# Improving Network Lifetime Based On Gateway Relocation in Wireless Sensor Networks

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*Abstract* — **In Wireless Sensor Networks (WSN), sensor nodes deliver sensed data back to the gateway node through multi hopping. The sensor nodes that are close to the gateway node become heavily involved in packet forwarding and it spends more battery power than others. Therefore, these nodes will quickly drain out their battery energy and decrease the network lifetime of the WSN. To increase network lifetime of the WSN, the concept of gateway patrolling is launched. In this paper, we propose Zone Based Gateway Patrolling (ZBGP) for mobile gateway in WSNs. In ZBGP, gateway node is moved towards the area of the sensors that generates more number of data packets (heavily loaded zone). The simulation results show that patrolling the gateway node towards the most number of packets attains significant energy savings as compared to the static approach which helps to improve the life of the entire network.**

*Index Terms* — **Wireless Sensor Networks, EBGP, Gateway Patrolling, ZBGP.**

## I. INTRODUCTION

Wireless sensor networks (WSN) consist of small sized sensor nodes which are deployed in a geographical area for sensing some environmental conditions like temperature, pressure, earthquake and vibration. Most essential component of WSNs are *Sensor node* and *Sink or Gateway node*. Sensor nodes are electronic device used to detect an abnormal event and report the sensed data periodically. Sensor node will send the sensed data hop-by-hop to a special node called *Gateway node* which will inform the supervisor via internet. As shown in Fig. 1, sensor node *h* detects an abnormal event and then it will send a alert message to the gateway to notify the supervisor via a predetermined routing path, say $P_{hG} = h - f - d - b - a - G$. Application of WSN [1] are huge, such as Industrial Sensing, Military application, Traffic Signal, Weather monitoring, etc.

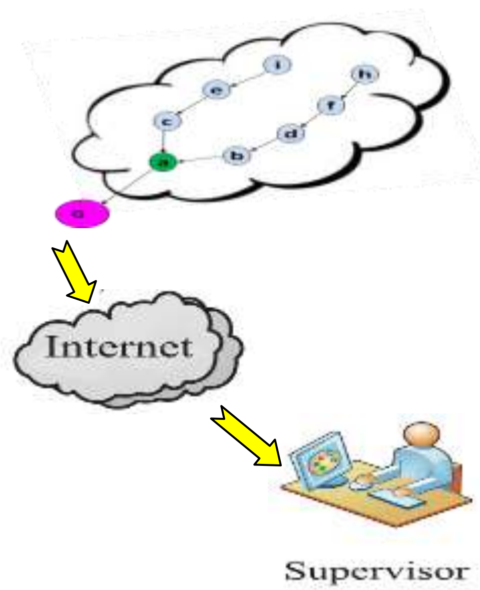


**Fig. 1. An operating scheme of a WSN. G: Gateway node, a: Hotspot node.**

Sensor nodes have a very limited battery energy compare to gateway node. Batteries have tiny capacity and recharging by energy scavenging is difficult and volatile. Hence the energy consumption of sensor node must be severely restricted. Based on the functions of sensor nodes, Power consumption can be separated into three domains: sensing, data processing, and data communication. Among these three domains, a sensor node consumes most energy in data communication. When a sensor node runs out of energy it cannot provide any service and consider as *dead node* [4]. The most of the energy aware routing follows multi hop path in order to minimize the total transmission power and energy. Nearly in all the sensor networks data are send towards a single gateway, hops near to that gateway becomes severely involved in packet forwarding and hence their batteries get depleted rather quickly. The nodes around the gateway would deplete their energy quicker, leading to an energy hole or hotspot problem around the gateway. If this happens then the sensors around the gateway stops from functioning, the gateway becomes isolated from the rest of the network and no more data can be transmitted to the gateway. As a result, the network lifetime ends soon and much energy of the nodes would be wasted [6].

Therefore energy conservation has been receiving bigger attention in WSN research works. The concept of gateway patrolling has been recently established for WSNs in order to increase the overall performance of WSN. When gateway patrolling is established different sensor nodes have higher data loads at different times, as the gateway patrol from one location to another. Left side of Fig 2 illustrates the gateway in its initial position and shaded region gives the *heavily loaded* sensor nodes around the gateway. If the gateway is static, this same set of sensor nodes always stay heavily loaded. But the gateway is allowed to patrol to a new location (as shown in right side of Fig 2) the load is transferred to a completely new set of sensor nodes. Eventually, the gateway patrol around, the set of heavily loaded sensor nodes changes and the energy dissipation is more equally distributed among all the nodes.

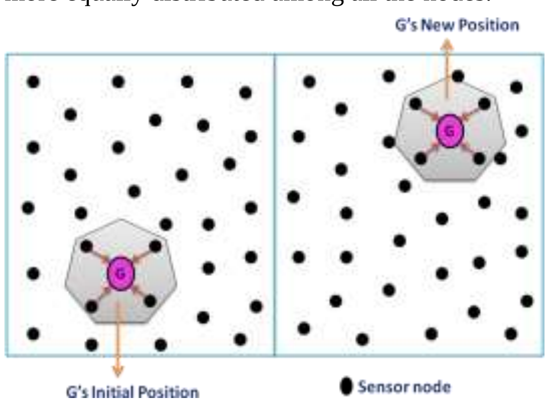


**Fig. 2. Gateway Patrolling of a WSN**

In earlier, gateway node is relocated based on the residual battery energy of the sensor nodes i.e Energy Based Gateway Patrolling (EBGP).But this method is not sufficient to improve the network lifetime because it only focuses on the residual battery energy of sensor nodes**.** In ZBGP (our proposed method), gateway node is patrol towards the sensors that generate the most number of packets. The simulation results show that patrolling the gateway attains significant energy savings as compared to the stationary gateway approach which helps to improve the life of the entire network.

The organization of this paper is as follows. In section II we will briefly describe some background related to the considered problem, which includes the energy model of a WSN, and the energy efficient routing scheme. In Section III, we will describe the ZBGP scheme in detail. The performance analysis is presented in Section IV. The conclusion and future works are given in the final section.

## II. THE BACKGROUND AND RELATED WORKS FOR THE GATEWAY PATROLLING

In this section, we will firstly briefly describe the energy consumption model for message relaying. Then, the energy-aware routing method (the MCP [9] ) that is adopted in the ZBGP method will be illustrated using a numerical example. At the end of this section, a few research works for gateway patrolling will also be addressed.

### *A. The Energy Consumption Model for WSNs*

In our energy consumption model, we take on the first order radio model [5]–[10] for later performance simulation. Let ET *x (k, d)* (and *ERx(k)*) denote the total energy required in a sensor node to transmit (and receive) a *k*-bits length message to (and from) a neighboring sensor node at distance *d* away, respectively. The energy consumed for message transmitting (*ET x(k, d)*) can be partitioned into two. The first part is the energy consumed in the transmitted electronic component and is equal to $k \times Eelec$ , where *Eelec* denotes the energy consumed for driving the transmitter or receiver circuitry. The second part is the energy consumed in the amplifier component and is equal to $k \times Eamp \times d^n$, where *Eamp* denotes the energy required for the transmitter amplifier. Note that, the receiving process performed in a sensor node only includes the first part of the energy consumption. Abbreviation the above descriptions, total energy consumption for message transmitting and receiving is as follows.

$$ETx(k, d) = k \times Eelec + k \times Eamp \times d^n \quad (1)$$

$$ERx(k) = k \times Eelec \quad (2)$$

Note that,in this paper, we let $n = 2$, $Eelec = 50nJ/bit$, and $Eamp = 100pJ/bit/m2$ in Equations (1) and (2).

### *B. An Energy-Based Multi-path Routing Protocol (The Maximum Capacity Path, MCP)*

Routing protocols design for message reporting in a WSN can normally be classified into two categories: static routing and dynamic routing. For the static routing type, when as the message reporting paths are determined, each sensor node will report its sensed data along the predetermined path to the gateway at any time (for example, shown in Fig. 1).

 

On the other hand, a dynamic routing protocol might alter the routing paths in each transmission round according to the current state of the sensor nodes residual battery energy. Due to the fact that the dynamic routing protocols can balance the load on each sensor node, it performs better for network lifetime extending than the static routing protocol [3]. In this paper, we use a dynamic routing protocol, called Maximum Capacity Path (MCP), as the basic routing protocol of the proposed gateway patrolling method. The MCP is proposed by Huang and Jan [9] and has also been established to perform well in extending network lifetime in a WSN. In the following, we will use an example to illustrate the procedure steps of the MCP routing algorithm.

A WSN and its current residual battery energy state of sensor node can be modeled by a capacity graph $G = (V, E)$, where set $V$ denotes the collection of sensor nodes and $E$ denotes all of the possible direct communication between sensor nodes. And let $r : V \rightarrow R+$ be the residual battery energy function to represent each sensor's residual battery energy. For example, as shown in Fig. 3(a), node $s$ stands for the gateway with infinity energy due to the fact that it can equipped with an extremely large capacity battery compared to that of the sensor nodes. The

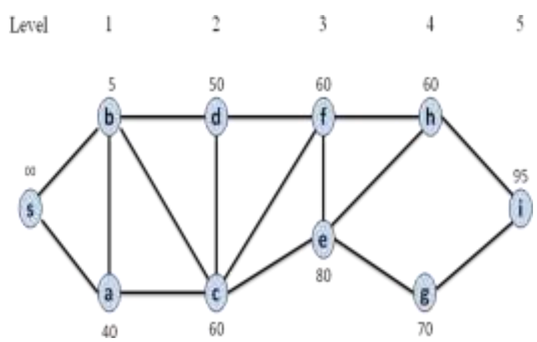


**Fig. 3(a) : Layering graph (G)**

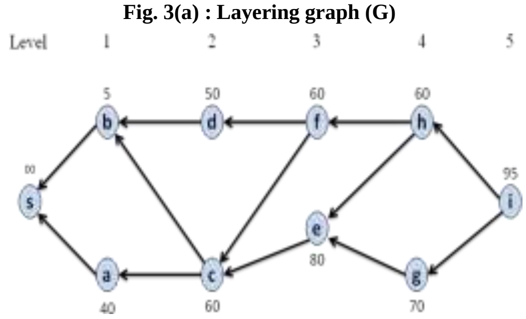


**Fig. 3(b) : Layered network (N)**

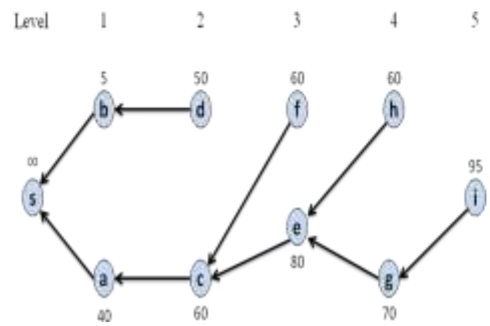


**Fig. 3(c) : Maximum Capacity Path**

value that is associated with node $a$ is equal to 40, which stands for the current residual battery energy of sensor node $a$. The MCP mainly consists of three procedure steps. They are, (1) *layering graph G into a layered network N;* (2) *determining the maximum capacity path for each sensor node;* and (3) *routing performed and residual energy updated.* The MCP will iteratively perform the above three steps for each round of message reporting.

Detailed operations for layering the graph in the first step are as follows. Let level number $Lv$ with respect to each sensor node $v \in V$ denotes the shortest path length from $v$ to the gateway $s$. For the example in Fig. 3(a), since the shortest path length from nodes c and $d$ to node $s$ are both 3, $Lc = Ld =$ 2. The layered network $N$ can be obtained from graph $G$ by deleting the edges $(u, v) \in E$ such that $Lu = Lv$ . For example, as shown in Fig. 3(a),since $La = Lb = 1$, $Lc = Ld = 2$ and $Le = Lf = 3$, then edges $(a, b)$, $(c, d)$ and $(e, f)$ will be deleted from $G$. Then the layered network $N$ obtained from $G$ is a directed graph, such that for all of the remaining edges $(u, v) \in E$ after the deleting operation, the directed edge $(u, v)$ from node $u$ to node $v$, if $Lu = Lv + 1$. Fig. 3(b) shows the resulting network obtained from $G$ in Fig. 3(a). Let $Pus = u, u1, u2, . . . , ul , s$ be a path from node $u$ to the gateway $s$ in $N$. And I let the capacity $c(Pus)$ of path $Pus$ be the minimum value of residual battery energy in path $Pus$ ; that is, $c(Pus) = \min\{ r (u), r (u1), r (u2), . . . , r (ul )\}$. Let $P^*us$ be the maximum capacity path with the maximum capacity value among every path from node $u$ to $s$. The resulting graph of the union of each maximum capacity path $P^*us$, $\forall u \in V$ will be the routing paths for message reporting. For example, Fig. 3(c) shows the resulting maximum capacity paths obtained from the layered graph $N$ of Fig. 3(b). The above operations are the second procedure steps of the MCP. Now, as a sensor node $u$ detects an unusual event or has sensed data to report to the gateway node $s$, then the message will be relayed along the maximum capacity path $P^*us$ to $s$. For example, the maximum capacity path $P^*fs = f, c, a, s$ . After the message relaying from node f to *s* along path *P**fs, the residual battery energy of each sensor node in the path is updated consequently. The above three procedure steps will be repeated for each transmission round until one of the nodes drains out its battery energy.

## III. THE PROPOSED ZONE BASED GATEWAY PATROLLING (ZBGP) METHOD

As mentioned earlier, one major problem reducing network lifetime is due to the fact that energy dissipation becomes extremely concentrated on the sensor nodes which are closer to the gateway node, especially those that are only one hop away from the gateway node. The goal of most energy-efficient routing and/or data gathering protocols is to spread the energy dissipation equally in the network, as much as possible. However, due to the limited transmission range of sensor nodes, it is difficult to completely solve this *Hotspot Problem*. Gateway patrolling is essential in WSN because patrolling the gateway node can balance the traffic load in the middle of multiple nodes and thereby reduces the miss rate of real-time packets. The ZBGP method uses the MCP [9] routing protocol, (which has been described in the previous section) as the basic message routing in order to gain the merit of enhancing network lifetime.

### ZBGP MECHANISM:

As random events are started, there are more data generated in particular regions of the network compared to others. Furthermore, there may be more paths from one *active* sub-region than another. This will lead to unequal distribution of load among different sensor nodes. Therefore, in addition to the geographical distance from active sensors to the mobile gateway, the final gateway position should take the load on the sensor nodes into account as well. So the gateway should move closer to the sensor nodes with heavy transmission loads to reduce the energy consumption of those heavily loaded sensor nodes.

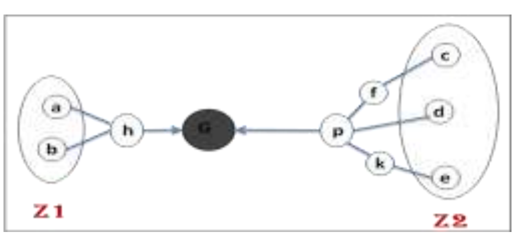


**Fig. 4(a). Gateway node lies mid-way between Z1 and Z2.**

For example, consider the situation in Fig. 4(a) with two event zones Z1 and Z2. According to the scheme in [11], the gateway node should be approximately mid-way between Z1 and Z2. However, in our proposed ZBGP scheme we consider not only the locations of the sensors, but also their load. Furthermore, in addition to the sensors generating data, i.e. those inside regions Z1 and Z2, we also try to minimize the load on all sensors, i.e. also those that are forwarding data. This means that the load on sensors *h1* and *h2*, are also taken into consideration.

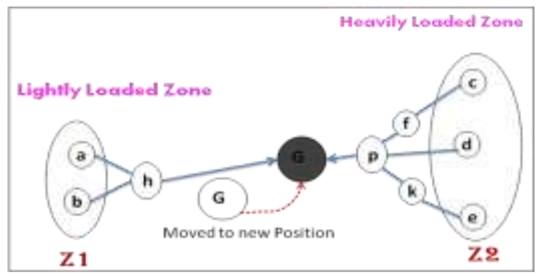


**Fig.4(b). Gateway node moved to near 'Heavily Loaded Zone'**

It is clear that the gateway node placement in Fig. 4(a) puts a much higher load on node *p*, and consequently results in a higher energy dissipation for node *p* compared to *h*. Now Z1 will be called as *Lightly loaded Zone* and Z2 as *Heavily loaded Zone*. If the gateway node is moved closer to *p*, i.e Heavily loaded Zone as shown in Fig. 4 (b), the transmission distance for *p* is reduced and can compensate for the higher data rate, leading to reduced energy consumption. Of course, this is achieved at the cost of increased energy consumption at node *h*. However, by distributing the energy dissipation more uniformly over all nodes, we can expect an overall improvement in the network lifetime.

Multiple advantages are arising due to ZBGP. First, the gateway will be close to nodes collecting maximum data, thus decreasing communication associated energy consumption. Moreover, the total latency time for data collection will be lesser. Furthermore, the packet throughput will be superior since it is probable that messages pass through fewer hops and travel smaller distances making them less likely to be dropped.

## IV. PERFORMANCE RESULTS

In order to evaluating the performance of the ZBGP scheme, we conducted several simulations in three different scenarios which will be described later. The compared methods are the ZBGP and the static gateway scheme. The static gateway scheme assumes that the gateway is not able to moving and stays static at all times. The comparison factor is the network lifetime of a WSN, for which the network lifetime is defined to be the number of message reporting rounds performed before the first sensor node drains out its battery energy [3]. The network lifetime is closely related to the network partition and network coverage ratio. If  node begins to die, the probability of network partition increases, and the network coverage ratio might decrease. The simulation environment settings are as follows.

**TABLE 1. SIMULATION PARAMETERS**

| | |
|---|---|
| Simulation software | NS2 |
| Simulation Area | 1000 x 1000 $m^2$ |
| Number of nodes | 10,50,100 |
| Gateway Node | Movable |
| Sensor Nodes | Static |
| Data rate | 2Mbps |

The three simulation scenarios of 1, 2, and 3 compared the resulting network lifetime performance with *Packet Delivery Ratio (PDR*), varying the *number of sensor nodes, Network Throughput* respectively. *Simulation scenarios 1:* PDR is defined as ratio of total data received by gateway to total data transmitted by sources. Fig.5 shows that network lifetime of ZBGP schemes is better than static gateway schemes in terms of PDR.

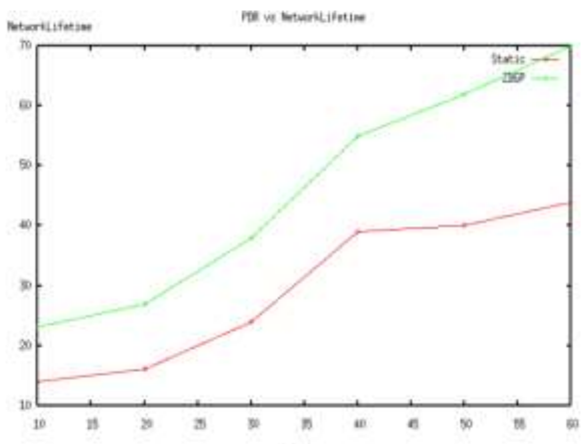


**Fig. 5. The network lifetime comparisons in simulation scenario 1 with PDR.**

*Simulation scenarios 2:* It gives the comparison results when the number of sensor nodes varies. As shown in this Fig.6, the ZBGP scheme is superior than static gateway for any instance of the number of sensor nodes. *Simulation scenarios 3:* Network Throughput states that the total number of data packets received at the gateway divided by the simulation time. Fig.7. clearly gives that ZBGP method is better than static approach.

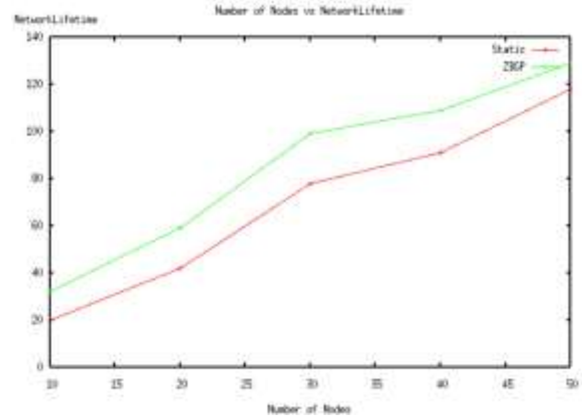


**Fig. 6. The network lifetime comparisons in simulation scenario 2 with a varying number of sensor nodes.**

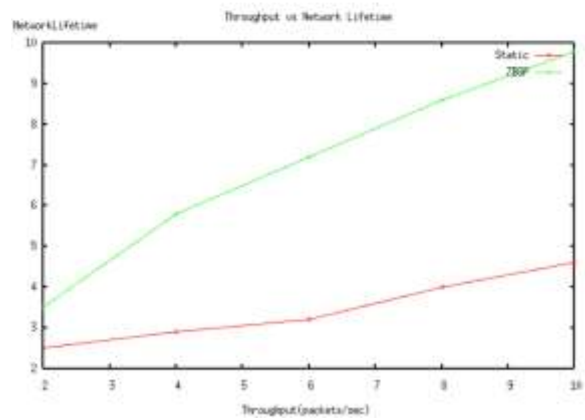


**Fig. 7. The network lifetime comparisons in simulation scenario 3 with Throughput**

## V. CONCLUSION AND FUTURE WORK

Gateway patrolling is yet another approach for prolonging network lifetime by avoiding the placement of the gateway at certain location for too long time. In this paper, we proposed Zone Based Gateway Patrolling (ZBGP) method, which takes the energy based routing protocol MCP as the basic routing method for message relaying. ZBGP takes the transmission load into account to adjust the gateway node position in response to the location of the heavily loaded sensors. The simulation results show that patrolling the gateway node based on the transmission load (the most number of packets) attains significant energy savings as compared to static approach.

As of now, work is carried out based on moving the gateway node with respect to residual battery energy and high transmission load separately. In future it is planned to move the gateway node, based on both residual battery energy and high data load.

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