3-Tier Heterogeneous Network Model for Increasing Lifetime in Three Dimensional WSNs

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Abstract. Homogeneous algorithms assume that the entire sensor node equipped with equal amount of energy. In this paper, a network model has been proposed which incorporate heterogeneity in term of their energy. The term heterogeneity means nodes equipped with dissimilar amount of energy. This model contains three tier node heterogeneity namely tier-1, tier-2, and tier-3 heterogeneity. We assume that nodes are equipped in three dimensions, not mobile, and randomly distributed. It performance is compared with 3D-ALBP, called 3D-hetALBP. Finally, the simulation results demonstrate that our proposed heterogeneous algorithm is more effective in prolonging the network lifetime compared with 3D-ALBP.

Keywords: Heterogeneous, target, sensing range, energy efficiency, sensor network.

1 Introduction

In last couple of years, there have been many studies on wireless sensor networks (WSNs) with respect to their applications in different areas such as security, health, disaster relief, environment, and home applications. Recent advancements in WSNs have enabled the development of low cost sensor networks. There are many issues that affect the design of WSNs such as fault tolerance, scalability, production costs, hardware constraints, network topology, transmission media, power consumption, etc. One of the major restrictions of these sensors is their limited energy. In a WSN, the sensor nodes are scattered in a region of interest and they have self-organizing ability. They collect information from the monitoring region, aggregate it, and then send it to sink or base station through a wireless link for further processing [1]. Since a sensor node has limited energy, it can transmit data to short distance and hence it is not possible in all deployments for a sensor node to directly communicate with sink. One of the most important features of sensor networks is cooperative effort of the sensor nodes. The sensor nodes allow random deployment strategies for different applications. Many distributed and centralized techniques concentrate on minimizing sensing energy by using smart scheduling, adjusting sensing ranges, heterogeneity and maximizing cover sets. In centralized techniques, it is assumed that a single node,

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usually called base station, has access to the entire network information such as sensing range, location and residual energy of all sensors. Using this information, the base station computes a schedule, which is then provided to each sensor node. In a distributed technique, a sensor can exchange information with its neighbors within a fixed number of hops, which is usually 1- or 2-hop information and then makes scheduling decision, i.e., it decides to move to on or off state. In off state, a sensor saves its energy. One of the solutions for energy problem is to implement mechanisms for efficient energy management. The important methods of efficient energy management are based on scheduling the sensor activity. In scheduling, a sensor node may be in one of the three states at a single time such as active state, deciding state and idle or sleep state. Implementation of energy heterogeneity in network may be another solution for energy problem. There is many type of resource heterogeneity in WSNs such as link heterogeneity, energy heterogeneity and computational heterogeneity, but energy heterogeneity plays a more vital role. All other resource heterogeneities indirectly depend on the energy heterogeneity. In energy heterogeneity, all sensor nodes in a sensor network have different amount of energy. Here, we have use load balancing protocol with adjustable sensing range for incorporating heterogeneity and three dimensions deployment of sensor nodes. In this paper, we propose an energy-efficient heterogeneous network model for maximizing the active duration of a sensor network. For energy-efficient network we use both scheduling and heterogeneity. Our proposed work describes 3-tier of heterogeneity of nodes in a network, called tier-1, tier-2 and tier-3 nodes. The tier-3 nodes have more energy as compared to the tier-1 and tier-2 nodes, and the tier-2 nodes have more energy than that of the tier-1 nodes. The number of sensor nodes in tier-1 is larger than that of the tier-2 and tier-3 nodes each.

The remaining of the paper is organized as follows. In Section 2, we discuss the literature survey related to prolonging the lifetime problems of sensor networks. Section 3 discusses the design of our 3-tier network model and deployment strategy. Section 4 provides a performance evaluation of the proposed work. We conclude the paper in Section 5.

2 Literature Review

In this section, we review the work related to prolonging the lifetime of WSNs. There are different approaches for increasing the network lifetime that include disjoint and non disjoint cover sets, scheduling, adjustable sensing range, and heterogeneity of sensor nodes.

In [2], Slijepcevic & Potkonjak discuss disjoint cover sets by dividing the monitoring area into the fields. Each field is observed by at least one sensor and each sensor covers one or more fields. In this method, the mutually exclusive sets of sensor nodes are selected in such a way that they can cover the entire monitored area. All cover sets remain active for equal amount of time and only a single cover set is active at a time. Berman et al. [3] has extended the work [2] by using scheduling mechanism to schedule the cover sets for enhancing the network lifetime. In [4], Berman et al. discuss another method, called load balancing protocol (LBP), for maximizing the lifetime. The LBP allow sharing the load among sensors and balancing the energy for sensors covering a target. This method uses scheduling mechanism and does not require cover sets to be disjoint. In scheduling, a sensor can be in one of the three states namely active, sleep and vulnerable. Initially, all sensors are assumed to be in vulnerable state. They broadcast their battery tiers along with the target covering information to its neighbouring nodes. By using this information, a neighbouring sensor changes its state and stay in that state until another sensor cannot cover the same target. The drawback of LBP is that it balances the load among the sensors rather the energy for covering the target. This problem has been overcome in a new deterministic energy- efficient protocol (DEEPS) [5]. In this method, the sensors can change their states from idle to active or vice versa while monitoring or communicating. It basically minimizes the energy consumption rate in sensing a target by sending the sensor nodes into sleep mode that have smaller energy with respect to that target. Cardei et al. [6] discuss adjustable range set covers (AR-SC) problem in which a maximum number of (non-disjoint) set covers are determined and the range of each sensor in such a way that each set covers all targets. The energy consumption of the sensor nodes is optimized by using the adjustable sensing range approach. Dhawan et al. [7] discuss two distributed algorithms to maximize the network lifetime for target coverage by providing adjustable sensing and communication ranges capabilities to sensors. Their works may be considered as an enhancement of distributed algorithms for fixed range sensors [4, 5].

The energy consumption can also be optimized if the sensor network supports node heterogeneity. Some of the important recent works based on heterogeneity are discuss in [8,9,10]. In [10], Qing et al. discuss two-level heterogeneity and multi-level heterogeneity model for WSNs. Two-level heterogeneity model considers the two types of sensor nodes. Categorization of sensor nodes is defined in term of their energies. The multi-level heterogeneity considers multiple types of nodes whose energies are defined from a given energy interval. Kumar et al. discuss a three level heterogeneous network model that considers three types of sensor nodes [8,9] namely normal, advanced and super nodes. The energy of a super node is larger than that of a advance node and that of a advance node is larger than that of a normal node. In this model, the number of normal nodes is more than the advance nodes and the number of advance nodes is more than the super nodes. In our proposed work, we also use three types of sensor nodes: tier-1, tier-2 and tier-3 that resemble to normal, advance and super nodes, respectively. Furthermore, we deploy the sensor nodes in 3-D environment. Our proposed model performs better than the existing models [8,9]. In next section, we discuss a proposed heterogeneous network model for wireless sensor networks.

3 Proposed Heterogeneity Network Model

In this section, we propose a heterogeneity energy model for increasing the lifetime of wireless sensor network. In this model network, the nodes are categorized into three types namely tier-1, tier-2 and tier-3. Let n be the total number of sensor nodes in a given network. The number of tier-3 nodes is $m/2$ times of the total nodes, each having α times more energy than that of a tier-1 node. Thus the number of tier-3 nodes, denoted by N_3, is given by

$$N_3 = ((m/2)*n) \tag{1}$$

The number of tier-2 nodes is m times of the total nodes, each having $\alpha/2$ times more energy than that of a tier-1 node. Thus the number of tier-2 nodes, denoted by N_2, is given by

$$N_2 = (m*n) \tag{2}$$

The remaining nodes are the tier-1 nodes, each having energy E_0. Thus the number of tier-1 nodes in the network, denoted by N_1, is given by

$$N_1 = n-N_2-N_3 = n-(m/2)*n-(m*n)$$

$$N_1 = ((1-(m/2)-m)*n) \tag{3}$$

The total energy of the network is obtained as the sum of energies of all tier-1 nodes, tier-2 nodes, and tier-3 nodes. Mathematically it is given as follows.

$$E_{total} = N_1*E_0 + N_2*\alpha*E_0 + N_3*(1+\alpha)*E_0 \tag{4}$$

Putting the values of N_1, N_2 and N_3 from (1), (2)and (3) in (4).

$$E_{total} = ((1-(m/2)-m)*n)*E_0 + (m*n)*\alpha*E_0 + ((m/2)*n)*(1+\alpha)*E_0$$

$$E_{total} = n*((1-(m/2)-m)*E_0 + m*\alpha*E_0 + (m/2)*(1+\alpha)*E_0)$$

After simplifying, we have E_{total} as follows.

$$E_{total} = n*E_0*(1+m*\alpha) \tag{5}$$

From (5), it shows that, the total energy of the network has increased by a factor of $(1+m*\alpha)$. In this network model, the deployment of sensor nodes is made in three dimensions. The points (x, y, z) covered by a sensor with range r that is centered at (x_1, y_2, z_3) satisfy the following relation.

$$(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 = r^2$$

$$(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2=r^2 \tag{6}$$

Equation (6) indeed represents a sphere in 3-D whose radius is r and centre is (x_1, y_2, z_3). All the points inside the sphere or its boundary will be monitored by the sensor placed at its centre.

4 Simulation Results and Discussions

In this section, we discuss the implementation of ALBP protocol for our proposed network model. This model explains 1-tire, 2-tire, and 3-tire heterogeneity of a WSN, and we call it as 3D-hetALBP. The energy models used in our simulation results are linear and quadratic energy models, commonly used energy models in literature [4,5]. The linear model is given by $e_p = c_1 * r_p$, where c_1, a constant, is given by $c_1 =$

$\frac{E_{Total}}{\sum_{r=1}^{p} r_p}$ and e_p refers to energy to cover a target at distance r_p. The quadratic model is given by $e_p = c_2 * r_p^2$, where c_2, a constant, is defined by $c_2 = \frac{E_{Total}}{\sum_{r=1}^{p} r_p^2}$.

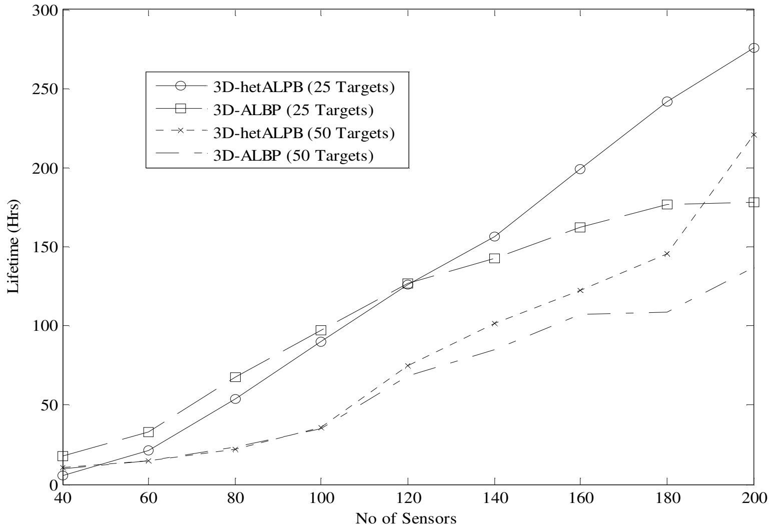

Fig. 1. Network lifetime with respect to number of sensors for linear energy model at 30M sensing range

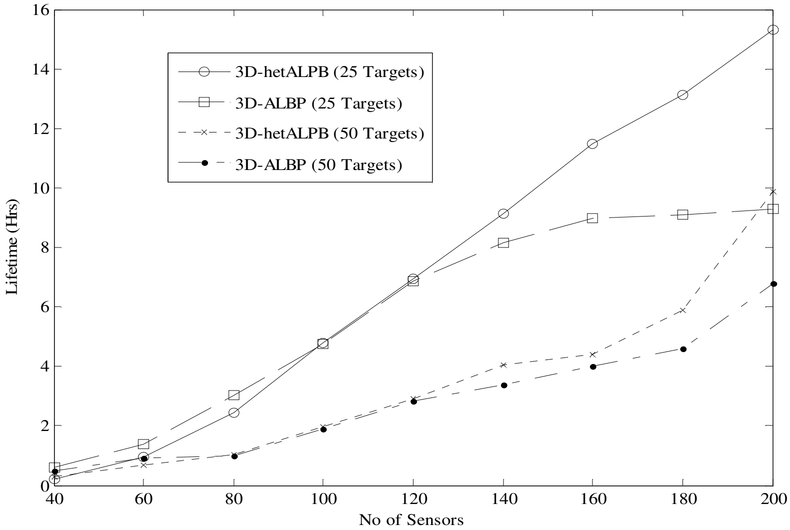

Fig. 2. Network lifetime with respect to number of sensors for quadratic energy model at 30M sensing range

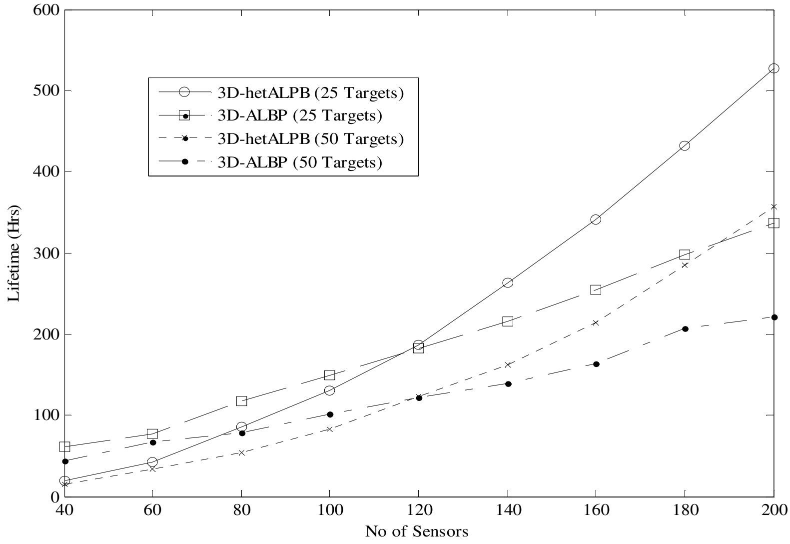

Fig. 3. Network lifetime with respect to number of sensors for linear energy model at 60M sensing range

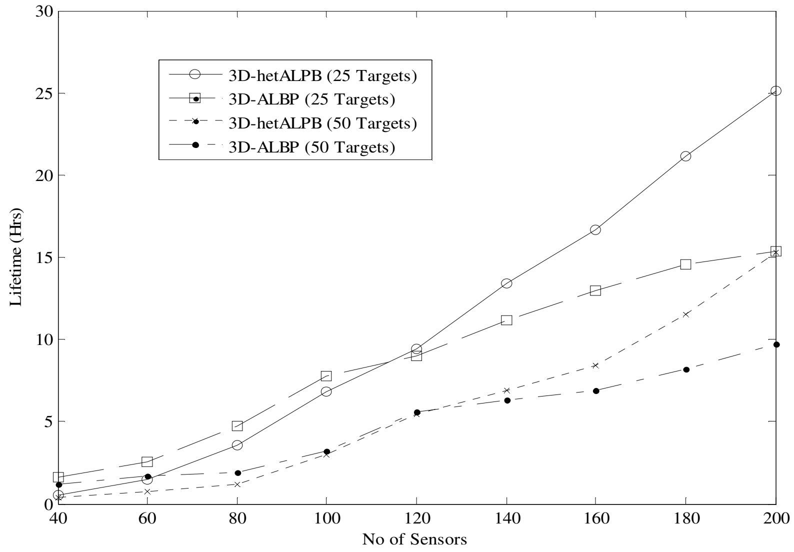

Fig. 4. Network lifetime with respect to number of sensors for quadratic energy model at 60M sensing range

We take monitoring area of size 100Mx100M for hosting two different number of targets i.e., 25 and 50 targets. The number of sensor nodes varies from 40 to 200 by taking two different maximum sensing ranges as 30M and 60M. We have used sensor initial energy as 2J and the values of α and m are taken as 2 and 0.3, respectively. In this scenario, we have carried out simulations for several sets of initial energies of the nodes and parametric values. In all cases, we got similar kinds of results: however, we have shown simulation results for the above mentioned input parameters, which are shown in Figs.1-4.

Figs 1 and 2 show the results for homogeneous 3D-ALBP and 3D-hetALBP using linear and quadratic energy models, respectively. Each of these figures shows network lifetime with respect to the number of sensors for sensing range 30M and, 25 and 50 targets, for homogeneous 3D-ALBP, 3D-hetALBP protocols. It is evident from these figures that the 3D-hetALBP protocol provides longer lifetime than that of the homogeneous 3D-ALBP protocol. We also observe from these figures that increasing the number of sensors increases the network lifetime. In Figs. 3 and 4, the sensing range has been taken as 60M and remaining parameters are kept unchanged. The heterogeneous 3D-hetALBP significantly performs better than the homogeneous 3D-ALBP. Increasing the density of targets decreases the network lifetime, whereas increasing the density of sensor nodes increases the network lifetime.

Figs. 5 and 6 show the network lifetime for our heterogeneous network model and existing heterogeneous network model [8,9] for linear and quadratic energy models, respectively, for the input parameters: 200 number of sensors, 25 & 50 targets, and 30M & 60M sensing range. It is evident from these figures that our proposed heterogeneous network model performs better than the existing model [8,9].

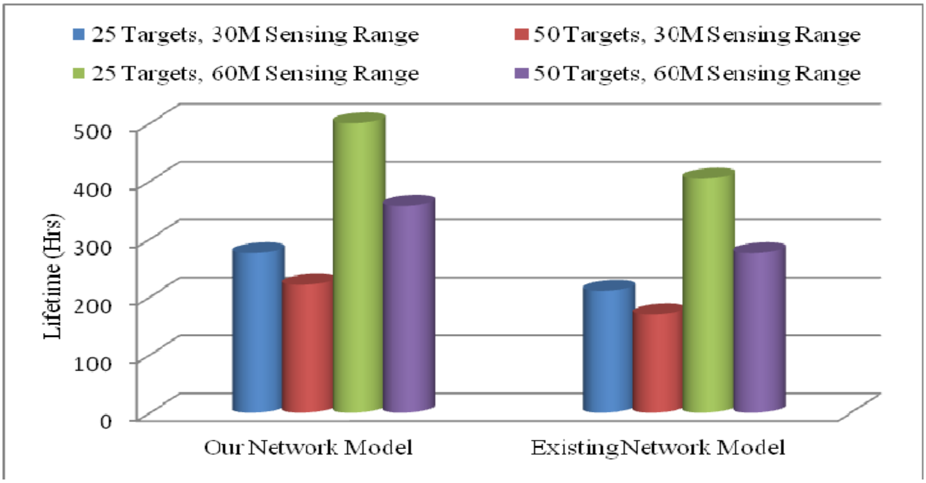

Fig. 5. Network lifetime comparison our and existing network model for linear energy model at different targets and sensing range

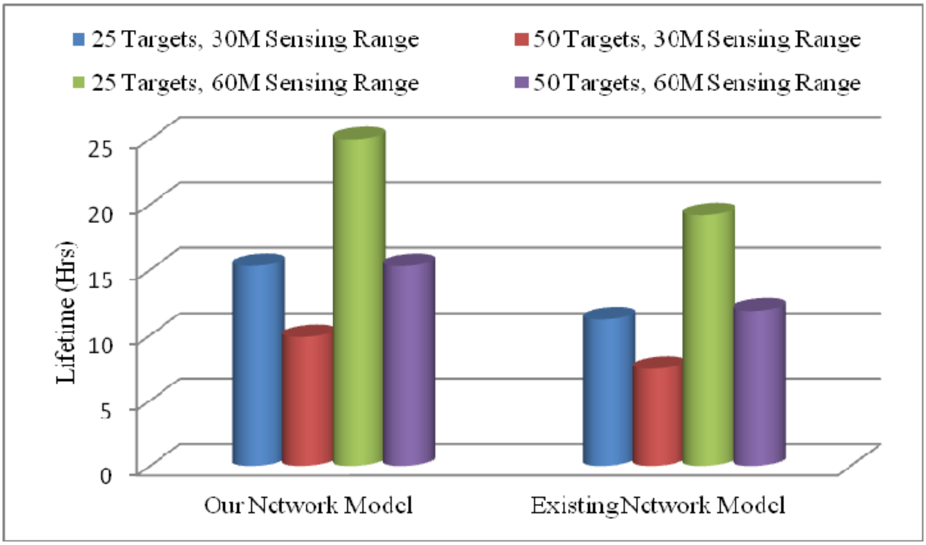

Fig. 6. Network lifetime comparison our and existing network model for quadratic energy model at different targets and sensing range

Another important parameter for network lifetime is the number of rounds when the first and last sensor nodes become dead. Tables I & II show the number of rounds when first and last nodes become dead for linear and quadratic energy models. It is evident from these tables that the first and last nodes become dead in more number of rounds using 3D-hetALBP than that of the homogeneous 3D-ALPB for both the linear as well as quadratic energy models.

Table 1. Round number when first and last nodes dead using linear and quadratic energy models in homogeneous 3D-ALBP and 3D-hetALBP for 30M sensing range, 200 sensors in 100Mx100M

30 M Sensing range and 200 number of sensors				
Cases	Linear energy model		Quadratic energy model	
	First node dead	Last node dead	First node dead	Last node dead
3D-hetALPB (25 Targets)	268	348	19	31
3D-ALBP (25 Targets)	166	186	06	21
3D-hetALPB (50 Targets)	249	257	11	25
3D-ALBP (50 Targets)	138	145	03	23

Table 2. Round number when first and last nodes dead using linear and quadratic energy models in homogeneous 3D-ALBP and 3D-hetALBP for 60M sensing range, and 200 sensors in 100Mx100M

60 M Sensing range and 200 number of sensors				
Cases	Linear energy model		Quadratic energy model	
	First node dead	Last node dead	First node dead	Last node dead
3D-hetALPB (25 Targets)	562	657	18	109
3D-ALBP (25 Targets)	314	409	08	100
3D-hetALPB (50 Targets)	339	418	07	77
3D-ALBP (50 Targets)	206	255	04	69

5 Conclusion

In this paper, we have proposed the 3D-hetALBP, an implementation of ALBP using 3 dimensional deployment and the heterogeneity model of tier-3 for WSNs. The model is capable to describe tier-1, tier-2 and tier-3 heterogeneity. The 3D-hetALBP provides longer network lifetime than the 3D-hetALBP for both linear and quadratic energy models. Furthermore, increasing the sensing range increases the lifetime of the heterogeneous sensor networks.

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