Performance Analysis of Power Optimization in MEMS based Wireless Sensor Network

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***Abstract*—MEMS (Micro Electronics Mechanical System) based wireless sensor network has huge variety of applications and its vital battery power is utilized in sensing, processing, routing and transmitting data to the base station. For efficient utilization of battery power, several techniques were proposed to enhance the lifetime of the wireless sensor network. Once wireless sensor network is deployed, battery recharge or replacement is not possible for human and wireless sensor network works until battery power of the entire sensor node get die. Modern routing protocols use their own algorithm for energy efficiency as they use probability based cluster head selection, as a result, the nodes having low battery power may be selected as cluster head and the nodes having high battery power may not be selected as cluster head. This creates unbalancing condition in wireless sensor network for network lifetime enhancement point of view. To address this limitation, we proposed our Power Optimization in MEMS Wireless Sensor Network which uses the concepts of energy level observation of nodes of cluster head selection. In this dissertation report, an innovative reactive routing protocol is proposed where sensor nodes have three different levels of energies. Proposed protocol uses ratio of current energy to initial energy for selection of cluster head in wireless sensor network. Simulation result shows that performance of our protocol gives significant energy efficiency and more network lifetime compared to other protocols.**

***Keywords*— Wireless Sensor Networks, Clustering, Energy Efficiency, Stable Election, Network Lifetime.**

I. Introduction

Micro-Electro-Mechanical Systems, (MEMS) is a modern technology which is defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are constructed using the technology of microfabrication [1]. The physical dimensions of MEMS devices varies from one micron on the lower end of the dimensional spectrum to several millimeters. Similarly, the types of MEMS devices varies from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. The term used to define MEMS varies in different parts of the world. In the United States they are predominantly called MEMS, while in some other parts of the world they are called Microsystems Technology or micro-machined devices.

While the functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics, the most notable (and perhaps most interesting) elements are the microsensors and microactuators. Microsensors and microactuators are appropriately categorized as “transducers”, which are defined as devices that convert energy from one form to another. In the case of microsensors, the device typically converts a measured mechanical signal into an electrical signal.

Wireless sensor network (WSN) is individual the group of wireless network which belongs to ad-hoc networks. Sensor networks are composed of nodes, essentially the sensor node has an explicit name that is “Sensor” since these sensor nodes are furnished with the smart sensors. Nodes of wireless sensor networks in the planted area, are a lesser category of mobile than the ad-hoc networks so the mobility in the case of ad-hoc is some more. In wireless sensor network, data are requested based on certain physical quantity, so wireless sensor network is basically data centric. A sensor involves an embedded processor, a transducer, small memory component, a unique wireless transceiver and all of these embedded devices work on the power provided by an involved battery. In this introductory chapter the motivation, introduction to sensor and wireless sensor network, its application and architecture and finally the organization of this dissertation report will be discussed.

II. MEMS based Sensor Nodes

Modern sensors are tiny electromechanical devices they are modern MEMS (Micro Electronics Mechanical System) [1]. Modern advanced technologies in microelectronic mechanical systems (MEMS) [2] and wireless communication technologies have developed low- cost, low-power, small sized, multi-functional and bi-directional smart sensor nodes in a wireless sensor network. Sensor usually sense the physical conditions like light, motion, vibration, temperature, sound, moisture, magnetic fields, electrical fields, gravity, humidity, pressure, radiation and other physical aspects and parameters of the external environment [3].

A sensor node usually measures the physical quantity and converts it into a signal which can be read out or noticed by an observer or by an electronic instrument. For example, a mercury glass thermometer normally converts the measured temperature into some expansion and contraction of mercury liquid which can be read out on a calibrated glass tube. As an example of a sensor thermocouple converts temperature into an output voltage which can be read out by a voltmeter. For more accuracy, most sensor nodes are calibrated against known standards.

Sensors are used in everyday objects such as touch-sensitive elevator buttons called tactile sensor and lamp which brightens or dims by touching the base. Also there are many innumerable applications of sensors for which most people are not aware. Applications of sensor include cars, aircrafts, machines, space shuttle, industry, robotics, automation and manufacturing. Another very common example of sensor is infrared sensor, there are so many applications of infrared sensor like flame detection, alcohol testing in industry, gas pipe leakage detection, petroleum exploration and space operation [4].

A sensor responds to a normal input quantity by generating a functionally related observed output usually in the form of an optical or electrical signal. The sensitivity of a sensor indicates how much the output of sensor changes when the measured quantity changes [5]. For example, if the mercury in a thermometer moves 1 cm when the temperature changes by 1 $°C$, then the sensitivity is 1 $cm /°C$. Sensor device that measure quantity of very small changes it must have very high sensitivities. The sensors also have a significant impact on what measurement they take, for example, when a normal room temperature thermometer is inserted into a hot cup of liquid then it usually cools the liquid while that liquid generally heats the thermometer.

The sensor device needs to be designed to have a slightly low effect on what measurement is taken, making the sensor some smaller usually improves this and it introduces other advantages. Scientific and technological progress allows more and more sensors to be manufactured on the microscopic scale as micro-sensors using MEMS (Micro Electronics Mechanical System) [6] technology. In most cases, a micro-sensor reaches a significantly higher speed and sensitivity compared with traditional approaches [7].

III. Literature Review

There exists a considerable research effort for the development of routing protocols in wireless sensor networks (WSNs). The development of these protocols is based on the particular application needs and the architecture of the network. However, there are several factors that should be taken into consideration when developing routing protocols for WSNs. Energy efficiency is the most important among these factors, since it directly affects the lifetime of the network. There have been a few efforts in the literature pursuing energy efficiency in WSNs.

A. Review of Energy Optimizing Protocol

In this section, energy optimizing protocols [8, 9] are reviewed based on their classifications. The sensor nodes are constrained to limited one time battery power resources itself, so the main purpose is how to design an effective and energy optimizing protocol in order to enhance the networks lifetime for specific application environment [10, 11] Routing protocols are generally classified into four categories as shown in Table I: Data Centric Protocols, Hierarchical Based Routing Protocol (Clustering), Location-Based Routing Protocol (Geographic) and Network Flow and QoS Aware Protocol depending on the network structure in WSNs [12, 13].

Among so many routing protocols, only five modern energy optimizing routing protocols LEACH [14], DEEC [15], DDEEC [16], EDEEC [17] and EDDEEC [18] are selected as a base for analysis and comparison.

B. LEACH (Low Energy Adaptive Clustering Hierarchy)

LEACH [14] was proposed by **Heinzelman** *et al.* in “An application-specific protocol architecture for wireless microsensor networks” for wireless sensor network.

LEACH [14] is basically a proactive routing protocol. The proactive routing protocols continuously try to send up-to-date sensed data to the base station in the wireless sensor network. This has as advantage that network connection time is fast, because when the first data packet is sent then routing information data is already available. A main disadvantage of proactive protocols is that they continuously use resources to communicate routing information, even when there is no traffic. In a network hundreds and thousands of sensor nodes dispersed randomly for even distribution of work load among nodes. These nodes sense data, transmit it to their associated cluster heads (CHs) which first receive, aggregate it and then send its data packets to the Base Station (BS) [14].

All the sensor nodes deployed in an environment are homogeneous and constrained in limited battery power. To distribute the burden or work among nodes, an improve network life clusters are formed. The sensor node devices are made to become CHs on turns. Nodes randomly elect themselves as CHs and it is done in a way that each node becomes CH once in the time period of $\frac{1}{P}$ round. CHs selection is done on probabilistic basis, each sensor node generates a random number r inclusive of 0 and 1, if the generated value is less than this threshold computed by formula given in Equation 1, and then this node becomes CH.

$$T_N = \begin{cases} \dfrac{P}{1 - P[r \ mod \ \dfrac{1}{P}]}, & \text{if } n \in G, \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

where,
T_N = Threshold
P = Desired change (probability) of being Cluster Head (CH)
r = Current round number
G = Set of nodes which are not became CH in $\frac{1}{P}$ round

Usually by using this threshold value, each sensing node will be a CH in $\frac{1}{P}$ rounds, thus probability remaining nodes are CH must be increased, since there are fewer nodes that are eligible to become CH.

C. DEEC (Distributed Energy-Efficient Clustering)

DEEC [15] was proposed by **Qing** *et al.* in “Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks”. DEEC [15] is a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks which is based on clustering, when the cluster-heads are elected by a probability based on the

TABLE I
CATEGORIES OF ROUTING PROTOCOLS

CATEGORIES	REPRESENTATIVE PROTOCOLS
Data Centric Protocols	Flooding and Gossiping, SPIN, Directed Diffusion, Rumor Routing, Gradient Based Routing, Energy-Aware Routing, CADR, COUGAR & ACQUIRE.
Hierarchical Protocols	LEACH, PEGASIS, H-PEGASIS, TEEN, APTEEN, DEEC, DDEEC, EDEEC & EDDEEC.
Location Based Protocol	MECN, SMECN, GAF & GEAR.
Network Flow & QoS Aware Protocols	Maximum Lifetime Energy Routing, Maximum Lifetime Data Gathering, Minimum Cost Forwarding, SAR & SPEED.

ratio between residual energy of each node and the average energy of the network. The round number of the rotating epoch for each node is different according to its initial and residual energy. DEEC adapt the rotating epoch of each node to its energy [15]. The nodes with high initial and residual energy will have more chances to be the cluster-heads than the low-energy nodes.Thus DEEC can prolong the network life-time, especially the stability period, by heterogeneous aware clustering algorithm [15]. This choice penalizes always the advanced nodes, specially when their residual energy deplete and become in the range of the normal nodes. In this situation, the advanced nodes die quickly than the others [15].

DEEC uses the initial and residual energy level of the nodes to select the cluster-heads. To avoid that each node needs to know the global knowledge of the networks, DEEC estimates the ideal value of network life-time, which is use to compute the reference energy that each node should expend during a round [15].

D. DDEEC (Developed Distributed Energy Efficient Clustering)

DDEEC [16] was proposed by **Elbhiri** *et al.* in "Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks". DDEEC [16] is based on DEEC [15] scheme, where all nodes use the initial and residual energy level to define the cluster heads. To evade that each node needs to have the global knowledge of the networks, DEEC [15] and DDEEC [16] estimate the ideal value of network lifetime, which is use to compute the reference energy that each node should expend during each n round. In this section, we consider a network with N nodes, which are uniformly dispersed within a $M \times M$ square region. The network is organized into a clustering hierarchy, and the cluster-heads collect measurements information from cluster nodes and transmit the aggregated data to the base station directly. Moreover, we suppose that the network topology is fixed and no-varying on time. It is assumed that the base station is located at the center [16]. Furthermore, this condition show a two-level heterogeneous network, where we have two categories of nodes, a mN advanced nodes with initial energy $E_0(1+a)$ and $a(1-m)N$ normal nodes, where the initial energy is equal to E_0. The total initial energy of the heterogeneous networks is given by:

$$E_{total} = N(1-m)E_0 + NmE_0(1+a) \quad (2)$$
$$= NE_0(1+am) \quad (3)$$

1) Radio Model of DDEEC: On the first, for the purpose of this protocol it uses similar energy model and analysis as proposed in DEEC [15]. According to the radio energy dissipation model and in order to achieve an acceptable Signal-to-Noise Ratio (SNR) in transmitting an $L-bit$ message over a distance d, the energy expended by the radio is given by:

$$E_{TX}(L,d) = \begin{cases} LE_{elect} + L\epsilon_{fs}d^2, & \text{if } d < d_0, \\ LE_{elect} + L\epsilon_{mp}d^4, & \text{if } d \geq d_0 \end{cases} \quad (4)$$

where E_{elec} is the energy dissipated per bit to run the transmitter (E_{TX}) or the receiver circuit (E_{RX}). The E_{elec} depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal. ϵ_{fs} and ϵ_{mp} depend on the transmitter amplifier model used, and d is the distance between the sender and the receiver. For the experiments described here, both the free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models were used, depending on the distance between the transmitter and the receiver. If the distance is less than a threshold, the free space (fs) model is used; otherwise, the multi path (mp) model is used. we have fixed the value of do like on DEEC at $d_0 = 70$.

E. EDEEC (Enhanced Distributed Energy Efficient Clustering)

EDEEC [17] was proposed by **Saini** *et al.* in "E-DEEC-Enhanced Distributed Energy Efficient Clustering scheme for heterogeneous WSN". EDEEC [17] adds heterogeneity in the network by introducing the super nodes having energy more than normal and advanced nodes and respective probabilities. EDEEC [17] has better performance as compared to DEEC in terms of parameters used. It extends the lifetime and stability of the network. EDEEC [17] for three types of nodes in prolonging the lifetime and stability of the network. Hence, it increases the heterogeneity and energy level of the network. Simulation results show that EDEEC [17] performs better than SEP with more stability and effective messages.

1) EDEEC Network Model: Sensor network is used with N nodes in MXM network field. There are three types of sensor nodes. They are normal nodes, advanced nodes and super nodes [17]. Let m be the fraction of the total number of nodes N, and m_o is the percentage of the total number of nodes which are equipped with b times more energy than the normal nodes, called as super nodes, the number is $N.m.m_0$. The rest $N.m.(1-m_0)$ nodes are equipped with a times more energy than the normal nodes; called as advanced nodes and remaining $N(1-m)$ as normal nodes [17].

F. EDDEEC (Enhanced Developed Distributed Energy Efficient Clustering)

EDDEEC [18] was proposed by **Javaid** *et al.* in "An energy-efficient distributed clustering algorithm for heterogeneous WSNs". Heterogeneous WSNs may contain two, three, or multitypes of nodes with respect to their energy levels and termed as two, three, or multi-level heterogeneous WSNs, respectively. EDDEEC [18] considers three-level heterogeneous network that contains three different energy levels of nodes: normal, advanced, and super. Normal nodes have E_0 energy. Advanced nodes of fraction m have a times more energy than normal nodes, i.e., $E_0(1+a)$. Whereas, super nodes of fraction m_0 have b times more energy than the normal ones, it means, $E_0(1+b)$. As N is the number of nodes in the network, then Nmm_0 , $Nm(1-m_0)$, and $N(1-m)$ are the numbers of super, advanced, and normal nodes in the network, respectively. The total initial energy of super nodes in WSN is as follows:

$$E_{super} = Nmm_0E_0(1+b) \tag{5}$$

The total initial energy of advanced nodes is as follows:

$$E_{advanced} = Nm(1-m_0)E_0(1+a) \tag{6}$$

Similarly, the total initial energy of normal nodes in the network is calculated as follows:

$$E_{normal} = N(1-m)E_0 \tag{7}$$

The total initial energy of three-level heterogeneous WSNs is therefore calculated as:

$$E_{total} = E_{super} + E_{advanced} + E_{normal} \tag{8}$$

$$E_{total} = NE_0(1+m(a+m_0b)) \tag{9}$$

The three-level heterogeneous WSN has $m(a+m_0b)$ times more energy as compared to the homogeneous WSN [18]. A homogeneous WSN also turns into heterogeneous after some rounds due to unequal energy consumption of nodes. CH nodes consume more energy, as compared to member nodes. After some rounds, the energy level of all nodes becomes different, as compared to each other. Therefore, a protocol which handles heterogeneity is more important than the homogeneous protocol [18].

IV. Proposed Algorithm

This section presents an innovative concept in wireless sensor network which is the proposed algorithm. The proposed algorithm implements the idea of probabilities for CHs selection based on initial and residual energy of nodes as well as the average energy of the network. The average energy of r^{th} round from is given by Equation 10:

$$E_a(r) = \frac{1}{N}E_{total}\left(1-\frac{r}{R}\right) \tag{10}$$

where,
R = the total rounds during the network lifetime. It is calculated by the Equation 11.

$$R = \frac{E_{total}}{E_{round}} \tag{11}$$

where E_{round} is the energy dissipated in a network during a single round and is calculated by Equation 12:

$$E_{round} = K\left(2NE_{elect} + NE_{DA} + l\epsilon_{mp}d^4_{to\ BS} + N\epsilon_{fs}d^4_{to\ CH}\right) \tag{12}$$

where,
K = The number of clusters,
E_{DA} = The data aggregation energy cost expended by CH,
$d_{to\ BS}$ = The average distance between the CH and the BS,
$d_{to\ CH}$ = The average distance between cluster members and the CH.
Now $d_{to\ BS}$ and $d_{to\ CH}$ can be calculated as Equation 13 and Equation 14:

$$d_{to\ BS} = 0.765\frac{M}{2} \tag{13}$$

$$d_{to\ CH} = \frac{M}{\sqrt{2\pi K}} \tag{14}$$

By taking the derivative of E_{round} with respect to k and equating to zero, we can find the optimal number of clusters k_{opt} and is calculated by Equation 15:

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\frac{\epsilon_{sf}}{\epsilon_{mp}}}\frac{M}{d^2_{to\ BS}} \tag{15}$$

At the start of each round, nodes decide on the basis of threshold whether to become CHs or not. The value of threshold is calculated by Equation 16:

$$Th(S_i) = \begin{cases} \dfrac{P_i}{1-P_i\left(mod\left(r,\frac{1}{P_i}\right)\right)}, & \text{if } S_i \in G, \\ 0, & \text{otherwise} \end{cases} \tag{16}$$

where G is the set of nodes eligible to become CHs for round r and p is the desired probability of the CH. In real scenarios, WSNs have more than two types of heterogeneity. Therefore, in proposed protocol, we use the concept of three-level heterogeneity and characterize the nodes as: normal, advanced, and super. The probability for three types of nodes given by proposed protocol is given below:

$$P_i = \begin{cases} \dfrac{P_{opt}E_i(r)}{(1+m(a+m_0b))E_a(r)} \times \dfrac{E_{res}}{E_0}, & \text{if } S_i \text{ is the normal node,} \\ \dfrac{P_{opt}(1+a)E_i(r)}{(1+m(a+m_0b))E_a(r)} \times \dfrac{E_{res}}{E_0}, & \text{if } S_i \text{ is the normal node,} \\ \dfrac{P_{opt}(1+b)E_i(r)}{(1+m(a+m_0b))E_a(r)} \times \dfrac{E_{res}}{E_0}, & \text{if } S_i \text{ is the normal node,} \end{cases} \tag{17}$$

Equation 17 primarily illustrates the difference between DEEC

[15], DDEEC [16], EDDEEC [18] and proposed protocol by defining probabilities for CH selection as DEEC, DDEEC, EDEEC and EDDEEC use probability based cluster head (CH) selection, however, the proposed protocol uses energy levels by using the ratio of E_0 (initial energy) to E_{res} (residual energy). It is the modification of of the existing EDDEEC protocol. The objective of this expression is to balance the energy consumption between nodes such that the stability period and network lifetime are increased. However, soon after few rounds, super and advanced nodes might have the same residual energy as that of the normals. At this point, DEEC punishes advanced nodes, proposed protocol punishes advanced as well as super nodes and proposed protocol is only effective for repeatedly selecting the CH.

A. Work Flow of Proposed Method

The Figure 1 represents the overall work flow of our proposed method. The proposed work flow can be expressed

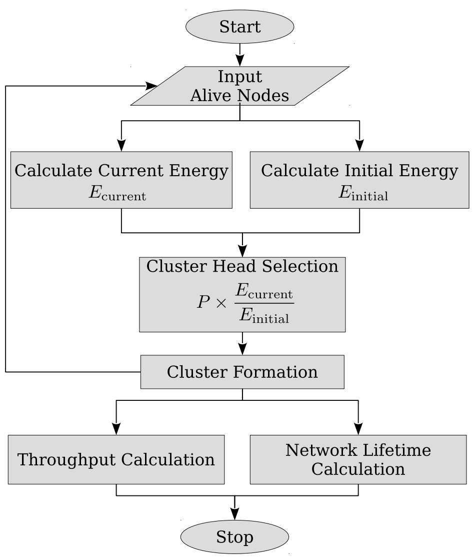

Fig. 1. Work Flow of Proposed Method

as the following pseudo-code.

Algorithm of proposed protocol:

Deploy the sensor nodes randomly across the network area.

for all sensor nodes ***do*** $i = 1$ to n, $S(i) = (X_i, Y_i)$

Randomly establish the sensor nodes.

end for

Calculate E_{current} and E_{initial} along with P and r.

Elect the cluster heads (CHs) based on $T(n)$.

Form the clusters, using elected CH.

for every cluster

Transmit the sensed data to the CH.

CH forwards it to the sink node.

end for

V. RESULT

Result metrics used in the simulations are based on the following:

1) Number of the alive nodes during each round (network lifetime).
2) Number of packets sent from the cluster heads (CHs) to the base station (throughput).

A. Result Analysis of Nodes Alive Per Round (Network Lifetime)

In Figure 2, DEEC protocol is shown as the black curve, DDEEC protocol is shown as the red curve, EDEEC protocol is shown as dashed blue curve, EDDEEC is shown as magenta curve and the proposed protocol is shown in Figure 2 as dashed dark blue curve. The graph of **??** for DEEC [15], DDEEC [16], EDEEC [17] and EDDEEC [18] represents the graph of nodes alive during each round (network lifetime). Again the proposed protocol performs better as compared to other protocol as shown in the graph.

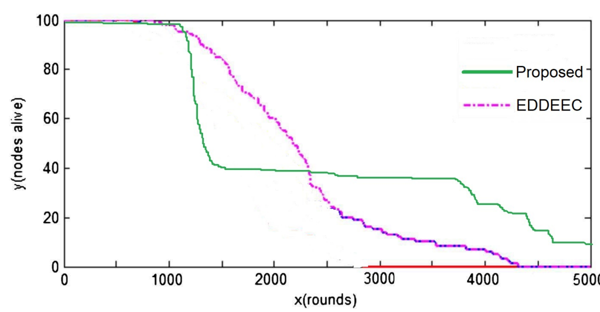

Fig. 2. Network Lifetime of EDDEEC and Proposed Protocol

B. Result Analysis of Throughput

The graph of Figure 3 plots the data packets send to the base station (BS) or throughput. Again the same colored curve are used for DEEC [15], DDEEC [16], EDEEC [17] and EDDEEC [18] protocols. For performance evaluation of

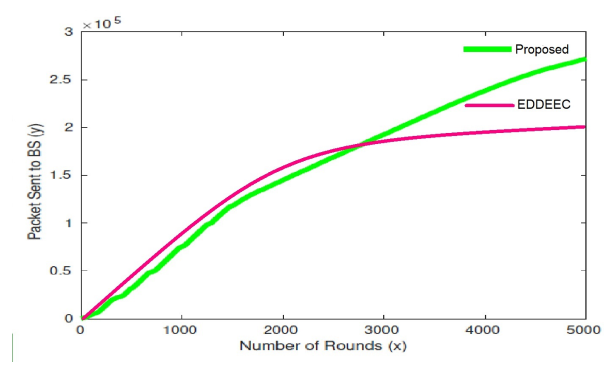

Fig. 3. Throughput of EDDEEC and Proposed Protocol

proposed protocol in MATLAB, the same initial parameter values are considered and the next parameter values as used in DEEC [15], DDEEC [16], EDEEC [17] and EDDEEC [18]. As shown in Figure 3, the proposed protocol presents maximum throughput as compared to these protocols.

VI. Conclusion

In this paper, an innovative protocol in Wireless Sensor Network as a reactive network routing protocol are proposed with considering three different levels of sensor node heterogeneity. The proposed protocol combines the best features of EDDEEC protocol and energy level evaluation method. Due to the concept of energy level based cluster head selection, hard and soft threshold value, three levels of node heterogeneity and being reactive routing network proposed protocol produces increase in energy efficiency, enhanced lifetime of network and also maximum throughput as shown in the simulation result. In comparison with DEEC, DDEEC, EDEEC and EDDEEC with the proposed strategy of proposed protocol.

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