Paper

Performance Comparison of Homogeneous and Heterogeneous 3D Wireless Sensor Networks

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Abstract—Recent developments in wireless sensor networks include their applications in safety, medical monitoring, environment monitoring and many more. Limited battery energy and efficient data delivery are most considered constraints for sensor nodes. Depletion of node battery ceases functioning of the node. The network lifetime can be enhanced with the help of Multi-Layer protocol (ML-MAC). This paper presents a practical approach including 3-dimensional deployment of sensor nodes and analyzes two different types of networks – homogeneous and heterogeneous WSNs. To analyze various QoS parameters, two types of nodes are considered in a heterogeneous network. The performance of both the networks is compared through simulations. The results show that ML-MAC performs better for a 3D heterogeneous WSNs.

Keywords—heterogeneous WSN, homogeneous WSN, ML-MAC, QualNet 6.1 Network Simulator, Wireless Sensor Networks.

1. Introduction

Wireless sensor networks (WSNs) consist of small sensor nodes. Typical sensor node consists of various parameter sensors, a microcontroller, a radio transceiver, and is mainly battery powered, which results in limited network lifetime. The WSNs are used in many fields such as habitat monitoring [1], [2] of wildlife [3] without intrusion, tracking of objects [4], ad hoc deployments for disaster management and precision agriculture [5]. WSNs are required to operate in an unattended environment for a long time in an autonomous way. Most of the WSNs existing run on battery supply and battery replacement or recharge is impossible. Scarcity of energy resource for sensor nodes may result in a short lifetime, so that energy management schemes are required to minimize energy consumption. It is important that the network nodes are low cost [6] to make sensor networks a technology that can be used in a large number of application areas.

In homogeneous WSNs, all sensor devices have the same characteristics such as energy consumption, processing capacity, and radio equipment. On the other side, if the devices that coexist in WSNs have different characteristics, the sensor network is referred as a heterogeneous WSN. In addition, sensors may sense different physical phenomena such as temperature, pressure, and humidity, thereby various reading rates are introduced at the sensors. All these characteristics can be considered as sources of heterogeneity of WSNs. The design of heterogeneous WSNs requires adaptive mechanisms that are able to react to different characteristics. For WSNs to be simple and energy conserving, limited processing resources and strong energy consumption constraints require Medium Access Control (MAC) methods.

In this paper, the performance of homogeneous and heterogeneous WSNs is compared by simulating a 3D sensor network in QualNet 6.1 network simulator. Further, the reduction in energy consumption is achieved by the use of ML-MAC protocol [7], which allows selective nodes to communicate and lets others to be inactive.

The remainder of this research paper is structured as follows. Related research works are described in Section 2. Simulation topology is elaborated in Section 3. Parameters for simulation evaluation are described in Section 4 and performance evaluation is presented in Section 5. Summary of this research paper is provided in Section 6.

2. Related Work

Energy conservation is an important research area for designing energy efficient wireless sensor networks. Jha *et al.* [7] proposed a multi-layer MAC (ML-MAC) protocol, which is a distributed content-based MAC protocol. In ML-MAC, time is divided into frames and each frame is divided into listen and sleep periods. The active period is sub-divided into L non-overlapping layers. A node wakes up only at its assigned layer timings. The simulation was done with 100 nodes in 200 s using ns2 simulator and Matlab and results show a significant reduction in node power consumption as compared to Sensor-MAC (S-MAC) protocol.

Thalore *et al.* [8] proposed an energy-efficient multi-layer technique (ML-MAC) for Wireless Personal Area Networks (WPANs) with 1000 nodes randomly deployed in a network to increase the network lifetime. The simulation was done using QualNet 5.2 software that supports sensor networks with large number of nodes and has sensor networks library for IEEE 802.15.4. The results show an improvement over 47% in network lifetime and improved throughput as compared to IEEE 802.15.4. This technique is further used to optimize the network parameters by varying node density and number of layers in a network [9].

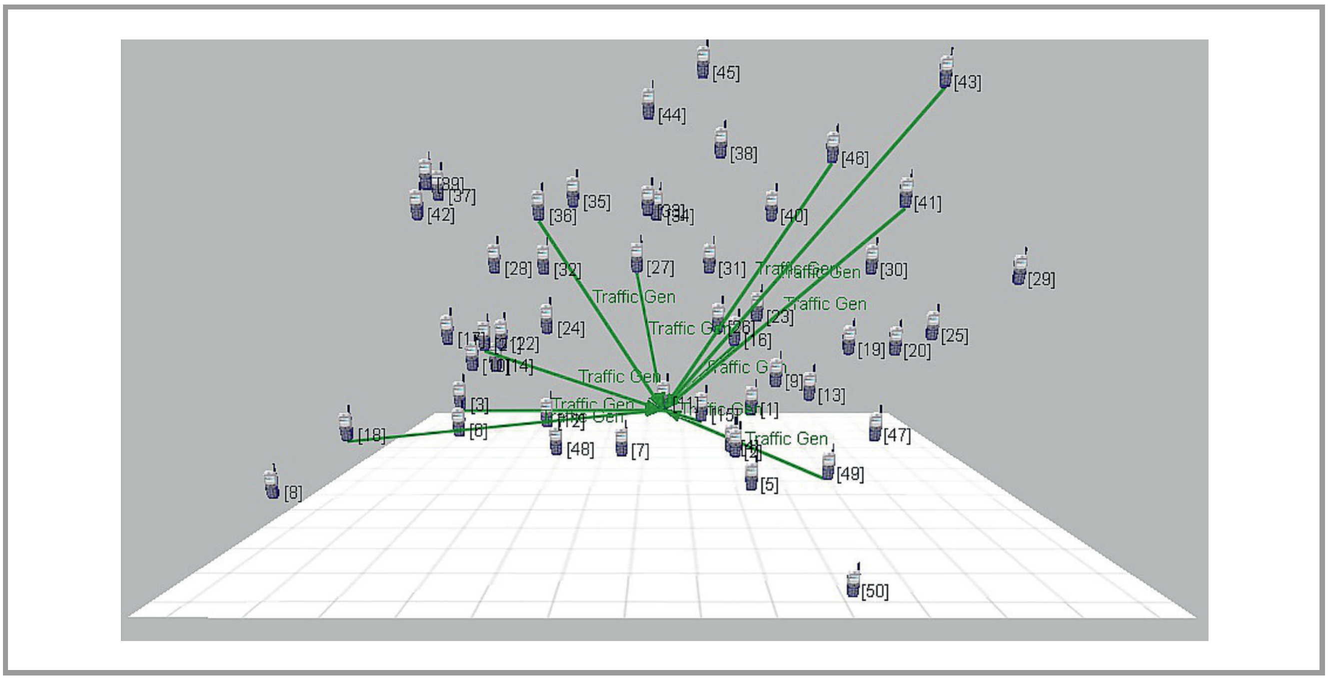

Fig. 1. Network scenario in QualNet simulator.

In most applications, sensor nodes are actually deployed in a 3D network but the performance analysis is done by considering the WSN as a 2D network. A number of researchers are considering the real time analysis of parameters to get exact analysis of the networks. Thalore *et al*. [10] evaluated the performance of IEEE 802.15.4 (ZigBee), in 2D and 3D terrains on the basis of QoS parameters like network lifetime, throughput, delay, and packets dropped. The work concentrated on the fact that a more practical way to analyze monitoring applications of WSNs includes designing a 3D network scenario. Gupta *et al*. [11] proposed a distributed protocol to schedule redundant sensors to sleep to minimize energy consumption. The scheduling reduces the number of active sensor nodes in a 3D heterogeneous network to prolong network lifetime.

Guo *et al*. [12] proposed a necessary condition for optimal deployment of sensors. This condition implies the coincidence of sensor node location and centroid of node's optimal sensing region. For the sensors with limited sensing range, dynamic deployment is used to improve sensing performance. Yuan *et al*. [13] developed an equilibrium model in order to find an optimum distribution strategy to improve the performance of predistribution protocols in terms of various parameters like cost, resilience, connectivity and lifetime. Heterogeneity is considered as an essential attribute of WSNs. The node deployment model uses supernetworks theory.

3. Simulation Topology

The main objective of the simulation is to compare the performance of 3D homogeneous and heterogeneous WSN using ML-MAC approach. The scenarios are simulated by varying the number of layers and keeping other network parameters as constant. ML-MAC approach for 3D sensor networks is implemented using QualNet 6.1.

The network topology in all the simulations uses wireless sensor nodes including one PAN coordinator (FFD) and $N-1$ end devices (RFDs) for homogeneous WSN while one PAN coordinator (FFD), $N-N_f$ end devices (RFDs) and N_f data forwarding nodes (FFDs) for heterogeneous WSN. The sensor nodes are deployed randomly over a $100 \times 10 \times 50$ m area for both networks. The 3D network is constructed in QualNet by taking the Z-plane into account. Because of random deployment, the distance between the source and sink nodes may vary. The sink node is a PAN coordinator (FFD) placed at the center of the network.

The network uses multilayering technique, which divides the network into L layers. During assigned simulation time, all the layers remain equally in active mode and the respective sensing nodes send sensed data during this time. The network supports two types of devices, a full function device (FFD) and a reduced function device (RFD). An FFD is provided with full protocol stack and can communicate with RFD and other FFDs. It can operate as a PAN coordinator, a coordinator or a device. On the other hand, an RFD is provided with limited protocol stack and can communicate with similar devices only (RFDs). RFD operates as a primary device, which senses data at primary level. Each network has one PAN coordinator (FFD) placed at centre, rest are devices (RFDs), which communicate either with PAN coordinator or with other FFDs (in case of heterogeneous network).

The traffic generation pattern is defined in the network by TRAF-GEN application, which is used for data packet generation. It helps each node generate a fixed number of messages according to specified inter-arrival rate. To route data from source to sink node in network, an ad hoc on demand distance vector (AODV) routing protocol [14] is used.

Figure 1 shows scenario in QualNet for 3D homogeneous and heterogeneous WSNs. The scenario setup for both the kinds of networks is same. The difference is the type of nodes that are used in the two networks.

3.1. Simulation Model in QualNet

Figure 2 shows the development environment platform in QualNet simulator, which allows developing custom codes, simulating their models and statistically analyzing performance metrics. In QualNet, WSN has been developed based on IEEE 802.15.4 standard and is modified to work as ML-MAC. The sensors are deployed on simulation terrain by using either drag& drop or specified placement model. They sense an activity based on range of sensor and location of activity.

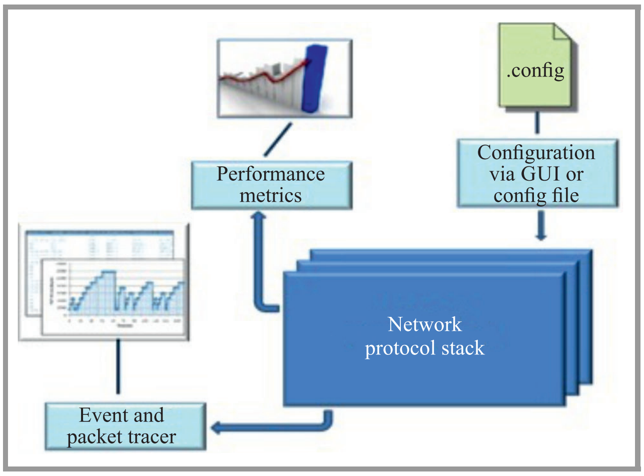

Fig. 2. Simulation model in QualNet 6.1 simulator.

While performing simulations, a WSN is considered with node density σ, which is deployed randomly on a 3D terrain. The network is centered at a PAN coordinator.

Figure 3 shows flowchart of the steps that are considered during network setup and simulation. The evaluation of network parameters depends upon the distance D_i between source and destination. Any event happening nearby a sensor node is detectable only if it is within the sensing range D_0 of the sensor.

Consider $\{n_1, n_2, \ldots, n_N\} \in N$ number of nodes in the network including the PAN coordinator, which are deployed randomly in a 3D environment. The network uses ML-MAC protocol, which divides the network into L non-overlapping layers with each layer having

$$N_i = \binom{N-1}{i} \text{ nodes}, \tag{1}$$

where $i = 1, 2, 3, \ldots, L$ and $L = 1, 2, 3, \ldots, 10$.

The node density σ for a 3D network can be expressed as:

$$\sigma = \frac{N_i}{A}, \tag{2}$$

where N_i is the number of active nodes in the network for a particular assigned layer and A is area covered by the network nodes.

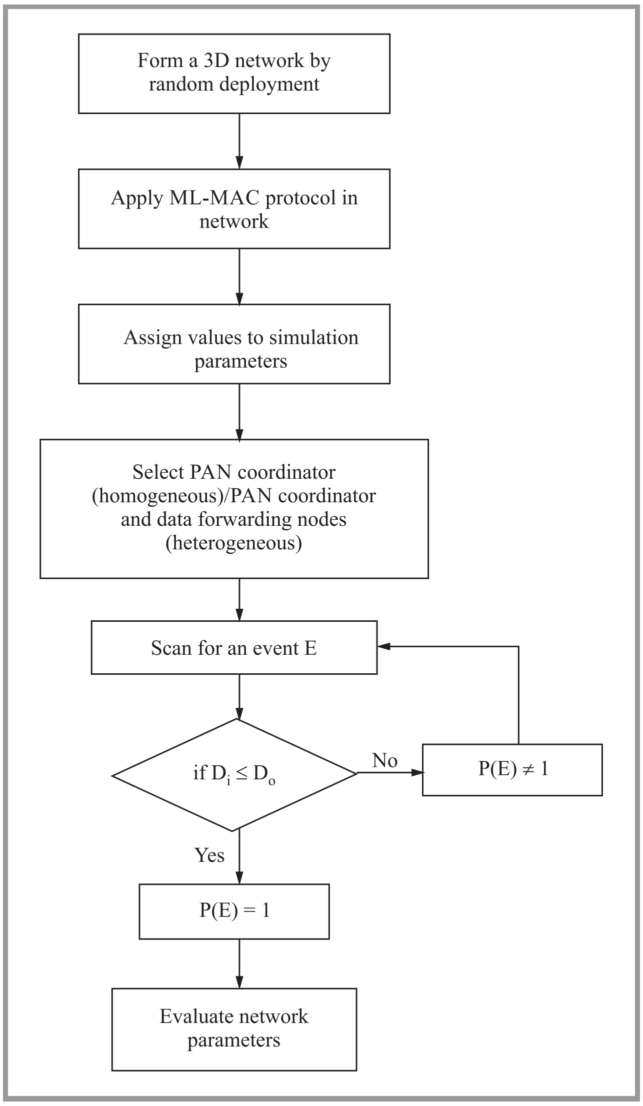

Fig. 3. Flowchart of steps during network simulation.

Equation (2) can also be written as

$$\sigma = \frac{N_i}{2(XY + YZ + ZX)}, \tag{3}$$

where X is network coverage on X-plane, Y is network coverage on Y-plane, Z is network coverage on Z-plane, and σ = density of 3D sensor network.

3.2. Node Attributes

It is assumed that network has only one PAN coordinator (sink node), with sufficient knowledge of network topology.

There are $N-1$ stationary sensor nodes acting as end devices, as well as data forwarding devices, which sense any activity happening and forward the information of the activity to the PAN coordinator respectively. All these nodes are battery powered with limited energy. All nodes in the network are provided with same initial energy and same transmission range.

4. Parameters of Simulation Evaluation

The performance parameters measured in this research paper are:

Network lifetime (NL). It is evaluated by residual energy of the nodes in the network [10]. The total consumed energy E_C is calculated, by the knowledge of total residual energy E_R and total initial energy E_t of the network:

$$E_C = E_t - E_R\,. \tag{4}$$

On the basis of consumed energy by the network over a specified simulation period, network lifetime is calculated as:

$$NL = \frac{(E_i \times T)}{E_C}\,. \tag{5}$$

Equation (4) is used to compare energy consumption in various terrains. To measure the energy consumption in a sensor network, different energy models are provided in QualNet.

Packet failure probability (P_{fail}). It is defined as failure of a transmitted packet from a node because of collision or interferences. The failure may occur if there is an overlap with a transmission of one node by other node.

$$P_{fail} = \frac{Number\_of\_frames\_collided}{Number\_of\_frames\_transmitted}\,.$$

Table 1
Simulation parameters for WSN

Parameter	Value
3D Area	$100 \times 100 \times 50$ m
Simulation time	3600 s
Number of nodes	100
Number of layers	varied from 1 to 9
Transmission range	30 m
Routing protocol	AODV
Antenna type	Omnidirectional
Message rate	1 packet/s
Message size	38 bytes
Energy model	Generic
Transmit circuitry power consumption	24.75 mW
Receive circuitry power consumption	13.5 mW
Idle circuitry power consumption	13.5 mW
Sleep circuitry power consumption	0.05 mW

Number of messages received (M). It is defined as number of data messages that are successfully received without collision on the destination or sink node.

Throughput (Th). It is calculated by counting total number of data frames received at the receiver node in one round of simulation time.

$$Th = \frac{Total\_number\_of\_data\_frames\_received\_at\_receiver}{Total\_simulation\_time}\,.$$

Table 1 shows list of parameters considered for the simulations for both homogeneous and heterogeneous WSNs in order to have proper comparison.

5. Performance Analysis of Outcomes

The simulations have been run for both homogeneous and heterogeneous 3D sensor networks using ML-MAC protocol keeping all the simulation parameters same (Table 1). Each set of simulations include a fixed node density and variable layers in a network.

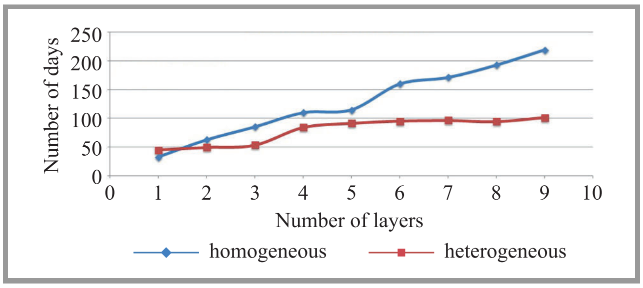

Fig. 4. Comparison of network lifetime for homogeneous and Heterogeneous WSNs.

Figure 4 compares the network average lifetime for homogeneous and heterogeneous WSNs. The graph indicates the life span of a network against the change in number of layers. Both the networks follows a similar trend with change in layers but since heterogeneous network has variety of nodes, the lifetime of heterogeneous network is less compared to homogeneous network, which follows star topology.

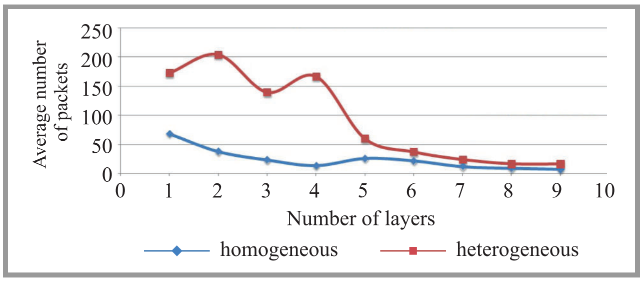

Fig. 5. Comparison of packets dropped for both networks.

Figure 5 compares number of packet dropped during channel access for data transmission. The graph indicates that for lower values of number of layers in network, packet drop rate is large in heterogeneous networks. However with increase in number of layers, the packet drop rate almost same for both the networks.

Figure 6 shows comparison of end-to-end delay for the both networks type. As the number of layers is increased, lesser nodes contend for the medium access for data transmission and thus the graph shows a significant decrease in delay in the network.

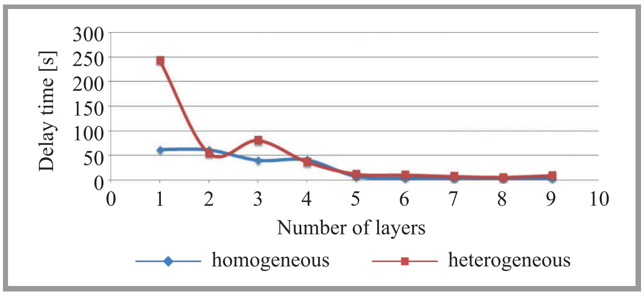

Fig. 6. Comparison of end-to-end delay for two networks.

Figure 7 shows the total data received by the PAN coordinator with change in number of layers for both networks. Figure 8 compares the throughput at the PAN coordinator receiver, which is the rate of message reception. Figures 7 and 8 follows the same pattern for homogeneous and heterogeneous WSNs.

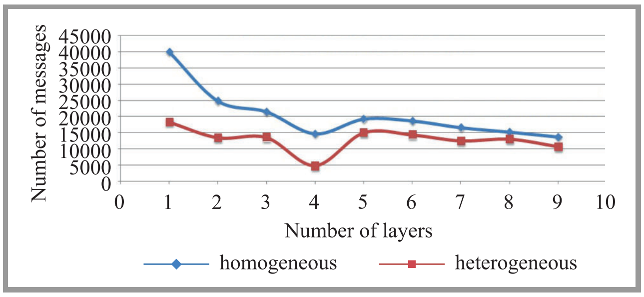

Fig. 7. Comparison of messages received for both WSN.

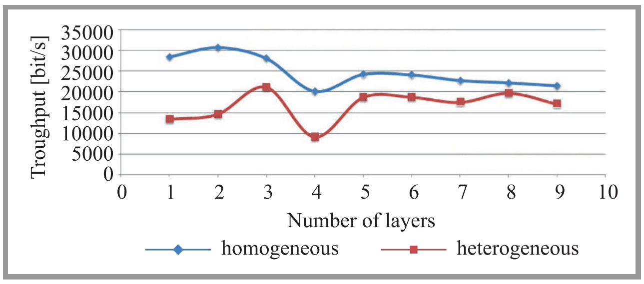

Fig. 8. Comparison of average throughput.

Figures 9 and 10 show the life chart of sensor nodes in Homogeneous and heterogeneous WSNs. The number of alive nodes in the network is calculated with the help of performance analysis metric from QualNet 6.1 called as Residual Battery Capacity, which provides the details

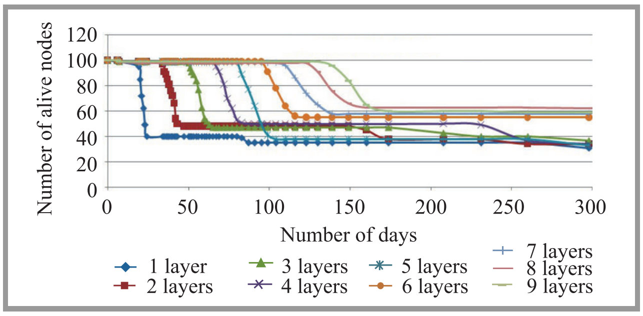

Fig. 9. Life chart of sensor nodes for homogeneous WSN.

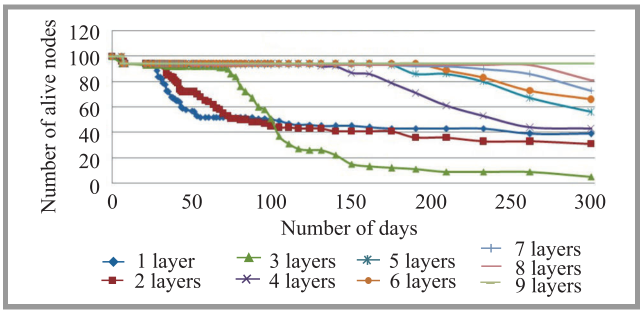

Fig. 10. Life chart of sensor nodes for heterogeneous WSN.

for individual nodes helping in calculating the lifetime of a sensor node.

6. Summary

The use of ML-MAC protocol improved the lifetime of network by the use of layers in the network. The results show that performance of a 3D sensor network follows the same trend for homogeneous as well as heterogeneous sensor networks. It is further recommended to vary the battery supply to the different nodes as per their functions in order to further improve the performance of heterogeneous network.

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