STUDY OF HETEROGENEOUS ENERGY MODELS IN WIRELESS SENSOR NETWORKS

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Abstract: Wireless sensor networks (WSNs) are separated into two categories based on their sensor nodes as homogeneous sensor networks and heterogeneous sensor networks. Recently, various heterogeneous energy models are discussed in which sensor nodes have different level of energy. In this paper, various heterogeneous energy models, which consist of two-level, three-level, four-level, and multi-level heterogeneity are discussed. The categorization of number of nodes and their respective energies for all the levels are also discussed. Furthermore, as the level of heterogeneity increases, the lifetime of the network also increases.

INTRODUCTION

WSNs consist of low battery power, low-complex and low-size devices, which are called as sensors. A sensor node can sense the area to gather data from the monitoring field and communicate that data through wireless links. The Collection of data by a sensor node is forwarded via single or multiple hops to a particular node, called as a base station and it can utilize the received data or it can forward to other networks connected through internet. On the basis of computational capability and energy contents, a WSN can be homogeneous or heterogeneous network. In a homogeneous WSN, there are tiny resource-constrained devices that have the same hardware capabilities [1]. The heterogeneous WSN employs devices of different capabilities. The sensors which are cheap are deployed with high density for monitoring the objects and the more powerful nodes provide persistent data storage, intensive processing and actuation. In real world applications, the heterogeneous WSNs have been found a better option than the homogeneous WSNs in the majority of cases. For example, in a battlefield, the sensor nodes need to be equipped with different energy levels in order to perform multiple tasks [2,3]. In heterogeneous WSNs, the workload is distributed among the nodes depending on their capabilities. In a heterogeneous network or non homogeneous network sensor nodes have different level of energy such as two-level, three-level, four-level etc. A WSN also can be used in several applications such as humidity, national security, temperature, healthcare, environmental monitoring, vehicular movement, pressure, soil makeup, noise levels, presence or absence of certain types of objects. Sensor network applications can be divided into two groups: querying applications and tasking applications. In querying applications, the information collected by sensors is processed based on the query that triggers the data collection action; for example, collecting the data about an event in the monitoring environment. In querying applications, the data collection is triggered by an event that is to be observed by the network. An event triggering forces the sensor node to perform some action. The data aggregation is done in order to avoid duplication of data as the adjacent nodes may send some identical data to sink. Sensors can also be coordinated to get a better idea about the event; for example, some sensors can be moved closer to the event.

In most of the WSNs, the battery is the sole energy source of a sensor node, which is generally impractical to charge or replace the exhausted battery unlike in other wireless networks. The sensor nodes are expected to work on batteries from several months to a few years without replenishing. The energy of a node has direct impact on the lifetime of a WSN because decrease in the power consumption increases the network lifetime [4]. Thus, the energy efficiency and its usage is an important design issue of a WSN.

A sensor consists of processing unit, sensing unit, transceiver and power unit. The processing unit has low speed processor and small size memory. The sensing unit contains sensing device to sense an event in the monitoring region and analog to digital converter (ADC). A sensor collects data in analog form and converts it into digital form for further processing. The transceiver unit contains transmitter and receiver to connect the processing unit to a base station which in turn is connected to external network. The power unit that does not have external supply provides energy to all units of the sensor. Besides these four units, a sensor can have some more units such as location finding unit and mobilizer depending on the application. The utility of a WSN lies in the fact that it is easily deployable, less costly, and does not require a fixed infrastructure. The crucial application of a WSN is that it can be used to collect information in such environments wherein it is not possible in any other way [5,6]. Besides their utilities in a variety of applications, the developments in MEM-based sensor technology have attracted researchers towards the WSNs. The rest of the paper is organized as follows. The various heterogeneous energy models are discussed in Section II. Finally the paper is concluded in Section III.

VARIOUS HETEROGENEITY ENERGY MODELS

In this section, various heterogeneous energy models for wireless sensor networks are discussed and they are given below.
a. Two-level heterogeneous model:
In two-level heterogeneity, there are two types of sensor nodes: advanced and normal nodes. Consider N sensor nodes that are deployed in a given rectangular area. Let $E_0$ be the initial energy of a normal node and $m$ be the fraction of the advanced nodes, which own a times more energy than the normal ones. Thus there are $mN$ advanced nodes equipped with initial energy of $E_a = (1 + \alpha)E_0$ and $(1 - m)N$ normal nodes equipped with initial energy of $E_0$. The total energy for two-level heterogeneity, denoted by $E_{two}$, of the network [1-13] is given by

$$E_{two} = N \times (1 - m) \times E_0 + N \times m \times E_a = (1 + \alpha)E_0 \times N \times m \times (1 + \alpha)$$

$$E_{two} = N \times E_a \times (1 + m \times (1 + \alpha))$$

(1)

b. Three-level heterogeneous models:
In this subsection, various three-level heterogeneous energy models are discussed and they are given below:

i. In this three-level heterogeneity model, there are three types of sensor nodes: super, advanced, and normal nodes. Consider $m$ fraction of $N$ as advance nodes and $m_1$ fraction of the advance nodes as super nodes. The normal nodes have $E_0$ as initial energy. The energies of advance and super nodes are respectively $E_a = (1 + \alpha + \beta)E_0$ and $E_s = (1 + \alpha + \beta + \gamma)E_0$. The total energy for three-level heterogeneity, denoted by $E_{three}$, of the networks [2-13] is given by

$$E_{three} = N \times (1 - m - m_1) \times E_0 + N \times m \times (1 - m_1) \times E_a \times (1 + \alpha + \beta) + N \times m_1 \times E_s \times (1 + \alpha + \beta + \gamma)$$

$$E_{three} = N \times E_a \times (1 + \alpha + \beta + \gamma) + N \times E_s \times (1 + \alpha + \beta + \gamma)$$

(2)

Thus, energy model in (2) can describe 1-level, 2-level and 3-level heterogeneity in a WSN.

ii. Here, a heterogeneity energy model to increase the network lifetime in a wireless sensor network is discussed [14, 15]. This model divides the nodes in the network into three classes, called as tier-1, tier-2, and tier-3 nodes. Assuming $\alpha$ as the total number of sensor nodes in the network, the number of tier-1 nodes is given by $(1 - (\beta/2))$ times of $\alpha$. The energy of a tier-1 node is assumed to be $1$ times of a normal node. The number of tier-1 nodes, $P$, is given by the following relation

$$P = (1 - (\beta/2) - \beta)$$

(3)

Assuming the number of tier-2 nodes as $\beta$ times of their number, $\gamma$, is given by the following relation

$$\gamma = (\beta/2)$$

(4)

The energy of a tier-2 node is assumed to be $4$ times more than the tier-1 node. Assuming the number of tier-3 nodes as $\delta$ times of $\gamma$, the number of tier-3 nodes, $\delta$, is given by

$$\delta = (\beta/2) \times (1 + \beta)$$

(5)

The energy of a tier-3 node is assumed to be $4$ times more than the tier-1 node. The total energy of the network is given by the following relation

$$E_{total} = P \times E_0 + Q \times E_0 + R \times (1 + \Phi) \times E_0$$

(6)

Equation (6), using the values of $\alpha$, $\beta$, and $\delta$ from (3), (4), and (5), can be written as follows

$$E_{total} = \alpha \times E_0 + (3 \times \alpha) \times E_0 + \beta \times \Phi \times E_0 + ((\beta/2) \times \alpha) \times (1 + \Phi) \times E_0$$

On simplifying, $E_{total}$ is given by

$$E_{total} = \alpha \times E_0 \times (1 + \beta)$$

(7)

Thus, energy model in (7) can describe tier-1, tier-2 and tier-3 heterogeneity in a WSN.

iii. In this subsection, a heterogeneous model of 3-level for WSNs is considered [16-20]. Let $N$ be the total number of sensor nodes in a WSN, which are divided into $N$, $\leq N$, and $\geq N$ number of sensor nodes in increasing order of their energy levels, where $0 \leq i \leq 1$. The nodes $\leq N$ may be designated as type-1 nodes, which have lowest energy level. The nodes $\geq N$ have maximum energy and are designated as type-3 nodes. The nodes $\leq N$ have energy that lies between type-1 and type-3 nodes and they are termed as type-2 nodes. Normalization of $\leq N$, $\leq 2$ and $\leq 3$ gives $1 = -1$. Let $E_1$, $E_2$ and $E_3$ denote the energy levels of type-1, type-2 and type-3 nodes, respectively; thus, $E_1 < E_2 < E_3$. It also assume that the number of type-1 nodes is more than the number of type-2 nodes and the number of type-2 nodes is more than the type-3 nodes. This assumption is not unrealistic because the nodes having maximum energy are costliest and their number should be minimum possible in order to reduce the network cost. The nodes having least energy are cheapest and hence they can be maintained as per requirement. The total energy of the WSN, denoted by $E_{total}$, is given by

$$E_{total} = N \times E_1 \times \Phi + N \times E_2 \times \Phi^2 + N \times E_3 \times (1 - \Phi - \Phi^2)$$

(8)

It may be written as follows

$$E_{total} = N \times E_1 \times \Phi + N \times E_2 \times \Phi^2 + N \times E_3 \times (1 - \Phi - \Phi^2)$$

(9)

Its solutions are given below:

$$\Phi_1 = -\sqrt{(E_2 - E_1) - (E_2 - E_1)^2 + 4 \times E_1 \times (E_3 - E_1)} \times 2 \times (E_3 - E_2)$$

$$\Phi_2 = \sqrt{(E_2 - E_1) - (E_2 - E_1)^2 + 4 \times E_1 \times (E_3 - E_1)} \times 2 \times (E_3 - E_2)$$

(10)

The minimum and maximum values of $\Phi$ are given by

$$\Phi_1, \Phi_2$$

respectively. Since $\Phi_1, \Phi_2$ are lower bound of $\Phi$, the valid solution of (9) is $\Phi$. Thus, the new equation as the following (LB $< \Phi$ $< 1$)

$$1 \geq \sqrt{(E_2 - E_1)^2 + 4 \times E_3 \times (E_3 - E_1)}$$

(11)

From (10), equation as

$$E_2 - E_1 \leq E_3(E_3 - E_1)$$

This relation is justified as all initial energies are positive and $E_2 > E_3 > E_1$. 

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13
Relation (11) helps determining LB under the given constraints.
In order to describe two types of nodes in (8), i.e., to have type-1 and type-2 nodes, and need to abolish third term in (8), which can be done by the following equation:
\[ 1 - \Theta - \Theta^2 = 0. \]
(12)
The solutions of (12) are \((\sqrt{5} - 1)\) and \((\sqrt{5} + 1)\).
Since \(\text{LB} < 1\), the valid solution of (12) is \(\Theta = (\sqrt{5} - 1)\). For this value of \(\Theta\), the model in (8) contains type-1 and type-2 nodes as the third term becomes zero.
For \(\Theta\), it has only one type of node because first two terms in (8) become zero. This is the case of 1-level heterogeneity, which is also called homogeneous WSN.
Here the only problem is that the model contains type-3 nodes only. This problem can be handled if it write in terms of \(E_1\), \(E_2\), and \(E_3\). The simplest relation it can have is given below:
\[ \Theta = \frac{E_5}{n*E_3}, \]
(13)
where \(n\) is a positive integer greater than 1 (\(n>1\)).
In present case, it take \(n=2\).
The relation (13) does not assume \(E_1 = E_2\) or \(E_2 = E_3\) or \(E_1 = E_3\). It simply forces the model (8) to have type-1 nodes rather than the type-3 nodes for homogeneous case.
When \(\Theta = 1\), it may be noted that there can be different relations of \(E_1\), \(E_2\), and \(E_3\) for that forces the model (8) to have type-1 nodes when it has only one type of nodes. But it have taken one of the simplest relations that forces the model (8) to have type-1 nodes, when it describes the homogenous network, in addition to satisfying all other constraints such as \(\text{LB} < (\sqrt{5} - 1)\) and \(E_1 < E_2 < E_3\), where \(\text{LB}\) denotes lower bound that is determined from (13).
When \(\Theta = (\sqrt{5} - 1)\), there are two types of nodes as third term in (8) becomes zero for this value of \(\Theta\). In this case, the network can be considered as 2-level heterogeneous WSN. It may be noted that the model (8) contains type-1 and type-2 nodes, not type-3 nodes. For any value of \(\Theta\) satisfying the inequality \(\text{LB} \leq \Theta \leq (\sqrt{5} - 1)\), the model contains all three types of nodes. In this case, the network can be considered as 3-level heterogeneous WSN. Thus, energy model in (8) can describe 1-level, 2-level and 3-level heterogeneity in a WSN.

c. Four level heterogeneous model:
In this subsection, a stage-four heterogeneous network model that is capable to describe the stage-one, stage-two, stage-three and stage-four is discussed [21]. Consider \(N\) be the entirety sensor nodes in the heterogeneous network. The entirety nodes for all four stage of heterogeneity in the network are denoted as \(N_1\), \(N_2\), \(N_3\), and they must satisfy the inequality \(N_1 > N_2 > N_3\).
In the network total energy is specified by
\[ E_{\text{total}} = \alpha* N * E_0 + \alpha^2 * N * E_1 + \alpha^3 * N * E_2 + \alpha^4 * N * E_3. \]
(14)
Where, \(\alpha\) is a parameter and \(E_0\), \(E_1\), \(E_2\), and \(E_3\) are the energies of stage-one, stage-two, stage-three, and stage-four nodes that must satisfy the inequality \(E_0 \leq E_1 \leq E_2 \leq E_3\).
The energy of stage-\(i\) sensor node is associated to the energy of stage-\(i\) nodes as follows:
\[ E_i = \alpha^i * N * E_0. \]
(15)
Using (14), (15) can be written as
\[ E_{\text{total}} = \alpha * N * E_0 + \alpha^2 * N * (E_0 + \theta_2) + \alpha^3 * N * (E_0 + \theta_2 + \theta_3) + \alpha^4 * N * (E_0 + \theta_2 + \theta_3 + \theta_4) \]
are new parameters.
It can further be simplified as
\[ E_{\text{total}} = N * (E_0 + (\alpha + \alpha^2 + \alpha^3 + \alpha^4)) + (\alpha^2 * \theta_2 + \alpha^3 * \theta_2 + \alpha^4 * \theta_2) \]
Stage-one heterogeneity: For \(\theta_1\), the model given in (16) contains only one type of nodes that are called as stage-one nodes and the total energy of the network for stage-one heterogeneity is given as
\[ E_{1-\text{stage}} = E_0 + (\alpha + \alpha^2 + \alpha^3 + \alpha^4) \]
The number of nodes in stage-one heterogeneity is given as
\[ N_1 = N * (\alpha + \alpha^2 + \alpha^3 + \alpha^4) \]
With the following condition
\[ \alpha + \alpha^2 + \alpha^3 + \alpha^4 \leq \text{LB} \]
Stage-two heterogeneity: For \(\theta_2\), the model given in (16) contains two types of nodes that are called stage-one and stage-two nodes and the total amount of energy of the network of stage-two heterogeneity is given as
\[ E_{2-\text{stage}} = E_0 + (\alpha + \alpha^2 + \alpha^3 + \alpha^4) + (\alpha^2 * \theta_2 + \alpha^3 * \theta_2 + \alpha^4 * \theta_2) \]
The number of stage-one and stage-two nodes in stage-two heterogeneity, denoted by \(N_1\) and \(N_2\), respectively, are given as
\[ N_1 = N * (\alpha + \alpha^2 + \alpha^3 + \alpha^4) \]
and \(N_2 = N * \alpha \)
With the following conditions
\[ \alpha + \alpha^2 + \alpha^3 + \alpha^4 \leq \text{LB} \]
Stage-three heterogeneity: For \(\theta_3\), the model given in (16) contains three types of nodes that are called stage-one, stage-two, and stage-three nodes and the total amount of energy of the network of 3-stage heterogeneity is given as
\[ E_{3-\text{stage}} = E_0 + (\alpha + \alpha^2 + \alpha^3 + \alpha^4) + (\alpha^2 * \theta_2 + \alpha^3 * \theta_2 + \alpha^4 * \theta_2) \]
The number of stage-one, stage-two and stage-three nodes in stage-three heterogeneity, denoted by \(N_1\), \(N_2\) and \(N_3\), respectively, are given as
\[ N_1 = N * (\alpha + \alpha^2 + \alpha^3 + \alpha^4) \]
\[ N_2 = N * \alpha \]
and \(N_3 = N * \alpha^3 \)
With the following conditions
\[ \alpha + \alpha^2 + \alpha^3 + \alpha^4 \leq \text{LB} \]
Stage-four heterogeneity: the model given in (16) contains stage-four of nodes that are called stage-one, stage-two, stage-three, stage-four nodes and the total amount of energy of the network of stage-four heterogeneity is given as
\[ E_{4-\text{stage}} = E_0 + (\alpha + \alpha^2 + \alpha^3 + \alpha^4) + (\alpha^2 * \theta_2 + \alpha^3 * \theta_2 + \alpha^4 * \theta_2 + \theta_3) \]
The number of stage-one, stage-two, stage-thrce, and stage-four nodes in stage-four heterogeneity denoted by \(N_1\), \(N_2\), \(N_3\) and \(N_4\), respectively, are given as
\[ N_1 = N * (\alpha + \alpha^2 + \alpha^3 + \alpha^4) \]
\[ N_2 = N * \alpha * \theta_2 \]
\[ N_3 = N * \alpha^3 \]
and \(N_4 = N * \alpha^4 \)
With the following conditions
\[ \alpha + \alpha^2 + \alpha^3 + \alpha^4 \leq \text{LB} \]
d. Multi-level heterogeneous network model:
In multi-level heterogeneity, the initial energy of sensor nodes is randomly allocated from the given energy interval \([E_0, E_0 + \text{LB}]\) where \(E_0\) is the lower bound of
the energy interval and $a_{\text{max}}$ determines the upper bound of the energy interval. Initially, the node $s_i$ is equipped with the initial energy of $E_0 = (1 + \alpha_1$, which is $a_1$ times more energy than the lower bound $E_0$ of the energy interval. The total initial energy of the network with multi-level heterogeneity [1,2,3], denoted by $E_{\text{multi}}$, is given by

$$E_{\text{multi}} = \sum_{i=1}^{N} E_0 (1 + a_i)$$

$$= E_0 \left( N + \sum_{i=1}^{N} a_i \right)$$

(17)

**An Example: How to use heterogeneity nodes?**

In this example, the scheduling in heterogeneous sensor nodes is considered. Here, three states for a sensor i.e, a sensor node can be in one of the three states: active, idle and deciding are discussed. In active state a sensor monitors the targets and in the idle / sleep state it conserves the energy. In the deciding state, it monitors targets and can change its current state.

In **2-level heterogeneity**, initially the advance nodes are active nodes and they monitor the targets. If any target is not covered by the advanced nodes then some of the normal nodes that can monitor uncovered targets become active nodes. When during the reshuffle time the energy level of the active nodes becomes less than that of the normal nodes, then some of the normal nodes that can cover all targets become active.

In **3-level heterogeneity**, initially the super nodes are active nodes and they cover the targets. In case some target is not covered by the super nodes, then some of the normal nodes that can monitor uncovered targets become active nodes. If some targets are still not covered by super/advance nodes, then some of the normal nodes that can monitor the uncovered targets become active nodes. When during the reshuffle time the energy level of the active nodes becomes less than that of the advance nodes (in case there are not active nodes) or normal nodes (which are not active nodes). These active nodes are replaced by the advance nodes. When the energy level of the active nodes becomes less than that of the super nodes (in active) or advanced nodes or normal nodes (in this order) then some of the super/advanced/normal nodes that can cover all targets become active nodes.

In **Multi-level heterogeneity**, initially the highest energy level nodes are active that cover all targets. If some targets are not covered by the highest energy level nodes, the nodes having less energy than the highest energy nodes that can cover the remaining targets become active. This process continues in a similar way as discussed for 3-level heterogeneity.

**CONCLUSION**

In this paper, different heterogeneous energy models have been discussed. The outcome of the paper can be summarized as follows. The performance of heterogeneous models increases as the level of heterogeneity increases, and it helps in prolonging the network lifetime.

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