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An Efficient Design of Cluster Size for Maximizing Outcomes of Direct Transmission in Cluster-Based Wireless Sensor Networks

Abd Elwahab Fawzy[1], Asmaa Amer[2], Mona Shokair[3] and Waleed Saad[4]

[1,2,3,4] Department of Electronics and Electrical Communications, Faculty of Electronic Engineering, Menoufia University, Menouf, Egypt.

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Abstract: Due to their vast prospective applications, researchers pay a great attention to Wireless Sensors Networks (WSNs) in the recent years. One of the most constraints related to sensor nodes is the small sized and portable battery integrated into the node itself. From the practical and economical point of view, it is risky, inefficient and infeasible option to recharge these batteries by human periodically. In this paper, we primarily focus on optimizing the transmission energy for each node; hence the energy utilization over the whole network is enhanced. In fact, the transmission energy increases exponentially with distance, hence Direct Transmission (DT) isn't preferred for far distances, therefore Multi-hop is more efficient. In this paper, it's assumed that there is always threshold distance, called characteristic distance d_{char}, which used as a judging metric to specify whether to use DT or Multi-hop transmission (MH) as an efficient transmission manner. If the distance is greater than d_{char}MH is used, else DT is preferred. We are interested in studying this distance in more details. This comes through two steps, the first step will be made by analyzing for the relation between the design parameters and the consumed energy of different transmission techniques hence, a general formula for d_{char} is excluded. In the second step, supplementary analysis will be performed to study the effect of design parameters on d_{char} . Finally, d_{char} is suggested to play a pivotal role in specifying the optimum size of the cluster. This minimizes the variance in node residual energy within the cluster.

Keywords: wireless sensor network, energy consumption, network lifetime, Stability period, Routing.

1. Introduction

Wireless Sensor Networks (WSNs) are composed of small size, low cost and limited resources sensor nodes. Normally these sensors are randomly deployed in a hostile environment. These nodes collaborate to perform specific tasks such as sensing and monitoring various types of physical conditions. As soon as these nodes sense the interested phenomena, they transmit the sensed data to unconstrained node which is often called the Sink or the Base Station (BS). BS works as a gateway between the sensing nodes and the end user [1]. At recent years, WSNs have been employed in a variety of applications, such as monitoring, military surveillance, industrial, agricultural producing, healthcare, intelligent home furnishing, security, safety applications [2].

In usual, Sensors are deployed in a hostile environment. Therefore, they are battery powered devices. These Portable batteries are integrated into this sensor during the fabrication process. Replacing or recharging of these batteries is not an available option according to the economical and practical point of view. It is important for these nodes to achieve the optimum use of its energy to live a long time without any external assistance.

In fact, Routing protocol is one of the leading facilities that play a vital role in energy consumption of nodes. At recent years, a variety of routing protocols had been proposed for WSNs [1, 3]. The main scope of these protocols is minimizing the energy consumption and enhancing the lifetime of the network [4, 5].

Initially, several transmission manners for conventional computer networking such as Direct Transmission (DT) and Multi-hop transmission (MH)

E-mail address: abdelwabfawzy@el-eng.menofia.edu.eg, asmaaamer2015@el-eng.menofia.edu.eg, mona.sabry@el-eng.menofia.edu.eg, waleed.saad@el-eng.menofia.edu.eg

were employed for WSN [6]. In DT, sensor nodes send the data directly to the BS. In MH, sensor nodes collaborate to relay the sensed data to the sink using the minimum cost route.

In [2, 4, and 6], Cluster-Based Routing Protocols (CBRP) concept was introduced to overcome the problems of DT and MH. In CBRP, the sensor nodes are grouped into numbers of separated clusters. At each cluster, there is a major node which is responsible for receiving the sensed data from member nodes, aggregate it in single block message hence, send it to the BS directly. This node is called Cluster Head (CH). Cluster-based algorithms are more efficient in satisfying the WSNs needs.

Assume that a far node needs to send its data to its CH. Since the consumed energy increases exponentially with distance, this node will avoid DT and begin to search for another near node to relay its data. This relay node will expend relay energy plus the transmission energy to send its own data to CH. The total expended energy by the relay node is much more than other traditional nodes leading to unbalanced energy consumption within the cluster. The variance of nodes residual energies is increased, leading to the quick death of the relay nodes. From previous, the distances between sensor nodes and CH have a direct impact on the energy consumption within the cluster; hence limiting the size of the cluster will help in balancing the energy consumption. Unlike traditional routing protocols where optimum cluster size plays a minor role, our paper focuses on maximizing the outcomes of DT through the efficient design of cluster size which will be inferred that, the size is dependent on the design parameters basically, regardless the nature of the sensing field.

The main contributions in this paper lie on the following steps:

a) A comprehensive analysis of different transmission manners will be performed to determine the maximum allowable distance between two nodes within a cluster in which DT needs less energy than MH. This distance is called the characteristic distance d_{char}.

b) It is noticed that, $\mathrm{d_{char}}$ totally depends on the design parameters, hence the influence of design parameters on this distance will be studied carefully.

c) The optimum size of a cluster can be deduced related to this distance; hence, a minimum number of clusters are selected. Therefore, the energy consumption becomes balanced over the whole network.

The rest of this paper is organized as follows: Related work will be presented in Section 2. System model will be introduced in Section 3. Compressive analysis to deduce a formula for characteristic distance will be performed in Section 4. In Section 5, the influence of design parameters on characteristic distance will be carefully studied. The derivation of the optimum size of CH in terms of $\mathrm{d_{char}}$ will be done in Section 6. In section 7, Simulation results will be shown using MATLAB. Finally, conclusions will be done in Section 8.

2. Related Works

In [6], W. R. Heinzelman, et. al. presented Low-energy adaptive clustering hierarchy (LEACH) for WSN. LEACH is accepted as a standard model for Cluster-based routing protocols in homogenous WSN. LEACH operation is divided into rounds. Each round is separated into two phases, called Setup phase and Steady state phase, which will be explained in the following:

A. Set-up phase:

It is concerned with CHs election strategy and cluster formation. In LEACH, there is an optimal percentage p (specified a priori) for nodes to be CH. It guarantees that each node will become CH exactly once every $1/p$ rounds. At each round, every non-CH nodes will generate a random number which compared with threshold value T (n). The node will be CH only if the random number is less than T (n) which is given by,

$$\mathrm{T\,(n)} = \begin{cases} \frac{\mathrm{p}}{1-\mathrm{p}(\mathrm{r} * \mathrm{mod}\frac{1}{\mathrm{p}})} & \text{if } \mathrm{n} \in \mathrm{G} \\ 0 & \text{else} \end{cases} \qquad (1)$$

Where $\mathrm{r, n, G}$ is the round number, the node's number and the set of nodes that haven't been used as CHs in previous $1/\mathrm{p}$ rounds respectively. The mod operation finds the remainder after division of r by $1/\mathrm{p}$. If node $\mathrm{n} \in \mathrm{G}$, this means node not be selected as CH in recent rounds. Once Clusters are formed and CHs are selected, each CH sends its information and Code Division Multiple Access (CDMA) code to the surrounded nodes. Non-CH nodes make a decision to join one of these CHs depending on the Received signal strength indication (RSSI). Non-CH nodes choose the CH that has the strongest received signal which is normally related to the nearest CH; hence send it a joining request. As soon as CHs receive joining requests, it determines a Time Division Multiple Access (TDMA) schedule and sends it to its nodes. The structure of clustering in LEACH protocol is shown in Fig. 1.

B. Steady State phase:

Steady state phase interests in data transmission. When the normal nodes receive the TDMA schedule from its CH, it uses the CDMA key and the TDMA schedules to communicate with the CH tills the next setup phase. Using clustering, the sensed data from normal nodes can be processed and aggregated locally by the CHs. The communication between CH and cluster members uses TDMA. The time divisions are shown in Fig. 2.

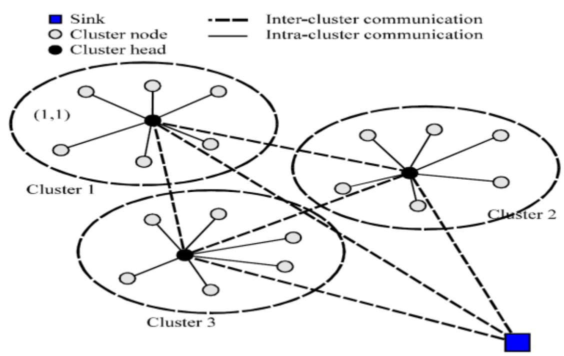


Figure 1. Clustering in LEACH.

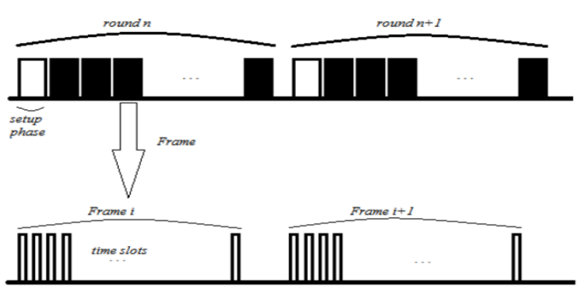


Figure 2. Timeline diagram of LEACH.

In LEACH protocol, cluster head selection is random; hence remarkable drawbacks appear such as:

- Number of cluster heads in each round is not equal.
- Non-uniform distribution of cluster heads through the sensing field.
- A different cluster size, which means some of the cluster heads serve a small number of nodes on the other hand; some of the cluster heads have a large number of nodes this leads to unbalance energy consumption within each cluster.
- Node's residual energy is not considered during CH selection.

Several approaches for enhancing LEACH had been introduced. Some of these protocols are interested in improving the CH selection process [7, 8, 9, 10] otherwise, the cluster formation process [13, 14] or the transmission process itself [11, 12, 16].

In [7], Energy-LEACH was introduced to improve the CH selection process. The residual energy of a node becomes the main factor which decides whether these nodes become CHs or not. The nodes with more residual energy become CHs in next round communication, and so on.

M. Sadat et al. presented a distance aware CH selection protocol in [8], where the probability of CH selection p is modified depending on the node's distance from the BS. Smaller p is determined for faraway nodes from the BS, hence these far clusters will be bigger. Far nodes will be CH less than close nodes to BS.

WSNs can be categorized into homogeneous or heterogeneous on the basis of the initial energy of nodes. If nodes' initial energies are equal, then it is homogeneous, else it is heterogeneous. Various types of routing protocols have been presented to be adapted to the heterogeneous networks. Ref. [9] introduced Stable Election Protocol (SEP) for two energy levels of WSN. Nodes are classified into advanced nodes and normal nodes depending on its initial energy. Advanced nodes have more energy than normal nodes. CH election probability relies on the initial energy of nodes. Therefore, advanced nodes are exposed to be CH than normal nodes. This is done by modifying the threshold values Thus; SEP enhances the lifetime of the network.

Distributed Energy Efficient Clustering algorithm (DEEC) was introduced in [10] for multilevel heterogeneous networks. DEEC enhances the lifetime of the network using a heterogeneous aware clustering algorithm. The probabilities of a node to be selected as CH are not fixed as LEACH or depend only on the initial energy of nodes such as the SEP, but the ratio between residual energy and the average energy of the whole network plays a vital role in CH selection. Nodes with high initial and residual energy are exposed to be CH more than lower ones.

In [11], Sensor networks can be classified into reactive or proactive according to the nature of the interesting application. In proactive networks, the nodes are responsible for sensing then transmitting the respective data to the BS in a periodic manner. The nodes in reactive networks send to the BS only if the sensed data overcomes threshold values which are specified previously. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) is a reactive protocol which was designed for critical time application. Nodes are arranged as in LEACH. The user set attributes (Hard Threshold HT, Soft Threshold ST) for each Cluster, which sends them to the member nodes consequently. The normal nodes send data to the BS only when the sensed Data exceeds these attributes.

In Most CBRP, there are two modes of transmissions [12]: Intra-Cluster Transmission and Inter Cluster Transmission. Intra-cluster transmission deals with the communication between nodes within the cluster. Inter Cluster Transmission interests in the communication between cluster heads and BS. Cluster size effect on the Inter and Intra-communication cost.

In [13], Energy Efficient Clustering Scheme was discussed. EECS forms the Cluster based on its distance from the BS. The communication between CH and BS is direct (single hop), hence far clusters consumes larger energy than near ones. In EECS, far nodes become smaller than near nodes to balance the consumed energies in Intra and Inter Cluster communications.

An Energy Efficient Unequal Clustering (EEUC) mechanism for WSN was introduced in [14]. EEUC uses Multi-Hop transmission between CHs to reach the BS; therefore cluster heads closer to BS are exposed to heavy relay traffic and tend to die early. The network is portioned into clusters of an unequal size where near clusters have a smaller size than far clusters.

In [15], the Multi-Hop transmission to send data from a source node to the BS was investigated briefly, and then the optimum number of hops to decrease the expended energy was deduced. Depending on the deduced optimum number of hops, Hob-based Energy Aware Routing (HEAR) was introduced in [16] as a proposed algorithm to enhance the energy efficiency and the lifetime of the network.

From previous protocols, we conclude that both the transmission manner and cluster size play an important role in minimizing the energy consumption through the network.

3. System Model

There are two models which will be explained in the following:

A. Network Model

Let us consider a number of sensors are randomly deployed within the interesting sensing field. These nodes are used to measure a locative function (say temperature, radiation or pressure), then the sensed data are sent to the BS. The following assumption is taken into consideration:

- The sink is an unlimited resource device.
- As soon as the sensor nodes are deployed, its location is maintained fixed.
- All sensor nodes know its location using GPS or any other location determination device.
- All sensor nodes are proactive.
- Close sensors have correlated data.
- The communication channel is symmetric (i.e. the energy cost for transmitting a message between two nodes is the same in both directions).
- The energy consumption of Sensing and processing is not considered here.

Each node is considered as a multi-tasks device which able to perform a variety of tasks such as transmitting, receiving, sensing, and processing data. The energy consumed for sensing and processing is relatively small, periodic and identical for all nodes, so it is neglected. Hence, the total expended energy becomes dependent on transmitting and receiving energy. Therefore, they have a direct influence in choosing the transmission policy.

B. Energy model

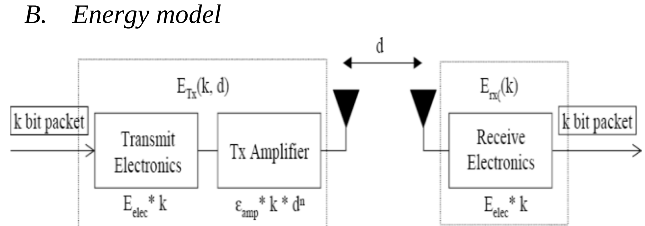


Figure 3. Radio Model[4].

A commonly used energy model is known as a first order radio model, which is shown in Fig. 3. This model used to clarify the expended energy by nodes over the network operation time. The related design parameters and their definitions are given in Table1.

TABLE 1. RADIO PARAMETERS.

Parameter	Definition	Value/Unit
E_{elec}	Energy dissipation in electronic circuits	50 nJ/bit
ε_{amp}	Energy dissipation rate to run (transmit / receive) amplifier	ε_{fs} = 10 pJ/bit/m^2 ε_{mp} =0.0013 pJ/bit/m^2
K	Data length	4000 Bits
D	Transmission distance	M
d_0	Threshold distance	$d\_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}}$ =87.7 m

The transmission power increases exponentially with the n-th power of distance (where,$2 \leq n \leq 4$). There are two models of losses depending on distance d between TX and RX which are given by:

- Free space(d^2 Power loss).
- Multipath fading (d^4 power loss).

To transmit k bits message over a distance d, the radio expends,

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

$$= \begin{cases} k * E_{elec} + k * \varepsilon_{fs} * d^2 \quad , & \text{if } d \le d\_0 \\ k * E_{elec} + k * \varepsilon_{mp} * d^4 \quad , & \text{if } d > d\_0 \end{cases}$$

And to receive this message, the radio expends,

$$E_{Rx}(k) = E_{Rx-elec}(k) = k * E_{elec} \quad (3)$$

ε_{fs} : free space loss coefficient ,

ε_{mp} : multipath loss coefficient.

If a node works as an intermediate node to relay data from source to destination, the node's radio expends,

$$E_{Fx}(k,d) = E_{Rx}(k) + E_{Tx}(k,d) \quad (4)$$

$$= 2k * E_{elec} + k * \varepsilon_{amp} * d^n$$

$$= \begin{cases} 2 * k * E_{elec} + k * \varepsilon_{fs} * d^2 \quad , & \text{if } d \le d\_0 \\ 2 * k * E_{elec} + k * \varepsilon_{mp} * d^4 \quad , & \text{if } d > d\_0 \end{cases}$$

Let we have the following scenario:

A number of sensing nodes are randomly deployed within a specific sensing field. After sensing data, a source node needs to send data to remote BS:

a) ***Whether to send data directly (DT) or use another node as a relay?*** From Section 4, it's concluded that there is a threshold distance which is used for solving this urgent question. The General formula for this distance is obtained mathematically.

b) On the basis of the previous answer, ***on which parameters is this characteristic distance depends on?*** The characteristic distance is dependent on the design parameters. In Section 5, the influence of the design parameters is studied rigorously with analysis and figures.

c) ***To which degree we are able to exploit this distance to optimize the cluster size?*** In Section 6, the optimum size of a cluster is determined based on the characteristic distance which is related to the design parameters. The design parameters have a direct impact on the size of clusters and the optimum number of clusters consequently. Given all the above analysis, the optimum number of clusters can be calculated at the start of the network depending on the design parameters, whatever the nature of the sensing field.

Using [4, 5], we first introduce:

Lemma 1:

In Single-hop transmission or DT, the transmission power increases exponentially with distance, hence farthest nodes drain its energy quickly. To overcome this problem, we use Multi-hop transmission policy, where sensor nodes collaborate to relay the sensed data to the BS. MH transmission is convenient for far nodes, on the other hand, DT adequate for near nodes. In our model, It is assumed that there is a threshold distance which is used as a judging criterion for solving the following question (***whether to transmit the data directly DT or through Multi-hop?***).

4. Deduction of Characteristic Distance

No doubt that in most real environments, sensors is not placed at equal intervals. In contrast to the network assumptions in [4, 6], the uniform distribution distance between nodes in our analysis isn't considered, hence our assumption are more practical. The relation between the expanded energies by DT and two-hop transmission has a great attention in the following sections. To illustrate this point, consider the linear network shown in Fig. 4. Node 2 is a source node which needs to send data to the BS. Node 1 is a relay node which able to receive data from node 2 then transmits it to BS. According to Section (II-2), there are three possible cases for distances d_1, d_2, d:

1- Free Space Model ($d_1, d_2 < d_o$ & $d \le d_o$).
2- Multipath Model ($d_1, d_2 > d_o$).
3- Hybrid Model ($d_1, d_2 \le d_o$ & $d > d_o$).
Where, $d = d_1 + d_2$. Each case of the above will be compressively analyzed.

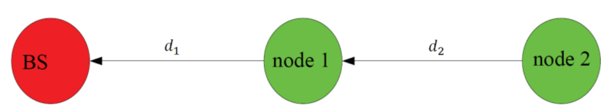


Figure 4. Relay node network model.

A. *The free space model (n=2, $\varepsilon_{amp} = \varepsilon_{fs}$)*

The consumed energy using Single-hop (DT) between node 2 and the BS and 2-hop transmission is given from (5) and (6) respectively:

$$E_{DT} = k * E_{elec} + k * \varepsilon_{fs} * d^2 \quad (5)$$

$$E_{2-hop} = \underbrace{k * E_{elec} + k * \varepsilon_{fs} * d_2^2}_{\text{Expended energy by node2}} + \underbrace{2 * k * E_{elec} + k * \varepsilon_{fs} * d_1^2}_{\text{Expended energy by node1}} \quad (6)$$

$$= 3 * k * E_{elec} + k * \varepsilon_{fs} * (d_1^2 + d_2^2)$$

Case 1: Direct transmission consumes less energy than 2-hop transmission if

$$\Delta E = E_{DT} - E_{2-hop} \le 0$$
$$k * E_{elec} + k * \varepsilon_{fs} * d^2 - \left(3 * k * E_{elec} + k * \varepsilon_{fs} * (d_1^2 + (d - d_1)^2)\right) \le 0$$

$$d_1 * (d - d_1) - \left(\frac{E_{elec}}{\varepsilon_{fs}}\right) \le 0$$
$$\Delta E = d_1 * (d - d_1) - \left(\frac{E_{elec}}{\varepsilon_{fs}}\right) \le 0$$

The optimum distance of d_1 can be estimated by setting the derivative of ΔE with respect to d_1. It is easy to prove that the maximum allowable distance to use DT (d_{char}) takes place when the total distance is halved. It is important inferences that, the 2 hop transmission consumes the same amount of energy as DT when the total distance between the target and the destination is halved. Substituting of d_1 and d_2 in by $d/2$, a formula for d_{char} can be deduced in (8):

$$d_1 = {}^{d}/_{2} \quad , \quad d_2 = d - {}^{d}/_{2} = d_1 \quad (7)$$
$$\frac{d_{char}^2}{4} \le \frac{E_{elec}}{\varepsilon_{fs}}$$
$$d_{char} \le 2\sqrt{{}^{E_{elec}}/_{\varepsilon_{fs}}} \quad (8)$$

B. The Multipath model (n=4, $\varepsilon_{amp} = \varepsilon_{mp}$)

The previous calculations in Section (IV-1) are suitable for small distances ($d \le do$) otherwise, for ($d > 2do$), more accurate analysis for large distances is needed to be discussed. The disbursed energy using DT between node 2 and the BS and 2-hop transmission is given by (9) and (10) respectively:

$$E_{DT} = k * E_{elec} + k * \varepsilon_{mp} * d^4 \quad (9)$$
$$E_{2-hop} = \underbrace{k * E_{elec} + k * \varepsilon_{mp} * d_2^4}_{\text{Expended energy by node2}} + \underbrace{2 * k * E_{elec} + k * \varepsilon_{mp} * d_1^4}_{\text{Expended energy by node1}} \quad (10)$$
$$= 3 * k * E_{elec} + k * \varepsilon_{mp} * (d_1^4 + d_2^4)$$

, Similarly as in (7)

$$d_1 = {}^{d}/_{2} \quad , \quad d_2 = d - {}^{d}/_{2} = d_1$$

Case 2: Direct transmission consumes less energy than 2-hop transmission if

$$\Delta E = E_{DT} - E_{2-hop} \le 0$$
$$k * E_{elec} + k * \varepsilon_{mp} * d^4 - (3 * k * E_{elec} + 2 * k * \varepsilon_{mp} * \left(\frac{d}{2}\right)^4) \le 0$$

$$\varepsilon_{mp} * \frac{7}{8} * d^4 \le 2 * E_{elec}$$
$$d_{char} \le 2 * \sqrt[4]{{}^{E_{elec}}/_{7 * \varepsilon_{mp}}} \quad (11)$$

C. The Hybrid model (2<n<4, $\varepsilon_{amp} \in \{\varepsilon_{mp}, \varepsilon_{fs}\}$)

The last calculations in Section (III-2) are suitable for large distances ($d > 2$ do) otherwise, Section (III-1) is appropriate for small distances ($d <$ do), but here, more accurate analysis for intermediate distances is needed to be discussed.

The exhausted energy in DT and 2-hop transmission is given from (12) and (13) consequently:

$$E_{DT} = k * E_{elec} + k * \varepsilon_{mp} * d^4 \quad (12)$$

$$E_{2-hop} = \underbrace{k * E_{elec} + k * \varepsilon_{fs} * d_2^2}_{\text{Expended energy by node2}} + \underbrace{2 * k * E_{elec} + k * \varepsilon_{fs} * d_1^2}_{\text{Expended energy by node1}} \quad (13)$$
$$= 3 * k * E_{elec} + k * \varepsilon_{fs} * (d_1^2 + d_2^2)$$

The same derivation is as in (7),

$$E_{2-hop} = 3 * k * E_{elec} + k * \varepsilon_{fs} * 2 * ({}^{d}/_{2})^2$$

Case 3: Direct transmission consumes less energy than 2-hop transmission if

$$\Delta E = E_{DT} - E_{2-hop} \le 0$$
$$\varepsilon_{mp} * d^4 - \frac{\varepsilon_{fs}}{2} * d^2 - 2 * E_{elec} \le 0$$
$$A * d^4 + B * d^2 + C \le 0$$

By solving this fourth order equation the characteristic distance can be calculated

$$d_{char} = \sqrt{\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}} \quad (14)$$

A general formula for d_{char}:

$$d_{char} = \begin{cases} 2 * \sqrt{E_{elec}/\varepsilon_{fs}} \ , & d_{char} \le do \\ \sqrt{\frac{-B+\sqrt{B^2-4AC}}{2A}} \ , & (do < d_{char} \le 2do) \\ 2 * \sqrt[4]{E_{elec}/7 * \varepsilon_{mp}} \ , & d_{char} > 2do \end{cases}$$

(15)

Where A $=\varepsilon_{mp}$, B $=-\varepsilon_{fs}/2$ and C $=-2E_{elec}$. However, the size of data that needs to be transmitted has a direct impact on the consumed energy, whether in transmission or receiving, the characteristic distance isn't dependent on the data size as shown in (15). As the data length is extended, the transmission energy needs to be raised while the characteristic distance remains constant as it is calculated in terms of the design parameters only.

5. The Effect of Design Parameters

Equation (15) shows that d_{char} is totally dependent on the design parameters E_{fs}, E_{mp} and E_{elec}. Normally these parameters aren't constant, but they relate to the hardware components. Varying design parameters have a direct impact on the characteristic distance value. Now, we are concerned with studying this effect on the details. Each of these three models for d_{char} will be studied separately.

A. Free Space Model

From (8), the characteristic distance depends on E_{elec} and ε_{fs} only. Here we pick one parameter as a variable and let all other parameters are being fixed.

- **First case**, let the fixed parameters are $E_{mp} = 0.0013$ pJ/bit/ m^2 , $\varepsilon_{fs} = 10$ pJ/bit/ m^2 , hence $d\_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} = 87.7\ m$, E_{elec} is changed from 2 to 18 nJ/bit.

Retrieval Formula (8), d_{char} is directly proportional to $\sqrt{E_{elec}}$. It's predicted that, d_{char} increases as long as E_{elec} increases.

As E_{elec} increases the relay cost (Energy dissipation in the electronic circuit) for possible intermediate node increased compared to the saved transmitting energy by dividing the transmission distance. Then it is preferred to use DT than MTE for larger ranges. The characteristic distance increases from 28.28 to 84.85 m, as E_{elec} varied from 2 to 18*nJ/bit*, as shown in Fig. 5.

- **Second case**, we kept $E_{mp} = 0.0013$ pJ/bit/m^2, $E_{elec} = 50$ pJ/bit, ε_{fs} varies from 18 to 40 nJ/bit/m^2.

At first, it is noticed that as ε_{fs} increases, d_o increases. From (8), d_{char} is inversely proportional to $\sqrt{\varepsilon_{fs}}$. Hence, d_{char} decreases as long as E_{elec} increases.

As E_{fs} increases, the transmitting energy (related to distance) increases compared with the relay cost of the possible intermediate node. Transmitting signal to far distance is avoided. Then it is preferred to use MTE than DT for large ranges. The characteristic distance decreases from 105.4 to 70.71 m, as ε_{fs} increases from 18 to 40 pJ/bit/m^2, as shown in Fig. 6.

3D plot for d_{char}, E_{elec} *and* ε_{fs} relation is shown in Fig. 7. Where, ε_{fs} varies from 10 to 100 pJ/bit/m^2 and E_{elec} varies from 0.5 to 19 nJ/bit as in [4]. It must notice that the design parameters are chosen carefully in order to be committed to this condition ($d_{char} \le d\_0$).

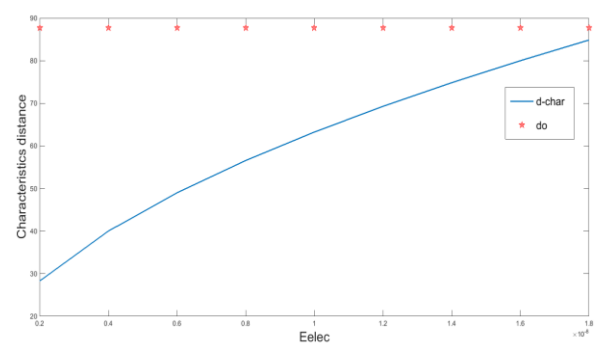


Figure 5. Characteristics distance of free space model at different E_{elec}.

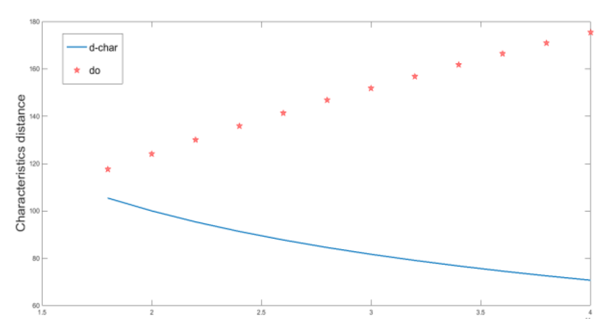


Figure 6. Characteristics distance of free space model at different E_{fs}.

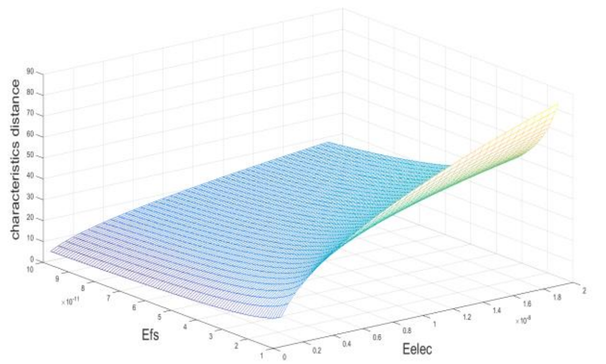


Figure 7. 3D Characteristics distance of free space model at $\varepsilon_{fs} \in 10 - 100$pJ/bit/m^2 and $E_{elec} \in 0.5 - 19$nJ/bit.

B. Multipath Model

As mentioned in (11), the characteristic distance depends only on E_{elec} and ε_{mp}.

- **First case**, let the fixed parameters be $E_{mp} = 0.0013$ pJ/bit/ m^2 , $\varepsilon_{fs} = 10$ pJ/bit/ m^2 , hence $d\_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} = 87.7$ m , E_{elec} varies from 540 to 520nJ/bit.

Recall the formula (11), d_{char} is directly proportional to $\sqrt[4]{E_{elec}}$. Hence, d_{char} increases tardily as long as E_{elec}increase.

As E_{elec} increases the relay cost (Energy dissipation in the electronic circuit) for possible intermediate node increase compared to the saved transmitting energy by dividing the transmission distance. Then it is preferred to use DT than MTE for larger ranges. The characteristic distance increases from 175.5 to 181.7 m, as E_{elec} varied from 540 to 620 nJ/bit, as shown in Fig. 8.

- **Second case**, we kept $E_{fs} = 10$ pJ/bit/m^2, $E_{elec} = 50$ nJ/bit and ε_{mp} varies from 0.02 to 0.12 pJ/bit/m^2.

At first, it is noticed that as ε_{mp} increases d_o decreases.
From formula (11), d_{char} *is* inversely proportional to $\sqrt[4]{\varepsilon_{mp}}$. Hence, d_{char} decreases slowly as long as E_{mp} increases.

As E_{mp} increase the transmitting energy (related to distance) increase compared with the relay cost of the possible intermediate node. Transmitting signal to far distance is avoided. Then it is preferred to use MTE than DT for wide ranges. The characteristic distance decreases from 48.89 to 31.23 m, as ε_{mp} varied from 0.02 to 0.12 PJ/bit/m^2, as shown in Fig. 9.

3D plot the relation between d_{char}, $E_{elec}$and ε_{mp} is shown in Fig. 10. where ε_{fs} varies from 0.0013 to 1 pJ/bit/m^2 and E_{elec} varies from 540 to 640 nJ/bit as in [4]. It must notice that the design parameters are chosen carefully in order to be committed to this condition *($d_{char} > 2d_o$).*

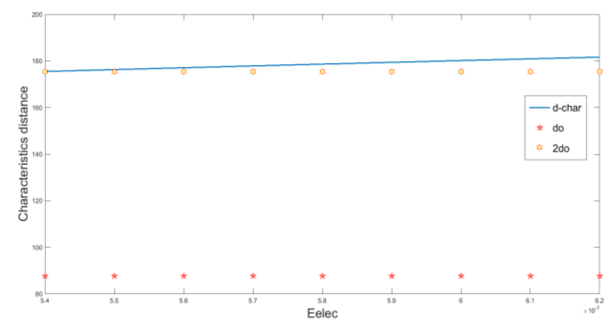


Figure 8. Characteristics distance of Multipath model at different E_{elec}.

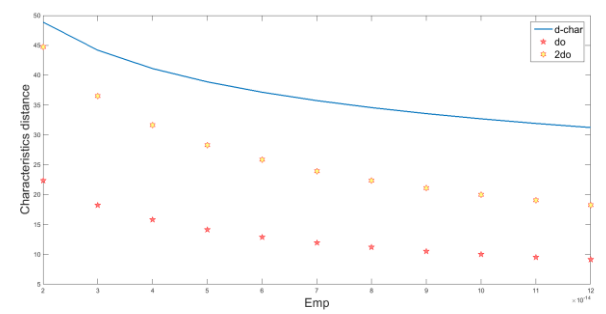


Figure 9. Characteristics distance of Multipath model at different ε_{mp}.

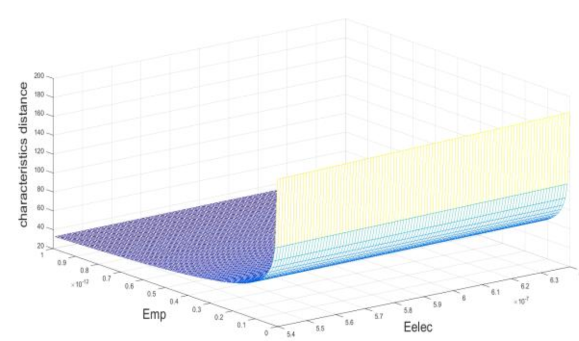


Figure 10. Characteristics distance of Multipath model at $\varepsilon_{fs} \in 0.0013 - 1$ pJ/bit/m^2 and $E_{elec} \in 540 - 640$ nJ/bit.

C. Hybrid Model

As noticed in (14), the characteristic distance depends on E_{elec} , ε_{mp} and ε_{fs} .one of these parameters would be variable and let other parameters be fixed, hence we get three cases:

i) ε_{fs}=10pJ/bit/m^2, ε_{mp}=0.0013 pJ/bit/$m^2$and $E_{elec} \in 20 - 540$ nJ/bit.

ii) E_{elec}=50nJ/bit, ε_{mp}=0.0013 pJ/bit/$m^2$and $\varepsilon_{fs} \in 5-16$ pJ/bit/m^2.
iii) E_{elec}=50nJ/bit, ε_{fs}=10 pJ/bit/$m^2$and $\varepsilon_{mp} \in 6-96$ pJ/bit/m^2.

- **First case:** as ε_{fs} and ε_{mp} are fixed, d_0 is constant. When E_{elec} increases the relay cost (Energy dissipation in electronic circuit) for possible intermediate node increases compared to the saved transmitting energy by dividing the transmission distance. Then it is preferred to use DT than MTE for larger ranges. The characteristic distance increases from 88.28 to 172.4 *m*, as E_{elec} varied from 20 to 540*nJ/bit*, as shown in Fig. 11.
- **Second case**: as ε_{fs} increases, d_0 increases, hence the efficiency of DT increase for larger distance; therefore d_{char}increase. The characteristic distance increases from 98.9 to 110.08 *m*, as ε_{fs} varied from 5 to 16 *PJ/bit/*m^2 as shown in Fig. 12.
- **Third case**: as ε_{mp} increases, d_0 decreases, hence the efficiency of DT decrease for larger distance; therefore d_{char}decrease. The characteristic distance decreases from 133.16 to 59.14 *m*, as ε_{mp} varied from 0.0006 to 0.0096 *PJ/bit/*m^2, as shown in Fig. 13. It must notice that the design parameters are chosen carefully in order to be committed to this condition ($d\_0 < d_{char} < 2d\_0$).

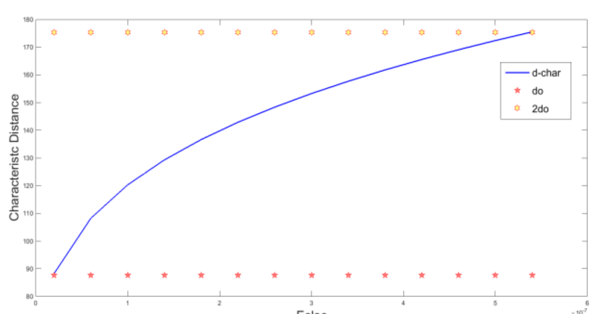


Figure 11. Characteristics distance of Hybrid model at different E_{elec}.

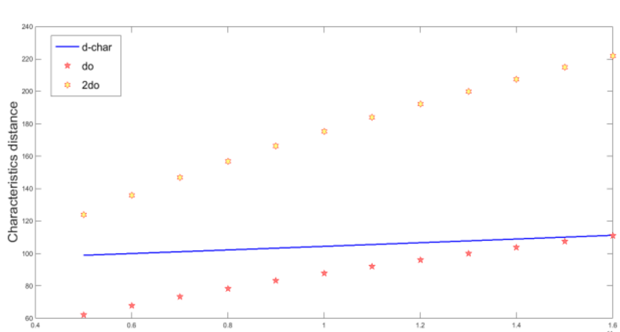


Figure 12.Characteristics distance of Hybrid model at different ε_{fs}.

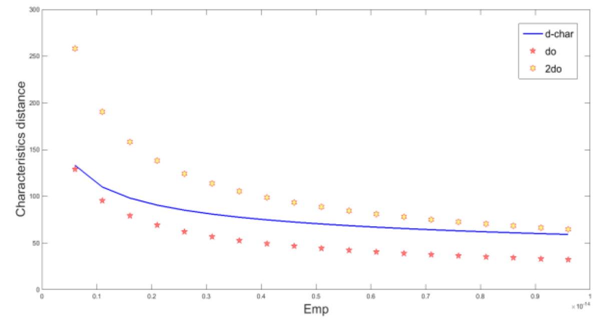
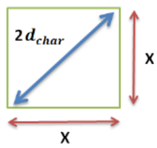
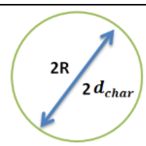
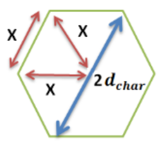


Figure 13. Characteristics distance of Hybrid model at different ε_{mp}.

6. CLUSTER SHAPE DESIGN

In MTE, near nodes to the destination will be used to relay larger amount of data per round, hence it consumes a larger amount of energy than far nodes. This maximizes the variance of the residual energy of nodes. Near nodes are exposed to quick death, causing energy hole problem at which some areas of the network will no longer be monitored. For all previous reasons, MTE isn't suitable for intra-cluster communication in hierarchical clustering protocols. DT is preferred in transmission within the cluster. A different cluster size leads to unstable energy consumption within each cluster. It's attractive to exploit d_{char} in cluster design as it's used as the maximum allowable distance within the cluster, hence the max distance between any normal node and the CH doesn't exceed d_{char}. The energy dissipation for all nodes can be reduced, moreover the common range transmission strategy for normal nodes can be applied, where the node transmit with the same power level without any power control as soon as it is informed that it's a non-CH node. Depending on the cluster shape, the area and sides of the cluster can be calculated in terms of d_{char} . Area and dimensions of most conventional cluster shapes such as, square, circular and hexagonal are calculated in Table 2. Figures for different network structures, which relate to a variety of cluster shapes, are shown in Fig. 14.

TABLE 2 AREA AND DIMENSIONS OF DIFFERENT CLUSTER SHAPES IN TERMS OF d_{char}.

Cluster Shape	Cluster area	Cluster dimensions
	$A_{square} = 2 * d_{char}^2$	$X \le \sqrt{2} * d_{char}$
	$A_{circular} = \pi * d_{char}^2$	$R \le d_{char}$
	$A_{hexagonal} = \left(\frac{3\sqrt{3}}{2}\right) * d_{char}^2$	$X \le d_{char}$

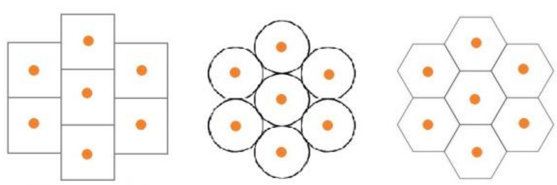


Figure 14. Different network structures using various cluster shapes.

Using (5), (6), (12), (7) and the radio parameters in Table 1, the total consumed energy for both DT and two-hop transmission techniques between two nodes at different transmission distances and E_{elec} are calculated are shown in Fig. 15. The cross sectional line which interconnects the two planes represents the characteristic distances at different E_{elec}. For smaller distances ($d < d_{char}$), the expended energy using DT requires lower cost than either 2-hop or multi hop techniques. If d_{char} is exploited in cluster design, the transmission energy will be optimized for each node moreover, no additional cost will be overloaded to the nearest nodes. The residual energy variance of nodes is minimized, and then the energy cost is balanced over the whole nodes in the network.

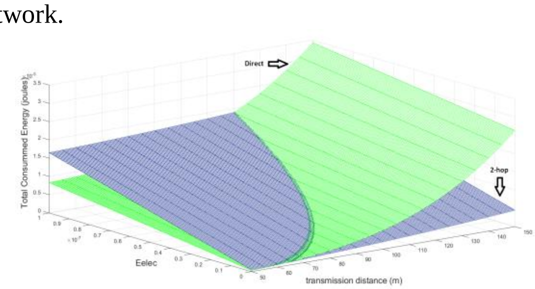


Figure 15. Total energy dissipated using DT and 2-hop routing (data length =4000 bit).

7. SIMULATION RESULTS

In this section, MATLAB simulator is used to evaluate our recommended design for cluster dimensions. Our simulation environment consists of n=104 nodes, 100 of them are randomly deployed through 300x300 sensing field, while the other 4 nodes have pre-determined locations (75, 75), (225, 75), (75, 225) and (225, 225). The base station is located at the center. The initial energy of each node equals 0.5J. The radio parameters are set to those in Table1. Using Table2 to implement our recommended design, the network is divided into 4 identical clusters as shown in Fig. 16. Transmission of data for DT, MTE, LEACH and our proposed design is simulated for only one round. The energy cost is shown in Fig. 17. It is observed that our design has the least energy cost compared to others, and then the transmission energy is optimized for the whole network. This plays an important role in enhancing the network lifetime after several sequences. In Fig.18, the residual energy of nodes after only one round is shown. The residual energy of our Proposed Design (PD) is nearly constant compared to the other transmission manners, hence our design helps in minimizing the variance of nodes through the network. Since the transmission energy for each node is optimized, energy whole problems are avoided.

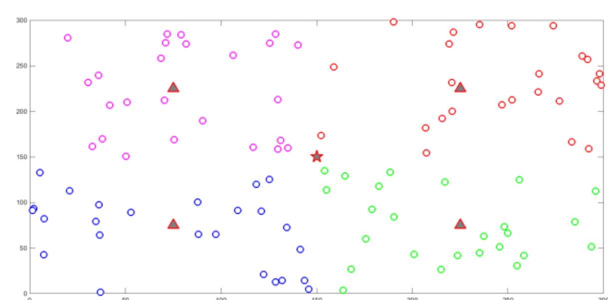


Figure 16. Network Model.

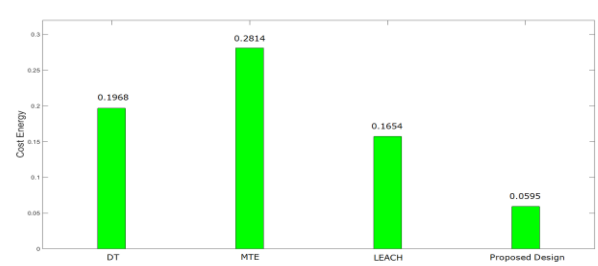


Figure 17. Total energy cost per round.

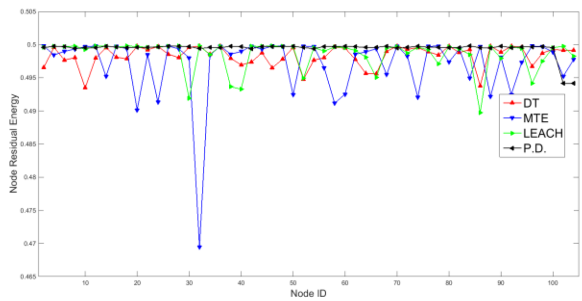


Figure 18. Residual energy of nodes after one round.

8. CONCLUSIONS

In this work, it's assumed that there is always threshold distance called characteristic distance d_{char} which used as a judging metric to specify the efficient transmission manner between two points. It is not allowable to use Multi Hop transmission with smaller distances than d_{char}. After comprehensive analysis of transmission energy for different transmission manners, we get that; this d_{char} doesn't depend on the data size, but it is totally depending on the design parameters. The effects of these design parameters are studied deeply with curves. d_{char} is exploited in CH design, as it's used as the maximum allowable distance between any two connected nodes within the cluster, hence the dimension of CH can be estimated initially depending on the design parameters whatever the nature of the sensing field. The simulation results show that, our design minimizes the variance in node power levels as the transmitted energy is optimized for each node within the cluster. Moreover, it reduces Energy cost; hence the energy performance of the whole network is enhanced.

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Abd Elwahab Fawzy received his B.Sc. degree in electronics and electrical communications engineering from Menofia University, Egypt, in 2013. Currently, he is demonstrator at the Department of electronics and electrical communications engineering, His major research interests include sensorNetworks, mobile communications, and network Security.

Mona Shokair received the B.E. and M.E. degrees in electronics engineering from El Menofia University, El-Menofia, Egypt, in 1993 and 1997, respectively. She received Ph.D. from Kyushu University, Japan, 2005. She was a lecturer in El-Menofia University from 2006 to 2011. Since 2012, she is Associated Professor in El-Menofia University. She received VTS chapter IEEE award from Japan in 2003. Now her current research is in OFDM system, WIMAX system, and cognitive radios.

Waleed Saad has received his BSc (Hons), M.Sc. and Ph.D. degrees from the Faculty of Electronic Engineering, Menoufia University, Menouf, Egypt, in 2004, 2008 and 2013, respectively. He joined the teaching staff of the Department of Electronics and Electrical Communications of the same faculty since 2014. In 2005 and 2008, he worked as a demonstrator and assistant lecturer in the same faculty, respectively. He is a co-author of many papers in national and international conference proceedings and journals. His research areas of interest include mobile communication systems, computer networks, cognitive radio networks, D2D communication, OFDM systems, interference cancellation, resource allocations, PAPR reduction, physical and MAC layers design, and implementation of digital communication systems using FPGA.

Asmaa Amer received her B.Sc. degree in electronics and electrical communications engineering from Menofia University, Egypt, in 2013. Currently, she is demonstrator at the Department of electronics and electrical communications engineering, Her major research interests include sensor Networks, mobile communications, and network Security.