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Base Station Positioning for Wireless Sensor Networks (Optimal Location)

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ABSTRACT

The location of wireless sensor networks is of great importance in the process of node deployment and is a key factor in extending the life of network nodes. This paper provides the answer to the question of where the base station should be placed in a given wireless sensor network with the ultimate goal of conserving energy and at the same time improving the energy efficiency of the wireless network itself. Heuristic algorithms (these are algorithms that find approximate solutions among all possible solutions obtained) are proposed to locate such locations at base stations.

Keywords: base station, wireless, algorithm, energy.

1. INTRODUCTION

In the literature, quite a number of heuristic algorithms have been proposed so far to find optimal solutions [1] for positioning base stations in two-level wireless networks.
Although these heuristic algorithms have proven to be effective, they still depend on their topology and are based on structural parameters. Akkaya [2], has discussed various methods for finding the optimal position at a given base station.
They proposed a model with a set of sensors and a base station, then studied the situation with a maximum of two jumps in the network, and then expanded it to more jumps. Also, Pan, [3] considered only free space losses and found that the minimum closed-circuit gives maximum life for a sensor network.

LMID (likelihood maximum inscribed disk) was suggested for the optimal location of sensor networks by a group of authors.
It is an algorithm based on the ratio of distances from sensor networks to base stations using small locations where the optimal point for setting up a base station is selected.
Also, E. Arkin, J. Mitchell [4] proposed a CLP algorithm for the optimal location of a given base station to increase the life of a sensor network, and by performing simulation procedures they obtained relatively good results using a different number of sensors deployed in a sensor field at random.

The optimal location of a given base station can be analyzed in terms of power consumption or the maximum lifespan of the sensor network. Although the two things mentioned above have almost the same goal, in reality, it is not so.Pan proved in his paper that the center of the minimum closed circle is the optimal location for n of n lifetimes. n of n lifetime means the time after which the first node stops working, "dies" or the time until n of n nodes remain active (alive).

2RELATEDWORK

In the literature, quite several heuristic algorithms have been proposed so far to find optimal solutions [5] for positioning base stations in two-level wireless networks.

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Pan proved in his paper that the center of the minimum closed circle is the optimal location for n of n lifetimes. n of n lifetime means the time after which the first node stops working, "dies" or the time until n of n nodes remain active (alive).If we denote by (x,y) and $(x_{i,} y_{i,})$ the coordinates of a base station and the i-th sensor then the energy required for the i-th sensor to transmit data is:

$$E = E_0((x - x_i)^2 + (y - y_i)^2)^{\alpha/2}$$

(1)where $E_0$is a constant. The energy consumed by all active sensors is $E = \sum_{i \in A} E_{i,}$ where A is a set of active sensors. To minimize the total energy consumption, the base station should be placed at a certain location where this amount is the smallest, which means that the optimal location $(x_{0,} y_0)$ is $(x_{0,} y_0) = \underset{(x,y)}{argmin} E$Unfortunately, there is no closed solution for the above expression, therefore a solution should be found with an optimization method based on the following more active sensors, there are times when they are closer to the base station while the others are at a greater distance, so because of the distance they will consume more energy than other sensors and their battery will run out faster To avoid this problem, the transmission energy for most remote sensors in the network should be minimized, which will balance the energy consumption. This strategy will be equivalent to minimizing the maximum distance between the base station and each active sensor in the network [7]

$$(x_{0,} y_0) = \underset{(\infty,y)}{argmin}(\max_{\forall i \in N} \sqrt{(x - x_{i)}^2 + (y - y_{i)}^2}) \quad (2)$$

This is called the minimum closed circle where $(x_{0,} y_0)$ is the center of the closed circle. This approach is also known as the Minmax algorithm for optimal base station location, which provides maximum life for a static base station in a two-tier wireless sensor network.Lin [8] minimized the total distance from the sensor node to the base station to reduce the number of data transmitted and positioned the base station in a higher density zone $\sum_{i=1}^{n} w_i \cdot d_i$with the sensor knots. This is the point where the distance is minimized, with $d_i$being the distance between the sensor and the base station while w_i being the density of the sensors near sensor i.

2.1. Defining the Problem

The energy consumption in a given sensor network for one cycle is equal to the sum of the energy consumed by all clusters:

$$E_{round} = \sum_{i-1}^{K} E_{cluster}(i) \quad (3)$$

The energy consumed in a given cluster head is:

$$E_{CH} = l E_{elec}(\frac{n}{k} - 1) + l E_{EDA} \frac{n}{k} + l E_{elec} + l \epsilon_{mp} d^4{}_{toBS} (4)$$

where l is the number of bits in each data message, $d^4{}_{toBS}$is the distance from the cluster head node to the base station, assuming an ideal case for data collection.Each non-cluster master node only needs to transmit data to the master cluster once during one round [9].

Assuming that the distance to the main cluster is very small, then the energy consumption follows the Friss model of free space d^2 - power loss).

Let n-sensors be evenly distributed in a rectangular field of (x_1, y_1), (x_2, y_2),..., (xn,yn) respectively and one base station as shown above.

The Euclidean distance between the base station and the network nodes is d_1,$d_2 d_3$,..,d_n respectively.

In this case for $d_i$we have:

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}$$

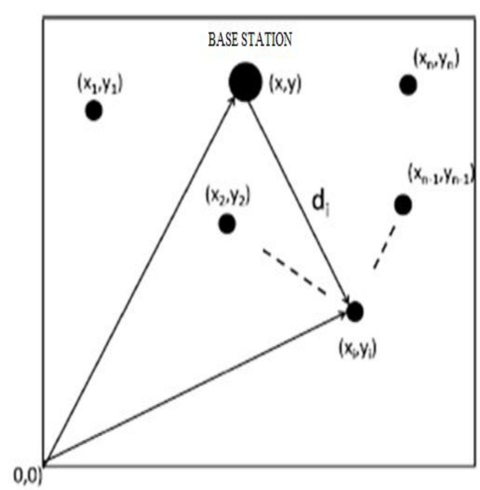

Figure.1. Wireless sensor network topology

Case 1:(d_i<d_0;∀i) Let d^2 be the sum of the squares of all the Euclidean distances reinforcement from all nodes:

$$E_{d^2}= L\epsilon_{fs}({d_1}^2 + {d_2}^2 + {d_3}^2 + \cdots {d_n}^2) \quad (5)$$

The sum of the squares of all Euclidean distances d^2will be the minimum at the center of the node, and the power consumption for amplification will also be minimal if the base station is located in that center (at that center of gravity).

Below we will explain mathematically how to get the minimum and maximum at a given proposed point

$$d^2 = {d_1}^2 + {d_2}^2 + {d_3}^2 + \cdots {d_n}^2$$

Combining the equations $d_i=\sqrt{(x - x_i)^2 + (y - y_i)^2}$and $E_{d^2}= L\epsilon_{fs}({d_1}^2 + {d_2}^2 + {d_3}^2 + \cdots {d_n}^2)$

We get

$$d^2 = \sum_{i=1}^{n}[(x - xi)^2 + (y - yi)^2] \quad (6)$$

$$d^2 = \sum_{i=1}^{n}[x^2 + {x_i}^2 - 2xx_i + y^2 + {y_i}^2 - 2yy_i] \quad (7)$$

If we expand the above amount we get

$$d^2 = n(x^2 + y^2) + \sum_{i=1}^{n}({x_i}^2 + {y_i}^2) - 2x\sum_{i=1}^{n}x_i - 2y\sum_{i=1}^{n}y_i \quad (8)$$

The following are the substitutions of the above expressions:

$$C_1 = \sum_{i=1}^{n}x_i \quad (9)$$

$$C_2 = \sum_{i=1}^{n}y_i \quad (10)$$

and

$$C_3 = \sum_{i=1}^{n}({x_i}^2 + {y_i}^2) \quad (11)$$

Using the $C_2 and\ C_3$relation (6) it gets the following shape

$$d^2 = n(x^2 + y^2) - 2xC_1 - 2yC_2 + C_3 \quad (12)$$

Now by differentiating (12) we will find the maximum and the minimum [(∂ (d^2)/∂x and (∂ (d^2)/∂y]

$$\frac{(\partial(\mathrm{d}^2)}{\partial \mathrm{x}}=2\mathrm{nx} - 2C_1=0 \quad (13)$$

Hence $x=\frac{C_1}{n}$

$$\frac{(\partial(d^2)}{\partial y} = 2ny - 2C_2 = 0 \quad (14)$$

$$y = \frac{C_2}{n} \quad (15)$$

$$\frac{\partial^2(d^2)}{\partial x^2}=\frac{\partial^2(d^2)}{\partial y^2}=2n (16)$$

Since ∂^2(d^2)/ ∂x^2 and ∂^2(d^2)/ $\partial y^2$are positive for all values of x and y, then (13), (14), (15) provide a minimum value of (5) ($d^2 = {d_1}^2 + {d_2}^2 + {d_3}^2 + \cdots {d_n}^2$)

We can now conclude that the sum of the squares of the distances from the point's n is minimized in the center of the given points

Case 2: (d_i>d_0;∀i) In the second case, the moment is analyzed when all nodes are very far from the base station and have only losses from multiple paths. In that case, it should be minimized

$$E_{d^4}= L\epsilon_{mp}({d_1}^4 + {d_2}^4 + {d_3}^4 + \cdots {d_n}^4) \quad (17)$$

Case 3 :(Some nodes with d_i<d_0 while the rest with d_i>=d_0.

When several nodes are close while the other nodes are further away from the base station then the following equation should be minimized:

$$E_{d^{2,4}}= L\epsilon_{fs}({d_1}^2 + {d_2}^2 + {d_3}^2 + \cdots {d_p}^2) + L\epsilon_{mp}({d_1}^4 + {d_2}^4 + {d_3}^4 + \cdots {d_q}^4) \quad (18)$$

where p + q = n and p, q> = 1Now minimizing $E_{d^{2,4}}$will depend on what types of nodes dominate power consumption, whether they are nearby nodes or a group of nodes farther from the base station.[10]If close nodes dominate which means p >> q, then the centroid of the n nodes will be the optimal position for the base station. In the case when q >> p, then the distant nodes will decide to determine the base station where the center of the q nodes (if q - nodes are symmetrically placed) will be the optimal position. In the case where both types of nodes dominate equally, then the optimal location of the base station can be determined by the proposed algorithm [11].

3. ALGORITHM FOR LOCATINGBASE STATIONS

Defining the problem:

The aim is to find the ideal location of the base station to minimize $E_{d^{2,4}}$ (11)

Step 1: Let be the point (C_x,C_y) of network nodes distributed in a given field. This is the point where E_d2is minimized and given by the following relations:

$$C_x = \frac{\sum_{i=1}^{n}xi}{n} \quad (19)$$

$$C_y = \frac{\sum_{i=1}^{n}yi}{n} \quad (20)$$

Step 2:

This is the step where you need to find the network nodes that are at least $d_0$away from the centroid.

Step 3:

Weights are calculated using a centroid for all nodes such as:

$$W_i = \begin{cases} 1 \\ \frac{d_{ic^2}}{d_{0^2}} \text{ако } d_{ic} < d_0 \text{ и } d_{ic} >= d_0 \end{cases} \quad (21)$$

Here d_{ic} is the distance between the i^{th} node and the centroid. The justification for the above mentioned weight is given in the following text.

3.1 CalculatingtheWeightsfortheProposed Algorithm

We take the weight as 1 for the nodes that are at least d_0-distance from the centroid and some other value for other nodes that are equal to or at a greater distance $d_0$from the centroid.

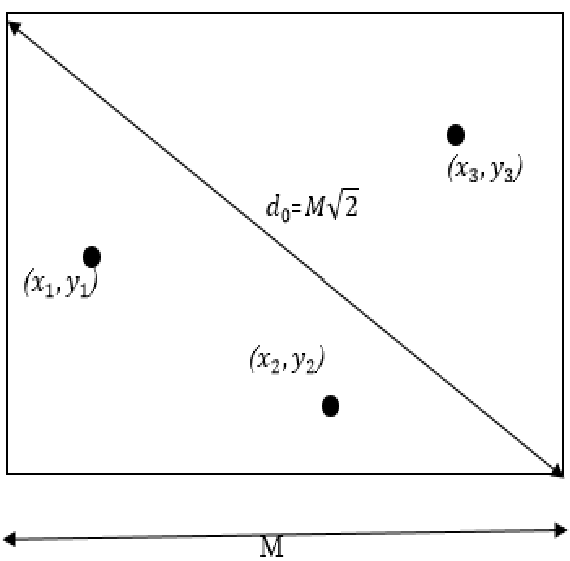

Figure 2.Algorithm weight calculation

We will propose a point P which will be the same as the centroid. The proposed point will be different only when the nodes are further away from d_0 from the centroid [11].

Let's have a square field with side length 'M' where M=$d_0/\sqrt{2}$.

In this case, wherever we place the base station, then in the process of transmitting data inside the quadratic field, all network nodes will have only losses due to the free path [12].

3.2OptimalLocationoftheBase Station–Example

Step: In this step, we will consider the centroid as one of the three vertices of a given plane and we will find the place of the orthocentre (Otherwise, the segment from the normal, which is drawn from any vertex of the triangle to the opposite side, is called the height of each triangle has three heights. The three heights of the triangle intersect at one point, which is called the orthocentre point O) for the nodes in the distributed sensor field. This will be where the energy E_d will be minimal and we will calculate it with mathematical equations by determining the slope of the lines on the sides of the triangle [13].

The slope of the side AB with the points (100,200) and (0, 0) will be determined as:

$$m_1 = \frac{y_2 - y_1}{x_2 - x_1} = 2$$

while for the segment CF, which is drawn from the vertex C of the triangle (Figure 3) to the opposite side AB and which is also perpendicular to that side, is also called the height of the triangle, the slope will be determined as:

$$m_1 \cdot m_2 = -1$$

Since the two lines are perpendicular to each other, this means that the slope of the segment will be

$$m_2 = -\frac{1}{2}$$

For the specific case, the mathematical equation for the segment CF will be given by the following expression:

$y - y_1 = m_2(x - x_1)$where x_1=300 и $y_1 = 30$,$m_2 = -\frac{1}{2}$

from where it will follow $y - 300 = -\frac{1}{2}(x - 300) \rightarrow$ *0.5* $x + y = 450$

If the same mathematical procedure is repeated for the slope of the sides BC and AD, the following equation is obtained:

$m_1 = \frac{y_2 - y_1}{x_2 - x_1}$=1 where the slope of the normal AD is $m_2 = -1$

$y - y_1 = m_2(x - x_1)$where x_1=10 and $y_1 = 200$ $m_2 = -1$

from where it will follow$y - 200 = -(x - 100) \rightarrow x + y = 300$

$x + y$ =300

By solving both of the above equations (*0.5* $x + y = 450$ and$x + y$ =30) is obtained *x*=-300 and*y*=600. These are the points that determine the orthocenter of the triangle shown assuming it will be the place where the energy Edwill be minimal.

Now knowing that the point of the orthocenter is determined, and that is (-300,600), we can determine the distance from the center (100,200) to the orthocenter (-300,600) using the following equation where it is obtained$d_1=\sqrt{(x-x_i)^2+(y-y_i)^2}$=565.6whereas now for the distance from the orthocenter to the points (0,300),(0,0) and (300,300) will be obtained accordingly:

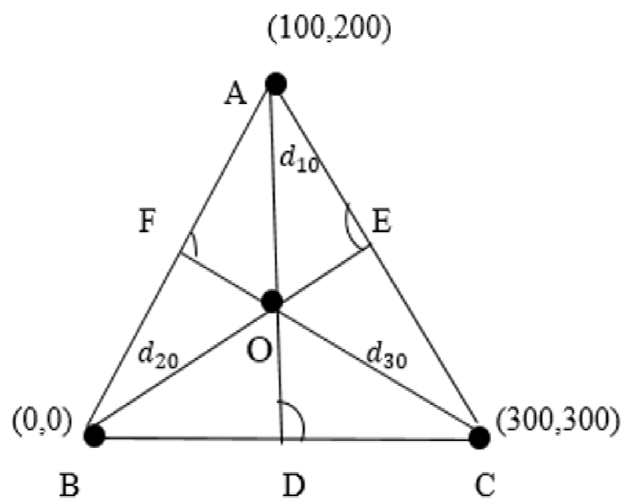

Figure 3 Calculation of energy consumption at the point of the orthocenter

d_{1ort} = 565.6 + 141.4 = 706.8, d_{2ort} = 565.6 + 223.6 = 789.2, d_{3ort} = 565.6 + 223.6 = 706.8

Taking into account the calculated distances we will determine the energy in the orthocenter for the three points which are

$E_{ort}=(\varepsilon_{ml}\cdot d^4{}_{1ort}+\varepsilon_{ml}\cdot d^4{}_{2ort}+\varepsilon_{fl}\cdot d^2{}_{3ort})/3=1.92\cdot 10^{-4}$ *J/bit-*

while the energy of the nodes in the optimal location is:

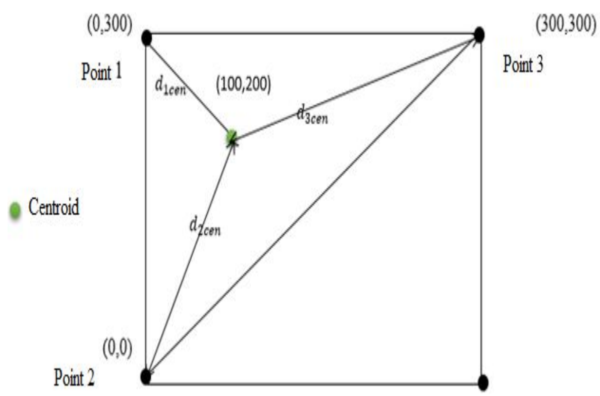

Figure 4.Base station energy calculation (Centroid)

$E_{optim}=(\varepsilon_{ml}\cdot d^4{}_{1optim}+\varepsilon_{ml}\cdot d^4{}_{2optim}+\varepsilon_{ml}\cdot d^4{}_{3optim})/3=2.11\cdot 10^{-4}$ *J/bit-*

Let us now consider the case where three points are given in a given square area with coordinates (0.300), (0.0,) and (300.300).

The centroid for these points results in (100,200).Distances from the centroid to points 1, 2, 3 using the expression $d_{i\,cen}=\sqrt{(x-x_i)^2+(y-y_i)^2}$the distances of d_{1cen},d_{2cen} andd_{3cen}will be calculated respectively.These points have the following values d_{1cen}=117.7 d_{2cen}=d_{3cen}=212.2.

Thus the energy in J / bit for the three network nodes in the centroid is

$$E_{cen}=\frac{\varepsilon_{fs}\cdot d_{1c}{}^2+\varepsilon_{mp}\cdot d_{2c}{}^4+\varepsilon_{mp}\cdot d_{3c}{}^4}{3}=2.08\,x10^{-6}\,J/bit$$

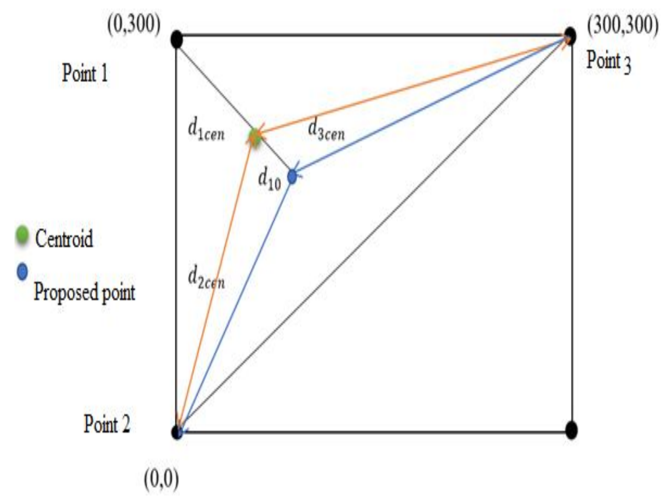

Figure 5. Base station energy calculation (suggested point)

The theoretical optimal position is also calculated by placing the base station at a distanced_{10}, from point 1 along the normal bisector of the line joining points 2 and 3.

Table 1 Energy efficiency of sensor nodes in Centroid

Side length	Number of network nodes				
↓	50	70	90	110	130
200 m	4.27	4.06	4.01	3.69	3.59
220 m	3.58	3.28	3.21	3.38	3.44
240 m	2.43	2.14	2.12	1.88	2.67
260 m	1.68	1.36	1.28	1.16	1.35
280 m	0.49	0.58	0.33	0.38	0.28

Optimal point is $(\frac{do}{\sqrt{2}}, 300 - \frac{do}{\sqrt{2}})$, the distances from points 1,2 3 will bed_{10},d_{20}andd_{30} respectively. Those distances will now have the following valuesd_{10}=72.3 and d_{20}=d_{30}=212.5. The d_{10}=72.3 и d_{20}=d_{30}=212.5. The energy in J / bit for the three nodes at the optimal point O is:

$$E_o = (\varepsilon_{mp} \cdot d^4{}_{10} + \varepsilon_{mp} \cdot d^4{}_{20} + \varepsilon_{mp} \cdot d^4{}_{30})/3 = 1.69\ x\ 10^{-6}\ J/bit$$

Analysing the energies obtained in the three mentioned positions, it is noticed that the location of the base station will be the most optimal to be placed at the point where the orthocenter is located. The average weight for the proposed point will be determined by:

$$X_p = \frac{0 + 0 + \frac{d^2 3\ optim}{d^2 0} 300}{1 + \frac{d^2 2optim}{d^2 0} + \frac{d^2 3optim}{d^2 0}} = 138.24$$

$$Y_p = \frac{300 + 0 + \frac{d^2 3\ optim}{d^2 0} 300}{1 + \frac{d^2 2optim}{d^2 0} + \frac{d^2 3optim}{d^2 0}} = 154.48$$

Thus obtaining the required proposed point (138.24, 154.48) the energy at the proposed point will now be:

$$E_{pr} = (\varepsilon_{fl} \cdot d^2{}_{1pr} + \varepsilon_{ml} \cdot d^4{}_{2pr} + \varepsilon_{ml} \cdot d^4{}_{3pr})/3 = 1.784 \cdot 10^{-4}\ J/bit-$$

Now by placing the base station at another location, i.e. in the middle of the line (150,150) the calculated value of the energy will be:

$$E_{SL} = (\varepsilon_{fl} \cdot d^2{}_{1SL} + \varepsilon_{ml} \cdot d^4{}_{2SL} + \varepsilon_{ml} \cdot d^4{}_{3SL})/3 = 2.18 \cdot 10^{-6}\ J/bit-$$

Comparing the obtained values of energies in different positions where it is assumed to be the base station, the following comparisons are obtained:

$$\frac{E_{pr} - E_{ort}}{E_{ort}} x100 = 1.79\ \%$$

from where it is noticed that in the proposed point we will have more energy consumption compared to the optimal location of the base station. In case a centroid is used, then the energy consumption is exceeded for

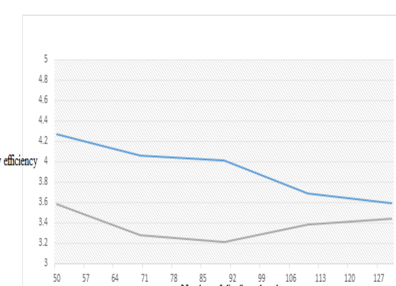

Figure 6. Energy efficiency in centroid and orthocenter

$$\frac{E_{cent} - E_{ort}}{E_{ort}} x100 = 2.01\ \%$$

In relation to the optimal point, while when the base station is placed in the middle of the line we have:

$$\frac{E_{SL} - E_{ort}}{E_{ort}} x100 = 2.38\ \%$$

The tables below provide calculations for different cases such as page length and the several network nodes active in a given space.

Table 2 Energy efficiency of sensor nodes in Orthocenter

Side length	Number of network nodes				
↓	50	70	90	110	130
200 m	4.43	4.24	4.18	3.75	3.81
220 m	3.83	3.44	3.48	3.54	3.61
240 m	2.62	2.33	2.37	2.01	2.79
260 m	1.83	1.52	1.48	1.35	1.51
280 m	0.71	0.73	0.55	0.59	0.42

The given Table 1 shows the way the energy consumption changes when we have different parameters such as the number of sensor nodes placed in a given space with variable page length, while the following Table 2 also shows the obtained results when the location of the base station is in the point where the orthocenter is located. As the number of sensor nodes grows, the losses from multiple propagations will be more evident compared to the losses during propagation through free space where we have no obstacles in "spreading" the signal. So we can conclude that energy efficiency will be better at the point where the orthocenter is located compared to the centroid. Figure 6

This indicates that the number of nodes affected by the loss in the case of multiple paths increases with the density of the nodes. The above tables confirm the same because as the number of nodes for a constant size of the topology increases and vice versa, the gain of amplified energy at a given proposed point decreases[14].

4. CONCLUSION

Increasing life expectancy and general decreasing power consumption are two different problems in wireless sensor networks.

The optimal point for obtaining the maximum lifespan of a given sensor network is the center of the minimum circle of all nodes. If all nodes have free space losses ($\alpha = 2$) then energy consumption is minimized when the base station is set in the centroid.

In the case when all nodes have losses from the so-called multiple paths –multipath loss ($\alpha = 4$) then the optimal location of the base station will be the point P.

In case we have combinations of the two cases mentioned above then a new location for the base station is proposed to minimize energy consumption. This point is the center of gravity of the distributed network nodes.

The results show that the proposed point in the orthocenter provides very good performance compared to the centroid such as the center of the minimum circle for sensor nodes.

All these achievements can be applied to the distribution of a given base station in an optimal location in two-level wireless sensor networks.

The placement of a given base station in an optimal location practically enables an evident balance of energy consumption and thus prolongs the life of the sensor nodes.

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