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Effect of Increasing Node Density on Performance of Threshold-sensitive Stable Election Protocol

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ABSTRACT

Wireless Sensor Network (WSN) has become an interesting field of research even as its technology is being used largely in Internet of Things (IoTs) and many areas of human endeavour such as civil surveillance, medical diagnosis and so on. This has attracted several research interest including improving the routing and energy efficiency of the sensor nodes in the network to prolong the life of the nodes and the entire system robustness. Hence, many routing protocols have been proposed to improve sensor networks. Nevertheless, most of the proposed protocols are implemented with just some 50 to 100 sensor nodes without considering the efficiency or effectiveness of these protocols in terms of increasing number of nodes per sensor network area (field). In this paper, the effect of increasing node density on performance of Threshold-sensitive Stable Election Protocol (TSEP) is presented. The number of nodes in sensor network of (100 × 100) square metre area was varied from 50, 100, 500, and 1000. The simulation study revealed that increasing the node density increased the number of node alive and throughput performance of TSEP. However, this came with a price as the simulation time was prolonged and the computational complexity increased. Generally, the essential take away or contribution of this paper was to examine the effectiveness of TSEP as the number of nodes per field (or area) in the network is increased, and the simulations conducted revealed that the performance efficiency of the routing protocol drops in terms of computational flexibility and capacity as the node density increases.

Keywords – **Node density, Number of nodes, TSEP, WSN**

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I. INTRODUCTION

In recent times, an area of research that has attracted attentions in wireless communication and Internet of Things (IoT) services is the design of Wireless Sensor Network (WSN). It is largely considered as one of the most vital technologies [1]. The technology is achieved by virtue of wireless connection of sensor nodes that are tailored to respond and detect certain type of inputs, which are physical parameters or factors that characterise the condition of the environment they are deployed. These parameters can be temperature, pressure, smoke, fire, heat, light, shadow, water and others depending on the purpose that the WSN is meant to serve.

A WSN can be regarded as a network of devices that use wireless links to communicate the information gathered or collected from a monitored environment. Within a WSN is a dedicated sensor node called sink or base station (BS) that acts as an interface or link between the sensor network and the user.

Typically, a WSN can have installed thousands of sensor nodes capacity, and with each node in the network being inherently resource-constrained. Also, a sensor node in WSN has limited processing speed, communication bandwidth, and storage capacity. After successful installation of a WSN, the sensor nodes are responsible for self-organizing an appropriate network infrastructure frequently with multi-hop interaction with them [2].

The deployment of wireless sensor nodes can be either random or regular. In random deployment, nodes are evenly distributed over the network, but in the case of regular deployment, the nodes are positioned in a static manner. Besides, nodes in WSN can be stationary or mobile and deployment in their environment can be randomly or by means of a proper deployment mechanism [3]. As a result of energy reduction that occurs in WSN during sensing or information gathering including data transmission and reception by sensor nodes, several routing protocols or algorithms such as Low Energy Adaptive Clustering Hierarchy (LEACH), Stable Election Protocol (SEP), Enhanced Stable Election Protocol (ESEP), Threshold Sensitive Energy Efficient sensor

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Network Protocol (TEEN), and Threshold-sensitive Stable Election (TSEP) have been proposed. These protocols are designed to address the challenges of energy efficiency in WSN. This is because in practical perspective, it is impossible to recharge or replace sensor nodes batteries once deployed.

In this paper, the performance of a reactive protocol employing three levels of heterogeneity called TSEP proposed by [3] is examined in this paper in terms of increasing sensor node density, which is the number of nodes for a given network field or area (that is number of nodes per area) . The study is designed to examine the efficiency of the protocol on increasing number of nodes.

II. CONCEPT OF THE STUDY

In this section, the idea or reason for the study is discussed considering existing framework in literature. The issue in designing and subsequent selection of routing protocol, and the effect of increasing number of nodes in WSN are presented.

2.1 Designing Routing Protocol

The selection of the best routing protocol for a WSN is a critical issue because of the available limited resources. Several factors must be taken into consideration for packets to be successfully delivered from source node to destination node [4]. Thus in routing protocols and algorithms design, there are exceptional factors that need to be considered some these factors are highlighted [4].

2.1.1 Energy Consumption

The prolonged existence of the energy stored in battery of a sensor node determines its life. This battery energy is limited and small taking into account the size of the node [5]. As a result, the major challenge in the design of routing protocol for WSN is the possibility of using less energy in transmitting data by the nodes. It is even more expensive in transmitting data than processing it in some cases [4]. As an example, to preserve more energy of sensor node battery, data aggregation and data transmission is performed by hierarchical routing cluster head (CH) [1].

2.1.2 Scalability

The term scalability means that there will be degradation of communicating system performance when the number of nodes increases [1]. The number of nodes in WSN can range from some tens to hundreds or even thousands. That is to say the number of nodes deployed in the field may vary [6]. Therefore, it is expected of or must for any routing protocol employed to be able to accommodate large number of nodes for a particular environment where the nodes are deployed to collect, process and transmit data.

2.1.3 Connectivity

In WSN area, nodes are densely deployed such that there is a prospect of isolating each node from another. Thus, even after the failure of some nodes, connection between nodes must remain [4].

2.1.4 Cost of Network

Given that WSN may comprise up to hundreds or thousands of nodes, it is very critical to justify the total cost of the network considering the cost of a node. Hence, with the cost of single a node affecting the overall network cost, it is very important to keep the cost of each node low as possible.

2.1.5 Data Aggregation

There may be quite a lot of unnecessary traffic as a result of redundant data that may be generated by several sensor nodes. Similar data from multiple nodes can be combined in order that number of transmissions will be minimized [7]. Data aggregation is the accumulation of data from different nodes employing suppression (removing duplicates), min, max, and average [8]. Some powerful and specialized nodes are assigned all functions of aggregation in some network design [4].

2.1.6 Quality of Service

The concern of many existing WSN protocols is mainly on offering energy efficient network operation but with less attention given to quality of service (QoS) support in WSN [6]. The QoS required by the application may be the extent of life time, the reliability of data, the energy efficiency, collaborative-process, and location-awareness [7]. The selection of routing protocols for a given application is affect by these factors.

2.1.7 Deployment of Node

Node deployment can be random or distributed. The deployment of node depends on application and affects routing protocol performance.

2.1.8 Operating Environment Conditions

The nodes intended to be deployed should be able to overcome the conditions of the environment given that a sensor network can be set up anywhere such as in the interior of machines, bottom of oceans (underwater sensing), chemical or biological contaminated environment, battle field beyond enemy lines (such as in military warfare), civil or military surveillance, and others.

2.1.9 Fault Tolerance

In process of deploying nodes in WSN, some nodes may fail probably because of empty battery, unfavourable environment, or physical damage. However, the failure of a mode or some nodes should not affect the sensor network [4]. Packet or data rerouting must be ensured by the routing protocol so that the packet can still get to the sink to avoid data loss. At times data redundancy may be the solution.

2.1.10 Data Latency and Operating Cost

Data latency and operating cost are considered critical factors that affect the design of routing protocol. Latency of data is caused by aggregation and multi-hop relays.

Additionally, excessive operating costs or complexity are created by some routing protocols in implementing their algorithms, which are not proper for networks that are seriously energy constrained.

2.2 Empirical Framework
[9] stated that in WSN, the number of nodes in the network is considered a most significant factor. The study was designed to determine the effect of number of nodes on WSN performance. Lifetime of network, energy consumption and throughput were considered as performance parameters to ascertain quality of service (QoS). The simulation study was done in NS-2.34 by means of Massachusetts Institute of Technology (MIT) extension LEACH protocol for various number of sensor nodes. The study concluded that increasing number of nodes resulted in reducing throughput, increasing energy consumption, and shortening of lifetime of network. The effect of varying number of nodes, pause time and nodes' mobility was considered in examining the performance of proactive and reactive routing protocols for WSN with throughput and packet delivery ratio (PDR) taken as performance metrics [10]. A number of performance parameters were presented to evaluate performance of trust and reputation management systems in WSN considering the effect of increasing number of nodes in [11]. The study by [12] involving the simulation of predictive-wakeup medium access control (PW-MAC) protocol using Net Logo simulator revealed that increasing number of nodes can bring about increased energy dissipation, reduced PDR, increased packet loss, increased duty cycles and increased throughput in WSN. [13] examined the effect of number of nodes and network area on performance of different distributed clustering protocols for WSN. It reported decreasing dead nodes with increasing nodes and increasing network area or field, increasing packet sent to base station and received packet with increasing number of nodes, decreased packet sent to base station and received packet with increasing network field. Also, increasing network field caused decreased network lifetime, whereas the number of tentative CH formed increased as number of nodes. The performance of routing protocols such as senior medium access control (SMAC) protocol, carrier sense multiple access with collision avoidance (CSMA/CA), and time division multiple access (TDMA) were investigated in terms increasing number of nodes using ns-2 simulator by [14]. Performance parameters considered in the study were throughput, end-to-end delay and energy dissipated.

III. TSEP ROUTING PROTOCOL

The TSEP routing algorithm will be described in this section and the simulation parameters presented. It is a reactive routing protocol in which more energy is consumed during transmission than sensing. It performed just once a given threshold is attained and three stages of heterogeneity [3].

In the protocol, energy model and optimal number of clusters is computed. Three levels of heterogeneity, which means nodes of different energy levels namely, normal nodes, intermediate nodes, and advanced nodes [3] characterised the sensor network. The nodes can be categorized in terms of energy possession as illustrated in Fig. 1.

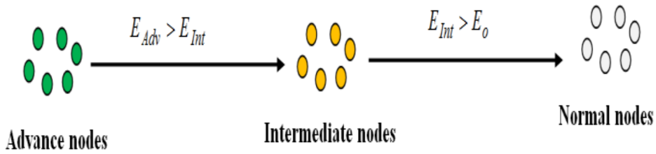

Fig. 1 Energy levels of nodes

From Fig. 1, the energy distribution of nodes in the network is illustrated and it is such that the advance nodes possessed the highest value of energy in the sensor network. The energy of the intermediate nodes is less than that of advance nodes but greater than of normal nodes. Mathematically, given n number of nodes in the network, b number of intermediate nodes, m number of advanced nodes, and then the number of normal nodes in the network is $n-(b+m)$.

The intermediate energy is μ times greater than energy of the normal nodes E_o. The energies of the advance nodes and the intermediate nodes are given by [3]:

$$E_{Adv} = E_o(1+\alpha) \quad (1)$$

$$E_{Int} = E_o(1+\mu), \text{where } \mu = \frac{\alpha}{2} \quad (2)$$

Expressing the total energy of each category in terms of the number of sensors gives:

$$\text{Normal nodes } = n..b(1+\alpha) \quad (3)$$

$$\text{Intermediate nodes } = nE_o.(1-m-bn) \quad (4)$$

$$\text{Advance nodes } = n.m.E_o(1+\alpha) \quad (5)$$

Therefore, the overall energy of the nodes is given by:

$$E_T = n..E_o(1+m\alpha+b\mu) \quad (6)$$

The optimal probability of nodes to be elected as a CH, considering that the nodes are divided on the basis of energy, is calculated as follows.

Optimal probability of normal node being elected as CH is given by:

$$P_{Nnodes} = \frac{P_{opt}}{1+m.\alpha+b.\mu} \quad (7)$$

Optimal probability of intermediate node being elected as CH is given by:

$$P_{Inodes} = \frac{P_{opt}.(1+\mu)}{1+m.\alpha+b.\mu} \quad (8)$$

Optimal probability of advance node being elected as CH is given by:

$$P_{Anodes} = \frac{P_{opt}.(1+\alpha)}{1+m.\alpha+b.\mu} \quad (9)$$

For the three levels energy heterogeneity sensor network, the calculation of threshold depends on their probability as expressed:

$$T_{Nnodes} = \begin{cases} \dfrac{P_{Nnodes}}{1-P_{Nnodes}\left[r.\text{mod}\dfrac{1}{P_{Nnodes}}\right]} & \text{if } n_{Nnodes} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (10)$$

$$T_{Inodes} = \begin{cases} \dfrac{P_{Inodes}}{1-P_{Inodes}\left[r.\text{mod}\dfrac{1}{P_{Inodes}}\right]} & \text{if } n_{Inodes} \in G'' \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

$$T_{Nnodes} = \begin{cases} \dfrac{P_{Anodes}}{1-P_{Anodes}\left[r.\text{mod}\dfrac{1}{P_{Anodes}}\right]} & \text{if } n_{Anodes} \in G''' \\ 0 & \text{otherwise} \end{cases} \quad (12)$$

where G', G'', G''' are the set of the normal nodes, intermediate nodes and advance nodes, which are yet to become CHs in the past respectively [3].

The simulation parameters used in this paper are presented in Table 1.

Table 1 Simulation Parameters

Parameters	value
E_{elect}	50 nJ/bit
E_{DA}	5 nJ/bit/message
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{mp}	0.0013 pJ/bit/m^4
K	4000
P_{opt}	0.1
n	50, 100, 500, 1000
α	1
m	0.1
b	0.3
Field dimension (x, y)	(100, 100) m
Sink node location (x, y)	(50, 50) m

IV. Simulation Results and Discussion

The performance evaluation has been conducted in MATLAB. The objective of this paper is to examine the effect of increasing number of nodes on the performance of TSEP routing protocols for a sensor network field of per (100 × 100) square metres in area. The performance metrics considered were number of alive nodes per round as shown in Fig. 2, number of dead nodes per round as in Fig. 3, and throughput, which is the number of packets transmitted from CH to BS as shown in Fig. 4.

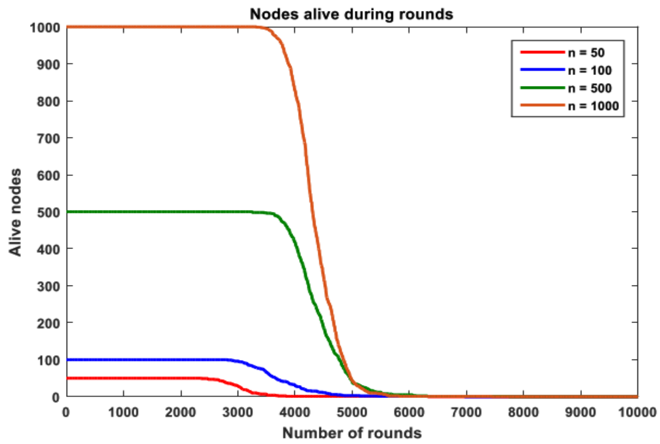

Fig. 2 Number of alive per round

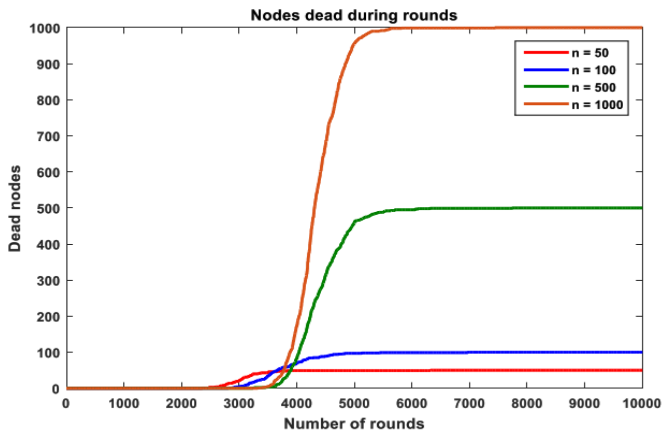

Fig. 3 Number of dead nodes per round

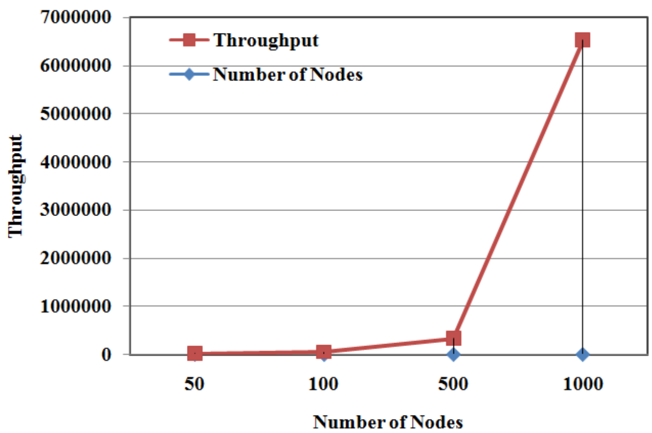

Fig. 4 Throughput per number of nodes

The plots in Fig. 2 to Fig. 4 show the simulation results of performance of the TSEP protocol enabled WSN evaluated in MATLAB. Table 2 shows the numerical analysis of the simulation plots with alive and dead nodes recorded at 3000 rounds.

Table 2 Numerical performance

Nodes	Alive nodes	Dead nodes	Throughput
50	29	21	13870
100	96	4	47950
500	500	0	335800
1000	1000	0	6526000

It can be deduced from Table 2 that as the number of node per area (node density) of WSN increases, the chances of more nodes being alive increases with respect to the number of rounds. Also, for the throughput which is regarded as the number of bits or packet successfully delivered or sent from the cluster head (CH) to BS increases as the number of nodes at a given sensor network area (nodes density or population of nodes) increases.

Though increasing node density increases throughput and the chances of more node to be alive in order to sustain the network, this comes with a price considering the cost of a sensor node. Also, as the number of nodes per area was increased, the simulation time and complexity increased using TSEP. Thus, using TSEP considering increased node as the network area remains (100 × 100) m^2, revealed prolonged simulation time and difficulty.

V. Conclusion

This paper has presented the effect of increasing node density on performance of TSEP. The study observed that as the number of nodes in the network is increased, the simulation time of TSEP was prolonged and as such resulting in difficult computational capacity. This means that TSEP computational complexity increased with increasing node density (that is reduced computational efficiency). The simulation study was conducted using MATLABR2015a.

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