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ORIGINAL ARTICLE

Energy efficient selective hop selection optimization to maximize lifetime of wireless sensor network

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Abstract The availability of low cost and tiny sensor devices has led to wide adoption of Wireless Sensor Networks (WSNs) for various application uses. The sensors have been adopted in various industries and organization applications such as environmental monitoring, pollution monitoring and so on. The sensor devices are powered by resources constrained battery devices and are deployed remotely. Preserving the battery of these devices is the major things in various application services. Cooperative based communication has attained wide interest due to its energy efficient benefits it offers. The major factor of cooperative transmission is selection of hop devices. Many clustering based cooperative transmission is adopted by various approach. These techniques are not efficient in enhancing the lifetime of sensor network since they considered minimizing energy consumption per bit only. To address this, we present a distributed MAC (Medium Access control) and transceiver optimization technique for selective hop device selection. The proposed model minimizes energy consumption per bit and maximizes the lifetime of sensor network. Experiments are conducted to evaluate the performance in terms of lifetime, communication overhead and node decay rate. The outcome shows significant performance improvement over existing model.

1. Introduction

WSN has been widely deployed for various application uses, such as health care, pollution monitoring, and environmental monitoring [1]. WSN is composed of low cost and tiny sensor devices which collects sensory information in a distributed manner and are self-organized. This feature allows the increased adoption of WSN in future wireless technology application such as green communication and Internet of things (IoT). The major concern of WSN is preserving battery since it is deployed remotely and it is practically not possible to replace/recharge battery [1,2]. Therefore developing a strategy to optimize energy dissipations has been considered in WSN [3] which has to address the following things.

Control packet overhead, the sensor device uses control channel to send and receive for various network related packet which consumes energy and induces overhead for transmitting less beneficial packets. Collisions, when two or more sensor devices trying to access same channel for transmission, there induces a collision as a result the data is lost. This result in packet retransmission as a result induces energy consumption

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overhead. Idle listening, the sensor device tries to receive probable data that is not transmitted. High transmission power, the energy of sensor devices is wasted due to unreasonable high power transmissions. Overhearing, the sensor devices obtain a packet which is not intended to this device as a result energy is depleted.

To preserve energy of WSN in [4,5] authors presented an energy harvesting technique and in [6,7] authors presented a cooperative transmission to preserve energy of sensor device. These models have considered minimizing energy depletion of sensor devices and did not considered enhancing lifetime of sensor network. To enhance the lifetime of sensor network, we need to consider the following features of WSN [8]: data collection initiation, network architecture, channel and energy depletion scheme and lifetime definition. In data collection initiation, the data collection can be classified into following type's event driven or clock driven. In event driven the data collection is activated by the sink. In clock driven the data is collected based on predefined clock set. In network architecture, sensor nodes are transmitting data to its nearby sink. In cluster network the member devices transmit the data to its cluster head and the cluster head transmit directly or through other cluster to the sink. Therefore the energy dissipation depends on type of network we adopt. In channel and energy depletion scheme, it depends on the nature of sensor device and its energy depletion characteristics. The energy depletion can be broadly classified into reporting energy depletion and continuous energy depletion. The reporting energy is the energy that is needed for data collection and continuous energy is the minimum energy that is required for lifetime of sensor network which consist of battery drainage and sleep strategy without data collection. Therefore the energy depletion depends on nature of network architecture, topology, energy model, channel condition and protocols considered. In lifetime definition, the lifetime of network is the amount of time that is spent by network from deployment to till it becomes non-functional. The lifetime is considered to be non-functional depends on specific applications. It can be as like percentage of sensor device death, loss of coverage, first sensor device death, or the network partitions.

Cooperative based hop transmission [9] has been proposed by various researchers which aid in improving energy efficiency of sensor device. Co-operative transmission improves energy efficiency of data transmission and balance energy consumption among sensor devices. Here, authors presented a single channel based cooperative transmission protocol, but it is not suitable for energy starved sensor network. Recently there has been increased adoption of co-operative based transmission for clustered sensor networks [10,11] where the hop devices are selected within a cluster member to transmit packet to nearby cluster. In [12,13,14,15,16] authors presented a co-operative based transmission for cluster network. In [12,13] authors presented a beamforming technique to optimize signal of source and hop device to be heard in destination. These models require accurate synchronization which induces computational complexity cost. In [11] authors presented an optimal solution to improve lifetime of sensor network. Their probability model is affected by fading and channel effects. In [14] authors presented a number of cooperative device and hop distance energy consumption model for multihop environment and in [16] authors presented a data aggregation strategy to minimize the end to end energy consumption per bit. Most of these techniques are designed for fixed network and have not considered distributed nature of sensor device in a network. Various existing protocol have considered minimizing energy consumption per bit based on channel state information [17,18] and did not considered maximizing lifetime of sensor network i.e., node death will result in loss of connectivity. Therefore preserving the lifetime of network is a most critical and important part in designing an efficient sensor network.

To address this, here we presents an optimization technique for hop device selection to enhance the lifetime of WSNs. The model considers distributed MAC (Medium Access Control) design and transceiver optimization for hop selection. The proposed model minimizes energy consumption per bit and maximizes the lifetime of sensor network. The architecture of proposed hop selection model is shown in Fig. 1.

The paper is organized as follows: In Section 2 the literature survey is presented. In Section 3 the proposed hop selection optimization model is presented. The penultimate section presents a simulation and experimental study. The concluding and future work is discussed in the last section.

2. Litterature survey

Recently many approaches and optimizing techniques have been proposed to preserve the energy of sensor device and enhance the lifetime of sensor network. The optimization such as MAC, physical, routing, transceiver power control, hop selection, clustere based and so on has been presented which is surveyed below.

In [17] authors presented a centralized based hop device selection strategy. The channel state information is used to choose hop device. They adopted a centralized approach where the central device choose number of hop devices required to support end to end bit error rate by using channel statistic and decision strategy. The decision strategy to select number of hop devices is upper bounded considering binary symmetric channel. Similarly, in [18] authors presented an energy minimization model of source to relay transmission. The model considers the channel state information to be compressed and only the subset of bits is transferred to hop device which is considered as good bits. They adopted a centralized approach to choose relay device that satisfies the bit error rate and packet delivery ratio for threshold selection. Simulation outcomes show performance improvement in achieving fair compression and energy efficiency and bit error rate.

In [21] authors presented a power control optimization strategy to maximize the lifetime of sensor network. The transceiver power is optimized considering both acknowledgment and data packet. Selecting high power node minimizes handshake failure. However it does not guarantee maximizing lifetime of network. Here they presented link level based handshaking mechanism to minimize energy consumption. Simulation is conducted to analyze lifetime performance for varied network size and density shows significant performance improvement.

In [22] authors presented an energy efficient routing strategy for sensor network by adopting clustering technique namely E^2R^2. They adopted a hierarchical based clustering protocol. Their model minimized the energy dissipation and

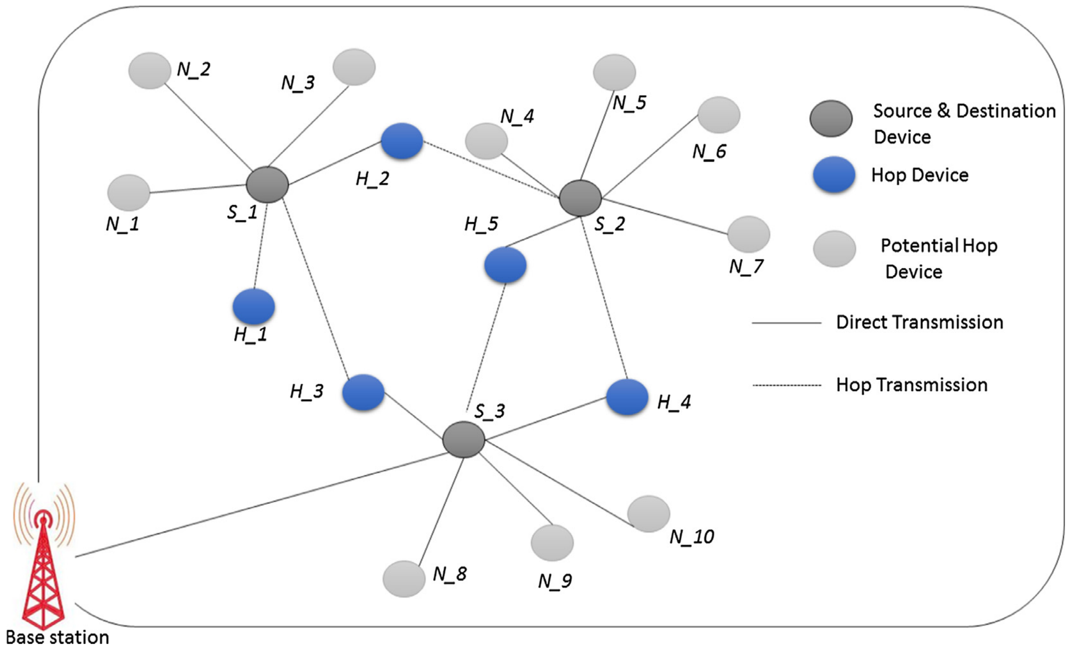

Fig. 1 Architecture of proposed energy efficient Hop selection model for sensor network.

reclustering time. The throughput of sensor device is used as a routing parameter. Based on the throughput level the packet transmission is done using multihop or direct manner. Simulation is done considering mobility of sensor device and compared with *LEACH* protocol which shows significant performance improvement in terms of lifetime of network, energy efficiency and throughput.

In [23] authors presented an energy efficient model by adopting clustering technique to enhance the lifetime of sensor network. They presented Clustering Tree control strategy Energy Forecasting model namely CTEF to preserve energy and balance the network. Their model considered energy, packet failure rate and link quality to define cost function of lifetime enhancement. Their model adopted multihop based transmission. Simulation is conducted for network lifetime performance and compared it with various existing model shows significant performance improvement.

In [24] authors presented a MAC optimization technique for under acoustic wireless sensor network. They highlighted that most existing MAC optimization is done considering channel utilization and bandwidth is neglected. To address this, authors in [25] presented bandwidth and MAC optimization technique for one dimensional linear multihop network. Here the maximum number of hop is required for the transmission is optimized and presented a scheduling strategy to allocate bandwidth considering channel capacity and network device traffic. The outcomes show that their optimization technique aids in improving energy efficiency of network.

The overall survey shows that most of the existing approach that have been developed so for considered minimizing energy of sensor device per bit of transmission. Very limited work is carried out so far in improving lifetime of sensor network. The survey shows that hop based transmission improves energy efficiency of network but the exiting MAC and transceiver power control strategy is not efficient in improving lifetime of network. Therefore there is need to develop an energy efficient protocol that enhance lifetime of sensor network. To achieve this, here we presents a MAC and transceiver power optimization technique for hop device selection that minimizes energy consumption per bit and maximizes the lifetime of sensor network which is presented below.

3. Proposed hop selection model to enhance lifetime of wireless sensor network

Minimizing energy may not ensure in enhancing life time of wireless sensor network, due to network topography and improper distribution of packets in network. Most of the existing protocols have been designed based on minimizing energy per packet to improve the lifetime of network [8]. In most other cases prolonging lifetime means preserving battery of one sensor node. Here we considered first node death as the criteria for network lifetime performance.

Many MAC [19] and routing protocols [20] have been presented in recent time to enhance the lifetime of sensor networks [30]. However co-operative hop based transmission has gained much interest in recent times but it is problematical, since it induces energy overhead computation on co-operative devices and also for both source and destination devices. This work presents an adaptive priority based hop selection to enhance the lifetime of sensor network. The model presents an ideal transceiver optimization strategy that fully capitalizes the minimum remaining energy.

Let's consider a^{th} candidate hop device, the transceiver optimization is expressed as follows

$$\begin{aligned} &\max_{P_{m'},P_{m''}}\ n_a(P_{m'},P_{m''}) := \min\ P_{sender} - \mathcal{C}_x P_{m'},\, P_a - \mathcal{C}_x P_{m''}) \\ &\text{Such that}\quad \frac{(2^{2W}-1)}{\mathcal{N}_{xa}} \leqslant P_{m'} \leqslant P_{\uparrow} \\ &P_{m'}\mathcal{N}_{xy} + P_{m''}\mathcal{N}_{ay} \geqslant (2^{2W}-1), \\ &0 \leqslant P_{m''} \leqslant P_{\uparrow}, \end{aligned} \tag{1}$$

where $\mathcal{C}_a = \mathcal{C}_r/W$ is the length of packets in symbol, P_x is the present energy resource in the a^{th} hop devices and P_{sender} is the present energy resource in sender devices. The hop devices has the information of P_{sender} which is embedded in *CFT* (Contention for Transmission).

In order to address the optimization problem in Eq. (1), the following objective function T is defined.

$$\max_{P_{m'},P_{m''}} \ T \tag{2l}$$

$$\text{Such that } \frac{(2^{2W}-1)}{\mathcal{N}_{xa}} \leqslant P_{m'} \leqslant P_{\uparrow}, \tag{2m}$$

$$P_{m'}\mathcal{N}_{xy} + P_{m''}\mathcal{N}_{ay} \geqslant (2^{2W}-1), \tag{2n}$$

$$0 \leqslant P_{m''} \leqslant P_{\uparrow}, \tag{2o}$$

$$P_{src} - \mathcal{C}_x P_{m'} \geqslant T, \tag{2p}$$

$$P_a - \mathcal{C}_x P_{m''} \geqslant T. \tag{2q}$$

The objective functions in Eq. (2) are considered to be linear problem which can be solved using methods [27–30].

An important thing to be considered is when $\mathcal{C}_{xy} \geqslant \mathcal{C}_{xa}$ there is no point in using hop device a for communication by the source/sender devices, as the communication with relay becomes much more difficult than to reach destination device. However using hop device if $\mathcal{C}_{xy} \geqslant \mathcal{C}_{ay}$ (and $\mathcal{C}_{xy} < \mathcal{C}_{xa}$) will still be constructive if energy resource at source is low and high at the hop device. Now let's consider that $\mathcal{C}_{xy} \geqslant \mathcal{C}_{xa}$ is satisfied, then the optimal strategy of Eq. (1) is computed as follows.

$$\frac{(2^{2W}-1)}{\mathcal{N}_{xy}} \leqslant P_{\uparrow},$$

$$\frac{(2^{2W}-1)}{\mathcal{N}_{xy}}\left(1-\frac{\mathcal{N}_{xy}}{\mathcal{N}_{xa}}\right) \leqslant P_{\uparrow}$$

$$\text{Such that } \widetilde{P}_m = \frac{\mathcal{N}_{ay}(P_{src-}P_a) + \mathcal{C}_x(2^{2W}-1)}{\mathcal{C}_x(\mathcal{N}_{ay}+\mathcal{N}_{xy})}$$

$$P_{m'} = \begin{cases} \frac{(2^{2W}-1)}{\mathcal{N}_{xa}}, & \widetilde{P}_m < \frac{(2^{2W}-1)}{\mathcal{N}_{xa}} \\ \widetilde{P}_m, & \frac{(2^{2W}-1)}{\mathcal{N}_{xa}} \leqslant \widetilde{P}_m \leqslant \frac{(2^{2W}-1)}{\mathcal{N}_{xy}} \\ \frac{(2^{2W}-1)}{\mathcal{N}_{xy}}, & \widetilde{P}_m < \frac{(2^{2W}-1)}{\mathcal{N}_{xy}} \end{cases} \tag{3}$$

$$P_{m''} = \frac{(2^{2W}-1) - P_{m'}\mathcal{N}_{xy}}{\mathcal{N}_{ay}}$$

Here the $\widetilde{P}_m$ is the ideal strategy of $P_{m'}$ for linear problem in Eq. (2). To support source to hop transmission, one has to set $P_{m'} < \frac{(2^{2W}-1)}{\mathcal{N}_{xa}}$, when $\widetilde{P}_m < \frac{(2^{2W}-1)}{\mathcal{N}_{xa}}$. Similarly there in no benefit of using hop transmission when $\widetilde{P}_m > \frac{(2^{2W}-1)}{\mathcal{N}_{xy}}$. The proposed optimization model for hop selection a not only depends on channel state ($\mathcal{N}_{xa}, \mathcal{N}_{xy}$, and $\mathcal{N}_{ay}$) but also on energy resource of sensor devices.

Now let us consider a more complex solution:

$$\frac{(2^{2W}-1)}{\mathcal{N}_{xy}} \leqslant P_{\uparrow,}$$

$$\frac{(2^{2W}-1)}{\mathcal{N}_{ay}}\left(1-\frac{\mathcal{N}_{xy}}{\mathcal{N}_{xa}}\right) \leqslant P_{\uparrow}$$

$$\text{Such that } \widetilde{P}_{m1} = \frac{\mathcal{N}_{ay}(P_{src-}P_a) + \mathcal{C}_x(2^{2W}-1)}{\mathcal{C}_x(\mathcal{N}_{ay}+\mathcal{N}_{xy})}$$

$$\widetilde{P}_{m2} = \frac{(2^{2W}-1)}{\mathcal{N}_{ay}+\mathcal{N}_{xy}} - \frac{\mathcal{N}_{xy}(P_{src}-P_a)}{\mathcal{C}_x(\mathcal{N}_{ay}+\mathcal{N}_{ay})}$$

$$P_{m1} = \begin{cases} \widetilde{P}_{m1}, & \frac{(2^{2W}-1)}{\mathcal{N}_{xa}} < \widetilde{P}_m < P_{\uparrow} \\ \frac{(2^{2W}-1)-P_{\uparrow}\mathcal{N}_{ay}}{\mathcal{N}_{xy}}, & \frac{(2^{2W}-1)}{\mathcal{N}_{xa}} \leqslant \frac{(2^{2W}-1)-P_{\uparrow}\mathcal{N}_{ay}}{\mathcal{N}_{xy}} \leqslant P_{\uparrow} \\ & \text{and } \widetilde{P}_{m2} > P_{\uparrow} \\ P_{\uparrow}, & \widetilde{P}_{m1} > P_{\uparrow} \\ & \text{and } 0 < \frac{(2^{2W}-1)-P_{\uparrow}\mathcal{N}_{ay}}{\mathcal{N}_{xy}} \leqslant P_{\uparrow} \end{cases} \tag{4}$$

$$P_{m2} = \frac{(2^{2W}-1) - P_{m1}\mathcal{N}_{xy}}{\mathcal{N}_{ay}}$$

Here under certain conditions both $P_{m'}$ and $P_{m''}$ can touch max energy $P_{\uparrow}$. The ideal strategy of $P_{m'}$ and $P_{m''}$ is the transitional output of $\widetilde{P}_{m'}$ and $\widetilde{P}_{m''}$ respectively, considering the limit Eqs. (2m) and (2o) removed from Eq. (2). To allow the source device to take part in transmission, Eq. (1) is modified. Let the source device, $\mathcal{N}_{xa}$ is changed to $\mathcal{N}_{xx} = \infty$ and $\mathcal{N}_{ay}$ is changed to $\mathcal{N}_{ay} = \mathcal{N}_{xy}$. Such that the source device has to assure that $n_x(P_{m'}, P_{m''}) = P_{sender} - \mathcal{C}_x(P_{m'} + P_{m''})$, which shows that the ideal strategy is satisfied on when the entire packet can be sustained by the present energy parameter of P_{sender}.

To compute the transceiver optimization to maximize the lifetime of sensor network, the hop device a has to obtain information of P_{sender}, P_a, $\mathcal{N}_{xa}, \mathcal{N}_{xy}$, and $\mathcal{N}_{ay}$. To achieves this, the sender device embed its energy resource P_{sender} in the *CFT*. Once obtaining the *CFT*, the device a keeps P_{sender} and computes $\mathcal{N}_{xa}$. Similarly the receiver device computes $\mathcal{N}_{xy}$ using *CFT* and then embedded in its *RFT*. Once the hop device obtain *RFT* message from the receiving devices, it then compute $\mathcal{N}_{ay}$ and decode the enclosed $\mathcal{N}_{xy}$. Each hop device computes its $n_a(P_{m'},P_{m''})$ using Eq. (1). If it finds an optimal solution then devices a takes part inhop competition. If it does not obtain any message from other device with a period of time (delay) it will send a beacon message which is as follows

$$m_a = M_{\uparrow} \times \frac{P_{src} - n_a(P_{m1}, P_{m2})}{P_{src}} \tag{5}$$

The higher the $n_a(P_{m'},P_{m''})$, lesser the delay for device a and is most probably will be chosen as the ideal hop device. The overall energy consumption for each packet for priority based hop transmission is computed as follows

$$P_{overall} = \min_{a \epsilon C_h} o_a(P_{m1}, P_{m2}) \tag{6}$$

Table 1 Simulation parameters considered.

Wireless sensor network parameter	Value
Network size	40 m × 40 m
Number of sensor devices	500, 600,700, 800, 900 & 1000
Number of base station	1
Initial energy of sensor devices	0.1 Joules (j)
Radio energy dissipation	50 nj/bit
Data packets length	2000 bits
Transmission speed	100 bit/s
Bandwidth	5000 bit/s
Idle Energy Consumption (Eelec)	50 nj/bit
Amplification Energy (Emp)	100 pJ/bit/m^2

In next section, the simulation study of proposed hop selection optimization for network lifetime enhancement is presented.

4. Simulation results and analysis

The simulation environment considered for both proposed and existing approach is Windows 8 single language, 64-bit, 2.4 GHz quad core Intel processor with 8 GB RAM and 1 GB dedicated Intel GPU. We have used SENSORIA Simulator [26]. The simulator is designed using dot net framework 4.0 and C# programing language. The simulator offers a rich GUI. The simulation is conducted to evaluate the performance of lifetime of sensor network. We considered lifetime performance considering first node death, loss of connectivity and total node death to analyze the efficiency. The proposed model is compared with [23,24,30]. The [23,24,30] have compared their model with LEACH protocol which achieved significant performance improvement. To compare with these models we obtained simulation results and compared with LEACH protocol. The simulation parameters considered to evaluate the performance of proposed approach is mentioned in below Table 1. Since in [23,24,30] the nodes are varied from 10 to 500, the following simulation parameters are considered to evaluate the performance of proposed approach for larger network density and these are defined by the author(s). The experimental results are compared with existing models [23,24,30] which shows significant performance improvement in terms of lifetime efficiency for varied scenarios.

In Fig. 2, the lifetime analysis performance considering total node death for varied sensor devices for both proposed and existing approach is shown. The lifetime improvement of 82.14%, 79.68%, 84.48%, 88.4%, 86.235% and 87.36% is achieved by proposed model over existing model considering

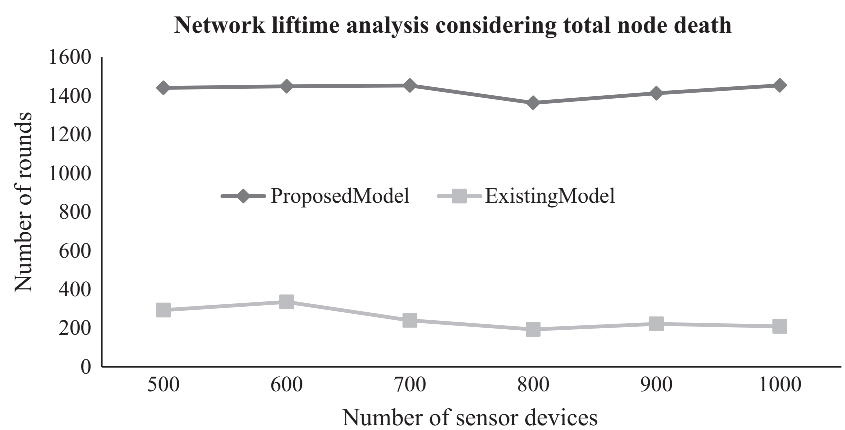

Fig. 2 Network lifetime analysis considering total node death.

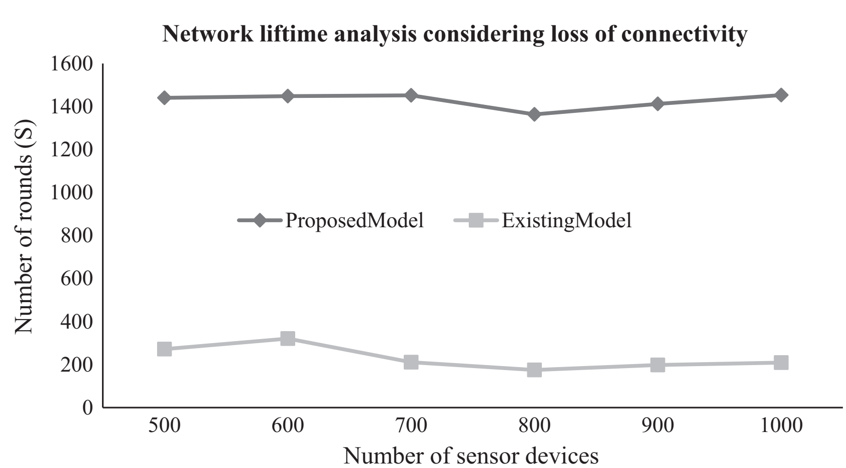

Fig. 3 Network lifetime analysis considering loss of connectivity for varied sensor devices.

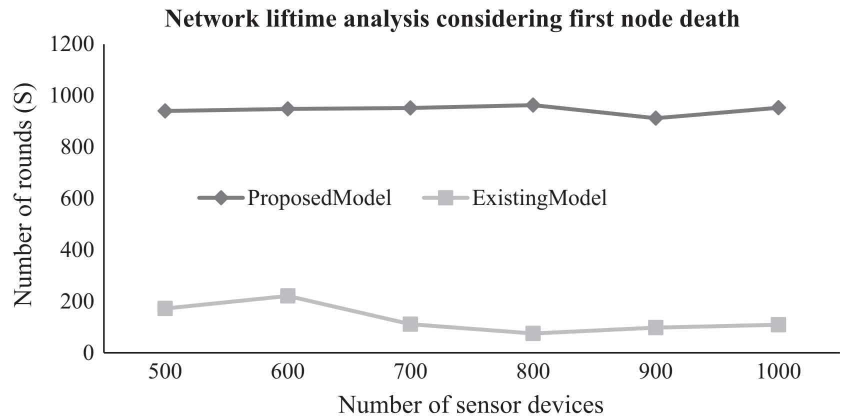

Fig. 4 Network lifetime analysis considering first node death for varied sensor devices.

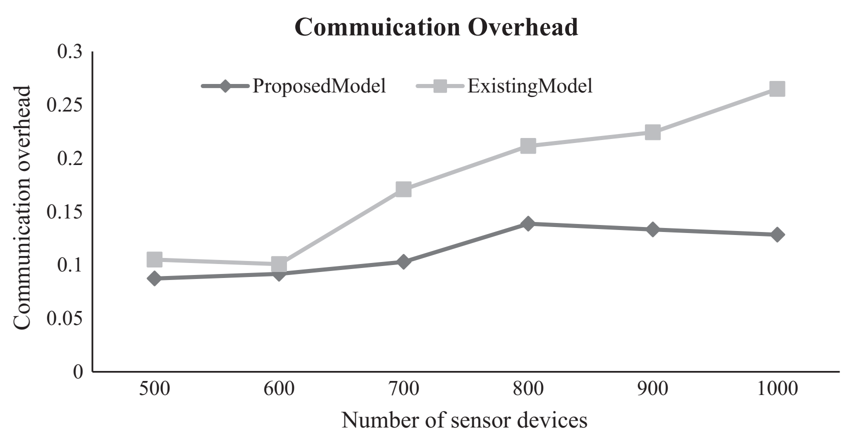

Fig. 5 Communication overhead considering total node death for varied sensor devices.

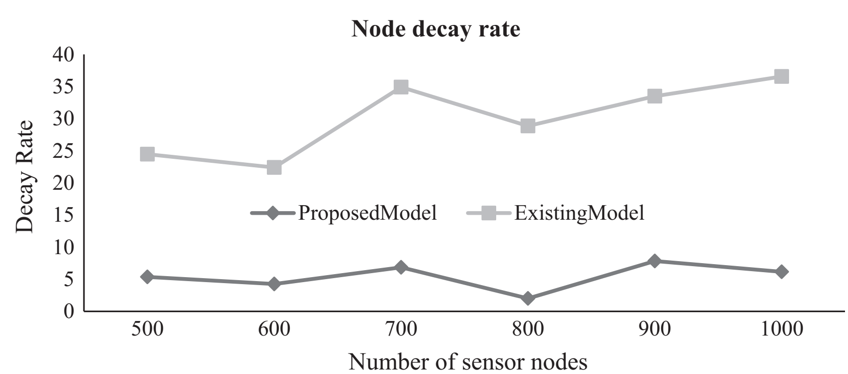

Fig. 6 Node decay rate considering total node death for varied sensor devices.

varied sensor devices from 500, 600, 700, 800, 900 and 1000 respectively. An average lifetime improvement of 84.88% is achieved by proposed model over existing model considering total sensor node death.

In Fig. 3, the lifetime analysis performance considering loss of connectivity for varied sensor devices for both proposed and existing approach is shown. The lifetime improvement of 81.12%, 77.84%, 85.47%, 87.17%, 85.98% and 85.62% is achieved by proposed model over existing model considering varied sensor devices from 500, 600, 700, 800, 900 and 1000 respectively. An average lifetime improvement of 83.39% is achieved by proposed model over existing model considering loss of connectivity.

In Fig. 4, the lifetime analysis performance considering first node death for varied sensor devices for both proposed and existing approach is shown. The lifetime improvement of 81.71%, 77.69%, 88.35%, 92.23%, 89.26% and 88.57% is achieved by proposed model over existing model considering varied sensor devices from 500, 600, 700, 800, 900 and 1000 respectively. An average lifetime improvement of 86.23% is achieved by proposed model over existing model considering first sensor node death.

In Fig. 5, the communication overhead performance considering total node death for varied sensor devices for both proposed and existing approach is shown. The computation overhead of 16.81%, 9.91%, 39.79%, 34.4%, 40.26% and 51.55% is reduced by proposed model over existing model considering varied sensor devices from 500, 600, 700, 800, 900 and 1000 respectively. An average communication overhead of 32.03% is reduced by proposed model over existing model considering total sensor node death.

In Fig. 6, the node decay rate performance considering total node death for varied sensor devices for both proposed and existing approach is shown. The node decay rate of 79.07%, 80.98%, 80.32%, 92.71%, 76.61% and 83.11% is reduced by proposed model over existing model considering varied sensor devices from 500, 600, 700, 800, 900 and 1000 respectively. An average node decay rate of 82.01% is reduced by proposed model over existing model considering total sensor node death.

5. Conclusion

Maximizing the network lifetime and minimizing energy consumption, energy per bit is most desired. Cooperative based transmission is adopted by various researchers shows energy efficiency improvement. Cooperative based communication minimized energy consumption per bit but could not guarantee lifetime enhancement since they adopted a centralized optimization strategy and due to application dynamics. To overcome these limitations, here we presented a dynamic MAC and transceiver optimization technique for selective hop selection that minimizes energy consumption per bit and maximize the network lifetime. Simulation is conducted to evaluate lifetime efficiency considering first node death, loss of connectivity and total node death, communication overhead and node decay rate to analyze the efficiency. An average lifetime improvement of 84.88%, 83.39% and 86.23% is achieved for proposed model over existing model considering total node death, loss of connectivity and first node death respectively. An average communication overhead reduction of 32.03% is achieved by proposed model over existing model considering total node death. An average node decay rate reduction of 82.01%is achieved by proposed model over existing model. The overall outcome shows the proposed model is scalable irrespective of application. In future work, the proposed model would consider cross layer designing to improve routing efficiency and also considers evaluating the performance of heterogeneous architecture.

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