

Where $c_e(u)$ is the current energy in sensor u, such as $c_{e(u)} \geq w(u,v) > 0$, and $w(u,v)$ is the energy required to make a single hop transmission from sensor u to sensor v, such that $w(u,v) > 0$. We also assume that the receiver of a message consumes no energy during message reception. Thus, the current energy in sensor (v) is not affected by the transmission from u to v. In our work the energy is divided into two ratios, one for data originated from the node (α), the other is for relays from other sensors (β); if the data is originated from the node itself, it will use the energy from the first ratio otherwise it will use energy from the other ratio.

An adjacency matrix can be used to represent directed graphs of WSN (Park and Sahni, 2006; Al-Sharaeh, et al., 2008; Al-Sharaeh, et al., 2009). The adjacency matrix of a finite directed graph **G** on n vertices (where $n = |V|$), is the $n \times n$ matrix such that, the non-diagonal entry a (i, j) = 1, represents the existence of an edge from sensor i to sensor j.

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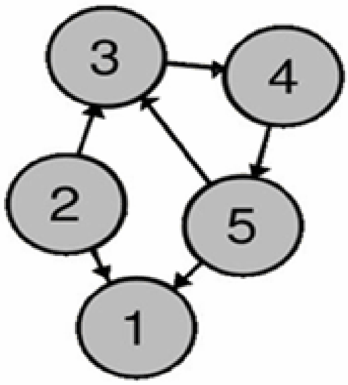
While the diagonal entry a(i, i) is assigned by zeros here because we assume that there is no internal loops in the WSN.

There exists a unique adjacency matrix for each graph. For example, Fig. 3.1.(a) shows a simple representation for sensor network S. A directed graph is used, where the represented nodes are sensors, and the edges represent the existence of edges between the sensor nodes. Fig. 3.1.(b) shows the adjacency matrix of the sensor network S modeled in Fig. 3.1.(a). It is obvious that Fig. 3.1.(b) depicts a network that has been implemented using one dimension to represent sensors. Such representation for sensors has been used by Al-Sharaeh, et al., (2009) in previous studies. In order to get more realistic results, we also represent sensors using 3D (3 dimensional) in one of our experiments; each sensor is represented using three dimensions: x, y, and z (Al-Sharaeh, et al., 2009).



	1	**2**	**3**	**4**	**5**
1	0	0	0	0	0
2	1	0	1	0	0
3	0	0	0	1	0
4	0	0	0	0	1
5	1	0	1	0	0

(a): Simple graph network representation (b): Corresponding adjacency matrix representation

Figure 3.1: Representation of wireless sensor network

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In most of the studies to represent a sensor location as well as connectivity a random number from Uniform distribution was used (Park and Sahni, 2006; Kar 2003). It is better to use the Uniform distribution for flat terrain environment, because the sensors can be distributed evenly as shown in Fig. 3.2, but the real environment usually characterized by terrains, such as in case of sensors deployed in high mountains or deep oceans. In this case, the Uniform distribution does not give a good realistic that match the terrain changes. For that, it is better to use Poisson distribution as it is best fits the asymmetric environment (Al-Sharaeh, et al., 2008; Al-Sharaeh, et al., 2009). Fig.3.3 shows sensor nodes distribution based on Poisson distribution, it is clear that the sensors location concentrated around the mean. This kind of deployment imitates a deployment of sensors via airplane in a terrain that is close to valleys.

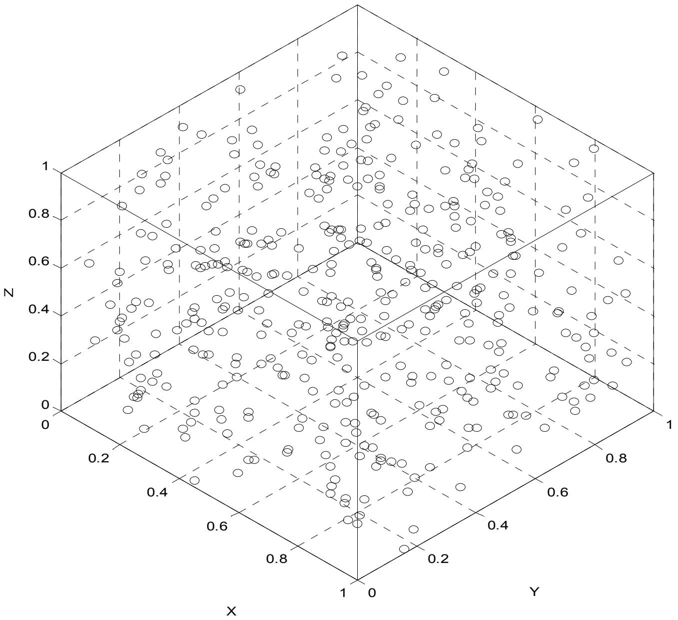

Figure 3.2.: 3D Sensor nodes distribution based Uniform distribution.

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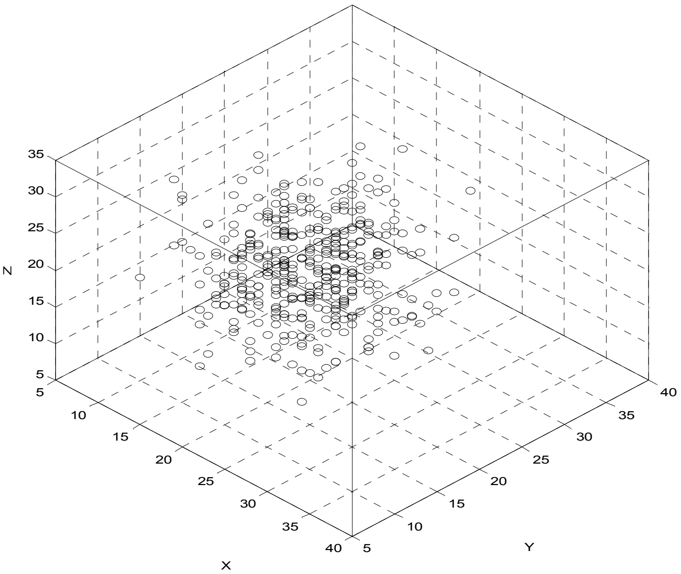

Figure 3.3.: 3D Sensor nodes distribution based Poisson distribution

An example of sensor deployment application is avalanching predictions, mountainous terrains portrait all the challenges that may face sensor deployment in order to make full coverage. For that, deployment strategy has a major effect on evaluating a routing heuristic. This is due to the fact of terrain changes of real life environment. Fig.3.4. depicts the landscape of typical environment that ranges from flat land, hilltop, cliffs, valleys, to mountains top. In order to make fair comparison between different routing protocols, a major attention should be paid to the deployment strategy. This factor can be taken into consideration by the way we generate the random graph that both simulate the position as well as the connectivity that at the end will simulate the way the sensors are connected.

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Figure 3.4.: Mountains Terrains for avalanche detection WSN application.

To determine connectivity between the nodes, we used a threshold which was equal to the mean of the dimensions of network nodes. All nodes were recursively checked by comparing their X-, Y- and Z-dimension in case of 3D deployment with the mean of the Euclidian dimensions for these 3 dimensions (X, Y, and Z) for all network nodes. For the case of 1D, we only work with just the X dimension. Each node with a dimension value greater than or equal to the mean of the same dimension will be considered connected, otherwise it will be disconnected (Park and Sahni, 2006). For example, if the X dimension of node A was equal to 10, and there are other three nodes in the network with their X dimensions equal to 11, 15, and 20. To determine if node A is connected we compare its X dimension with the threshold which is the mean of all network node dimensions and this is equal to 56(11 + 15 + 20+ 10). Node A is considered not connected because 10 is not larger than 56.

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3.2. Details of energy-aware routing heuristics used

We have used two well known heuristics to apply ERPMT on, these two different heuristics were proposed to extend the lifetime of the network and they obtained the best lifetime in the literature. The first heuristic used CMAX (capacity maximization) heuristic which makes admission control. That is, it rejects some routes that are possible (Kar, 2003). Using CMAX (capacity maximization) heuristic, each link in the network is represented by a corresponding weight. A weight of a link is increased by the energy consumed to pass through that link; it's also increased by the energy spent by the transmitting node. CMAX heuristic provides a single path for each message (i.e. no multiple paths are used), and all messages are assumed to be routed directly after they enter the system. Occasionally, using admission control, the CMAX heuristic can reject messages if they are considered to be too detrimental to the network's residual capacity. The specification of the shortest path in CMAX heuristic is done with respect to the links weights.

The other heuristic is OML (Online Maximum Lifetime), which employs two shortest path computations to route each message. To maximize lifetime, it is recommended to delay as much as possible the depletion of a sensor's energy to a level below that needed to transmit to its closest neighbor (Park and Sahni, 2006). OML heuristic is an enhancement of the CMAX heuristic and uses a two-step approach where they remove those edges with low energy from the graph, and then run Dijkstra's on a graph where the edge weights have been modified in such a way that the paths found usually use nodes with high energy levels and edges with low energy costs.

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Fig.3.5 shows the details of our first proposed heuristic, which is ERPMT_C and it is an enhancement over the CMAX, where we assume that the current energy in each sensor is divided in two ratios, the first is for the sensor originated data (α), the other is for relays from other sensors (β). For each routing step there are two steps. In step one; every edge with a sensor that has not adequate energy to make a single hop transmission is eliminated from the graph. Then each remaining link is assigned a weight using Formula 3.2:

$$w(u,v) = w(u,v) * (\lambda_c{}^{a(u)} - 1) \tag{3.2}$$

Where λ_c is a heuristic parameter, a (u) is the percentage of the initial energy that has already been spent at the sensor node and calculated as in Formula 3.3:

$$a(u) = \begin{cases} 1 - \mathrm{c_{e\,1}(u)/i_e(u)} \\ 1 - \mathrm{c_{e2}\,(u)/i_e(u)} \end{cases} \tag{3.3}$$

In the second step, the source-to-destination path in the modified Graph is computed. If a path is not found, then the request failed. Otherwise it is used unless it is larger than a specified threshold σ.

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Heuristic 2 ERMPT_C

Assumption: Divide the current energy of each sensor into ce_1 and ce_2:

ce_1= Total energy $*$ α and ce_2= Total energy-ce_1

For each routing request $r_i = (s_i, t_i)$ two steps are done:

Step 1: [Initialize]

(a) Eliminate from G every edge (u, v) for which:

$c_{e1}(u) < w(u, v)$ if $u = s_i$

$c_{e2}(u) < w(u, v)$ if $u \neq s_i$

(b) Change the weight of every remaining edge (u, v) to:

$$w(u,v) = w(u,v) * ({\lambda_c}^{a(u)} - 1)$$

Where λ_c is a heuristic parameter , a(u) is the percentage of the initial energy that has already been spent at the sensor node and calculated as:

$$a(u) = \begin{cases} 1 - c_{e\,1}(u)/i_e(u) \\ 1 - c_{e2}(u)/i_e(u) \end{cases}$$

Step 2: [Shortest Path]

Let P be the shortest source-to-destination path in the modified Graph.

Step 3: [Wrap Up]

If no path is found in Step 2, the route is not possible. Use P for route if its length is less than σ.

Figure 3.5: ERPMT_C Heuristic

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In Fig.3.6 details of the second heuristic (ERPMT_O) are shown. As in ERPMT_C we assume that the energy in each sensor is divided into two ratios α and β. Then for each routing request r_i= (s_i, t_i), two steps are done:

- **Step 1: [Compute G″]** :

1. All edges are removed from G such that $c_{e\,1}(u)$ or $c_{e\,2}(u)$< w (u, v); as these edges have less power than required for a single transmission. The resulting graph is G` = (V, E`).

2. Determine the minimum energy path P`$_i$ from $s_i$ to $t_i$ in G`,This is done using a shortest path algorithm (dijikstra).

If there is no path from the source s to destination t, then the routing request fails, but if routing request exists, then P` is used to compute the residual energy using Formula 3.4 :

$$\text{minRE} = \min \{r_e\,(u)|inP\} \qquad (3.4)$$

Then the graph G`` = (V, E``) can be obtained by removing all edges (u, v) in E` with $c_{e\,1}(u)$ or $c_{e\,2}(u)$ – w (u, v) < minRE. As a result, all the edges with residual energy below (minRE) will be pruned from the graph and the reduction of energy from sensors that are low on energy could be prevented.

The second step in the procedure is to find the path to be used to route the request r, we begin with G`` and assign weights to each (u,v) in E`` ;this is done to balance the desire to minimize total energy consumption as well as the desire to prevent the depletion of a sensor's energy.

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let eMin (the energy needed by sensor u to transmit a message to its nearest neighbor in G``) as expressed in Formula 3.5:

$$\text{eMin(u)} = \min \{ \text{w(u, v)} \mid \text{(u, v)} \in \text{E``} \} \tag{3.5}$$

Now, let (u, v) be defined as in the following Formula:

$$\rho(u,v) = \begin{cases} 0 & if\ c_e(u) - w(u,v) > eMin(u)\ \ and\ \ u = s_i \\ 0 & if\ c_e(u) - w(u,v) > eMin(u)\ \ and\ \ u \neq s_i \\ c & otherwise \end{cases} \tag{3.6}$$

Where the c symbol is a non-negative constant and it is an algorithm parameter. Then a (u) is defined for each u in V as a (u) = minRE / $\mathrm{c_{e\,1}(u)}$ or $\mathrm{c_{e\,2}(u)}$ and the weight w`` (u, v) assigned to edge (u, v) in E`` is computed using Formula 3.7:

$$\mathrm{w``(u,v)} = (\mathrm{w(u,v)} + \rho(\mathrm{u,v}))(\lambda_{\mathrm{c}}{}^{\mathrm{a(u)}} - 1) \tag{3.7}$$

Where λc is another non-negative constant -an algorithm parameter.

As can be seen, the weighting function, through ***ρ***, assigns a high weight to edges whose use on a routing path causes a sensor's residual energy to become low.

Also, all edges emanating from a sensor whose current energy is small relative to minRE are assigned a high weight because of the term. Thus the weighting function discourages the use of edges whose use on a routing path is likely to result in the failure of a future route. Finally, we Find the shortest path P``i in G`` and Use it to route from s to t.

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Heuristic 1 ERPMT_O

Assumption: Divide the current energy of each sensor into ce_1 and ce_2,such that:

$$ce_1 = \text{Total energy} * \alpha \quad \text{and} \quad ce_2 = \text{Total energy-}ce_1$$

For each routing request $r_i = (s_i\,, t_i)$ two steps are done:

Step 1: [Compute G″]

(a) G′ = (V, E′), where $E' = \begin{cases} E - \{(u,v) | ce_1(u) < w(u,v)\} & if\ u = s_i \\ E - \{(u,v) | ce_2(u) < w(u,v)\} & if\ u \neq s_i \end{cases}$.

(b) Let P_i be a shortest s_i to t_i path in G′.

If there is no such P_i, the route request fails, then stop.

(c) Compute the minimum residual energy minRE for sensors other than t_i on P_i as :

$$minRE = \min\ \{r_e\,(u) | in\ \ P\}$$

$$r_e\,(u) = \begin{cases} ce_1(u) - w(u,v) & if \quad u = s_i \\ ce_2(u) - w(u,v) & if \quad u \neq s_i \end{cases}$$

(d) Let G″ = (V,E″) where $E'' = \begin{cases} E' - \{(u,v) \quad \text{if} \quad ce_1(u) - w(u,v) < minRE \ \ and \ \ u = s_i\ \}. \\ E' - \{(u,v) \quad \text{if} \quad ce_2(u) - w(u,v) < minRE \ \ and \ \ u \neq s_i\}. \end{cases}$

Step 2: [Find route path]

(a) Compute the weight w″(u, v) for each edge of E″ as :

$$\mathbf{w``(u,v) = (w(u,v) + \rho(u,v))(\lambda_c{}^{a(u)} - 1)}$$

Where:

$$\rho(u,v) = \begin{cases} 0 & if\ c_e(u) - w(u,v) > eMin(u) \ \ and \ \ u = s_i \\ 0 & if\ c_e(u) - w(u,v) > eMin(u) \ \ and \ \ u \neq s_i \\ c & \qquad\qquad\qquad\qquad otherwise \end{cases}$$

c symbol is a non-negative constant and it is a heuristic parameter.

eMin is the energy needed by sensor u to transmit a message to its nearest neighbor in G``

eMin(u) = min { w(u, v) | (u, v) Є E``}

$$a(u) = \begin{cases} minRE/ce_1(u) & if \ \ u = s_i \\ minRE/ce_2(u) & if\ u \neq s_i \end{cases}$$

(b) Let $P``_i$ be a shortest from $s_i$ to $t_i$ path in G``.
(c) Use $P``_i$ to route from s_i to t_i.

Figure 3.6: ERPMT_O Heuristic

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4. Experiments and Results

ERPMT (Efficient Routing Management Technique) was implemented in Matlab, the Operating System was Windows XP SP3 installed on a PC with 3.20 GHz processor and 894MB of RAM. The OML (Online Maximum Lifetime) and the CMAX (Capacity Maximization) were implemented using the new power management technique in Uniform and Poisson distributions for both 1D and 3D dimensions. In each of 10 networks 20 sensors were randomly populated. The energy required by a single-hop transmission between two sensors was assumed to be $0.001 * d^3$, where d is the Euclidean distance between two sensors. And the transmission radius and initial energy for each sensor were set to 5, 100 respectively. Finally, the c was set to $0.001 * r_T^3$, where r_T is the transmission radius (Park and Sahni, 2006). The simulation results show the effects of applying the power management technique in different distribution types on the network lifetime.

The main objective for this thesis is to test the effect of applying our new power management technique (ERPMT) to the existing energy aware routing heuristics for extending lifetime, such as OML which obtain the best lifetime in the literature and the CMAX which achieves less lifetime when compared to OML.

In our experiments, the power at each sensor has been divided into two ratios of the total node energy; the first is for the data sent by the sensor itself (α), the other is for data relays from other sensors (β). These two ratios were divided in two ways; the first by dedicating less power than or equal to β for α. The second is done by assigning higher power than β for α.

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4.1. Dedicating power less than or equal to β for α

Here α was 50%, 40%, 30%, 20%, and 10% of total node energy.

4.1.1. Average lifetime using Uniform distribution for α ≤ β

A twenty sensor networks were deployed to be randomly distributed using Uniform distribution. Because of random values, in some experiments there are odd values. But since they are few, we can ignore them and take our decision from the majority.

Fig.4.1. shows the average lifetime for 10 networks with 20 sensors in each network for the OML and ERPMT_O (with different cases) heuristics. It is obvious that when applying our ERPMT_O technique the lifetime has increased in all cases, for the case of α=10% has the lowest average lifetime and for α= 50% the highest average lifetime was achieved.

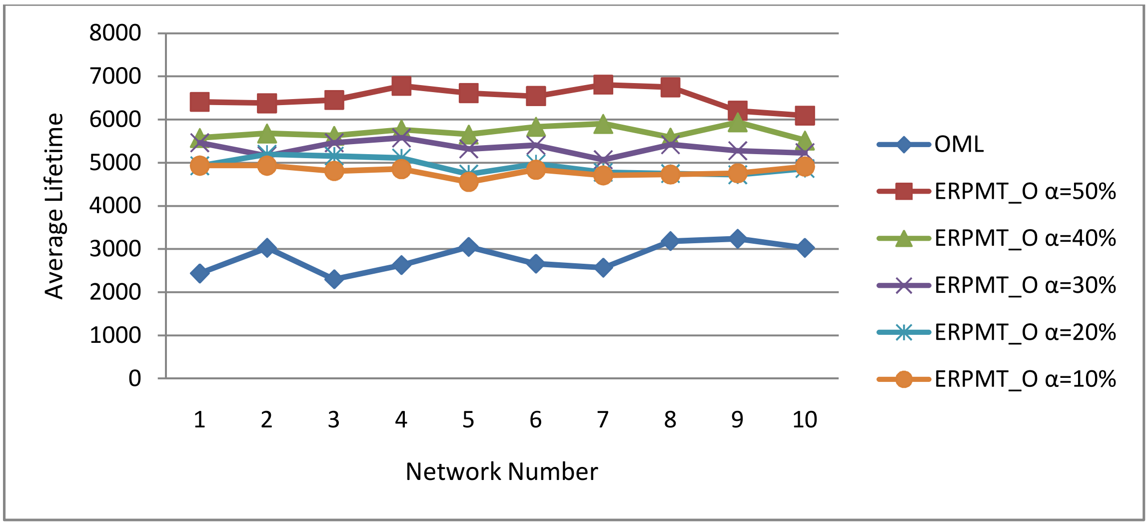

Figure 4.1: Average lifetime routing for OML and ERPMT_O (α≤ β) using Uniform Distribution

The same results (increased lifetime) are obtained in the case of using CMAX, Fig.4.2. shows the results of the same experiment on CMAX. As previous researches (Park and Sahni, 2006), we concluded that the CMAX has fewer lifetimes than OML, but we can

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control CMAX with ERPMT to gain higher lifetime than the original OML. However, CMAX is less affected by ERPMT; the improvement gained is less than that of OML. And this is because of that the CMAX is more stable than OML.

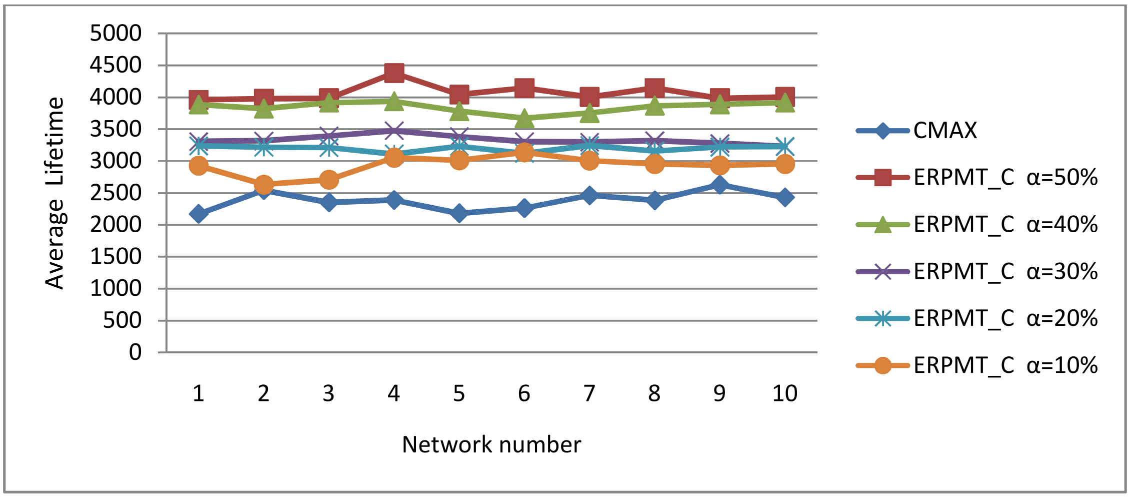

Figure 4.2.: Average lifetime routing for CMAX and ERPMT_C (α≤ β) using Uniform Distribution

Table 4.1. shows the percentage difference in lifetime between OML (without ERPMT) and ERPMT in different cases, by using Formula 4.1. Note that, if the result is negative then there is a reduction in lifetime, otherwise, it is an improvement. The average lifetime for the ERPMT in case of α=50% is **56.74**% better than the OML.

$$\%\ \text{Difference} = \ \left((Avg.ERPMT\_O - Avg.OML) / (Avg.ERPMT\_O) \right) * 100\% \qquad (4.1)$$

Table 4.1.: Percentage difference between OML and different cases of ERPMT (α ≤ β) using Uniform Distribution.

Technique used	OML	ERPMT_O				
		α=50%	**α**=40%	**α**=30%	**α**=20%	**α**=10%
Avg. Lifetime	2811.2	6499.8	5707.4	5336	4917.4	4800.4
Percentage Diff.		56.74%	50.74%	47.31%	42.83%	41.43%

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We have noticed that the lifetime of the node increased and as a result the network lifetime increased by increasing the energy ratio dedicated for the sensor own data (the optimal value of α is 50% and this is shown later in results). This increase is due to the power expenditure management that has prevented the early depletion of energy for certain nodes which are used frequently as relays for other nodes; the nodes energies are used fairly so that no expenditure is concentrated on just some nodes while others are not used and all the nodes energies are investigated to prolong the lifetime of the overall network as much as possible.

4.1.2. Average lifetime using Poisson distribution for $\alpha \leq \beta$

The same effect(higher lifetime) was gained when changing to Poisson distribution which gives a better description for the real environment. Fig.4.3 shows the average lifetime for 10 networks with 20 sensors in each network, here also higher lifetimes were obtained using power management technique (ERPMT). Poisson distribution gives lower lifetimes than Uniform in all corresponding cases and this agrees with previous researches (Al-Sharaeh, et al., 2008; Al-Sharaeh, et al., 2009).

But when using power management in Poisson distribution we can gain higher lifetimes than OML in Uniform distribution without using ERPMT.

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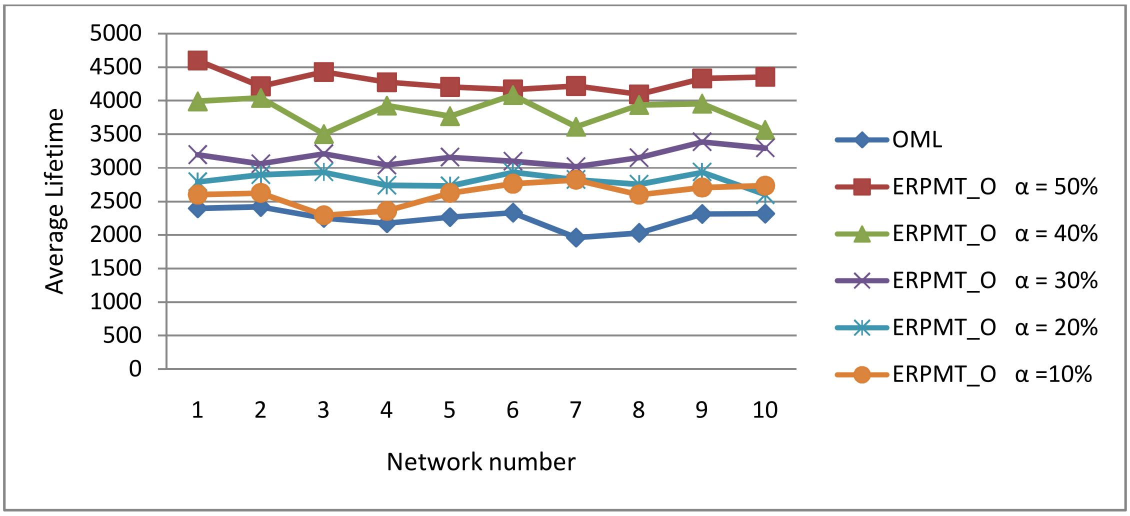

Figure 4.3: Average lifetime routing for OML and ERPMT_O (α≤ β) using Poisson distribution

Also, in case of Poisson distribution the differences between different power Divisions are less than in case of Uniform distribution.

Fig.4.4 shows the results of applying the same experiment on the CMAX, here the same effect as in CMAX in Uniform distribution was gained.

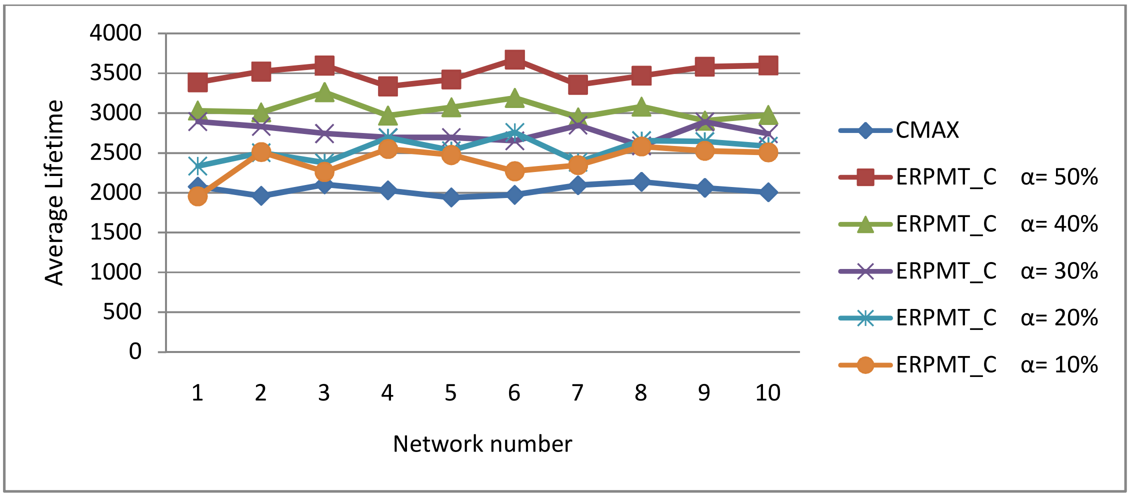

Figure 4.4: Average lifetime routing for CMAX and ERPMT_C (α≤ β) using Poisson distribution

Table 4.2 shows that in case of Poisson distribution, ERPMT_O is 47.69% better than OML and as we decrease α the percentage decreases, but still an improvement.

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Table 4.2: Percentage difference between OML and different cases of ERPMT ($\alpha \leq \beta$) using Poisson distribution.

Technique used	OML	ERPMT_O				
		α=50%	α=40%	α=30%	α=20%	α=10%
Avg. Lifetime	2242.4	4287.3	3837	3178.2	2812.6	2610.8
Percentage Diff.		47.69%	41.55%	29.44%	20.27%	14.11%

4.2. Dedicating more power for α than β

In these experiments α was larger than β, α was set to 60%, 70%, 80%, 90%, 100% (single hop transmission).

4.2.1. Average lifetime using Uniform distribution for $\alpha > \beta$

Fig.4.5 shows the results of applying the second way of ERPMT on the OML in Uniform distribution. It is clear that as the power dedicated for the sensor generated data increased the lifetime decreased. this decrease in lifetime is resulted because as we increase the value of α above 50% of total power we tend to single hop transmission which consumes more power and results on decreased lifetime. In addition, the oppurtinity for a node to find a path to route through it decreases, and as a result the lifetime decreases.

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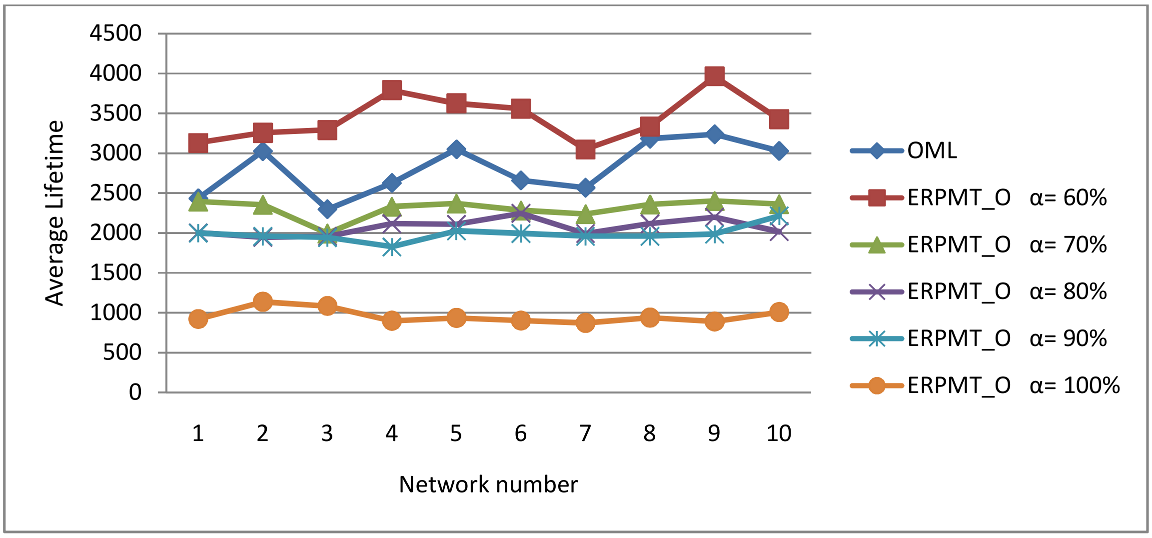

Figure 4.5: Average lifetime routing for OML and ERPMT_O (α>β) using Uniform distribution

Fig.4.6 shows results of the same experiments on CMAX, the same result also here but as we discussed before that CMAX is less affected to the changes between different cases than in case of OML, and that is because the stability of the CMAX heuristic.

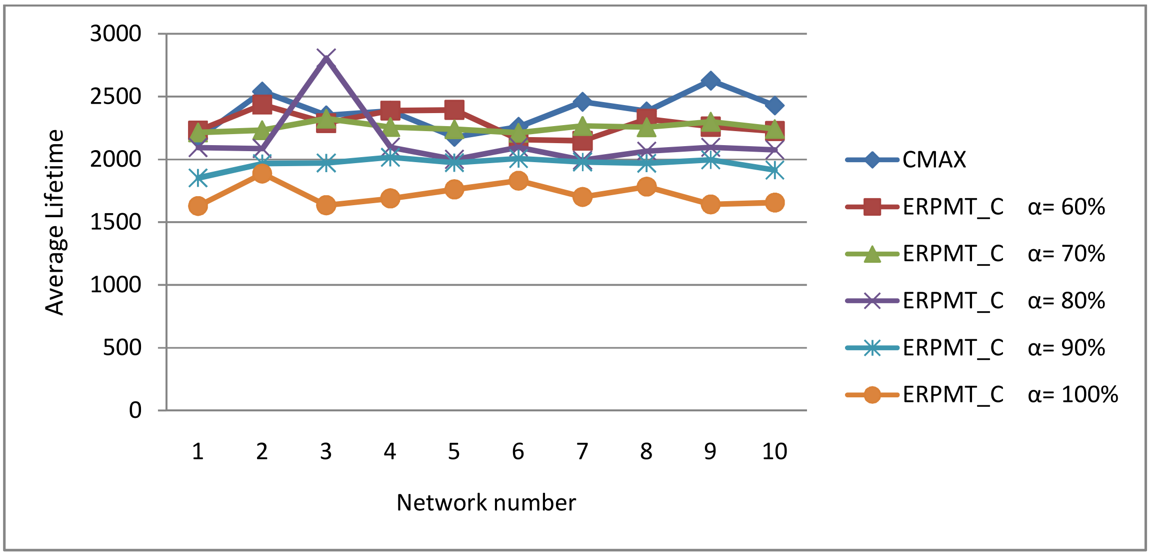

Figure 4.6: Average lifetime routing for CMAX and ERPMT_C (α>β) using Uniform distribution

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Table 4.3 shows the percentage difference in case EPRMT with α>β, EPRMT is 18.3% better than OML in case of **α**=60%, but as α increases a reduction in the performance resulted.OML is 17.9 better than EPRMT with α= 70%. As α increases more reduction in the performance occurred.

Table 4.3: Percentage difference between OML and different cases of ERPMT (α > β) using Uniform distribution

Technique used	OML	ERPMT_O				
		α=60%	**α**=70%	**α**=80%	**α**=90%	**α**=100%
Avg. Lifetime	2811.2	3441.4	2307.4	2070.6	1986.1	959.3
Percentage Diff.		18.3%	-21.83%	-35.76%	-41.5%	-193%

4.2.2. Average lifetime using Poisson distribution for α > β

Fig.4.7 and Fig.4.8 show the results of applying ERPMT in Poisson distribution for OML and CMAX respectively. As in Uniform case, the lifetime decreases until it reaches its lowest values in case of α= 100% which is equal to single hop transmission in that each node is responsible of sending its own data.

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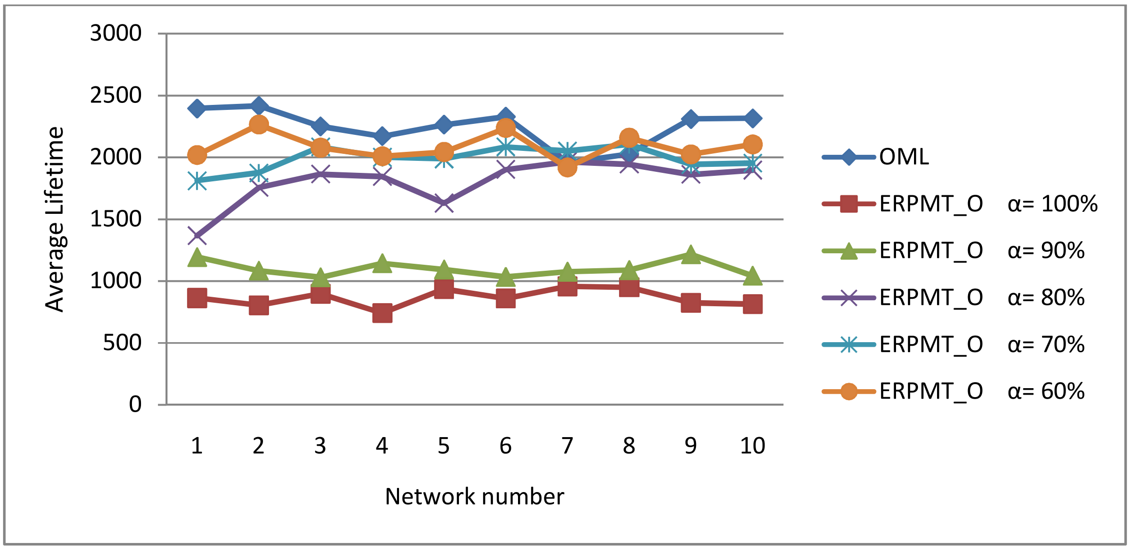

Figure 4.7: Average lifetime routing for OML and ERPMT_O (α > β) using Poisson distribution

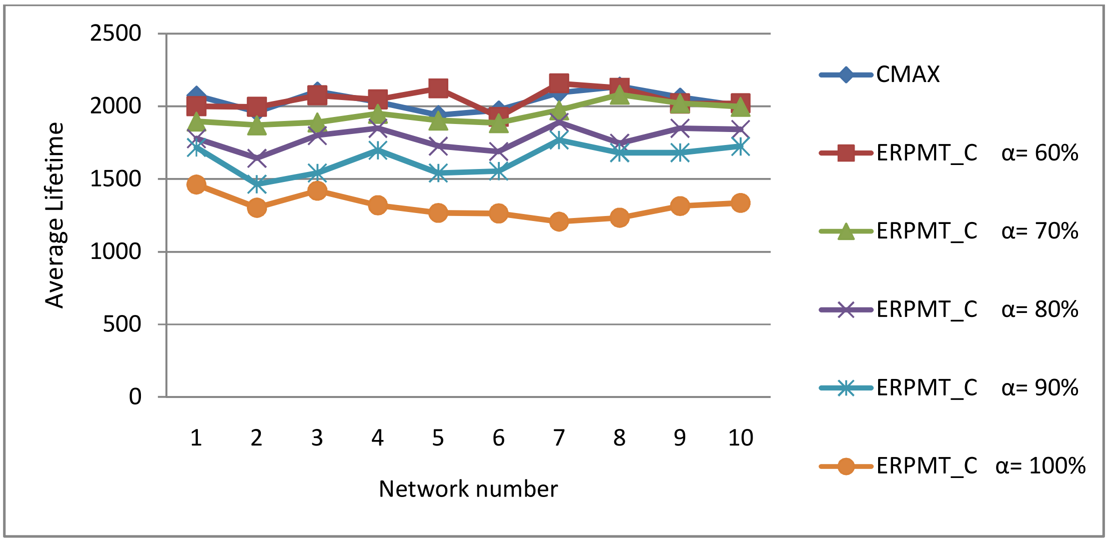

Figure 4.8: Average lifetime routing for CMAX and ERPMT_C (α > β) using Poisson distribution

Table 4.4 shows the percentage difference in ERPMT_O with different α values, all cases cause reduction in OML performance, but as we noticed that the reduction is less than that of Uniform distribution cases. Also, there is no improvement in case of α=60%.

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Table 4.4: Percentage difference between OML and different cases of ERPMT (α > β) using Poisson distribution.

Technique used	OML	ERPMT_O				
		α=60%	α=70%	α=80%	α=90%	α=100%
Avg. Lifetime	2242.4	2083.9	1988.9	1802.7	1099.1	863.2
Percentage Diff.		-7.6%	-12.7%	-24.39%	-104%	-159.7%

4.3. Effect of Network size on network lifetime

As the number of sensors increases, the lifetime of the network increases. These results were shown previously by Park and Sahni, (2006), and in our experiments. Fig.4.9 shows the lifetime of the network for different number of nodes in case of OML in Uniform distribution using the power management technique in case of α= 50% of total energy. It can be noticed that as the number of nodes increases the lifetime also increases. Our experiments in all cases give the same result. Our interpretation to this result is that by increasing the number of nodes there is an increased opportunity for the nodes to find a path and send their data through. As a result, the lifetime increased.

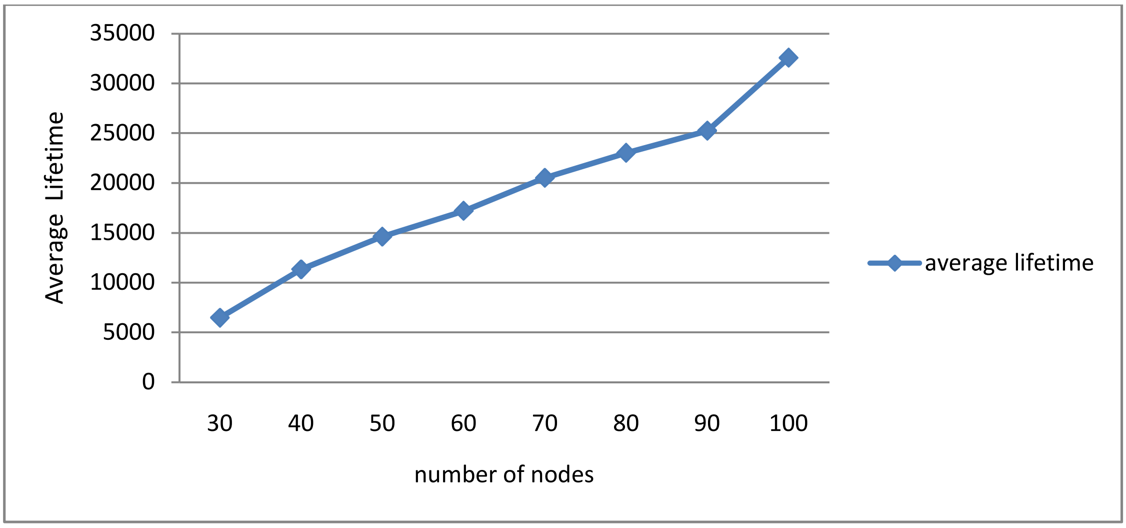

Figure 4.9: Average lifetime for ERPMT_O with different number of sensor nodes using Poisson distribution (α= 50% of total energy)

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4.4. Effect of changing the representation from 1D to 3D

As we showed in our previous study by Al-Sharaeh, et al. (2008), that changing the representation for sensors in the network from 1D to 3D gives us a better description of the real environment for the kind of deployment where sensors are floating in space, such as Tsunami prediction applications. The results were higher lifetimes but with the same relation between OML and CMAX. We found that the lifetime in case of Poisson distribution was higher than in case of Uniform distribution; that is because the majority of nodes are close to each other and more paths could be found.

Similarly here when we change the representation from 1D to 3D and repeat our experiments the results we got agree with what discussed previously by Al-Sharaeh, et al. (2008), The following figures show the results obtained.

Figure 4.10 is for a comparison between ERPMT_O with **α=50%** using Uniform distribution in 1D and 3D. Figure 4.11 is the same but in Poisson distribution.

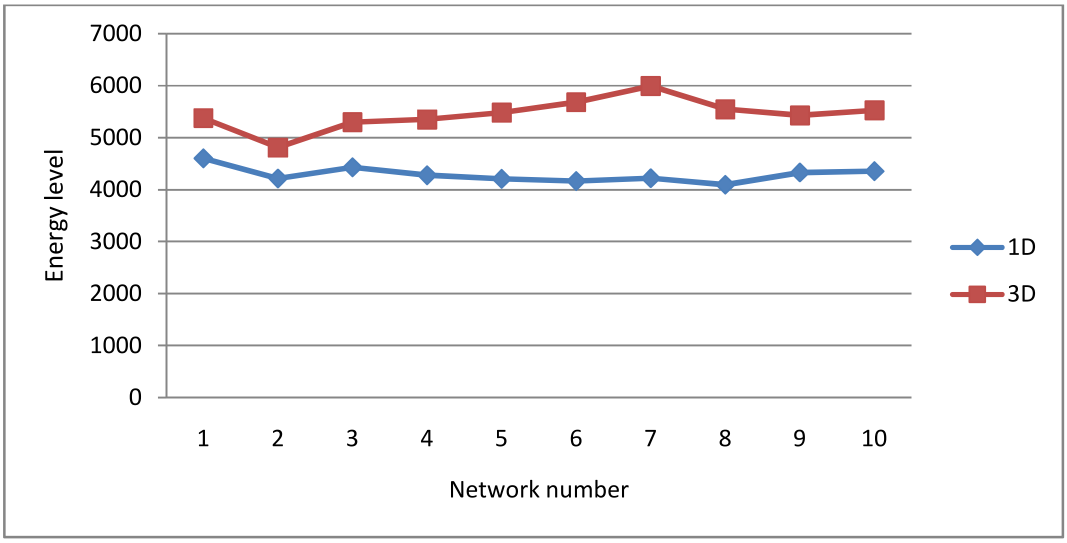

Figure 4.10: Comparison between Average lifetime for ERPMT_O with **α=50%** routing using 1D and 3D Uniform Distribution.

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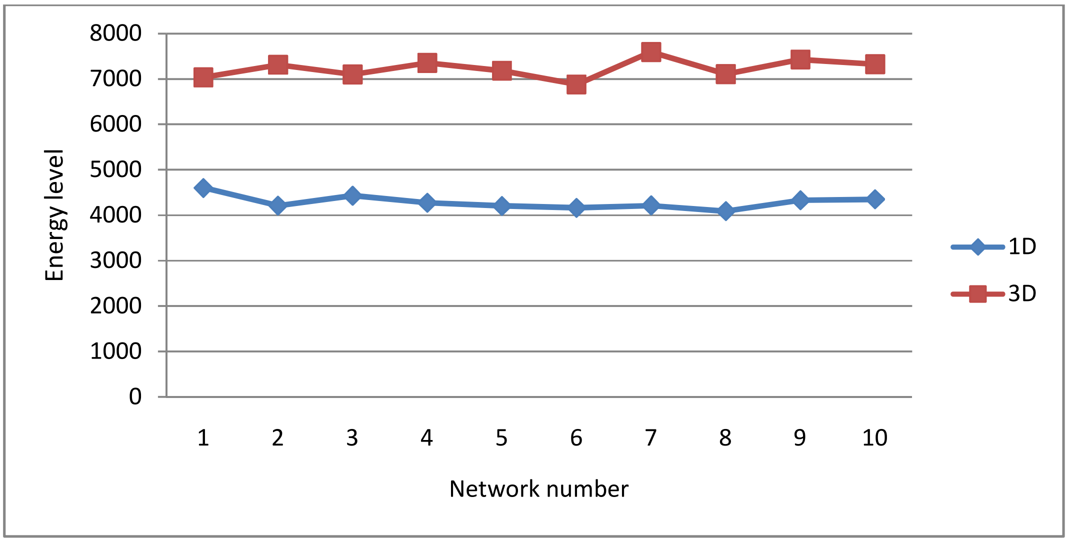

Figure 4.11: Comparison between Average lifetime for ERPMT_O with **α=50%** routing using 1D and 3D Poisson distribution.

Fig.4.12 shows a comparison between 3D OML in Poisson and Uniform distributions using power management (ERPMT_O with **α=50%**), in case of Poisson distribution the lifetime is higher than in the Uniform distribution which agrees with Al-Sharaeh, et al. (2008).

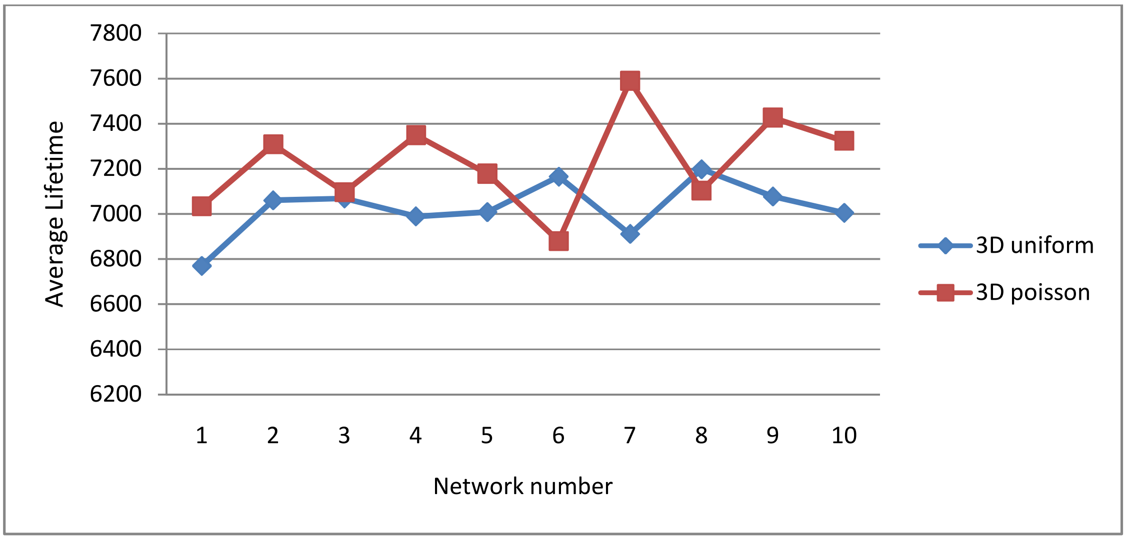

Figure 4.12: Comparison between Average lifetime for ERPMT_O with **α=50%** routing using 1D and 3D Poisson distribution.

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4.5. Effect of power management on energy expenditure and network coverage

Fig.4.13 shows the energy expenditure in joules for OML in different cases: without using power management (OML), ERPMT_O with equal ratios for α and β, ERPMT_O with α ≤ β, and ERPMT_O with α > β. We interpret this result by that when α > β this means that we tend more to single hop transmission which expends more power. But in case of α ≤ β the expenditure is approximately the same and are close to the case of OML without using power management.

Previous researches attributed the higher lifetimes they gained to the fact that their proposed heuristics or techniques use less power. in ERPMT this is not the case, we still expend power equal to what expended in the others, so our expectations is that the lifetime is higher because we do a power management that is; the power expenditure is distributed fairly among all nodes in the network and not concentrated on just some of them as other techniques do. Although the expenditure is the same, we gain higher lifetimes.

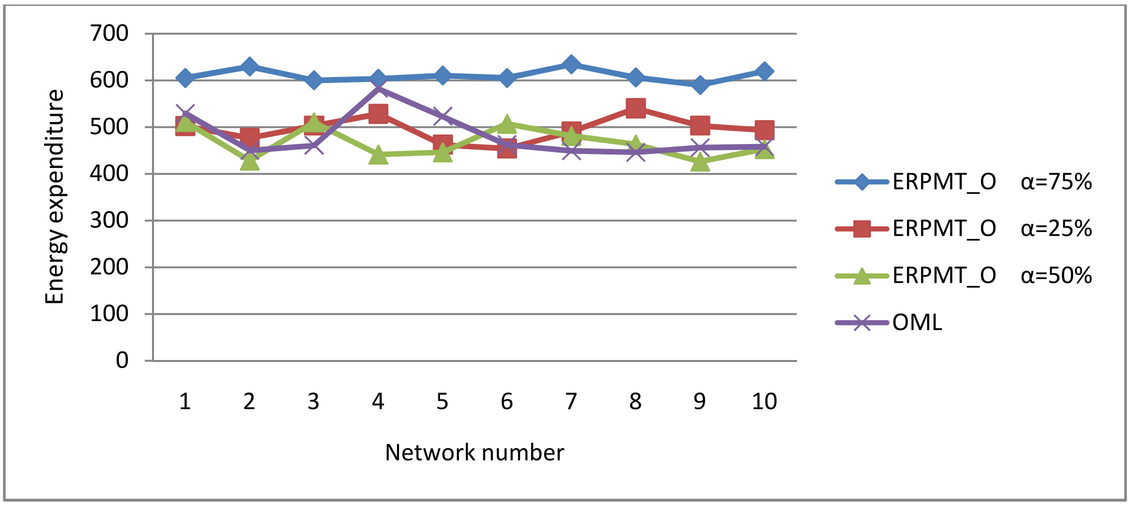

Figure 4.13: Comparison between Power expenditure for OML routing using Poisson distribution and ERPMT_O in different cases.

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Along with higher lifetimes we gained, the coverage of the network is preserved as much as possible for the same reason as increased lifetime. Using power management technique has made the power expenditure in the network highly fair between the nodes. Every node has a ratio for itself and another one for others, no nodes will die because of frequently using it as a relay to the sink or other nodes. This will prevent formation of blind areas which cause loss of coverage in these areas and as a result, the data measured becomes unreliable.

To assure what discussed above, we have measured the energy levels in joules of the network nodes with and without applying ERPMT at the end of lifetime for each. Fig.4.14 shows the energy levels of the network nodes without using ERPMT technique. We found that they deviate from their average by 24.85% and they vary widely from each other, some of them still have high energy while others do not have energy adequate for sending (areas contain these nodes are blind). We note that the expenditure varies depending on the position of the node; nodes that are closer to the sink (1 hop distance) consume more power and as we go far from the sink (2 hops or more distance) the expenditure decreases. In our example, nodes 1, 6, 8, 11, and 17 are 1-hop far from the sink, so they consume more power than 2-hop distance nodes, such as node 9.

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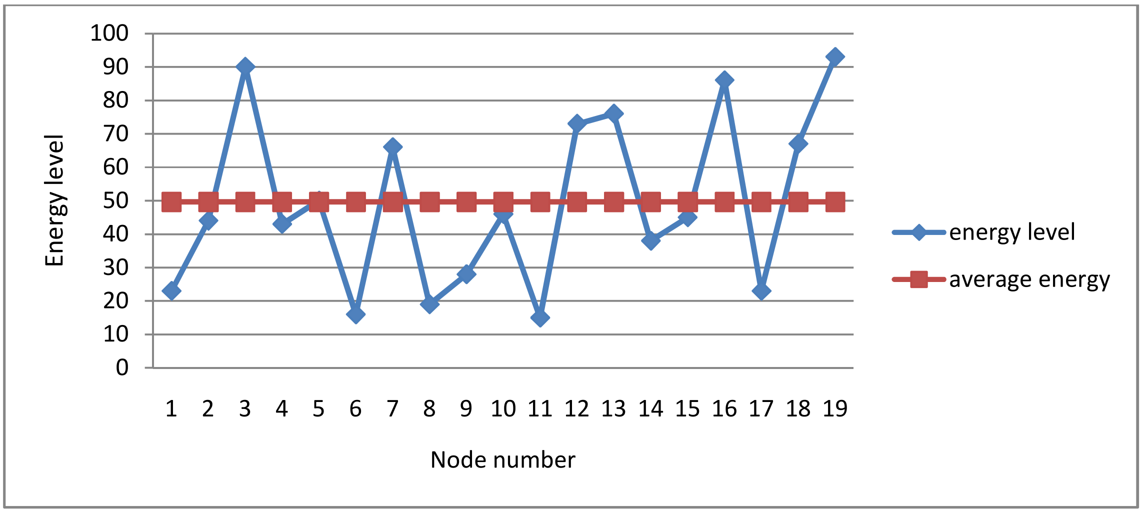

Figure 4.14: Comparison between energy levels for OML routing using Poisson distribution.

On contrast, Fig.4.15 shows the energy levels in joules when using ERPMT. The energy levels here are close to each others and close to the mean of their energy levels; they only deviate by 8.43% from the mean, which means that the entire network is always covered. The energy consumption is distributed evenly on the nodes regardless of its position from the sink node.

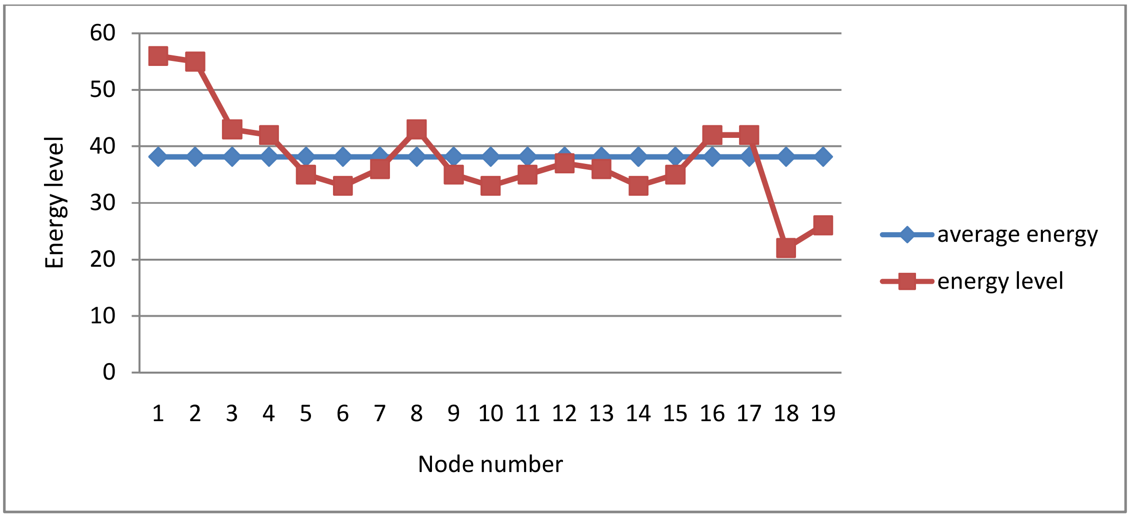

Figure 4.15: Comparison between energy levels for ERPMT_O routing based on Poisson distribution with α= 50%.

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5. Conclusion and Future Work

5.1. Conclusion

We present an efficient routing technique that maximize the lifetime and coverage of wireless sensor networks, which employs an efficient power management technique that works at the node level by dividing each sensor node energy into two ratios; the first is for sensor generated data and the other is for data relayed from other nodes.

The evaluation that results from our extensive runs shows that applying our technique, which called ERPMT (Efficient Routing Power Management Technique), results in up to 56.7% improvement on the existing heuristic lifetimes. This percentage improvement is obtained in the best case of ERPMT which is the case when α= 50%, that is, when the node energy is divided into two equal ratios. As we decrease α to a ratio less than 50%, the improvement will be reduced. However, it remains above the lifetime of OML or CMAX. Our results also show that increasing α to a ratio more than 50% will result in degradation of the network lifetime as well as increasing the power expenditure.

Energy expenditure measures we have done revealed that the increased lifetime does not come from reduced energy consumption, but it is the result of a well-organized one. The energy expenditure is fairly distributed among the nodes and not concentrated on some of them only. The power is used efficiently and in a correct way to increase every single node lifetime, which in turn will increase the overall network lifetime.

Increased coverage is obtained when applying ERPMT for the same reason as increased lifetime. The energy levels in the network nodes remain close to each other and they deviate only by 8.43% from the mean of the network nodes energy levels; no nodes will die because of unfair routes while others still have high levels of energy and continue

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the functioning of the network while some areas are not covered. So, partitions and blind areas are prevented. As a result, the whole area is covered and data collected along the lifetime of the network is reliable.

In ERPMT, changing the representation of the network sensors into 3D results in increased lifetime. And changing the distribution of sensors from Uniform to Poisson decreases the lifetime in case of 1D, but increases it in case of 3D; that is because the majority of nodes are close to each other and more paths could be found. These results concerns deployment is consistent with our previous studies by Al-Sharaeh, et al. (2008) in the same concern.

5.2. Future Work

In our future work, we will study the effect of changing the transmission radius (r_T) and the effect of physical location of the sink node on the network lifetime, energy expenditure, and on network coverage.

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Appendix A

To insure that the energy expenditure is distributed among network nodes evenly regardless of their distance from the sink node, we have measured energy levels of 1-hop, 2-hop nodes and compared them, the following table shows the Remaining energy levels for network nodes using OML and ERPMT_O:

Node no.	OML	ERPMT_O	ce_1	ce_2
1	81	43	19	24
2	33	51	21	30
3	17	46	21	25
4	34	39	30	9
5	49	56	32	24
6	24	38	18	20
7	57	42	19	23
8	76	43	24	19
9	30	51	34	23
10	49	43	22	21
11	19	37	26	11
12	20	43	19	24
13	85	46	23	23
14	41	48	21	27
15	56	53	30	23
16	34	49	24	25
17	84	44	23	21
18	49	43	19	24
19	27	40	18	22
Avg. remaining energy	45.5263	45	23	22

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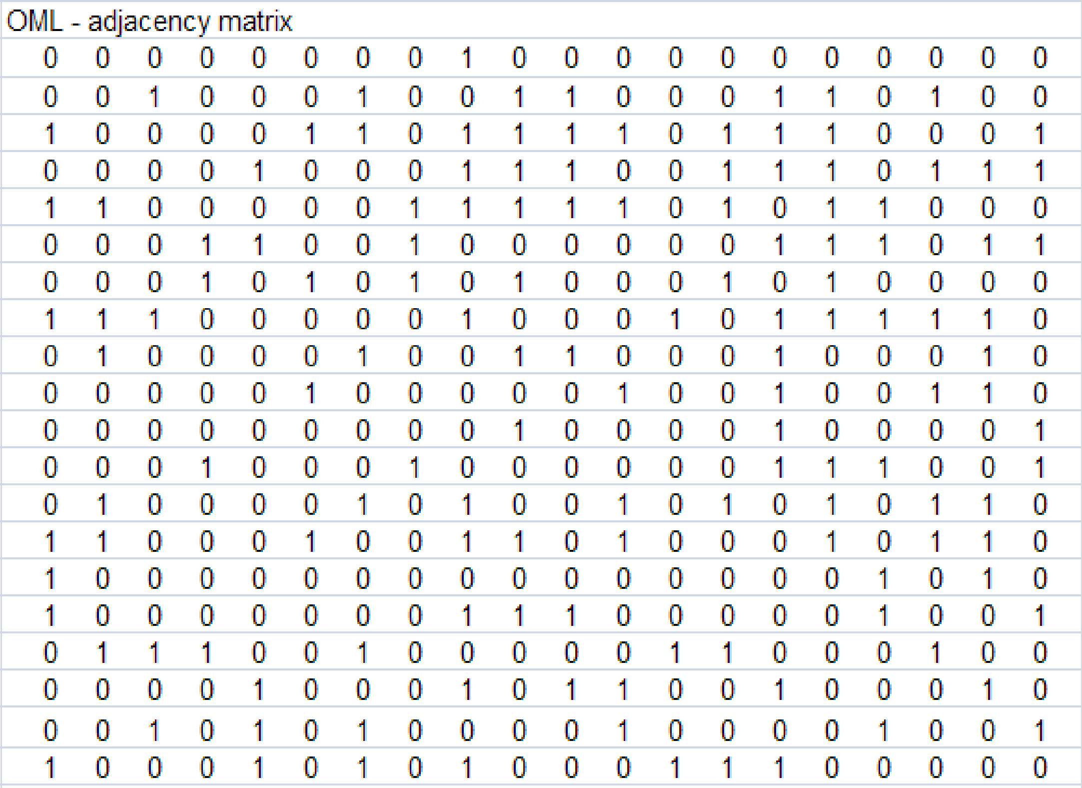
OML (Without ERPMT):

The adjacency matrix was as follows:



OML - adjacency matrix																			
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0	0	1	1	0	0	0	1	1	0	1	0	0
1	0	0	0	0	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1
0	0	0	0	1	0	0	0	1	1	1	0	0	1	1	1	0	1	1	1
1	1	0	0	0	0	0	1	1	1	1	1	0	1	0	1	1	0	0	0
0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	1	1	0	1	1
0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	0
1	1	1	0	0	0	0	0	1	0	0	0	1	0	1	1	1	1	1	0
0	1	0	0	0	0	1	0	0	1	1	0	0	0	1	0	0	0	1	0
0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	1	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1
0	1	0	0	0	0	1	0	1	0	0	1	0	1	0	1	0	1	1	0
1	1	0	0	0	1	0	0	1	1	0	1	0	0	0	1	0	1	1	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	0	0	1
0	1	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0
0	0	0	0	1	0	0	0	1	0	1	1	0	0	1	0	0	0	1	0
0	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1
1	0	0	0	1	0	1	0	1	0	0	0	1	1	1	0	0	0	0	0

From the above adjacency matrix, we found 1-hop and 2-hop nodes, and compute the average energy levels for both of them, shown in the following table :

	avg. remaining energy
1-hop nodes (3,4,6,11,12,16,19)	25
2-hop nodes (2,5,7,8,9,10,13,14,17,18)	55.3
all nodes	45.5263

We note that 1-hop nodes deplete their energies faster than others.

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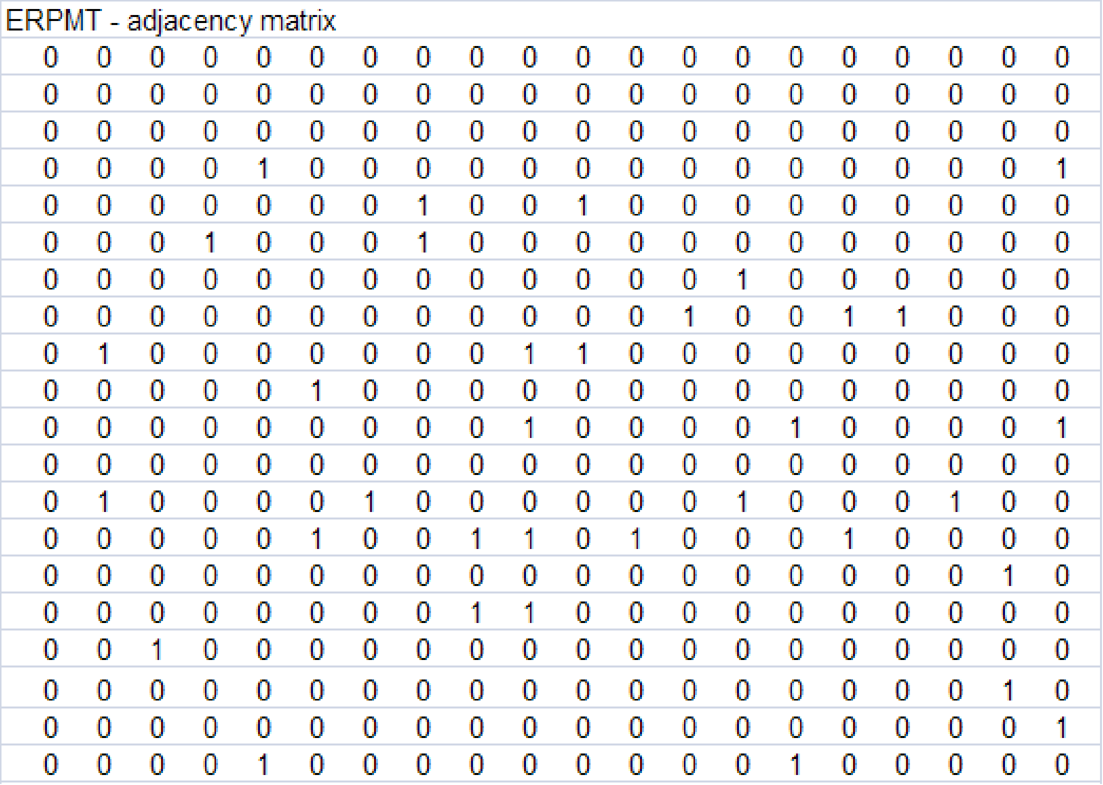
ERPMT:

The adjacency matrix was as follows:



ERPMT - adjacency matrix

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0
0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0
0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Energy levels are shown in the following table:

	Avg. rem. energy	Avg. rem. ce1	Avg. rem. ce2
1-hop(4,11,19)	38.6667	24.667	22.6
2-hop(5,6,9,15,18)	48.2	14	19.4
all	45	23	22

The same expenditure for all nodes approximately, there is no big difference between energy expenditure for 1-hop nodes and 2-hop nodes.

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تقنية توجيه فعالة تطيل عمر وتغطية شبكات الاستشعار اللاسلكية

إعداد

ريما حسني محمد حسن

المشرف

الدكتور صالح الشرايعة

الملخص

أصبحت شبكات الاستشعار اللاسلكية تحظى بشعبية كبيرة في السنوات القليلة الماضية.واحدة من القضايا الرئيسية في هذه الشبكات هي محدودية قدرة البطارية.لذلك فانه من المهم تطوير حلول فعالة لاستخدام الطاقة للحفاظ على سير عمل هذه الشبكات لأطول وقت ممكن.

معظم طاقة العقد تنفق على نقل البيانات، لذلك تم اقتراح العديد من تقنيات التوجيه لاطالة عمر الشبكة مثل تقنية الحد الاقصى لمدى الحياة (OML) وتقنية تعظيم قدرة البطارية (CMAX)، و قد حصلت OML على افضل النتائج فيما يتعلق باطالة عمر الشبكة اللاسلكية.

المشكلة الرئيسية في معظم التقنيات المقترحة هي انها تقوم بايجاد الطريق ذو الطاقة الدنيا و تستخدمه لكل اتصال مما يؤدي الى استنزاف طاقة العقد على طول هذا الطريق خاصة العقد القريبة من مصب البيانات و التي ستحمل المزيد من حركة البيانات مما يؤدي الى تقسيم الشبكة و تكوين المناطق العمياء وهي التي لا يمكن ان تشعر بها اي عقدة ونتيجة لذلك فان البيانات المجموعة تصبح غير موثوقة.

في هذه الرسالة نقدم تقنية جديدة للحصول على عمر و تغطية اعلى للشبكة عن طريق ادارة الطاقة على مستوى العقدة عن طريق تقسيم طاقة العقدة الى قسمين : الاول لنقل للبيانات التي تنشأ من العقدة نفسها(α)،و الآخر لتوصيل البيانات من العقد الأخرى(β).هذه التقنية ،و التي تدعى (تقنية فعالة للتوجيه و ادارة الطاقة)، قد طبقت على OML و CMAX للحصول على النسخ المعدلة منها و التي هي ERPMT_O وERPMT_C على الترتيب بهدف دراسة اثر ذلك على عمر الشبكة، الطاقة المستهلكة، و التغطية.

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علاوة على ذلك ، أخذنا في الاعتبار تباين التضاريس ودرسنا تأثيرها على مسار التقنيات الموجودة مثل (OML ، وكذلك ERPMT_O وERPMT_C). لمحاكاة تباين التضاريس استخدمنا نوعين من التوزيعات (الموحدة وبواسون) لتمثيل الشبكة بواسطة الرسم البياني الموجه .

النتائج التي تم التوصل اليها من خلال اجراء تجارب مكثفة كشفت تفوق كلا التقنيتان المقترحتان على التقنيات الموجودة. فقد حسنتERPMT عمر الشبكة بنسبة ٥٦,٧ % في افضل حال و هو عندما تكون α تساوي ٥٠% من الطاقة الكلية. كذلك فانه تم منع تكون المناطق العمياء و تم زيادة تغطية الشبكة كنتيجة للتوزيع العادل لمصروف الطاقة . حيث ان مصروف الطاقة لا زال مساوي لل OML،و لكنه في حال التقنية التي توصلنا لها يكون اكثر تنظيما و موزع بشكل عادل أكثر . حيث ان مستويات الطاقة تتحرف فقط بمقدار ٨.٤٣% عن متوسط الطاقة في الشبكة كاملة.و هذا على العكس من حالة عدم استخدام ERPMT حيث ان الانحراف يصل الى ٢٤,٨٥%. وهكذا، فانه عن طريق الجمع بين تقنية توجيه فعالة و تقنيتنا الجديدة لادارة استخدام الطاقة حصلنا على تقنية توجيه وادارة طاقة فعالة لاطالة عمر و تغطية الشبكات اللاسلكية.

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