# Extensible Network Lifetime Using Relay Selection Scheme on Wide Area Wireless Sensor Networks

**M. Parameswari, T. Sasilatha, S. Vijayalakshmi, P. Divya Bharathi, A. Aishwarya**

***Abstract:*** ***One of the most important metrics in wide area wireless sensor networking (WAWSN) is to maximize the network lifetime. In this paper, a relay selection scheme is proposed under the topology constraints to maximize the lifetime of WAWSNs through solving an optimization problem where relay selection of each node acts as optimization variable. Considering the diversity of the sensor nodes in WAWSNs, the optimization problem takes not only energy consumption rate but also energy difference among sensor nodes into account to improve the network lifetime performance. Since it is Non-deterministic Polynomial-hard (NP-hard) and intractable, a heuristic solution is then designed to rapidly address the optimization. The simulation results assumed indicates that the proposed relay selection scheme has better performance in network lifetime compared with existing algorithms and that the heuristic solution has low time complexity with only a negligible performance degradation gap from optimal value. Furthermore, we also assumed simulations based on a general WAWSN model to comprehensively illustrate the advantages of the proposed algorithm.***

***Keywords:*** ***WAWSNs, Lifetime, Energy Consumption, Residual Energy, Relay Selection, Optimization, Heuristic Solution.***

## I. INTRODUCTION

Wide Area Wireless Sensor Networks (WAWSNs) have recently emerged as a subfield development of Wireless Sensor Networks (WSNs) and a promising technology in wide-range communication area to provide many important and useful applications in different domains such as vital sign monitoring, interactive gaming, research centers and telemedicine. In general, a WAWSN consists of one coordinator and a set of sensor nodes that have to be very simple, tiny and harmless to the human body. At the same time, the coordinator acts as a sink which collects all the information attained by the sensors and communicates it to the user or the remote server for further processing. In order to provide satisfactory services in applications, network lifetime of WAWSNs ought to be highlighted as a crucial parameter. As we know, sensor nodes deployed in WAWSNs are minimized in size, which means they are mostly supplied by non-renewable and energy-limited batteries. When one or more devices have to be implanted, enormous stress is caused by the battery replacement/recharging, which, in some cases, may require more cost and energy. Furthermore, each node in WAWSNs has its unique function that can not be alternatively executed by other nodes. When one sensor runs out of power, WAWSNs will not perform well or even stop working. As a result, it is a necessity to prolong the lifetime of each sensor node in WAWSNs to relieve the stress of frequent recharging/replacement, especially the sensor node that may be exhausted first (The coordinator has sufficient energy compared to sensor nodes).

In IEEE 802.15.6, which is specifically designed for WAWSN communication, topology is specified commonly as a ring topology and can be extended to a two-hop tree topology. This extension indicates that cooperative transmission of a sensor node through a relay is an alternative choice instead of direct one-hop transmission to the coordinator. The authors have proven that appropriately using cooperative transmission can effectively save energy and prolong the lifetime of sensor nodes that are relatively far away from the coordinator through mathematical analysis and numerical simulation. That is to say, rationally utilizing the combination of direct transmission and cooperative transmission to sensor nodes in WAWSNs can improve lifetime performance of the whole network. Hence, an appropriate relay selection is of great importance in cooperative transmission strategy to prolong the network lifetime of WAWSNs.

In this paper, a relay selection scheme called the Extending LifeTime Relay Selection Scheme (short for ELRSS) is proposed to maximize the lifetime of WAWSNs through formulating and solving an optimization problem where relay selection of each node acts as the optimization variable under the topology constraints specified in the IEEE standard. The proposed scheme not only regards the transmission depletion condition of each sensor node as relay selection criterion, but also considers the factor of energy difference among sensor nodes according to the fact that sensor nodes deployed on different locations of the area selected have different sensing tasks and thus their node sizes and battery capacities may be diverse. Moreover, inferred from the fact that the network can function well only when all the nodes stay alive, in our formulated problem, the aim is to improve the minimum lifetime of sensor nodes within a WAWSN, which provides maximum improvement of network lifetime.

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In more designing detail of our relay selection scheme, we firstly derive that the lifetime of WAWSNs is a function of relay selection results. Then, regarding relay selection of each node as optimization variable, a network lifetime maximization problem that considers both energy consumption rate and residual energy is formulated with the target of maximizing the minimum lifetime of sensor nodes in the network. Considering that the optimization problem is an NP-hard binary integer problem and intractable, especially in the case where the number of the nodes in WAWSNs is large, a heuristic iterative solution is designed to rapidly solve the optimization problem with low time complexity. The results assumed indicate that the proposed scheme has better performance in network lifetime compared with other existing methods. Moreover, the result is assumed to show that the heuristic solution can effectively reduce the time complexity with only a negligible performance degradation gap. The rest of this paper is organized as follows. Section 2 consists of related works. In Section 3, the system model considered in this paper is described. The optimization variables, optimization problem formulation and corresponding constraints are defined in Section 4. Thus implementation discussion is done in Section5. Finally, we conclude the paper and briefly discuss the future works in Section 6.

## II. RELATED WORK

To extend network lifetime, there are already a number of routing protocols and relay selection algorithm for WSNs in the literature. Youssef et al. proposed an energy-aware routing algorithm that uses a minimum number of hops for transmission of data. By varying the transmission distance, the interconnections between the nodes can be changed and different network topologies can be obtained. An energy balanced robust scheme based on swarm intelligence that chooses the next node based on node's local information was suggested by Zhang and Shen. This method balances load evenly among the nodes and is able to achieve longer lifetime. Another approach proposed has reduced 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. a relay selection algorithm was proposed to formulate an optimization problem to maximize user data rates and minimize the total transmission power of the network. However, porting these solutions from WSNs to WAWSNs is not problematic due to the different network architectures and operating conditions. In WSNs, hundreds to thousands of sensor-nodes cover large areas, offering a considerable degree of redundancy, and use multi-hop communications.

## III. SYSTEM MODEL

In this section, we first emphasize the conception of network lifetime of WAWSNs. Then, a brief description of the network model and the energy consumption model is presented based on which the proposed algorithm is implemented and analyzed.

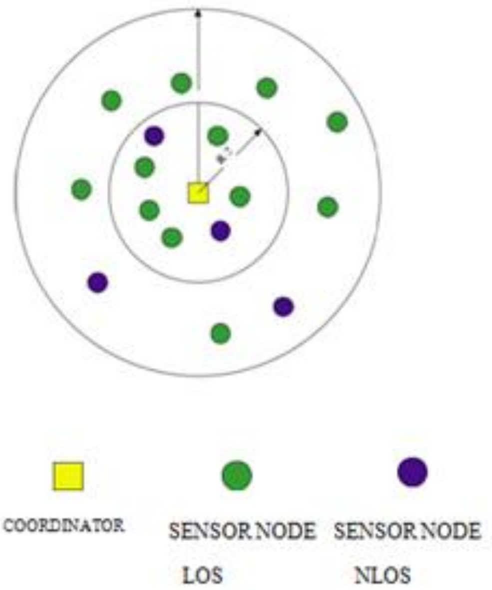


**Fig. 1**

### *3.1. Conception of Network Lifetime*

As discussed before, a WAWSN is very different from a WSN. In a WSN, network lifetime is generally specified as the time duration between the network initialization/restart to the point when the last sensor or the majority of sensor nodes die. However, in a WAWSN, each sensor node is irreplaceable due to its unique function. The exhaustion of one sensor node may lead to network failure. As a consequence, network lifetime of a WAWSN in this paper is denoted as the time duration between the initialization/restart of a WAWSN to the point when the first sensor node in the network exhausts.

### *3.2. Network Model*

In this paper, we consider a WAWSN with one coordinator and l sensor nodes on a wide area for ex: hospital or research center as shown in Figure 1. The coordinator is placed at the center of an area while the sensor nodes are deployed in the different parts of the coverage area. Both direct transmission and cooperative transmission are allowed in the network. The sensor nodes deployed in the main area can be selected as relay nodes because of their shorter distance from the coordinator. Relay nodes should not only transmit their own information to the coordinator, but also relay the information from some other nodes when selected as relay. In addition, relay nodes are allowed to use direct transmission only to comply with the IEEE 802.15.6 two-hop tree topology restriction. Only uplink data transmission from sensor nodes to the coordinator is considered due to application scenarios like health monitoring where most of the information transmitted are sensed data. We assume that the coordinator knows the network topology and the distance between each pair of nodes including itself. A simple Time Division Multiple Access (TDMA) Media Access Control (MAC) is employed in this model to deal with multi-sensor transmission.


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Note that this MAC is a common used version of beacon-enabled superframes MAC specified in IEEE 802.15.6 (see [8] for more details). More specific, time is divided into superframes which has fixed length. A superframe has two parts: the active part and the inactive part. The active part consists of fixed-length time slots and each sensor node has one orthogonal time slot to send its sensed data to the coordinator without collision. If a sensor node is selected as a relay, more time slots are given to it. The number of the extra time slots for a certain relay is decided by the number of relayed sensors it has. Each sensor node transmits the sensed data to the receivers (either relay or the coordinator) in its dedicated slot, whereas relay nodes, if necessary, listen to their corresponding sensor nodes for data reception and transmit the relayed data together with their own data to the coordinator in their allocated slots. During the inactive part, nodes go to sleep mode. When a WAWSN sets up or re-starts, the time slots allocation will be made by the coordinator depending on the relay selection results. Normal sensor nodes are allocated time slots first before relay nodes. In this paper, it is assumed that all nodes have enough sensed data to send during their allocated slots.

### *3.3. Energy Consumption Model*

In WAWSNs, energy is consumed mainly on transmission, sensing and abnormal energy waste including idle listening, collision and overhearing. As described in the previous subsection, a TDMA, MAC is implemented. Thus, it is considered that there is no energy consumed on abnormal energy waste. Moreover, the energy cost of sensing is so small that can be neglected when compared with transmission costs. As a consequence, we focus on the energy consumed by transmission. We have chosen the transmission energy consumption model in, which is widely used in many WSN related works. The energy cost to guarantee reliable transmission during transmitting and receiving are described in Equations (1) and (2) as follows:

The model takes dn as energy costs due to channel variation and the path loss in respect with

$$E_{tx}(k, d, n) = E_{TXelec}\ k + E_{amp}\ k\ d^n, \qquad (1)$$

$$E_{rx}(k) = E_{RXelec}\ k \qquad (2)$$

distance d between sender and receiver. Etx represents the transmission energy, Erx the receiver energy, ETXelec and ERXelec the energy the radio dissipates to run the circuitry for the transmitter and receiver, respectively, and Eamp is the energy for the transmitter amplifier. The specific values of these parameters are hardware dependent. In addition, k represents the number of bits sent for the transmission. n is pathloss coefficient related to shadow effect. As introduced in Section 1, when making relay selection, the amount of energy in each node may not be always the same. Two conditions should be taken into consideration:

- A WAWSN set up with sensor nodes with different battery capacities.
- A WAWSN resumes from a restart when each sensor node has already depleted energy under different consumption rates.

The diversity of energy storage of each node in the network can bring obvious influence on the performance of WAWSNs. Hence, when making relay selection, the amount of energy in each node must be taken into consideration.

$$L_i = \frac{E_i}{C_i} \qquad (3)$$

Therefore, according to the Central Limit

Theorem and the indication, we adopt normal distribution to represent the energy storage condition of each sensor node. Meanwhile, we select an appropriate upper bound and lower bound for the energy storage values to avoid extreme large or small random values in normal distribution, which is impossible to appear in reality. In summary, the residual energy of the ith sensor node when making a relay selection in this paper follows truncated normal distribution which is represented as the following:

$$E_i\ N(m, s^2),\ m \quad D \quad E_i \quad m + D,$$

where m and D are standard values for the residual energy and maximum energy deviation from standard value in each node, respectively, while s2 stands for the energy difference degree among sensor nodes. Larger values of s2 reflects more residual inequality in the network.

## IV. OPTIMIZATION PROBLEM FORMULATION

In this section, the optimization variables, relay selection matrix and lifetime function are introduced first. Then, an optimization problem considering both energy consumption rate and residual energy of each sensor node, aiming to maximize the network lifetime of WAWSNs, is described in detail.

### *Function and Problem Formulation*

Defining $L_i$ as the lifetime of the ith sensor node, which stands for how many superframes the ith node can function well before it runs out, it can be mathematically represented as:

where $C_i$ is defined as the ith sensor node's energy consumption rate, which stands for the amount of energy consumed by the ith sensor node in one superframe. Using Equations (1) and (2), $C_i$ can be further expressed as:

$$C_i = E_{tx}(k, d_i, n)\ (1 + R_i) + E_{rx}(k)\ R_i,$$

the lifetime of WAWSNs is decided by the minimum lifetime of sensor nodes in the network. Therefore, the lifetime of WAWSNs can be expressed as:

$$\text{Lifetime} = \min_{i21,\ ,1} L_i. \qquad (4)$$

## V. RESULT ANALYSIS

Firstly, before the lifetime performance comparison, the time complexity performance of the heuristic solution and its convergency loop condition are analyzed.


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From a theoretical perspective, when we use the enumeration method to solve the optimization, the time complexity is O(2n n). However, when it comes to the proposed heuristic iterative solution, the time complexity is only O(n n). On the other hand, from the experimental perspective in Table 3, which illustrates the average time cost to solve the optimization in the simulation with the varying number of nodes in the network, the enumeration costs much more than the proposed rapid solution. In more detail, the time taken by enumeration grows very fast with the increasing number of nodes, even more than an hour when the number of nodes is 20 in our simulation. While the proposed solution grows much more smoothly within a hundred microseconds. The simulation results in Table 1 match the theoretical analysis on time complexity of enumeration and the proposed solution.

**Table 1: Time complexity of the algorithms.**

| Nodes | Enumeration | The Rapid Solution |
|---|---|---|
| 6 | 0.008530s | 0.000010s |
| 8 | 0.084878s | 0.000016s |
| 10 | 0.834952s | 0.000017s |
| 12 | 7.510353s | 0.000025s |
| 16 | 104.487781s | 0.000028s |
| 20 | 6532.097615s | 0.000039s |

The hardware settings for implementing the simulation in this paper: CPU i-7 2600 3.4 GHz; Memory 8 G RAM. Figure 2 shows the convergency loop performance of the proposed rapid solution when the iteration ended in the simulation.

It can be seen from the figure that the proposed solution always converges to a loop no matter how many nodes are involved (if the iteration can not converge to a loop, then the loop size will be represented by ¥), which means that the iteration of the proposed solution can always converge to an end in the simulation. The average loop size is close to 2 which indicates that the majority of the loop size in the simulation is 2.

Furthermore, it can be seen that when the number of nodes grows, the maximum and average loop size increase due to the fact that the dimensions of X become larger, which brings more binary value combinations for the relay selection matrix.

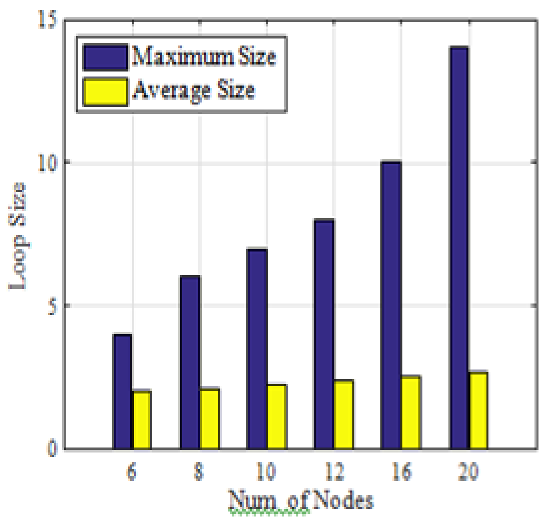


**Fig.2: Convergence loop performance comparison**

Performance evaluation assumed:

| Parameter | Value |
|---|---|
| **Network Model** | |
| Number of sensor nodes l | 16 |
| Number of relay nodes m | 6 |
| Packet size k | 1200 bit |
| Time slot duration | 10 ms |
| Superframes duration | 700 ms |
| **Energy Consumption Model** | |
| $^{E}$TXelec | 16.7 nJ/bit |
| $^{E}$RXelec | 36.1 nJ/bit |
| $^{E}$amp | 1.97 nJ/bit |
| *M* | 2 J |
| D | 1 J |
| n(LOS) | 3.38 |
| n(NLOS) | 5.9 |

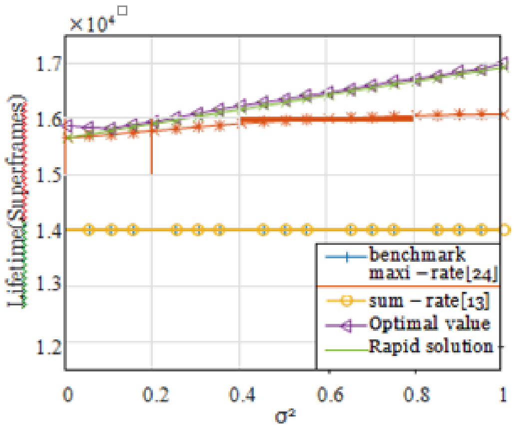


**Fig.3: Network lifetime performance comparison**

*5.1 Implementation Discussion*

In addition to the performance evaluation of our proposed relay selection scheme through simulations, in this part, we make a brief introduction to how to implement our relay selection scheme in a real WAWSN system so as to validate the feasibility of the proposed scheme. We first list the parameters needed to execute our relay selection scheme and describe the methods to obtain the values of these parameters:

- di,j: the distance between each pair of sensor nodes and the distance between sensor nodes and the coordinator;
- n : the transmission path state (LOS/NLOS) between each pair of nodes including the coordinator;
- ETXelec, ERXelec, Eamp : the energy consumption parameters;


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- k : the packet length in the network;
- Ei : the energy storage condition of each sensor node in the network.

As the total number of sensor nodes in a WAWSN is not large, di,j can be measured manually after the sensor nodes have been deployed as well as n, e.g., the transmission path state of each pair of nodes according to the location of each node. Furthermore, the energy consumption parameters are obtained depending on the transceiver types of sensor nodes in the networks. k is specified by the communication protocol and is easily known by WAWSN users. Ei can be known by two means depending on two conditions: (A) if the relay selection is invoked at the network initialization where each sensor node is full of energy, we can directly obtain the energy storage information from the sensor node type and battery information; (B) if the relay selection is invoked at a restart from a network recovery, the coordinator can set a request flag in the beacon frame in order to inform each sensor node to report its residual energy condition in the following transmitting time slots as shown in fig 3. When all of the above parameter values are obtained, the coordinator records this information in its memory and has the ability to execute the relay selection scheme.

Then, we illustrate how to implement our relay selection scheme in two cases. In the first case where a WAWSN is at the initialization stage, the coordinator will directly execute the relay selection scheme at the beginning of the first superframe since it has all values needed to execute the relay selection scheme and load the relay allocation results and the corresponding timeslot allocation in the beacon frame. Then, in the beacon transmission slot, the coordinator broadcasts the beacon frame to all of the sensor nodes in the network. As each node must listen and receive this beacon frame, all of the sensor nodes in the network will know their transmission strategy and their relay nodes, if needed. In the second case, e.g., a WAWSN restarts, where the energy storage condition of sensor nodes is unknown, the coordinator sets a request flag in beacon frame at the beginning of the first superframe and allocates timeslots for each sensor node in the network to report their energy storage conditions.

## VI. CONCLUSION

As a result, in the first superframe, sensor nodes send their energy storage information to the coordinator in their allocated report slots. After the coordinators have received all of the report frames, it invokes the proposed relay selection scheme and loads the results and the corresponding timeslot allocation in the next beacon frame, which will be broadcasted in the second superframe. Then, in the second superframe, each node will know its transmission strategy and their relay nodes. It should be emphasized that the low complexity of the rapid solution in our proposed scheme guarantees that the coordinator can finish the algorithm in the interval between the point when the coordinator has received all the energy storage reports to the slot for broadcasting the next beacon frame. Furthermore, it should be noticed that the implementation discussed here does not involve the detailed interaction procedures between the coordinator and sensor nodes that will be further studied in the future.

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