# Analyses of Energy-Aware Geographic Routing Protocols for Wireless Sensor Networks

Khaled Hadi
Computer Engineering Department, Kuwait University, Kuwait
Email: khaled.hadi@ku.edu.kw

***Abstract*—In this paper, we analyze energy-aware geographical routing protocols with different parameters in wireless sensor networks. Geographic routing is a forwarding protocol that relies on geographic-position information. It is an on-demand type of routing that uses a "greedy" forwarding approach, in which a sensor node forwards a packet to a neighbor closest to the destination node. We study, through simulation, the effect of geographical energy aware routing on packet delivery, hop count, live nodes, and cluster hit rate values over a sensor network's lifetime. Our study is accomplished over two types of network architectures: flat and identical sensor nodes and two- level nodes divided into cluster nodes, and regular sensor nodes.**

***Index Terms*—sensor networks, geographical routing, energy aware routing**

## I. Introduction

Wireless Sensor Networks (WSNs) contain smaller, lower-cost computing sensor devices that can be deployed on a large scale to accomplish numerous applications. WSNs must receive information from the physical world and fuse it to achieve application goals. Limited energy capacity is currently the main challenge for WSNs, and extending the lifetime of such networks is very important. Because routing plays a large role in this type of network, developing an energy-aware routing protocol in WSNs is very challenging, and many research efforts have been made in recent years [1], [2].

An on-demand forwarding protocol that relies on geographic-position information is called geographic (location) routing. Herein, a "greedy" forwarding approach allows a sensor node to forward a packet to a neighbor closest to the destination node [3].

In our study, we introduce a variation of a Geographic and Energy Aware Routing (GEAR) protocol, as described in [2]. We chose to route through GEAR because it is localized and based on distance to destination and the residual energy of neighboring nodes. The changes in the introduced protocol are simple tweaks of balanced routing by multiplying two parameters: distance to destination and consumed energy level. We run GEAR and modified GEAR routing on identical and heterogeneous network architectures. In heterogeneous architectures, some nodes are more powerful than others in diverse resources [4].

The present paper is organized as follows: Section II reviews some existing approaches to handling routing in sensor networks; system assumptions are examined in Section III; the discussion of GEAR and our modified GEAR is presented in Section IV; and an evaluation of GEAR and modified GEAR is given in Section V. Finally, we conclude our paper in Section VI.

## II. Related Works

Routing protocols in sensor networks are generally classified into three categories: data centric, location-based, and hierarchical.

A data centric protocol is different from traditional address-based routing in which the network layer manages routes between addressable nodes. Flooding and gossiping [5] are two basic mechanisms that relay data without using routing algorithms or topology maintenance. These protocols incur redundancy of packets, and packets circulate the networks until the hop count limit is reached. However, Sensor Protocols for Information via Negotiation (SPIN) [6] and directed diffusion [7] use descriptors to reduce redundant packets, and they need to know only one single-hop neighbor for topology changes.

For location-based routing, the location information is needed to forward packets to a specific destination. This process will eliminate a number of transmissions because most of the time the route constructed between source and destination is the shortest possible one. It is a very simple protocol in which the sensor node just forwards a packet to the nearest neighbor to the destination node according to the node location. It is also better in handling network scalability and partitioning [3]. Geographic Adaptive Fidelity (GAF) [8] is location-based routing that forms a logical grid for the covered area. It allows only one node to stay awake and keeps the others in sleep mode to save energy. Routing here is constructed between active nodes in logical grids. GAF also rotates active and sleep states among nodes in each logical grid for load balancing. GEAR [2] is also a location-based form of routing.

However, hierarchical routing is designed to save energy consumption by limiting multi-hop communication within a specific cluster head instead of a remote sink, as well as by reducing data aggregation and

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fusion to decrease transmitted messages [9], [10]. One example of hierarchical routing is Low-Energy Adaptive Clustering Hierarchy (LEACH) [1], which is most popular in sensor networks. Cluster forming in LEACH is based on received signal strength, and cluster heads are used as a router to the sink. We use the cluster architecture in some part of our study. However, the cluster-head nodes are distributed uniformly in a grid fashion in the sensor area.

We study geographic routing because it can be made practical approach to scalable wireless routing. [11] proposed a fix on the routing which enables correct geographic routing on arbitrary connectivity. The approach is confirmed practical in simulation and further testbed measurements.

## III. Assumptions

The general system assumptions in this study are:

- There are two types of network architectures under study: one is a flat architecture in which the sensor nodes are identical and distributed randomly across a given region. The other is a cluster architecture in which there are a few powerful, cluster-head nodes responsible for gathering information from the regular sensor nodes.
- Each sensor can be equipped by GPS [12], or through other techniques such as triangulation [13], to determine its own position sufficiently and accurately.
- Sensor parts of sensor nodes are active to keep the sensor area under surveillance all times, but their radio communications remain off. To accomplish this, sensor nodes' radio communications can use low-energy paging channels [14], [15] and [16]. With this setup, a very low-power radio is used to monitor the channel at all moments. This channel monitoring can be operated with just a few microwatts, and monitoring circuits are responsible for awakening the nodes when appropriate.
- If there is a discovered event, then we must assume that this event is detected by a single sensor node. However, multiple sensors detecting an object are ignored in our setup, as this requires using a data-aggregation protocol to handle the many messages triggered by such an event—something outside the scope of this paper.
- An object event can emerge randomly and uniformly in any part in a sensor area, not with standing that reason dictates that no objects can be spontaneously created within a region under surveillance.
- The cluster-head nodes are computationally more powerful, so we must assume they are not limited in their functioning by energy constraints; for example, we should assume any given cluster head can be recharged. However, regular sensor nodes are powered by batteries, i.e., a fixed amount of energy.

We have implemented the energy model presented in [1]. When transmitting, the radio expends energy according to the following:

$$E_{TX}(k,d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2 \quad (1)$$

When receiving, the radio expends energy according to the following:

$$E_{RX}(k,d) = E_{elec} \times k \quad (2)$$

here, $E_{elec}$ is the radio dissipation required in (*nJ/bit*) to run the transmitter and receiver circuitry, $\varepsilon_{amp}$ in (*pJ/bit/m$^2$*)is the energy consumed by the transmitter's amplifier, and $d$ is thetrans mission range for a $k$-bit message.

## IV. Energy Aware Geographic Routing Protocols

In this section, we first briefly describe GEAR protocol [2]. GEAR is an adjustable form of routing, in which there is a tunable parameter that weighs between distance to destination and the consumed energy fora node. In addition, the original GEAR has a learned cost used when there is a hole, in which the transmitting node becomes that closest to the destination, creating a local minimum. Therefore, the transmitting node needs to forward backward to find non-shortest route to the destination. In our simulator, we neglect this case, and the transmitting node stops forwarding if there is a hole. Estimated cost expressed below is used when there is no hole:

$$c(N_i, D) = \alpha d(N_i, D) + (1-\alpha) \times e(N_i) \quad (3)$$

where $\alpha$ is a tunable weight, $d(N_i, D)$ is the distance from the $N_i$ neighbor to the destination normalized by the largest distance among all neighbors of $N_i$, and $e(N_i)$ is the consumed energy at node $N_i$ normalized by the largest consumed energy among neighbors of $N_i$.

We slightly modified the cost function based on the GEAR equation: Instead of adding weight to the normalized distance and consumed energy, we multiply them together as follows:

$$c(N_i, D) = d(N_i, D) \times e(N_i) \quad (4)$$

## V. Simulation Results

### A. Simulation Setup

TABLE I. Simulation Parameters

| | |
|---|---|
| Number of regular nodes | 2,000 |
| Number of cluster nodes | 9 |
| Communication range | 30 m |
| Sensing range | 30 m |
| Data-packet size | 24 bytes |
| ACK-packet size | 12 bytes |
| $E_{elec}$ | 1,400(nJ/bit) |
| $\varepsilon_{amp}$ | 900(pJ/bit/m$^2$) |
| Start-energy level at node | 20 mJoules |

The simulation results we present throughout this work are based on the following simulator setup: The regular sensor nodes are identical and distributed uniformly over a 600m×600m rectangle, and each sensor knows its own location. Additionally, for the cluster architecture, the cluster-head nodes are distributed and spaced uniformly in a grid fashion in the sensor area. Table I displays the simulation parameters used in all our experiments.

### *B. Simulation Results*

As mentioned earlier, we consider two types of sensor network architectures: 1) a flat network, in which all sensor nodes are identical and 2) a hierarchical network, in which nodes are divided into cluster-head nodes and regular sensor nodes. In each architecture, we evaluate the following parameters: 1) the average packet-delivery success, 2) the average hop count, and 3) the average number of live sensor nodes according to GEAR and modified GEAR with product as in (3) and (4), respectively. Additionally, we evaluate the cluster hit rate in the hierarchical network. The cluster hit rate is defined as the percentage of times each regular sensor reports to its own cluster head. Due to the weight factor toward normalized consumed energy in the routing protocols or the energy depletion in the sensor node, one sensor node could forward a packet to another sensor node that has a different cluster head than itself, which creates a cluster miss.

In the simulator, we generate 200 events triggered by the detection of an object in the sensor area. These events occurred during the lifetime of the experimental sensor networks. These 200 events are averaged over a total of 5,000 simulations.

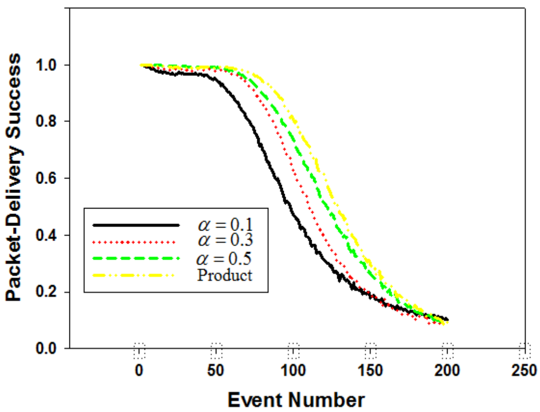


Figure 1. Packet-delivery success as a function of the number of events that occur during a given mission for a cluster (hierarchical) architecture

For the hierarchical network architecture, the experiment results, shown in Figure 1, suggest that, for all methods, the packet-delivery ratio declines as the number of generated events increases. This is due to the depletion of some sensor nodes' energy over time, as depicted in Figure 2. Draining sensor nodes' energy creates void areas in the sensor networks, making some packets' delivery impossible. However, the simulation also showed that GEAR with product decreased more slowly than the other approaches because of the large number of live sensor nodes. The decline, however, is faster for both the packet-delivery ratio and the number of live nodes when α = 0.1because of the greater weight on energy consumed rather than on finding the shortest distance to the destination. In addition, in general, as α decreases, the both aforementioned parameters energy also declines. The product approach, i.e. the modified GEAR, performs much like GEAR when α = 0.5. The same reasoning also applies in flat architecture, as depicted in Figure  and Figure . However, whenα = 0.5, packet-delivery success is better in unmodified GEAR than in the product approach, which is not the case for cluster architecture. This isdue to the larger average hop count, as shown in Figure, which also affects the average number of live nodes in the network.

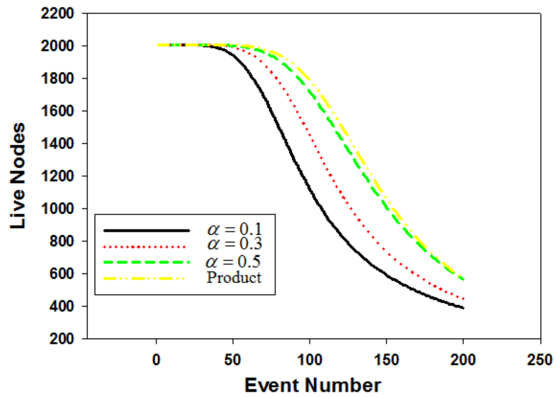


Figure 2. Average number of live sensor nodes as a function of the number of events that occur during a given mission for a cluster (hierarchical) architecture

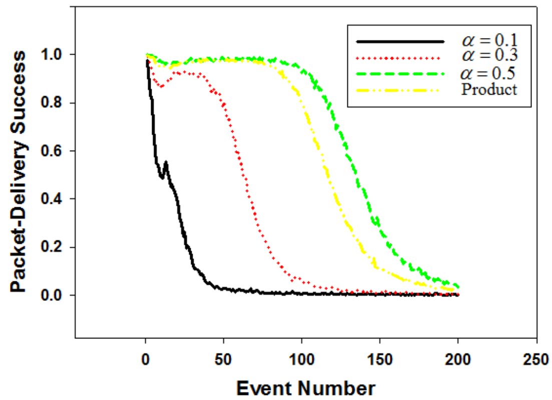


Figure 3. Packet-delivery success as a function of the number of events that occur during a given mission for a flat architecture

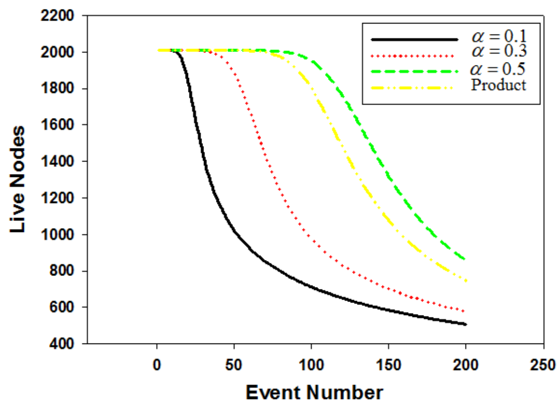


Figure 4. Average number of live sensor nodes as a function of the number of events that occur during a given mission for a flat architecture

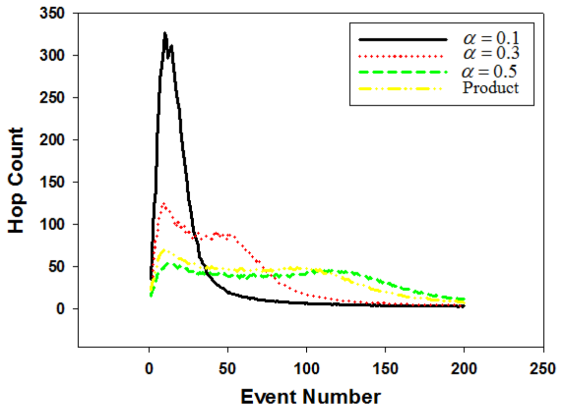


Figure 5. Average number of hop count as a function of the number of events that occur during a given mission for a flat architecture

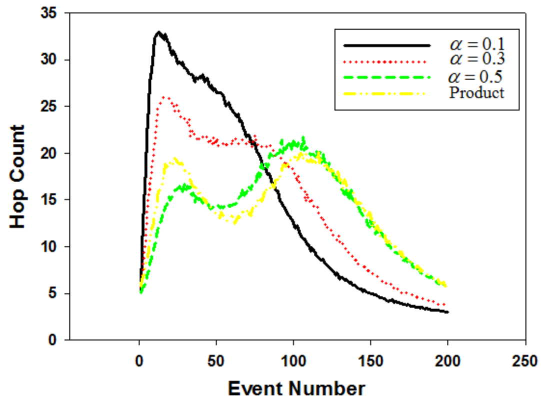


Figure 6. Average hop count as a function ofthe number of events that occur during a given mission for a cluster (hierarchical) architecture

The path to destination can be represented by the average hop count, as depicted in Figure for cluster architecture. For all approaches, the hop count starts with a small value—around five hops on average—and starts increasing depending on the$\alpha$ value. The hop count then reaches a peak value and declines again, but the more interesting thing is that when $\alpha$ = 0.5 and for the product approach, the hop count has two local maximum values and drops in the middle because of the increase in the cluster hit ratio, which will be discussed in the next paragraph. The hop count increases faster as$\alpha$ decreases, and more weight is given to consumed energy rather than selecting the distance to the next neighbor in GEAR. For all methods, the drop in hop count at the end of the sensor network's life time is due to the appearance of void areas due to the depletion of energy. The same effect occurred in the flat architecture in Figure, but the average hop count is much larger due to the average larger distance between source and destination nodes. We can see that the average hop count has a more or less constant value over the sensor network's lifetime when $\alpha$= 0.5 and for the product approach, but it then starts degrading due to the increase in dead nodes.

The cluster-head hit ratio, which is defined as the percentage of the packet-delivery success from a sensor node that senses an event to its cluster head node, is depicted in Figure . Here, we calculate the cluster hit ratio conditioning on successful packet delivery to either the sensor node's cluster or the other cluster. The cluster hit ratio starts with 100% hitting of its own cluster node, but it then decreases as time goes by and increases again for some values of $\alpha$. Even though the cluster hit ratio decreases, the packet delivery is still successful to other cluster-head nodes in the networks. As $\alpha$value increases, the hop count also increases, as explained before, which increases the chance of a packet reaching a sensor node that has a different cluster head from the original, which thus decreases the cluster hit ratio. The cluster hit ratio increases again for some values of $\alpha$ because of the void areas that occur in networks, forcing the packet to be delivered to its closer, original destination cluster head. The early increase for the product approach and GEAR with$\alpha$ = 0.5 results in the second rise of packet-delivery success, as depicted in Figure .

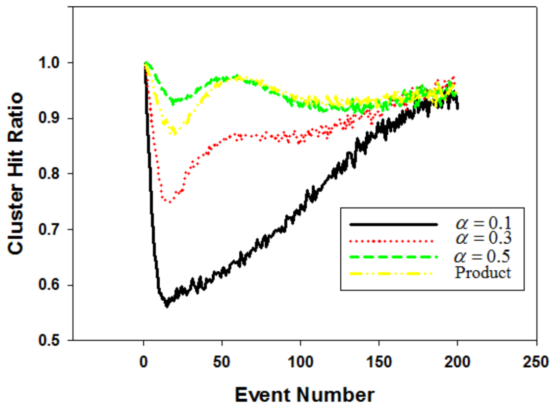


Figure 7. Cluster hit ratio as a function of the number of events that occur during a given mission for a cluster (hierarchical) architecture

## VI. Conclusions

We studied GEAR and modified GEAR routing protocols on sensor networks under different parameters—packet-delivery success, live nodes, hop count, and cluster hit ratio—during the sensor network's lifetime. We have shown through the above simulation that the modified GEAR (the product approach) performs much like the original GEAR when the tunable parameter $\alpha$equals 0.5, which is considered the best value choice for the GEAR protocol; however,the modified GEAR works slightly better in a cluster architecture.

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**Khaled Hadi** received his Ph.D. from the University of Massachusetts, Amherst, in 2009, in Electrical and Computer Engineering and his MS Degree from the School of Information and Computer Sciences, University of California, Irvine, in 2004. He received the BS in Computer Engineering in 1999 from Kuwait University. He is currently an assistant professor of computer engineering at Kuwait University. His research interests include sensor networks, computer networks, distributed systems, and operating systems.