Stable Election Protocol for Three Dimensional Clustered Heterogeneous Wireless Sensor Network

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Abstract - Stable Election Protocol (SEP) is one of the first protocol which introduce the heterogeneous phenomena in the wireless sensor network. It's based on clustering strategy in the goal to optimize the lifetime of the network. However, the authors are considered that the deployment of nodes is done in Two-Dimensional (2D) environment within reason to simplify the calculation analysis. Unfortunately, this approximation influence greatly in the formation of the clusters as it was based on the distance between nodes. Thus, it decreases the performance of the network as the lifetime and throughput parameters. In this paper, we demonstrate that the Three-Dimensional (3D) architecture in SEP protocol is closer to reality than the 2D distribution.

Keywords: - Wireless sensor networks, SEP protocol, Energy-efficiency, 2D and 3D HWSN, Network lifetime.

1 Introduction

Recently, the development of the embedded system and wireless communication technologies have enabled the appearance of the tiny nodes called wireless sensor network WSN that are equipped with sensing unit, processing unit and communication unit [1]. All these units are generally powered with a simple battery which his replacement is usually impossible. These nodes are deployed in the large area in the goal to monitoring this field and send the detection event toward the base station. Energy consumption in this network is dissipated up in three essential functionalities of WSNs such as detection, data aggregation, and the communication. According to literature [2], this last operation consumes more energy compared to the others. Therefore, to prolong the lifetime of these nodes, the direct transmissions must be avoided [3]. To reduce long distance transmissions, the simple idea is to divide network into small regions of nodes called clusters which each of them is managed by one node named cluster head CH [4]. As it collects the data from member nodes and sends them toward base station or through other CHs by using multi-hop communication, its energy is depleted very quickly. Some researchers propose to select these CHs periodically while based on a threshold [5] [6] [7] [8]. All of these protocols and others assume that all nodes of the network have the same energy level. This means that the network is homogeneous. However, sensor nodes don't have the possibility to maintain energy in the same way during the cycles, the fact that they don't have the same position in the network [9]. This means that the network is heterogeneous. In this context, many searchers call for consider, first of all, that the network is heterogeneous in the goal to converge into the reality and minimize the estimations [10][11][12].

Generally, the HWSNs have many applications such as underwater sensor network, Ocean column monitoring, monitoring railway tunnels, and underground tunnels in the mine. In these applications, the nodes are deployed in three-dimensional environment (3D) which has been modeled by the searchers in two-dimensional space (2D). However, this assumption is invalid in the reality when the height of the network is no negligent [13].

In this paper, we applied the 3D architecture in Stable Election Protocol (SEP) [9] which is one of interesting protocol under heterogeneous environment and we show by computer simulation how this 2D approximation is not reasonable.

The rest of the paper organization is done as follows: Section II summarizes the related work. Problem Statement is provided in section III. Three-dimensional stable election protocol for wireless sensor network models has introduced in section IV. The Simulation results are carried out in section V. Finally we conclude our research work and give some perspectives in section VI.

2 Related Work

In the last years, the researchers focalize their ideas around the clustered heterogeneous WSN with the goal to prolong the lifetime of these tiny nodes. G. Smaragdakis et al. have proposed Stable Election Protocol for clustered heterogeneous wireless sensor networks (SEP) [9] to stabilize in the most, the heterogeneous two-level hierarchical network by choosing each node her own election probability. M. Baghouri et al. have improving this protocol by using the fuzzy logic approach by computing the choice that each node to become cluster head [14]. SEP-FL is based on two criteria: the distance from the base station and the residual energy level of each node type. The SEP-FL increases the stability period and decreases the instability of the sensor network as compared with LEACH (Low Energy Adaptive Clustering Hierarchy) and SEP. This protocol provides longer interval of stability for large values of additional energy brought by advanced nodes. M. Baghouri et al. prove by simulation that 2D environment approximation is not valid in the some applications [15]. They compared 3D architecture in LEACH protocol with 2D and show that the lifetime and throughput of the network decrease considerably witch can't neglect them in the some applications. Xi Zhang et al. [16] have described mechanism of three dimensional clustering to maximize the lifetime of network by considering the minimum coverage rate constraint. This paper proposed new protocol by enhancing the LEACH protocol using the basic assumption of SEP protocol in which advanced nodes have more energy than initial node. Attarzadehet al. [17] have describe the method of clustering called three dimensional clustering which resolve the restriction of two dimensional clustering by providing the different surface for review space. This paper define the three different levels, first for sink node which is at highest point, second level is first cluster heads and third level is for different number of nodes which are active. This method is used to achieve better performance of network. Sensor coverage is a primary design factor considered for wireless sensor network deployments. 2D ideal plane (X. Bai et al, S. Kumar et al) [18] [19] or 3D full space models (C. F. Huang et al, M. Watfa et al) [20] [21] is considered. A recent study described presented by (Linghe Kong et al.) [22] proves that the coverage of sensor networks in practical environments is a 3D complex space and short comings of the existent sensor coverage models are clearly described. In this paper, the authors cite the Tungurahua volcano monitoring project and define the Coverage Dead Zone problem that exists by adopting 2D surface coverage model for 3D sensor networks or ideal sensor network deployments. In addition to the coverage dead zone, non-existent links are also established.

Based on the analysis above, we find that few works on 3D deployment have been studied for HWSNs. Driven by this observation; we will show by simulation that these assumptions and approximations to 2D surface are not reasonable in some applications of HWSN.

3 Problem Statement

Let us consider a set of 20 nodes deployed randomly in the 3D space shown in Figure 1. According to the clustering-based topology, each CH aggregated the data from the member nodes and then transmits them to the base station via a multi-hop communication. Let us consider likewise a set of same nodes deployed in 2D environment figure 2. The nodes undergo the same process of electing the cluster heads than the 3D terrain. By analysis of these figures, we remark that some nodes which are attached with one cluster head in 3D space, are join other cluster head in 2D environment. Indeed, node number 16 join cluster head number 12 in 3D architecture, however, it join cluster head number 2 in the 2D environment.

To clearly understand this error, let us calculated the distance between these two nodes to their cluster heads in the different case of deployment:

In case of 3D environment:

$$d_{16-12} = \sqrt{\begin{array}{c}(60.6951+39.5642)^2+(94.1067+33.5918)^2 \\ +(78.6517-61.9229)^2\end{array}} \quad (1)$$

$$d_{16-12} = 163.2136 \quad (2)$$

$$d_{16-2} = \sqrt{\begin{array}{c}(-60.6951+0.8480)^2+(-94.1067+79.4774)^2 \\ +(78.6517+97.3745)^2\end{array}} \quad (3)$$

$$d_{16-2} = 186.4964 \quad (4)$$

In case of 2D environment:

$$d_{16-12} = \sqrt{(60.6951+39.5642)^2+(94.1067+33.5918)^2} \quad (5)$$

$$d_{16-12} = 162.3540 \quad (6)$$

$$d_{16-2} = \sqrt{(-60.6951+0.8480)^2+(-94.1067+79.4774)^2} \quad (7)$$

$$d_{16-2} = 61.6092 \quad (8)$$

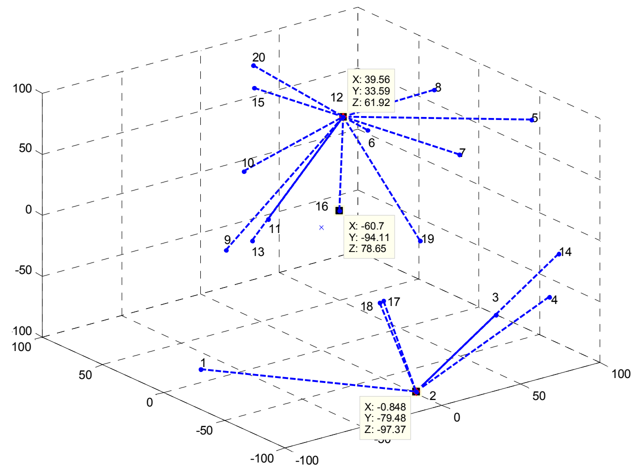

Figure 1: Three-dimensional Wireless Sensor Network model

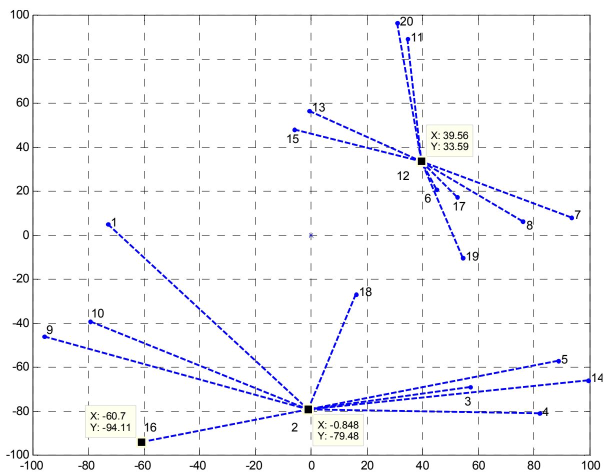

Figure 2: Two-dimensional Wireless Sensor Network model with same configuration

From this example, it is clear that node number 16 attached to the cluster head number 12 in the 3D environment and chooses the cluster head number 2 in the 2D architecture.

Therefore it is difficult to model the network in 2D environment because a node attached with a cluster in 3D space will not necessarily be tied with the same cluster in 2D architecture since the distance is not the same.

Generally, the fact that the distance between the nodes is not properly calculated accurately, influence on the clusters formation in the network and consequently it leads to a bad clustering and therefore a bad energy consumption management.

In this paper, we demonstrate by simulation that the modeling of the network by 2D environment is not realistic. Indeed we applied the 3D model in SEP and we show that this model is more stable than the 2D model.

4 Three-dimensional Stable Election Protocol for Wireless Sensor Network Models

5.1. Network Model

This section describes the network model and other basic assumptions:

1. N sensors are uniformly distributed within a square 3D rectangular field of area $A = M \times M \times M$. The Base Station is positioned at the center of the square region. The number of sensor nodes N to be deployed depends specifically on the application.

2. All nodes are deployed randomly.

3. Each sensor can sense the environment in the 3D sphere of radius r.

4. All sensors are homogeneous, i.e., they have the same capacities.

5. All the sensor nodes have a particular identifier (ID) allocated to them. Each cluster head coordinates the MAC and routing of packets within their clusters. (see Figure 2)

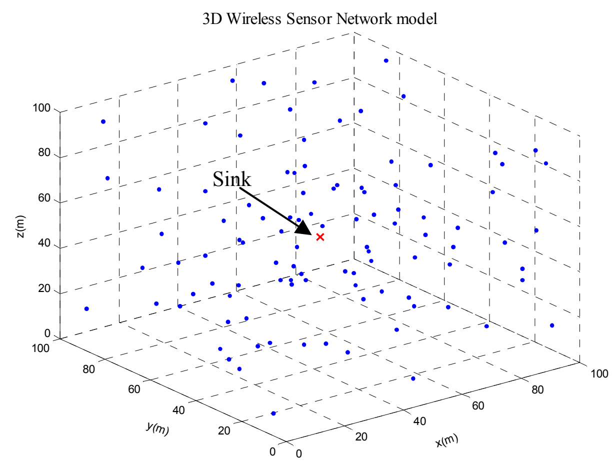

Figure 3: Three-dimensional Wireless Sensor Network model

5.2. Energy Model

This study assumes a simple model for the radio hardware where the transmitter dissipates energy for running the radio electronics to transmit and amplify the signals, and the receiver runs the radio electronics for reception of signals [7]. Multipath fading model (d^4 power loss) for large distance transmissions and the free space model (d^2power loss) for proximal transmissions are considered. Thus to transmit an $l-$bits message over a distance d, the radio expends:

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d) \quad (9)$$

$$E_{Tx-elec}(l) = lE_{elec} \quad (10)$$

$$E_{Tx-amp}(l,d) = \begin{cases} l\epsilon_{fs}d^2, when\ d < d_0 \\ l\epsilon_{mp}d^4, when\ d \geq d_0 \end{cases} \tag{11}$$

Where d_o is the distance threshold for swapping amplification models, which can be calculated as $d_o = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}$

To receive an $l\ bits$ message the receiver expends:

$$E_{Rx}(l) = lE_{elec} \tag{12}$$

To aggregate n data signals of length $\mathrm{l-bits}$, the energy consumption was calculated as:

$$E_{DA-expend}(l) = lnE_{DA} \tag{13}$$

5.3. Optimal number of cluster

We assume there are N nodes distributed uniformly in $M \times M \times M$ 3D region. If there are c clusters, there are on average N/c nodes per cluster. Each cluster-head dissipates energy receiving signals from the nodes and transmitting the aggregate signal to the base station. Therefore, the energy dissipated in the cluster-head node during a single frame is:

$$E_{CH} = l\frac{N}{c}E_{elec} + l\frac{N}{c}E_{DA} + l\epsilon_{mp}d_{toBS}^4 \tag{14}$$

Where l the number of bits in each data message is, d_{toBS} is the distance from the cluster head node to the BS, and we have assumed perfect data aggregation E_{DA}.

The expression for the energy spends by a non-cluster head is given by:

$$E_{nonCH} = lE_{elec} + l\epsilon_{fs}d_{toCH}^2 \tag{15}$$

Where d_{toCH} is the distance from the node to the cluster head.

Let $\mathrm{E[d_{toBS}]}$ be the Expected distance of cluster head from the base station. Assuming that the nodes are uniformly distributed, so it is calculated as follows:

$$E[d_{toBS}^2] = \int_0^{x_{max}}\int_0^{y_{max}}\int_0^{z_{max}} (x^2+y^2+z^2)\,f(x,y,z)dxdydz \tag{16}$$

Where $\mathrm{f(x,y,z)}$ is the probability density function of three dimensions random variable $X(x,y,z)$ which is uniform and given by:

$$f = \frac{1}{V_T} = \frac{1}{M^3} \tag{17}$$

If we assume that base station is the center of the network we can passing in the spherical coordinates:

$$E[d_{toBS}^2] = \int_0^{r_{max}}\int_0^{\pi}\int_0^{2\pi} r^2 f(r,\theta,\varphi)r^2\sin\theta\,drd\theta d\varphi \tag{18}$$

The area of network is aspheric with radius $r_{max} = M \times \sqrt[3]{3/4\pi}$.

If the density of sensor nodes is uniform throughout the area then becomes independent of r, θ and φ then:

$$E[d_{toBS}^2] = \frac{3}{10}\left(\frac{3}{4\pi}\right)^{\frac{2}{3}} M^2 = 0.5312M^2 \tag{19}$$

The expected squared distance from the nodes to the cluster head (assumed to be at the center of mass of the cluster) is given by:

$$E[d_{toCH}^2] = \int_0^{r_{max}}\int_0^{\pi}\int_0^{2\pi} r^2 f(r,\theta,\varphi)r^2\sin\theta\,drd\theta d\varphi \tag{20}$$

If we assume this area is a sphere with radius $r_{max} = M \times \sqrt[3]{3/4\pi c}$ and $f(r,\theta,\varphi)$ is constant for r, θ and , (10) simplifies to:

$$E[d_{toCH}^2] = f\int_0^{M\times\sqrt[3]{3/4\pi c}}\int_0^{\pi}\int_0^{2\pi} r^3\sin\theta\,drd\theta d\varphi \tag{21}$$

If the density of nodes is uniform throughout the cluster area, then $f = c/M^3$ and

$$E[d_{toCH}^2] = \frac{3}{10}M^2\left(\frac{3}{4\pi c}\right)^{\frac{2}{3}} \tag{22}$$

Therefore, the total energy dissipated in the network per round, E_{Total} , is expressed by:

$$E_{Total} = cE_{cluster} \tag{23}$$

Where $E_{cluster}$ the energy is dissipated in cluster which giving by:

$$E_{Cluster} = E_{CH} + \left(\frac{N}{c} - 1\right)E_{nonCH} \approx E_{CH} + \frac{N}{c}E_{nonCH} \tag{24}$$

This can be calculated by:

$$\begin{aligned} E_{Cluster} = l\left(\frac{N}{c}E_{elec} + \frac{N}{c}E_{DA} + \epsilon_{mp}d_{toBS}^4\right) \\ + l\left(\frac{N}{c}E_{elec} + \frac{N}{c}\epsilon_{fs}d_{toCH}^2\right) \end{aligned} \tag{25}$$

Therefore, the total energy dissipated in the network is simplified by:

$$\begin{aligned} E_{Total} = l\Bigg(2NE_{elec} + NE_{DA} + c\epsilon_{mp}d_{toBS}^4 \\ + N\epsilon_{fs}\frac{3}{10}M^2\left(\frac{3}{4\pi c}\right)^{\frac{2}{3}}\Bigg) \end{aligned} \tag{26}$$

We can find the optimum number of clusters by setting the derivative of E_{Total} with respect to c to zero

$$\frac{\partial E_{Total}}{\partial c} = 0 \tag{27}$$

$$C_{opt} = 0.2147 \times \left(N\frac{\epsilon_{fs}}{\epsilon_{mp}}\frac{M^2}{d_{toBS}^4}\right)^{\frac{3}{5}} \tag{28}$$

The optimal probability for becoming a cluster-head can also be computed as:

$$P_{opt} = \frac{C_{opt}}{N} \tag{29}$$

5.4. Three-dimensional SEP:

As SEP, in three-dimensional Stable Election Protocol the nodes are divided into two type's normal nodes and advanced nodes which have more energy than the normal nodes. In this network the CHs are formed based on the probability.

Every node decides whether to become CH in the current round. A random number is selected between 0-1 and if this value is less than the threshold $T(i)$ for a node i then that is selected as a CH.

Where:

$$T(i) = \begin{cases} \dfrac{P_{opt}}{1 - P_{opt}\left(r \times mod\left(\frac{1}{P_{opt}}\right)\right)} & if\ i \in G \\ 0 & otherwise \end{cases} \tag{30}$$

Where, G is the set of nodes that not been CH

Probability for advanced nodes to become CH is

$$P_{adv} = \frac{P_{opt}}{1 + \alpha \times m}(1 + \alpha) \tag{31}$$

Where α and m are the heterogeneity factors.

Then threshold for advanced nodes

$$T_{adv}(i) = \begin{cases} \dfrac{P_{adv}}{1 - P_{adv}\left(r \times mod\left(\frac{1}{P_{adv}}\right)\right)} & if\ i \in G \\ 0 & otherwise \end{cases} \tag{32}$$

Probability for normal nodes is

$$P_{nrm} = \frac{P_{opt}}{1 + \alpha \times m} \tag{33}$$

Then threshold for normal nodes

$$T_{nrm}(i) = \begin{cases} \dfrac{P_{nrm}}{1 - P_{nrm}\left(r \times mod\left(\frac{1}{P_{nrm}}\right)\right)} & if\ i \in G \\ 0 & otherwise \end{cases} \tag{34}$$

After the CH head is formed the CH sends an advertisement message to its member nodes so the nodes come to know to which CH they belong to. CH then assigns a TDMA Scheduling. So every node sends data to the CH in the slot assigned to it.

When the data is received the cluster head aggregates this data and send it to the base station this phase is the transmission phase.

5 Simulation results

5.1. Parameter settings

In this section, we study the performance of SEP 3D protocol under different scenarios using MATLAB. We consider a model illustrate in the figure 3 with $\mathrm{N} = 100$ nodes randomly and uniformly distributed in a $100m \times 100m \times 100m$ field. To compare the performance of SEP 3D with SEP 2D protocol, we ignore the effect caused by signal collision and interference in the wireless channel. The radio parameters used in our simulations are shown in Table1.

TABLE I
ENERGY MODEL PARAMETERS

Parameter	Value
Initial Node Energy	0.5J
N	100
P	0.05
$\mathrm{E_{elec}}$	50 nJ/bit
$\mathrm{E_{DA}}$	5 pJ/bit
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{mp}	0.0013 pJ/bit/m^4
$\mathrm{d_{toBS}}$	100 m
l	500 Bytes
Rounds	2000
α	2
m	0.1

5.2. Simulation metrics

Performance metrics used in the simulation study are:

- Energy consumption analysis
- Number of alive nodes per round.
- Percentage of Node death
- Throughput
- Decrease:

$$Decrease = \frac{Performance\ of\ SEP\ 3D - Performance\ of\ SEP\ 2D}{Performance\ of\ SEP\ 2D} \times 100 \tag{35}$$

5.3. Simulation results

5.3.1. Energy consumption analysis

The performance of SEP 3D is compared with that of the original SEP in terms of energy and is shown in Figure 4. With the use of 3D deployment of nodes, the energy consumption of the network is decreased. This is due to the gain of the energy dissipated by height of network. From the graph it is clear that SEP 3D decrease twice the energy savings than SEP protocol.

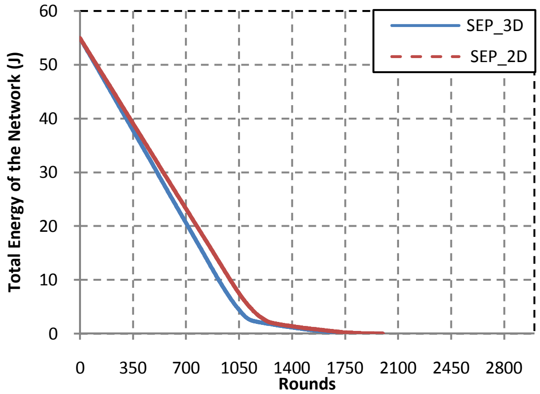

Figure 4: Energy analysis comparison of SEP 3D and SEP 2D.

5.3.2. Network lifetime

The number of nodes alive for each round of data transmission is observed for the SEP 2D and 3D protocols to evaluate the lifetime of the network. Figure 5 and Figure 6 show the performance of SEP 3D compared to SEP 2D. It is observed that the SEP 3D is less perform than SEP 2D due to energy dissipation of individual node throughout the network which depend essentially on the distance between nodes and sink.

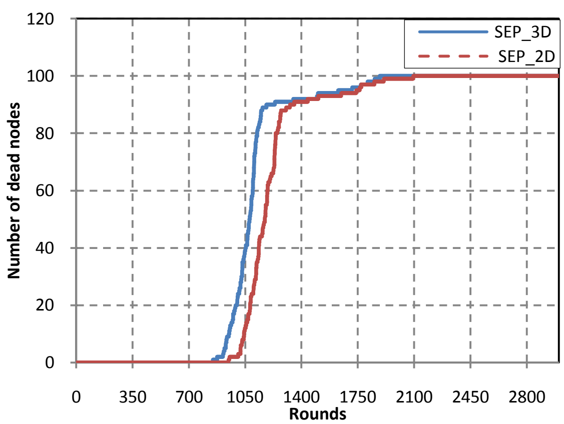

Figure 5: Number of dead nodes per round comparison of SEP 3D and SEP 2D.

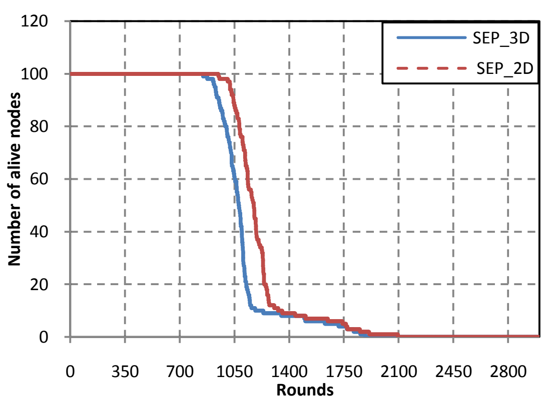

Figure 6: Number of alive nodes per round comparison of SEP 3D and SEP 2D.

5.3.3. Throughput

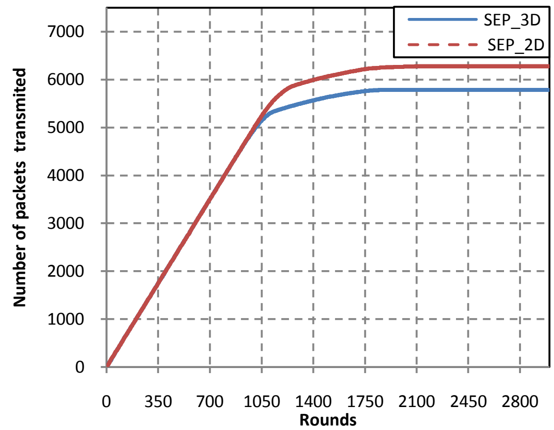

Figure 7: Throughput SEP 3D and SEP 2D comparison.

Referred to figure 7, it show clearly that SEP 3D provide a poor throughput compared to SEP 2D protocol, this decrease is justified by the low lifetime which give the three dimensional deployment of the nodes in the network.

5.3.4. Decrease

Generally, we can illustrate the decrease of the SEP 3D in the Figure 8. It's noted that the throughput decreases about 8% as much than SEP 2D due to its less energy. Whereas, SEP 3D outperforms the lifetime of SEP 2D by about 10%. In the other hand, SEP 3D consumes about 11% more energy than SEP 2D.

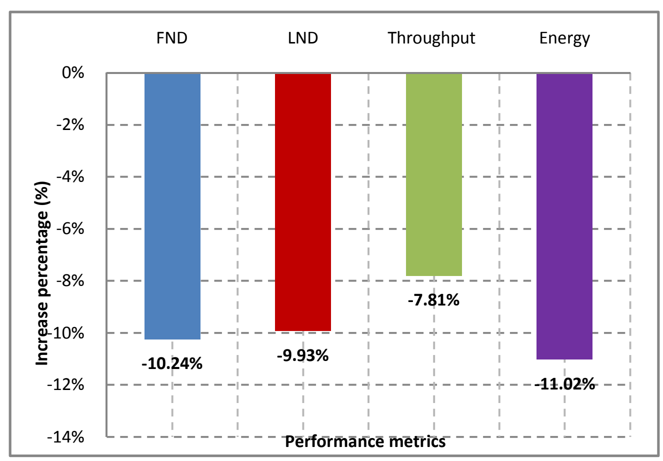

Figure 8: Decrease of SEP 3D compared to SEP 2D.

5.4. Result analysis

From our simulations, we observed that SEP 3D consumes more energy and delivers less packets to the base station. These results can be interpreted by the difference of distance between nodes in both situations which naturally causes by the random deployment of nodes.

5.5. Optimal value of heterogeneity parameters:

We increase the fraction m of the advanced nodes from 0.1 to 0.2 and a from 1 to 7. Figure 9 shows the performance parameters decrease between SEP 2D and SEP 3D. We observe that best value to approximate 3D-SEP to 2D-SEP is a=4 in the case that m=0.1 and a=5 in the case that m=0.2.

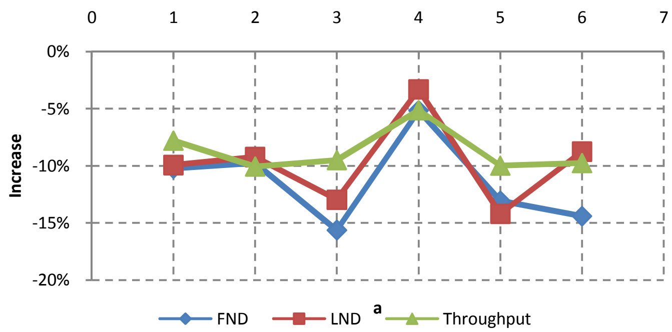

Figure 9: Decrease of SEP 3D compared to SEP 2D for m=0.1.

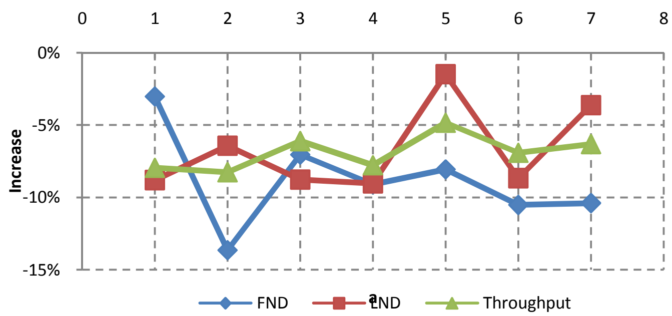

Figure 10: Decrease of SEP 3D compared to SEP 2D for m=0.2.

6 Conclusion and future work

In recently, 3D wireless sensor networks have known a great prevalent due to their large applications such as underwater, space communications, atmospheric, forest or building.

The analytic of 3D WSN is more complexity than the analytic in 2D WSN. Therefore, many researches project the 3D WSN in 2D WSN. In this paper, we demonstrate by simulation, that this approximation is not reasonable if the height of network is greater than length and breadth of this network.

We strongly believe that projection of WSN in 2D environment is unjustifiable in reason that the 3D WSN is much closer to our physical word.

As future work, we will work to optimize the energy consumption of this network, since the number of cluster head in 3D WSN gives more result than 2D WSN.

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