SECURE AND ENERGY EFFICIENT RELAY NODE SELECTION USING OPPORTUNISTIC ROUTING ALGORITHM FOR WSN

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ABSTRACT

In wireless sensor network routing protocol design and energy savings optimization is important because most of times nodes are in moving condition and deployed in remote area. This work focuses on minimizing energy consumption and maximizing network lifetime for data relay in one-dimensional queue network. An Energy Saving via Opportunistic Routing (ENS_OR) algorithm is designed to ensure minimum power cost during data relay and protect the nodes with relatively low residual energy. ENS_OR adopts a new concept called energy equivalent node (EEN), which selecting relay nodes based on opportunistic routing theory, to derive the optimal transmission distance for energy saving and maximizing the lifetime of whole network.

Keywords: Energy efficiency, one-dimensional (1-D) queue network, opportunistic routing, relay node, wireless sensor network (WSN)

INTRODUCTION

A wireless sensor networks (WSN) are spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring and so on.

The main contributions of this paper include the following.

I. We calculate the optimal transmission distance under the ideal scenarios and further modify the value based on the real conditions.
J. We define the concept of EEN to conduct energy optimal strategy at the position based on the optimal transmission distance.
K. We introduce the forwarder list based on the distances to EEN and the residual energy of each node into EEN for the selection of relay nodes.

L. We propose ENS_OR algorithm to maximize the energy efficiency and increase the network lifetime.

II. RELATED WORK

In recent years, there are several studies on routing-related parameters, like connectivity-related parameters and density of the distributed nodes, in 1-D queue networks. Previous works [8] and [9] studied the connectivity probability of two certain nodes versus the entire network. Other work in [10], [11] investigated on uniformly and independently distribution under the assumption that the transmission range is fixed among sensor nodes. Some energy-efficient approaches have been explored in the literature [12]–[14]. As transmitting data consumes much more energy than other tasks of sensor nodes, energy savings optimization is realized by finding the minimum energy path between the source and sink in WSNs. In [12], the the-oretical analysis about the optimal power control and optimal forwarding distance of each single hop was discussed. There is a tradeoff between using high power and long hop lengths and using low power and shorter hop lengths. With this in mind, minimum energy consumption can be achieved when each sensor node locates with the optimal transmission distance away from others in dense multihop wireless network. The most for-ward within range (MFR) [13] routing approach has also been considered in 1-D queue networks, which chooses the farthest away neighboring node as the next forwarder, and eventually results in less multihop delay, less power consumption. Another approach proposed in [14] reduces the total consumed energy based on two optimization objectives, i.e., path selection and bit allocation. Packets with the optimum size are relayed to the fusion node from sensor nodes in the best intermediate hops. Surprisingly, the benefit of optimal bit allocation among the sensor node has not been investigated in 1-D queue networks.

The unreliable wireless links makes routing in wireless networks a challenging problem. In order to overcome this problem, the concept of opportunistic routing was proposed in [15]. Compared with traditional best path routing, opportunistic routings, such as extremely opportunistic routing (ExOR) [16], geographic random orwarding (GeRaF) [17], and efficient QoS-aware geographic opportunistic routing (EQGOR) [18], take advantage of the broadcast nature of the wireless medium, and allow multiple neighbors that can overhear the transmission to participate in forwarding packets. However, these routing protocols did not address exploiting OR for selecting the appropriate forwarding list to minimize the energy consumption, and optimize the design of an energy-efficient OR protocol for wire-less networks. However, these routing protocols did not address exploiting OR for selecting the appropriate forwarding list to minimize the energy consumption, and optimize the design of an energy-efficient OR protocol for wireless networks. Mao *et al*. [19] introduced an energy-efficient opportunistic routing strategy called energy-efficient opportunistic routing (EEOR), which selects a forwarder set and prioritizes them using energy savings optimization solution of forwarding data to the sink node in WSNs.

While all of these routing methods to improve the energy efficiency of individual node or the whole network can min-imize energy consumption, it is equally important to focus on other objectives such as network lifetime and residual energy of relay nodes. Therefore, it is reasonable to take residual energy of sensor nodes as a primary metric into consideration.

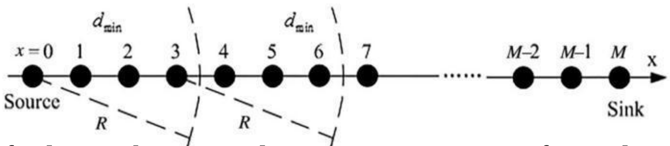


Fig. 1. Queuing model of relay with maximal transmission range of *R* and minimal transmission range *d*min

III. NETWORK AND ENERGY MODELS

In this section, the network model and energy model will be described.

A. Network Model

We consider a multihop WSN in a 1-D queue model as shown in Fig. 2. We assume that our scheme is targeted for relatively dense network, i.e.,each relay node has plenty of neighboring nodes. Nodes have some knowledge of the location information of their direct neighboring nodes and the position of the source node and the sink node. Every wireless sensor node has fixed maximum transmission range R and minimal transmission range dmin. The 1-D queue network is then constructed by a connected graph G = (V, E), where V is a set of sensor nodes aligned on a single line and E is a set of directed links between communication nodes. We set the indices {0, 1, 2, . . . , h, n, . . .,M − 1,M} from left to right, and two specific nodes with index 0 and index M among them as the source node and the sink node. Let N (h) represents as the neighbor set of a node h, i.e., n ∈ N (h). Each directed link (h, n) has a nonnegative weigh w (h, n), which denotes the total energy dissipation in transmission and receiving required by node *h* to its neighboring node *n*.

B. Energy Model

In this work, we refer to a simplified power model of radio communication as it is used in [20] and [21]. The energy consumption can be expressed as follows:

$$ET = (Eelec + \varepsilon amp d)\, B \qquad (1)$$

where *E*elec is the basic energy consumption of sensor board to run the transmitter or receiver circuitry, and εamp is its energy dissipated in the transmit amplifier. *d* is the distance between transmitter and receiver, τ is the channel path-loss exponent of the antenna, which is affected by the radio frequency (RF) environment and satisfies $2 \leq \tau \leq 4$. *ET* denotes the energy consumption to transmit a *B*-bit message in a distance *d*. On the other hand, the energy consumption of receiver *ER* can be calculated as follows:

$$ER = EelecB. \qquad (2)$$

In our model, since the noise and environmental factor are constant, only the transmitter can adjust its transmission power to make *ET* reach a minimum value.

IV. OPTIMAL TRANSMISSION SCHEMES

In this section, energy consumption analysis is conducted on the proposed 1-D model, where data are delivered to sink node through hop-by-hop connected relay nodes. Our objective is to design an energy-efficient opportunistic routing strategy for each relay node that ensures minimum power cost and protects the nodes with relatively low residual energy. Theorem 1 proves the optimal transmission distance *d*op of sensor node under large-scale 1-D queue network. In order to minimize *Ch*, we use the average value inequality.
According to inequality (4), we have

$$C_h \geq (2n-1)E_{\text{elec}}B + \frac{\varepsilon_{\text{amp}}\left[\sum_{i=1}^{n}(x_i - x_{i-1})\right]^{\tau}}{\cdots}$$

$$C_h^{\min}(n) = (2n-1)E_{\text{elec}}B + \frac{\varepsilon_{\text{amp}}(M - x_h)^{\tau}B}{n^{\tau-1}}. \quad (5)$$

One way to optimize the overall energy consumption during data relay is to take a derivative with respect to hop. We take the first derivative of *Cmin h* with respect to *n* as

$$\partial C_h^{\min}/\partial n = 2E_{\text{elec}}B - (\tau - 1)\frac{\varepsilon_{\text{amp}}(M - x_h)^{\tau}B}{n^{\tau}} = 0. \quad (6)$$

This global minimum/maximum can be calculated as follows:

$$n_{\text{op}} = \frac{[(\tau-1)\,\varepsilon_{\text{amp}}]^{1/\tau}(M - x_h)}{(2E_{\text{elec}})^{1/\tau}}. \quad (7)$$

Then, we take the second derivative of Then, we take the second derivative of C_h^{min} with respect to *n* asFrom (8), we deduced that (7) is the global minimum with respect to the energy consumption of node *h*. Hence, the corresponding optimal transmission distance *d*op for node *h* is given by

$$d_{\text{op}} = \frac{M - x_h}{n_{\text{op}}} = \{(2E_{\text{elec}})/[(\tau-1)\varepsilon_{\text{amp}}]\}^{1/\tau}$$
$$d_{\min} < d_{\text{op}} \leq R. \quad (9)$$

Therefore, the proof of Theorem 1 is finished. However, Theorem 1 is an ideal model for multihop 1-D queue network. However, the distance between optimal next relay node to source node could not actually equal to *d*op. Fig. 3 depicts a realistic environment, where the optimal next relay node of node *h* based on Theorem 1 would possibly be set between two real relay nodes. To solve the problem, we further address Theorem 1 that uses the idea of EEN to select the optimal next relay nodes.

V. OPPORTUNISTIC ROUTING ALGORITHM FOR RELAY NODE SELECTION

In this section, we further analyze the energy consumption of large-scale network under 1-D model.
A. *Problem of Optimal Energy Strategy*

In order to acquire the minimum energy consumption during data transmission in whole network, we introduce the concept of EEN to conduct energy optimal strategy at the position based on the optimal transmission distance *d*op. However, the optimal energy strategy does not explicitly takes care of the residual energy of relay nodes in the network. For instance, in the case of hop-by-hop transmissions toward the sink node, the relay nodes lying closer to the EENs tend to deplete their energy faster than the others, since *d*op is a constant. As a consequence, this uneven energy depletion dramatically reduces the network lifetime and quickly exhausts the energy of these relay nodes. Furthermore, such imbalance of energy consumption eventually results in a network partition, although there may be still significant amounts of energy left at the nodes farther away. Therefore, we should readdress the optimal energy strategy for large-scale network from Theorem 1. Inspired from the opportunity routing approach, EEN is formed by jointly considering the distribution of real nodes and their relay priority. The specific algorithm to choose EEN is described in the following section.

B. *Forwarder Set Selection for Optimal Energy Strategy*

In the proposed Theorem 1, we conclude that the energy consumption function (5) is convex with respect to the number of hops *n*. We can achieve optimal energy strategy by choosing optimal hops *n*op to determine optimal transmission distance *d*op. In addition, factors such as energy-balanced of a network and the residual energy of nodes are also considered while selecting the available next-hop forwarder. We assume that node *h* is sending a data packet to sink, and *h* + *i* is one of neighbors of node *h*. If it is closer to the estimated result in (9) and has more residual energy, the neighboring node *h* + *i* can be a forwarding candidate, then the network can obtain better energy usage. Moreover, these eligible candidates rank themselves according to their distances from the EEN and the residual energy of each node as

$$P(h+i) = \begin{cases} (d_{h+i} - d_h)\left[\frac{1}{|d_{h+i} - d_{\text{op}}|} + (E_{h+i} - \zeta)\right] \\ (h+i) \in F(h), \quad -R \le i \le R \end{cases} \tag{10}$$

where *dh*+*i* − *dh* is the distance between node *h* and neighbor node *h* + *i*, *Eh*+*i* denotes the residual energy of node *h* + *i*, and *ζ* denotes the value of energy threshold. *F*(*h*) (*F*(*h*) ⊆ *N*(*h*)) is the selected forwarding candidate set of node *h*. The larger the value of *P*(*h* + *i*) is, the higher priority of the node will be. Only the forwarder candidate with the highest priority is selected as the next forwarder. We use above forwarding candidate set to decide corresponding energy saving strategy, which is specifically achieved through the following opportunistic routing algorithm, called ENS_OR.

C. *ENS_OR Algorithm*

In this section, we will describe how to select and prioritize the forwarder set using optimal energy strategy on each node, and how to choose the optimal relay node among potential forwarders that respond in a priority order. In addition, the transmitted data can be naturally classified into two categories:1) the former is the collected data of its own; and 2) the latter is the relay data from other nodes. Obviously, we should distinguish incoming data (the data of second category) by tracing the ID of sender. Eventually, we introduce ENS_OR algorithm for energy saving to select the next relay node which has the highest priority in forwarder set to forward the incoming ENS_OR algorithm. Algorithm 1 depicts the pseudocode of ENS_OR algorithm.

VI. PERFORMANCE EVALUATION IN DIFFERENT METRICS

II. Simulation Scenario Experiments

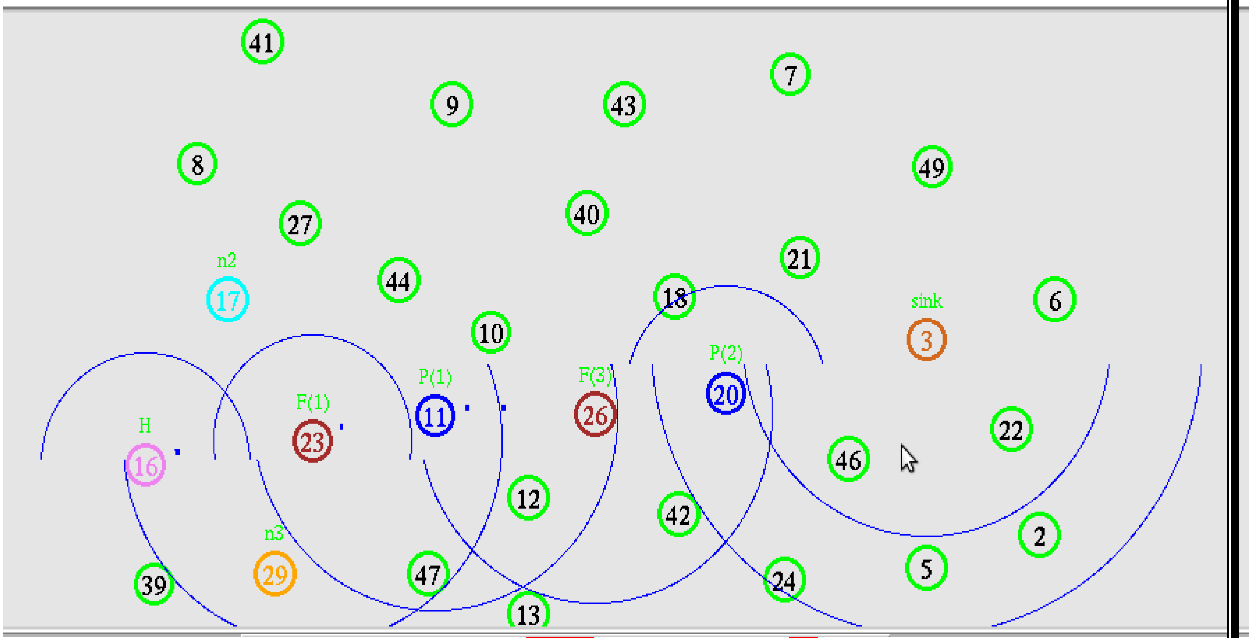
Simulation Environment: We conduct the simulation experiments using MATLAB with 100 nodes uniformly and independently distributed over a line. Each node has the same frequency B = 1 Mbit/s, and firmware character Eelec and εamp in (1) is set as 50 × 10−9 J/bit and 100 × 10−12 J/bit/m2, respectively. Path-loss exponent of environment τ is 2. Hence,

The value of optimal transmission distance $d$op in (9) is approximately equal to 31.6 m. Since Eelec and εamp, τ are fixed, no matter how the distance between two nearest nodes changes, $d$op still will be 31.6 m, without change. The longest transmission distance of a single hop is 50 m and the initial energy is 720 mJ. Other simulation parameters are listed in Table I. In this one-source-one-sink topology, a node can only act as a relaying node. In this paper, we ignore the interference among the generated signals of each node. To fully analyze the performance of ENS_OR, we compared it with the methods GeRaF and minimum transmission energy (MTE) which represent the transmission power strategy with minimum transmission power, to satisfy quality of service (QoS) requirement of reception.

2. *Performance Metrics:* We define four main measurable metrics to evaluate the effectiveness of ENS_OR algorithm or data forwarding in 1-D queue networks.

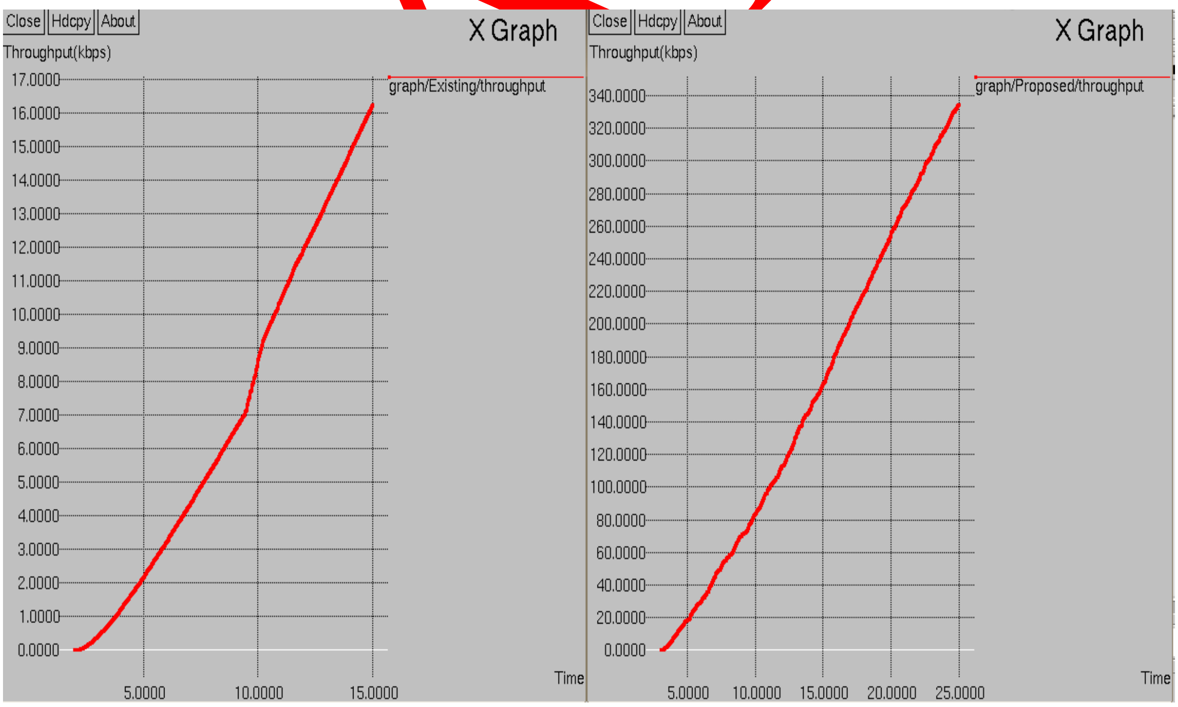
1) Average of residual energy (ARE): Relay nodes left with more average residual energy indicates that all the relay nodes are alive for longer time, which would help to prolong network lifetime.
2) Standard deviation of residual energy (SRE):We use SRE as a metric to quantify the energy balance characteristic of the routing protocol, we have noticed that high standard deviation in the estimations of residual energy implies the unbalanced energy dissipation among sensor nodes, and lowering SRE is important for the routing protocol.
3) Receiving packets ratio (RPR): RPR is defined as the ratio of the amount of packets received by the sink to the total amount of packets sent by the source. In order to effectively avoid the network partition, the sink should receive most of the packets sent from the source, and eventually results in a good connectivity of the network.
4) First dead node (FDN): We define this metric to evaluate the influence of the network connectivity. As the first energy exhausted node appears, the probability of network partition increases, and the connectivity of the network goes bad.
5) Network lifetime (NL): The network lifetime of a 1-D queue network is defined as the time when the sink is unable to receive packet sent from the source. The network lifetime is closely related to the energy consumption and network partition. The higher

the network lifetime is, the more effectively the balance of energy consumption will be achieved, and the more likely the network partition is going to happen.



Packets send via energy saving node

The above fig shows that packets send from source (H) to destination (sink) via energy saving relay nodes



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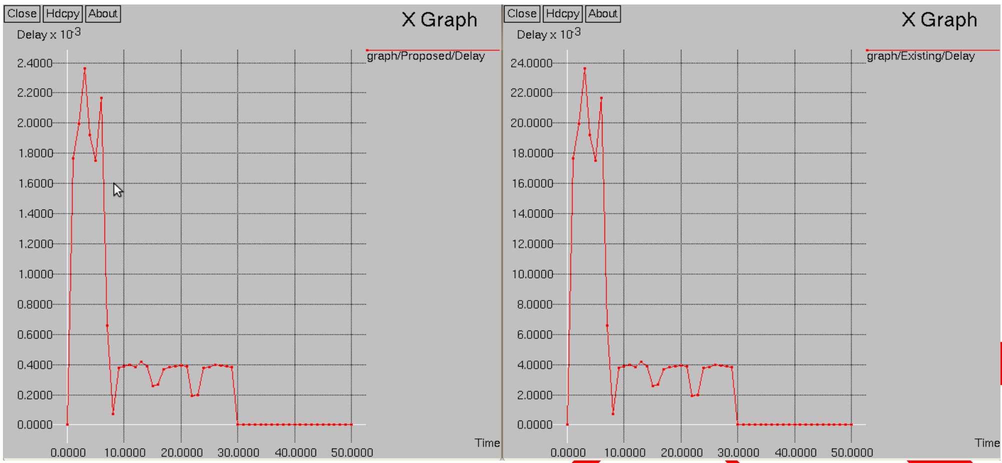
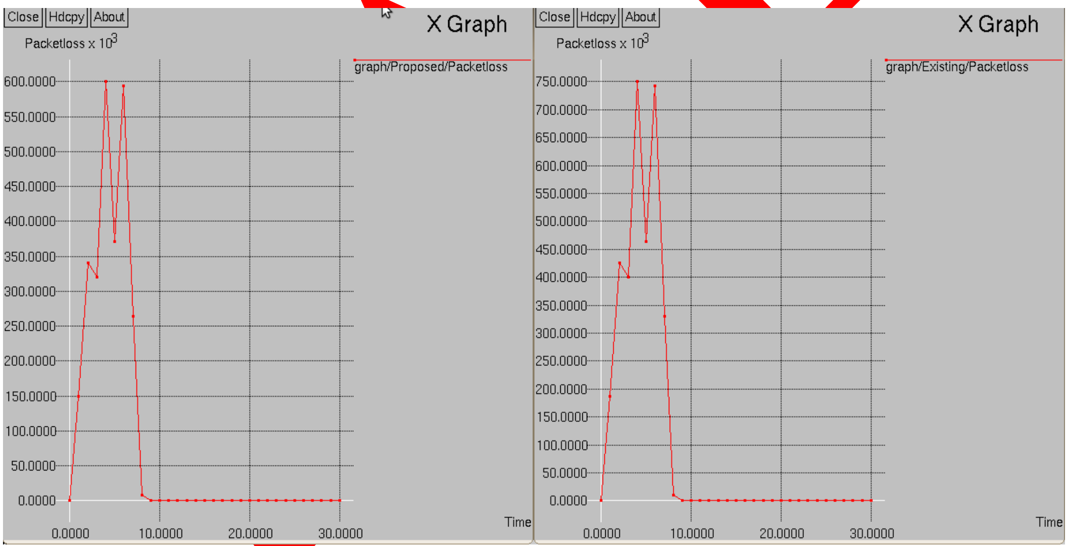
The above fig shows that the throughput comparison between existing method vs proposed method (left side shows existing throughput and right side shows proposed throughput)



The above fig shows that the delay comparison between existing method vs proposed method (right side shows existing delay and left side shows proposed delay)



The above fig shows that the packet loss comparison between existing method vs proposed method (right side shows existing packet loss and left side shows proposed packet loss)

CONCLUSION

In this research focus on minimizing energy consumption and maximizing network lifetime of 1-D queue network where sensors' locations are predetermined and unchangeable. For this matter, knowledge from opportunistic routing theory to optimize the network energy efficiency by considering the inferences among sensor nodes in terms of both their distance to sink and residual energy of each other. This work implement opportunistic routing theory to virtually realize the relay node when actual relay nodes are predetermined which cannot be moved to the place according to the optimal transmission distance. This will prolong the lifetime of the network. Hence, main objective is to design an energy-efficient opportunistic routing strategy that ensures minimum power is cost and protects the nodes with relatively low residual energy. Numerous simulation results and real tested results show that the proposed solution ENS_OR makes significant improvements in energy saving and network partition as compared with other existing routing algorithms.

In the proposed routing algorithm will be extended to sleep mode and therefore a longer network lifetime can be achieved. Apart from that, an analytical investigation of the new energy model include sleep mode will be performed and also security will be added in the entire network

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