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무선 센서 네트워크를 위한 에너지 효율적인 데이터 인지 라우팅 프로토콜

(Energy-Efficient Data-Aware Routing Protocol for Wireless Sensor Networks)

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요 약

센서 네트워크의 많은 응용분야에서 센서 노드가 감지하는 데이터는 긴급성에 따라 크게 일반 데이터와 긴급 데이터로 분류할 수 있다. 주기적인 상황 모니터링과 같은 일반 데이터는 손실이나 지연을 어느 정도 허용할 수 있는 반면에, 화재 경보와 같은 긴급 데이터는 손실 없이 실시간적으로 전달이 이루어져야 한다. 본 논문에서는 이와 같은 데이터의 특성에 따라, 긴급 데이터의 전달 신뢰도를 높이면서 일반 데이터 전달의 에너지 효율을 고려한, 무선 센서 네트워크를 위한 에너지 효율적인 데이터 인지 라우팅 프로토콜을 제안한다. 제안한 방안은 크게 두 가지 아이디어로 되어 있다. 첫째, 긴급 데이터에 대한 네트워크 생존율과 신뢰도를 향상시키기 위해, 각 센서 노드는 자신의 배터리 잔여량이 임계치 이하로 떨어지면 긴급 데이터만 전달하게 된다. 둘째, 긴급 데이터에 대한 전달 신뢰도를 높이고, 일반 데이터 전달의 에너지 소모를 줄이기 위해 데이터 종류에 따라 차별화된 전달 방법을 사용한다. 규칙적으로 발생하는 일반 데이터는 에너지 효율성을 증가시키기 위해 단일 경로 기반의 데이터 전달 방안을 사용하며, 긴급 데이터는 높은 신뢰성을 보장하기 위해 방향성 플러딩 방법을 사용해 싱크로 전달한다. 시뮬레이션을 통해 제안 방안이 긴급 데이터 전송에 있어 높은 신뢰성을 보장하면서, 일반 데이터 전달의 에너지 소모를 줄여 네트워크 생존율을 크게 증가시킬 수 있음을 보였다.

Abstract

In many applications of wireless sensor networks, sensed data can be classified either normal or urgent data according to its time criticalness. Normal data such as periodic monitoring is loss and delay tolerant, but urgent data such as fire alarm is time critical and should be transferred to a sink with reliable. In this paper, by exploiting these data characteristics, we propose a novel energy-efficient data-aware routing protocol for wireless sensor networks, which provides a high reliability for urgent data and energy efficiency for normal data. In the proposed scheme, in order to enhance network survivability and reliability for urgent data, each sensor node forwards only urgent data when its residual battery level is below than a threshold. Also, the proposed scheme uses different data delivery mechanisms depending on the data type. The normal data is delivered to the sink using a single-path-based data forwarding mechanism to improve the energy-efficiency. Meanwhile, the urgent data is transmitted to the sink using a directional flooding mechanism to guarantee high reliability. Simulation results demonstrate that the proposed scheme could significantly improve the network lifetime, along with high reliability for urgent data delivery.

Keywords : energy efficient, data aware, routing protocol, wireless sensor network.

I. Introduction

Wireless sensor networks can be used in a wide variety of applications, such as fire alarm systems, environmental monitoring systems, military

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surveillance systems, and so on. In these applications, sensed data can be classified either normal or urgent data according to its time criticalness. Normal data such as periodic monitoring is loss and delay tolerant, but urgent data such as fire alarm or detecting invasion is time critical and should be transferred to a sink with reliable.

Crucial importance to wireless sensor networks is saving energy, because battery-power is limited and expensive in a sensor node. Thus, energy-efficient communication techniques are essential for increasing the network lifetime[1]. Many routing protocols have already been proposed for wireless sensor networks with energy efficiency, network lifetime, and reliability as key design issues[2]. But, since these conventional routing protocols do not differentiate sensed data type for forwarding mechanism, they cannot satisfy the different requirements of various data type simultaneously.

Accordingly, by exploiting sensed data characteristics, we propose a novel energy-efficient data-aware routing protocol for wireless sensor networks, which provides a high reliability for urgent data and energy efficiency for normal data.

The proposed scheme consist of two key ideas. First, each sensor node decides forwarding or discarding of a received data according to the data type and its residual battery energy. In the proposed scheme, in order to enhance network survivability and reliability for urgent data, each sensor node forwards only urgent data when its residual battery level goes below than a threshold. Second, the proposed scheme uses different data delivery mechanisms depending on the data type. The normal data is delivered to the sink using a single-path-based data forwarding mechanism to improve the energy-efficiency. Meanwhile, the urgent data is transmitted to the sink using a directional flooding mechanism to guarantee high reliability.

Simulation results demonstrate that the proposed scheme could significantly improve the network lifetime, along with high reliability for urgent data delivery.

The remainder of this paper is organized as follows. Section II presents related work then the proposed scheme is explained in Section III. Simulation results are presented in Section IV, and final conclusions are given in Section V.

II. Related Works

In the case of the classical flooding protocol, the source node starts sending a packet that needs to be flooded to all its neighbors. Each recipient node then stores a copy of the packet and rebroadcasts the packet exactly once. This mechanism continues until all the sensor nodes in the network have received the packet [3]. The sensor nodes are also required to save the source ID and sequence number of the packet in their memory, enabling the sensor nodes to uniquely identify each packet and prevent broadcast the same packet from being broadcast more than once. However, classical flooding can lead to severe problems, including radio collision and redundant forwarding, thus several methods have been proposed to solve these problems[4~5].

For example, directional flooding protocols utilize the directional information to achieve efficiency in data delivery[4~5], where the flooded packets are guided in the "right direction" towards their destination or the sink, thereby eliminating unnecessary packet forwarding and reducing the total energy consumption. However, such methods assume that all the sensor nodes know their own location information and the sink's location information use of a location system such as a global positioning system (GPS), as the flooding decision is made based on the directionality information towards the sink [6]. Hence, existing directional flooding protocols have large traffic overheads, as all the data messages are transmitted to the sink through multiple paths, plus the use of a location system involves additional energy consumption. There is also a reliability problem, as only the hop-count and directionality are considered when establishing paths between the sensor nodes and the sink for a multi-hop route.

Thus, even though the distance between neighbor nodes may be very short, the radio communication state can be bad due to environmental obstacles, such as mountains and buildings[6].

Therefore, the reliable link quality estimation-based routing (LQER) protocol[7] was proposed to solve the realistic problems with existing directional flooding schemes and integrates the approach of the minimum hop field and link quality estimation to improve the energy-efficiency and reliability of the wireless sensor network. However, LQER still suffers from complex overheads, an inordinate energy dissipation for the link quality estimation process, and unbalanced energy consumption in the data delivery process. In this regard, the proposed scheme overcomes these problems by considering the hop-count as well as the signal strength and residual battery energy level.

Directed diffusion (DD)[8] is a data-centric dissemination protocol for wireless sensor networks. Typically, the data in sensor networks is collected or processed information a physical phenomenon, while an event is a short description of a sensed phenomenon. In the case of DD, the data is named using attribute-value pairs, while a sensing task is disseminated throughout a sensor network as an interest in named data, where the dissemination sets up gradients within the network designed to draw events. Thereafter, events start flowing towards the interest originators along multiple gradient paths. The sensor network then reinforces one or a small number of these paths. Finally, data from the source is delivered to the sink via a high data rate path after gradient establishment. However, measuring the data rate of links in wireless sensor networks is difficult, as the data rate of a link can only be accurately measured through bi-directional communications[2, 6].

In this regard, the proposed scheme uses an RSSI value as a link quality indicator to reduce the overhead caused by the additional control message and link quality estimation. Furthermore, since the power consumed by each node depends on various factors, such as the event sensing rate and distance from the sink node, this disparity in the energy consumption in wireless sensor networks causes an imbalance in the residual battery energy level of the node, resulting in a diminished overall network lifetime[9]. Thus, the proposed scheme uses the residual battery energy level of the sensor node for an urgent data delivery mechanism to prolong the network lifetime.

Ⅲ. Energy-Efficient Data-Aware Routing Protocol

This paper proposes an energy-efficient data-aware routing protocol for wireless sensor networks. We assume that the sensed data is classified either urgent or normal data. The proposed scheme provides a high reliability for urgent data and energy efficiency for normal data.

1. Overview of the Proposed Scheme

The proposed scheme consist of two key ideas. First, each sensor node decides forwarding or discarding of a received data according to the data type and its residual battery energy. If the residual battery energy level is higher than a threshold, the sensor node forwards both urgent and normal data. Otherwise, the sensor node forwards only the urgent data and discards the normal data. This mechanism can enhance network survivability and reliability for

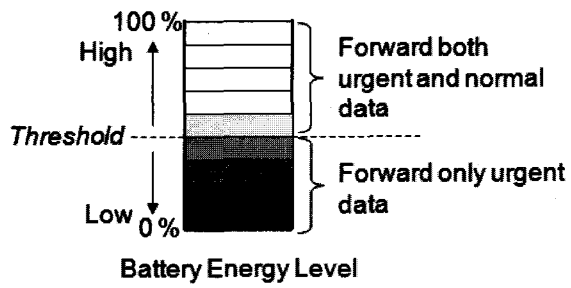


그림 1. 센서노드에서 배터리 잔여량과 데이터 유형에 따른 처리 방법

Fig. 1. Data handling mechanism according to the data type and the residual battery energy level at a sensor node.

urgent data. Fig. 1 shows the basic concept of data handling at each sensor node according to the data type and the residual battery energy level.

Second, the proposed scheme uses different data delivery mechanisms depending on the data type. The normal data is delivered to the sink using a single-path-based data forwarding mechanism to improve the energy-efficiency. Meanwhile, the urgent data is transmitted to the sink using a directional flooding mechanism to guarantee high reliability.

Fig. 2 shows an overview of the proposed scheme. When a sensor node receives a data message, it first checks data duplication. If this message is duplicated, then the sensor node discards this duplicate message. Otherwise, it checks the data type of received message. If this message is urgent data, then the sensor node forwards this message using a directional flooding mechanism. Otherwise, if this message is normal data, it checks its residual battery energy level. If its residual battery energy level is higher than the threshold, then the normal data is delivered to the sink using a single-path-based data forwarding mechanism. Otherwise, it discards this normal data.

In the following sections, we illustrate the overall operation of the proposed scheme, including a directional flooding mechanism for urgent data and a single-path-based data forwarding mechanism for normal.

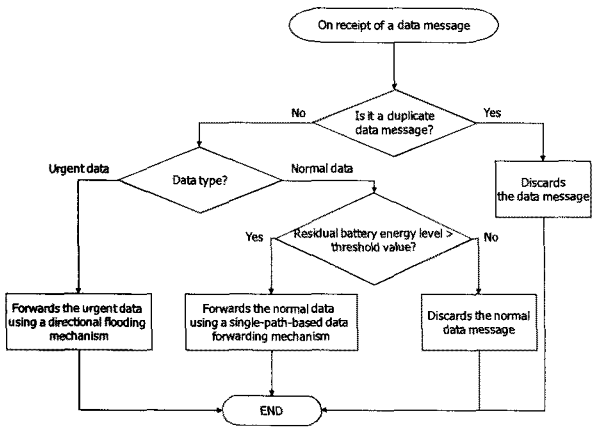


그림 2. 센서노드에서의 제안방안 동작개요

Fig. 2. Operational overview of the proposed scheme at a sensor node.

2. Operation of the Proposed Scheme

The proposed scheme consists of two phases: network discovery and data delivery as explained in the following sections.

A. Network Discovery Phase

The network discovery phase covers the sink discovery and neighbor discovery. Since sensor nodes simultaneously learn the hop count to the sink and 1-hop neighbor information when receiving a Net_DSV messages, the proposed scheme does not use separate hello messages for periodic neighbor discovery. When a sensor node receives a Net_DSV message, it compares the sequence number for the previous Net_DSV message with that the new Net_DSV message. If the new Net_DSV message has a higher sequence number, the sensor node then updates its neighbor entry. Otherwise, the sensor node discards the newly received Net_DSV message. As a result, the sensor nodes create a neighbor information table entry and learn their hop count from the sink node.

The neighbor information table entry managed by a sensor node maintains 1-hop neighbor information and the connectivity state for data delivery. As such, the table entry for a node is composed of the node ID, HC (hop count), RSSI, RE (residual energy) , and operation mode (OP) for its neighbor nodes, where a neighbor node is a 1-hop neighbor with a higher or identical hop-count value. The OP indicates whether the neighbors are in a forwarding mode, meaning a next-hop node for delivering the data towards the sink. The threshold level of the RE is decided according to the characteristics and goal of the application. When a sensor node receives the first Net_DSV message, it creates a neighbor information entry based on the information included in the Net_DSV message, although only the minimum amount of information on the 1-hop neighbors is maintained to minimize the occupied memory size. This entry is then periodically updated based on a periodic Net_DSV broadcasting mechanism. When a sensor node receives a Net_DSV message, it

표 1. 네트워크 탐색 알고리즘
Table 1. Network discovery algorithm.

```
Network discovery algorithm
HC: current hop-count of a sensor node
HCrecv: hop-count of Net_DSV message
last_seq: sequence number of the last Net_DSV message
current_seq: sequence number of the current Net_DSV
             message

When a sensor node receives Net_DSV message in the
initial neighbor discovery phase:

if (HC > HCrecv) then
  HC <- HCrecv;
  creates the neighbor information table
  with hop-count, RE, and RSSI of Net_DSV message;
else
  discards Net_DSV message;
end if

When a sensor node receives Net_DSV message in the
data delivery phase:

if (last_seq < current_seq) then
  HC <- HCrecv;
  updates the neighbor information table;
else if (last_seq == current_seq and HC > HCrecv) then
   HC <- HCrecv;
   updates the neighbor information table;
else
   discards Net_DSV message;
end if
```

rebroadcasts the Net_DSV message after increasing the hop-count by 1 and setting the source address to its node ID.

Table 1 shows the network discovery algorithm. The sink broadcasts a Net_DSV message to the network with the hop-count set to 1. If a sensor node then receives a Net_DSV message with a smaller hop-count, that Net_DSV message is considered to have the latest sequence number, in which case, the sensor node rebroadcasts the Net_DSV message after increasing the hop-count by 1 and converting the source address to its node ID, while also updating its own hop-count value and neighbor information entry. Otherwise, the sensor node discards the received Net_DSV message. This process continues until all the sensor nodes receive a Net_DSV message at least once.

B. Data Delivery Phase

In the proposed scheme, a sensor node selects a different data delivery mechanism according to the kind of data: normal or urgent. Table 2 illustrates the data delivery algorithm, and the mechanism details are given in the following sections.

표 2. 데이터 전달 알고리즘
Table 2. Data delivery algorithm.

```
Data delivery algorithm
HC: current hop-count of a sensor node
HCrecv: hop-count of Net_DSV message
RE: normalized residual energy level of a sensor node
REth: threshold level of residual energy

When a sensor node receives Data message:

if (Data type == urgent) then
  if (HC < HCrecv) then
    broadcasts Data message;
  else
    drops Data message;
  end if
else
  if (RE > REth and HC < HCrecv) then
    selects the node that has the largest value of RSSI
    among forwarding nodes with RE=1 in the neighbor
    information table;
  else
    drops Data message;
  end if
end if
```

(1) Normal Data Delivery Mechanism

In the case of delivering normal data to the sink, a sensor node uses a gradient-based data forwarding mechanism, where the normal data is forwarded to the 1-hop neighbor with the largest RSSI value and RE=1 (sensor node has the higher residual battery energy level than the threshold) among the forwarding nodes in the neighbor information table entry. Intermediate nodes also use the same mechanism to deliver normal data to the sink.

Fig. 3 shows the normal data delivery when the RE value of the current forwarding node is 0. Initially, node D delivers its normal data to the forwarding node, node G, in the neighbor information entry. In this manner, intermediate nodes also

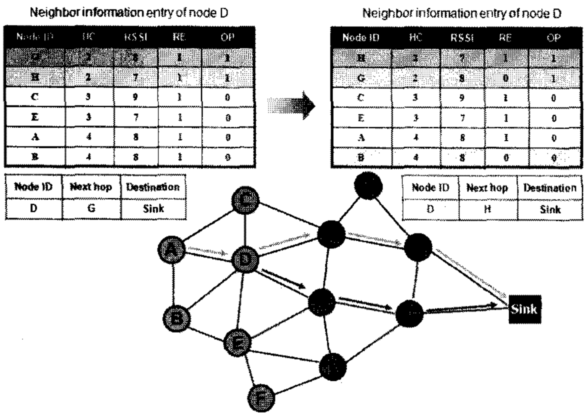


그림 3. 전달 노드의 RE 값이 0일때 일반 데이터 전달 방법 예

Fig. 3. Normal data delivery when RE value of the current forwarding node is 0.

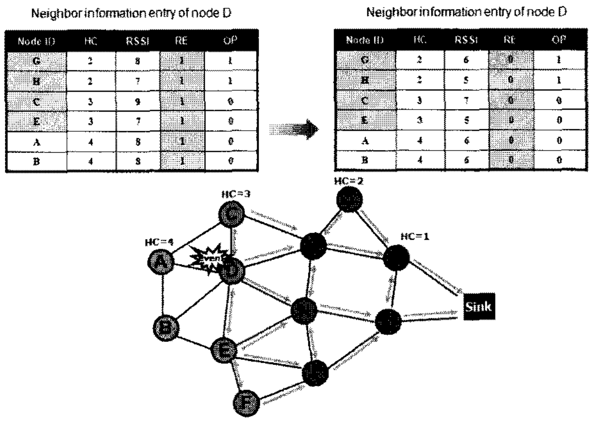


그림 4. 모든 1홉 이웃노드의 RE 값이 0일때 긴급 데이터 전달 방법 예

Fig. 4. Urgent data delivery when RE values of all 1-hop neighbors are 0.

forward the 1-hop neighbor with the largest RSSI value and RE=1. Therefore, the single path to deliver the normal data of node D to the sink is {D-G-K-Sink}, thereby improving the energy-efficiency and network lifetime of the wireless sensor network. However, over time, the residual battery energy levels of the neighbor nodes decrease due to the communication process and environmental obstacles.

Thus, in the case that the RE value for node G changes from 1 to 0, due to a decrease in its residual battery energy level as shown in Fig. 3. Node D changes the node G to the node H with an RE=1 in order to forward its normal data to the sink. Thereafter, the single path is changed as {D-H-L-Sink}.

(2) Urgent Data Delivery Mechanism

In the case of delivering urgent data to the sink, a hop-count-based directional flooding mechanism is used to guarantee high reliability. When a sensor node transmits urgent data, the 1-hop neighbor nodes with the same or a smaller hop-count rebroadcast the received urgent data, allowing the urgent data from node A to arrive at the sink through multiple data paths. Meanwhile, the neighbor nodes with a larger hop-count discard the received urgent data to avoid unnecessary transmission of the same data message.

In Fig. 4, when node D senses an event, it delivers the urgent data including information about the event, to the sink using a hop-count-based directional mechanism. When neighbor nodes C, E, G, and H receive the urgent data message from node D, they perform directional flooding towards the sink. Even when the RE values for all the 1-hop neighbors are 0, the nodes that receive the urgent data from node D still transmit that data to the sink using directional flooding. Therefore, the proposed scheme can maintain a high reliability for urgent data.

IV. Performance Evaluation

For performance evaluation, we compare the proposed scheme with classical flooding and directional flooding methods in terms of energy consumption and packet delivery ratio. We assume that the classical flooding and directional flooding schemes do not differentiate data type for forwarding.

For simulation, we use a TOSSIM simulator [10]. A grid-random topology is generated to guarantee the network connectivity, and the network dimensions are assumed to be 300m×300m. The characteristics of sensor nodes are set to the specifications of a MICAz mote[11~12]. The performance of the proposed scheme is evaluated for 100, 200, and 300 sensor nodes, respectively. The RE threshold value is set at 10% of the full energy level, and the transmission range of each sensor node is 40m. A lossy propagation model is used, and the ratio of urgent data among the data generated by a sensor node is assumed to be 1%.

1. Energy Consumption

Fig. 5 shows the total energy consumption for the three schemes when varying the number of sensor nodes with a fixed network size. As expected, in all cases, the classical flooding scheme consumes substantially more energy than the other schemes. However, the proposed scheme consumes approximately 25% less energy than the directional flooding scheme, due to the use of single-path-based data forwarding when delivering normal data messages to the sink. Therefore, the proposed scheme improves the energy-efficiency by reducing the number of redundant transmissions for normal data.

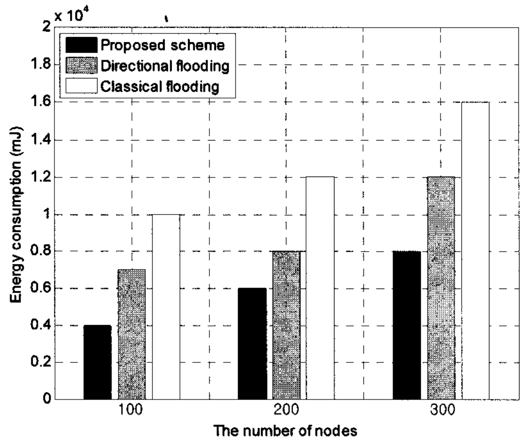


그림 5. 센서 노드 수에 따른 전력소모 비교
Fig. 5. Energy consumption vs. the number of sensor nodes.

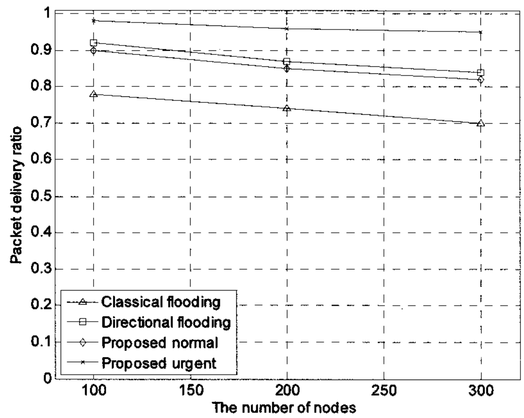


그림 6. 센서 노드 수에 따른 패킷 전송 비율
Fig. 6. Packet delivery ratio vs. the number of sensor nodes.

B. Packet Delivery Ratio

Fig. 6 compares the packet delivery ratio versus the number of nodes. As the number of sensor nodes increases, all three schemes experience a decrease in the packet delivery ratio due to the increased data collisions. The classical flooding scheme exhibits the smallest packet delivery ratio, because this scheme causes the network overloading by basic flooding, resulting in a higher data collisions and loss.

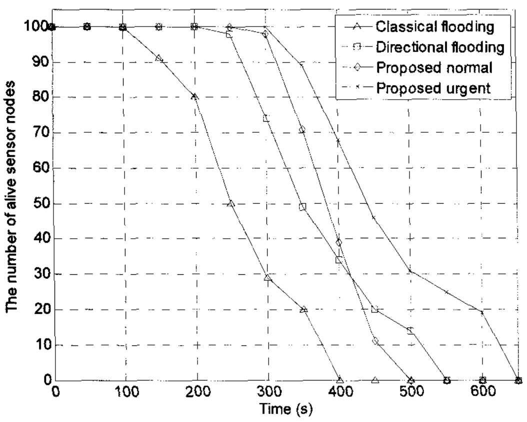
The proposed scheme shows the highest packet delivery ratio of about 95-97% for the urgent data, while it shows a similar, but a little less packet delivery ratio for the normal data than the directional flooding scheme. From these results, we know that the proposed scheme provides a more reliable delivery for the urgent data, compared with existing schemes.

C. Network Lifetime

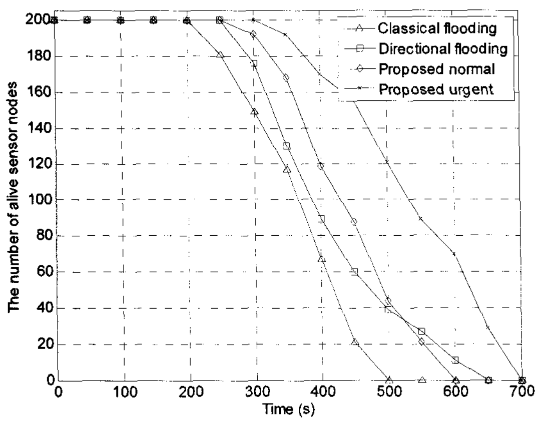
Fig. 7 shows the number of alive sensor nodes as time passes. We assume that a sensor node is alive if it can forward a data message. In the case of the proposed normal, a sensor node is assumed to be alive if its residual battery energy level is higher than the threshold (10% for simulation). The simulation environment is simplified with a limited battery power = 2J and the ratio of urgent data is 1%.

Compared with other schemes, the proposed scheme can prolong the network lifetime for the urgent data at the expense of the normal data. The reason is that the proposed scheme forwards the urgent data until their residual battery energy level becomes 0%, while it forwards the normal data only when the residual battery energy level of the sensor node is higher than the threshold.

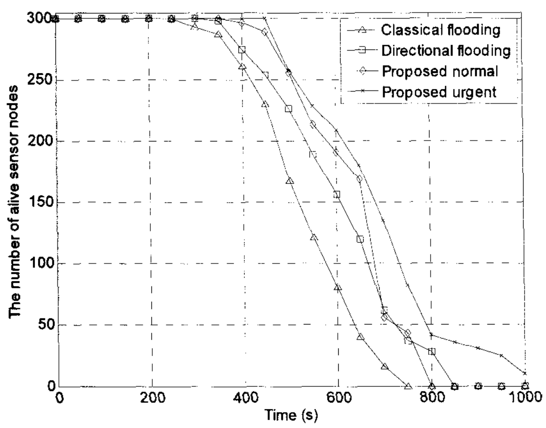
This figure shows that the proposed scheme can significantly improve the network lifetime of the urgent data by about 20-25% at the expense of network lifetime of the normal data, compared with



(a) 100 sensor nodes



(b) 200 sensor nodes



(c) 300 sensor nodes

그림 7. 네트워크 생존 시간 비교
Fig. 7. Comparison of network lifetime.

that of the directional flooding. But, compared with the classical flooding scheme, the proposed scheme exhibits a higher network lifetime for both the urgent and normal data.

Simulation results demonstrate that the proposed scheme could significantly improve the network lifetime, along with high reliability for urgent data delivery.

V. Conclusion

This paper proposed a novel energy-efficient data-aware routing protocol for wireless sensor networks, which provides a high reliability for urgent data and energy efficiency for normal data.

In the proposed scheme, in order to enhance network survivability and reliability for urgent data, each sensor node forwards only urgent data when its residual battery level is below than a threshold. Also, the proposed scheme uses different data delivery mechanisms depending on the data type. The normal data is delivered to the sink using a single-path-based data forwarding mechanism to improve the energy-efficiency. Meanwhile, the urgent data is transmitted to the sink using a directional flooding mechanism to guarantee high reliability.

Simulation results demonstrated that the proposed scheme could significantly improve the network lifetime, along with high reliability for urgent data delivery.

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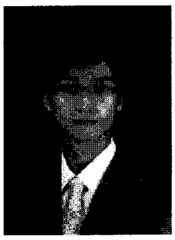

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