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Design of the Fuzzy-based Mobile Model for Energy Efficiency within a Wireless Sensor Network

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Abstract

Research on wireless sensor networks has focused on the monitoring and characterization of large-scale physical environments and the tracking of various environmental or physical conditions, such as temperature, pressure, and wind speed. We propose a stochastic mobility model that can be applied to a MANET (Mobile Ad-hoc NETwork). environment, and apply this mobility model to a newly proposed clustering-based routing protocol. To verify its stability and durability, we compared the proposed stochastic mobility model with a random model in terms of energy efficiency. The FND (First Node Dead) was measured and compared to verify the performance of the newly designed protocol. In this paper, we describe the proposed mobility model, quantify the changes to the mobile environment, and detail the selection of cluster heads and clusters formed using a fuzzy inference system. After the clusters are configured, the collected data are sent to a base station. Studies on clustering-based routing protocols and stochastic mobility models for MANET applications have shown that these strategies improve the energy efficiency of a network.

Index Terms: Fuzzy Inference System, FND, MANET, Stochastic mobility model, WSN

I. INTRODUCTION

Wireless sensor networks (WSNs) are currently used for various research tasks. The required low power consumption of such networks has been a challenging area of study, and is important to certain applications where frequent battery replacement is impractical. The low-cost requirement is a key consideration in applications having numerous connected nodes. To address the challenge of global usability, a globally operational device must be developed for maximizing the production, marketing, sales, and distribution efficiencies of products with embedded WSN devices and for avoiding regional variations that are individually monitored through the distribution chain. Security in a WSN is vital, and the network must be aware of its current and potential users. Moreover, data throughput requirements should be considered in terms of the communication efficiency of the network, and message latency depends on the quality-of-service requirements. The mobility of a WSN is a key research challenge, particularly in mobile ad-hoc network (MANET) applications. If the mobility pattern of the nodes in the network can be predicted, the performance of the routing protocol will be significantly improved; therefore, many studies have attempted to understand such mobility [1-4]. To model the node mobility, representative random mobility models typically generate movement patterns at random. Such node movement models are simple to implement for expressing the movement characteristics of individual nodes. The mobility models proposed in MANETs provide several different methods for achieving various goals by approaching them

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from varying perspectives. Therefore, the routing protocol design of a MANET aims to provide a mobility model suitable for specific applications. In a MANET, the mobility functionality of the nodes is one of the main services that the system must provide. Mobility support is extremely important in application scenarios, particularly for the Internet of Things. Therefore, understanding the mobility in a MANET is essential for understanding the system and identifying its key characteristics and limitations. When a sensor node moves in the service field area, an efficient communication protocol from the physical layer to the transport layer is required. This means that the node mobility affects the routing protocol. Application-specific goals must be effectively fulfilled, while meeting the node mobility and constrained movement requirements. Therefore, understanding the mobility characteristics of the nodes will improve the network performance [5-8].

Section 2 describes previous research conducted on WSNs and fuzzy inference systems (FISs). Section 3 then describes related studies on tasks related to WSNs, MANETs, mobile sensor networks in terms of mobility models, and WSNs utilizing an FIS. Next, Section 4 discusses the proposed mobile stochastic model; its performance and stability are verified by applying it to a clustering-based routing protocol for efficient energy management. Finally, Section 5 presents an evaluation of the experimental results and some concluding remarks.

II. Related Research

A. Mobility Model used in WSN

Various methods have been studied to extend network lifespan and improve the performance in a new deployment environment, according to the movements of the wireless sensor nodes. Some models have used a single mobile node to collect the measured information from static sensor nodes. Another mobility model is a network where only one or two nodes move, and can be categorized as a different type of model. Some models with multiple mobile nodes place the mobile nodes in areas to obtain the best coverage and connectivity over the entire sensor field [2].

The mobility model of a MANET can be classified into two categories, i.e., homogeneous and heterogeneous, using a data-centric measurement. A homogeneous mobility model has a group of mobile nodes that use the same mobility model to move within the network. A heterogeneity model is based on having a single mobile node move within a network according to a specific mobility model evaluation and on the final experiment results. The movement model classification can be further classified into subcategories, as shown in Fig. 1.

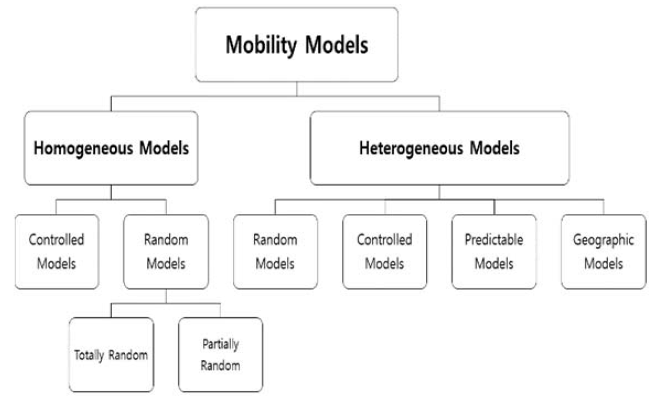

Fig. 1. Mobility model classification.

B. Mobile Ad-hoc Network

A MANET is a distributed self-organizing network composed of multiple mobile nodes; each of which can act as a router and communication facility. A MANET is a special type of network having constraints in terms of energy consumption, network bandwidth, number of mobile nodes, and changes in topology. The clustering used in a MANET has several advantages, including facilitating the routing and reducing the energy consumption, which helps with network management. In a MANET, the network overhead can be reduced by utilizing a small amount of temporary storage during routing. The clustering technique strengthens a MANET because a communication failure within one cluster will only affect that specific cluster and not the entire network. Clustering can also improve the throughput, spatial reuse, and scalability. Fig. 2 illustrates the structure of the fuzzy mobile sink protocol system [9-11].

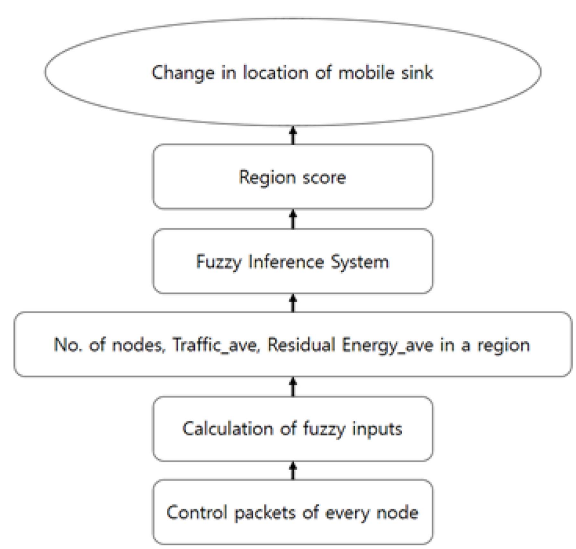

Fig. 2. Architecture of fuzzy sink mobility protocol.

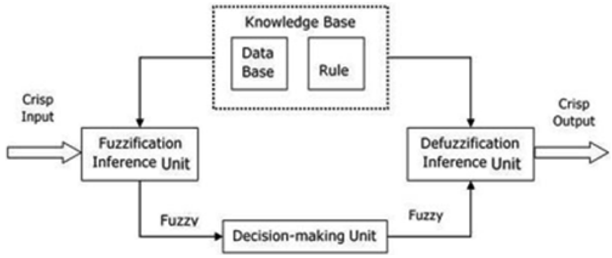

Fig. 3. Block diagram of an FIS.

C. Fuzzy Logic

An FIS is an expert IF-THEN rule-based system that can quantitatively express human undertones or ambiguity, i.e., natural language. The rules used here are based on expert knowledge or heuristics. Fig. 3 shows an FIS block diagram [12-14].

The created rules play an important role in the system performance. In this study, the protocol used for a performance verification aims to efficiently select a cluster head (CH) in a MANET environment, route all sensor nodes around the CH, and transmit the measured data to the destination base station (BS). To maximize the energy efficiency, an FIS is used as the CH selection method. As the nodes move during every round, the existing sensor field environment changes, as does the arrangement of sensors within the sensor field. As all environments change, a new CH is selected to adapt to the new sensor field environment, and a new routing path must be formed in the direction of the entire network around the elected CH in an energy efficient manner.

III. Proposed Method

In many applications of WSNs, individual nodes are used, including both mobile and static. In addition, energy efficiency using energy-limited batteries has become an important issue. These requirements are problematic for medium access control and routing protocol designs. In this section, we describe a mobility model that can accurately indicate when node movement occurs, verify the stability of the designed stochastic mobility model, and describe in detail how to efficiently manage energy use.

A. Sensor Field Node Movement Environment

When a node moves in a sensor field, the sensor nodes configure their own network, and transmit the data measured by each node to the CH, starting from the scenario under which the CH transmits the BS. We propose a mobility model that can reflect changes in the external environment through the movements of the sensor nodes. Various mobility models are available depending on the application used; however, in this section, using a stochastic mobility model is suggested in terms of the number of moving nodes and their movement distances.

The assumptions for a mobile sensor field environment are as follows.

1. There are two types of nodes used in the sensor field: mobile and fixed nodes.
2. As the number of rounds, i.e., time, progresses, the mobile and stationary nodes can alternate their roles at random.
3. The movement range of the sensors is limited to a predetermined sensor field area. .
4. There are no newly added nodes.
5. The locations of all nodes are known using GPS.
6. The movement distance of the moving nodes per round is limited to a range facilitating smooth communication.

B. Sensor Field Node Movement Environment

For the node movement management of MANET, the RWPMM(Random WayPoint Mobility Model) is a random model used for node mobility. This model shows how the position, velocity, and acceleration change over time. This mobility model was applied for simulation purposes when evaluating new network protocols. It is one of the most popular mobility models for evaluating MANET routing protocols.

In a random-based mobility simulation model, the moving nodes move freely and randomly with no restrictions. Specifically, the destination, velocity, and direction are all chosen independently of any other nodes. This model has been used in many simulation studies.

With this type of mobility model, a frequently occurring problem is the use of unnatural paths. Unlike the RWPMM, the actual protocol or mechanism applied to the proposed model should be robust, and demonstrate reasonable movement characteristics in the node movement pattern. In addition, a uniform velocity distribution U(0, Vmax) creates a situation wherein each node remains in a stationary state.

The number of nodes that have moved in a certain sensor field space can be expressed as follows.

$$N_{move} = N * P_{move}. \quad (1)$$

Here, N_{move} is the number of nodes where movement has occurred during a certain period; N is the number of populations, i.e., the total number of nodes; and P_{move} is the probability of occurrence corresponding to the number of mobile nodes.

The number of mobile nodes, $N_{i\text{-}move}$, can be rewritten as

$$N_{i-move} = N * P_{i-move}, \quad (2)$$

where $P_{i\text{-}move}$ is the probability that i nodes will move, and i = 0, 1, 2, ... , N.

$$P_{i-move} = P(X = i), i = 0,1,2 \dots, N \cdot \quad (3)$$

A Poisson distribution is a discrete probability distribution, similar to a binomial distribution, and the most widely used among discrete distributions. A Poisson distribution is used to determine the number of occurrences of an event within a certain time and space, as well as its probability.

$$N_{i-move} \sim POI(X), \quad (4)$$

where the random variable X, which is the number of moving nodes, follows a Poisson distribution satisfying (4); λ is the expected value; and $POI(\blacksquare)$ is the Poisson distribution. The Poisson distribution characteristics is expressed as follows:

$$E(X) = \lambda \cdot \quad (5)$$

$$Var(X) = \lambda \cdot \quad (6)$$

The mean and variance of random variable X of the Poisson distribution have characteristics that are consistent with the expected value of λ.

C. Fuzzy Logic Algorithm

FIS is an IF-THEN rule-based expert system that can quantitatively express human undertones, i.e., natural language. The rules used here are based on expert knowledge or heuristics. The rules that are created play an important role in the system performance.

The protocol used for a performance verification in this study aims to efficiently select a CH in a MANET environment, route all sensor nodes around the CH, and transmit the measured data to the final BS. To maximize the energy efficiency, the FIS is used as the CH selection method. As the nodes move every round, the existing sensor field environment changes, as does the deployment of sensors within the sensor field. As all environments are changed, a new CH is elected to adapt to the new sensor field environment, and a new routing path must be formed in the direction of the entire network around the elected CH in an energy efficient manner.

IV. Simulation and Results

The radio wave model used in this study is as follows. The free-space propagation model is the simplest path loss model, where there is only a direct path signal between the transmitter and receiver without any atmospheric loss or multipath components. The relationship between the transmit and receiving power is expressed as

$$\mathrm{P_r} = \mathrm{P_t G_t G_r}\left(\frac{\lambda}{4\pi d}\right)^2 \cdot \quad (7)$$

The energy consumed by each sensor for transmission is proportional to the number of data bits transmitted to E_{TX} and the transmission distance. Here, E_{TX} can be expressed as $E_{TX}(l, d)$ using (8):

$$E_{TX}(l,d) = E_{TX} - elec(l) + E_{TX} - amp(l,d) = \begin{cases} lE_{elec} + l \in_{f\partial} d^2, d \le d_0 \\ lE_{elec} + l \in_{mp} d^4, d > d_0 \end{cases} . \quad (8)$$

$$d_0 = \sqrt{\frac{\in_{fs}}{\in_{mp}}}, \quad (9)$$

where d_0 is the critical distance according to the path loss model.

Table 1 lists the values of the parameter variables applied during the simulation.

In the random mobility model, the number of mobile nodes is a fixed value according to the movement ratio, and the movement distance is set randomly. Table 2 lists the number of mobile nodes and the moving distance conditions according to each mobility model. To analyze the stability of the proposed mobility model, we used the existing LEACH (Low Energy Adaptive Clustering Hierarchy)-mobile protocol and a fuzzy-based protocol that utilizes the mobility factors of the proposed mobility model. For comparative verification, the first node dead (FND) values, confirming the efficiency of the energy consumption, were used.

Figs. 4(a) and 4(b) show the experiment results obtained by applying the three mobility models, while changing the node movement rate in the fuzzy-based routing protocol. The

Table 1. Parameters and their meaning

Parameter Variables	Values
Sensor Size (M × M)	100 × 100, 200 × 200
Initial Energy (E_0)	0.5 J
Transmission Energy (E_{elec})	50 nJ/bit
Data Absorption Energy (E_{DA})	5 nJ/bit/signal
Amplifying Energy ($\in_{fs}$)	10 pJ/bit/m^2
Amplifying Energy ($\in_{mp}$)	0.0013 pJ/bit/m^2

Table 2. Mobility model

	Random	Semi-stochastic	Stochastic
Move Node	Fixed	Random Variable, Poisson Distribution E(·) , VAR(·)	Random Variable, Poisson Distribution E(·) , VAR(·)
Move Distance	Random	Random	Random Variable $d \le \frac{R_{MAX}}{2}$

(a) FND of 3 mobility models in fuzzy-based protocol I.

(b) FND of 3 mobility models in fuzzy-based protocol II.

Fig. 4. FND simulation results of moving model.

field sizes were 100 × 100 and 200 × 200. Regarding the change in the number of node movements, the semi-stochastic mobility model showed a 55% reduction in the improvement range. The stochastic movement model increased the improvement range by 67% compared to the random mobility model in a 100 × 100 field environment. In the 200 × 200 sensor field environment, the improvement range was reduced by 96% and 14%. Consequently, the semi-stochastic mobility model showed stable characteristics, regardless of the field size, and the stochastic mobility model showed stable characteristics in a relatively larger field environment.

Table 3 summarizes the experimental results after applying the three mobility models to the two protocols, under the same conditions as the changes in the node movement rate.

Table 3. Experimental results of mobility model

	Random	Semi-stochastic	Stochastic
Maximum	264	285	295
Minimum	159	232	242
Improvement range	105	53(▲98%)	57(▲84%)
Average rate of change	43.5%	20.5%	20.9%

V. Conclusion

In a MANET, which is a special type of WSN, various mobile environment models exist depending on the specific application. A shortage of efficiency, due to limited resources and battery problems, is a major issue when applying a MANET. Based on the several attempts made to increase the energy efficiency, it has been proven that energy consumption can be effectively managed through clustering, which is a hierarchical grouping technique. In this study, a stochastic mobility model was designed to express the environmental changes from node movement. The stochastic mobility model was designed by dividing the number of moving nodes by their moving distance. In the design of the stochastic model, node movement was treated as a random variable containing random properties, instead of simply expressing such properties. The moving distance of the nodes was also considered a random variable. When designing the routing algorithm in a MANET, where mobile nodes exist, if the stochastic model is applied, the individual characteristics of the movement sensor field and the overall movement characteristics can be considered simultaneously. In terms of energy, the proposed stochastic model will help in developing energy-efficient routing protocol networks that are robust to mobile field environments.

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