DTOR: Dynamic Tree Organizing Routing for Mobility Support in Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) basically perform a function to collect sensing data by the request of users. The request is forwarded to a corresponding gateway (GW), and the GW collects data from a sensor or a group of sensors. In this scenario, the destination of each sensing data is only the GW where each data is collected through a different path. This implies that the topology in this environment would be a tree-structure where traditional collection based routing protocols may be suitable to support WSNs without mobility support. However, recent WSNs, which support the mobility of each sensor node, cannot collect data correctly using existing collection based routing protocols since the destination GW can be changed during data transmission. To resolve this problem, we propose a collection based routing protocol, called dynamic tree organizing routing (DTOR), for mobility support in WSNs where we use two types of messages, beacons and advertisements, for energy-efficient topology management and fast handover detection. Furthermore, we select a link based on the weighted link estimation where both the link quality and the node type are taken into account. DTOR shows better performance than existing schemes with only beaconing in terms of energy consumption, network lifetime, end-to-end latency and delivery ratio by using the node advertisement, the efficient link estimation, and the adaptive beaconing.

Keywords: Wireless sensor networks, SON, Mobility, Handover, Routing

1 Introduction

The advances which have been made in wireless and micro-machine technologies have made it possible to develop wireless sensor networks (WSNs). A WSN is generally composed of a large number of sensor nodes, and a few data collectors called *gateways* (GWs). Sensor nodes are responsible for generating sensory data and reporting them to their GW, and GWs play a role of collecting and delivering sensory data to the users through IP networks.

The topology of WSNs is basically a tree-structure rooted at GWs since data from each sensor node is sent to the GW through a variety of paths. In this tree-structure, existing collection based routing protocols [1-2] are appropriate to WSNs without mobility. However, traditional collection based routing protocols does not support WSNs with mobility which have been introduced recently [3-4]. These kinds of WSNs ensure the mobility of each of sensor nodes, and the request type can be on-demand, periodic, or event-driven. Even though a sensor node transmits only one time for the on-demand request, it should continually provide data for the periodic or event-driven request. This implies that even if the destination GW has been changed, the data should be correctly transmitted to the changed GW. To do that, each mobile node should know that its GW has been changed, and then it should request the GW to allow association and re-registration. However, this problem has been not considered in existing works. Furthermore, it is extremely necessary to construct a reliable network and a self-organizing network (SON) in WSNs where the topology change can be caused by failure, temporary power-down, and mobility very frequently. Therefore, WSNs should support the dynamic topologies and provide self-configuration and organization.

In this paper, we propose a collection based routing protocol, called dynamic tree organizing routing (DTOR), for mobility support in WSNs where we employ the node advertisement to avoid unnecessary flooding overhead, the efficient link estimation to find a best link, and the adaptive beaconing to reduce energy consumption. Our performance evaluation shows that DTOR outperforms existing protocols with only beaconing in terms of energy consumption,

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network lifetime, end-to-end delay and delivery ratio.

The remainder of the paper is organized as follows. Section 2 introduces related works. In Section 3, we propose our DTOR in detail. After Section 4 gives performance evaluation, we conclude the paper in Section 5.

2 Related Works

Early classification of routing protocols for WSNs have been well defined in [5-7] whereby the routing techniques could be classified into three categories based location-based routing. Flat based routing considers that all nodes deployed in the network are assigned an equal role. Hierarchical based routing considers that all nodes play different roles in the network. In location-based routing, the position of each sensor node is used as a routing metric. All of these routing protocols can also be classified into multipath-based, query-based, negotiation-based, QoS-based, and coherent-based according to the protocol operation. However, such classification is currently ambiguous because routing protocols are still evolving in hybrid form, and both applications and network structures have been much diversified. Thus, new types of routing protocols in WSNs called intelligent and knowledge-based routing have been proposed recently [8-11]. Dynamic three-dimensional fuzzy routing based on traffic probability (DFRTP) [8] selects a next node using fuzzy decision making with the input of distance and number of neighbors. As a result, DFRTP accomplishes enhanced lifetime and packet delivery ratio. Routing Protocol using Fuzzy system and Neural node (RPFN) [9] uses fuzzy decision making and neural networks to perform hop-by-hop delivery with four parameters which are remaining energy, distance, available buffer and link quality. Intelligent and Knowledge-based Overlapping Clustering Protocol (IKOCP) [10] partitions the whole network into clusters using multicriteria decision-making controller and the LEACH-improved protocol with support vector machine-based mechanism for inner-cluster routing. FSB-System [11] is a detection system for fire, suffocation and burn using fuzzy theory, multi-criteria decision making and an RGB model whose result is routed to the sink based on the probability. Above studies are very novel and efficient, but their main goal is not to support mobility. It is worth noting that intelligent and knowledge-based routing can be combined with our proposed scheme for further enhancement since it is complementary to ours. In this section, we introduce schemes related to our work in order to provide more clear background rather than describe the specific taxonomy.

2.1 Collection Based Protocols

We consider a common network structure that data is converged into a GW without intermediate cluster headers because this architecture is very simple as well as widely used. Routing protocols for this structure usually organize routing paths into a form of tree around the GW, and queries from the GW are delivered to the destination sensor nodes via multi-hop. Such routing protocols are called as *collection based protocols*.

Ad hoc on-demand distance vector (AODV) [12] is one of typical collection based protocols for mobile ad-hoc networks (MANETs). It is a reactive routing protocol that establishes a route to a destination only on demand. It discovers a path whenever a source node needs to communicate with another node for which it has no routing information in its table. The path discovery is performed by exchanging RREQ-RREP packets between the source node and the destination node. Thus, AODV is an efficient algorithm in terms of energy efficiency, bandwidth utilization, and overhead of routing table caching. However, it is likely to build a path with poor end-to-end reliability by long unreliable links. Besides, if connectivity to the current parent is lost and no potential parents are available, the node declares itself to have no parent, disjoins from the tree, and sets its routing cost to infinity.

MintRoute [13], ETX [14], and CTP [15] have commonly introduced a link discovery method to solve problems occurred by unreliable links. MintRoute uses the passive neighbor discovery method where nodes snoop on periodic data messages, and each routing table entry contains link estimation information and routing data. MintRoute performs largely two policies, Insertion Policy, and Eviction and Reinforcement Policy, for the routing table maintenance. Since the size of the routing table is limited, the node must decide whether to discard information associated with the source or evict another node from the table when the table is full. This is decided by link estimation called a window mean with exponentially weighted moving average (WMEWMA). MintRoute also employs a FREQUENCY algorithm for estimating the most frequent values over a stream using limited space. As a result, MintRoute does not require a predefined link quality threshold and is robust under varying connectivity characteristics. Combination of WMEWMA and FREQUENCY have empirically yielded high end-to-end success rate in sizable networks on a resource-constrained platform. ETX, which is an expected transmission count, can be used as a novel link estimation method to find reliable links. It showed that the path discovery using traditional link metrics such as a minimum hop count is not a reasonable approach at all in the dense environment because many wireless links have intermediate loss ratio. To discover reliable links, ETX measures the delivery ratio by exchanging dedicated link probe packets. In addition, this metric is adapted to DSDV and DSR to evaluate the performance [14]. As a result, it shows that ETX finds a route with significantly higher throughput than a minimum hop-count metric, particularly for paths with two or more hops. CTP provides best-effort any-cast datagram communication to one of the collection roots in a network. The data path validation is processed by link estimation using ETX. The GW broadcasts a cost of zero and the cost of a route is the sum of the costs of its links. Each data packet contains the transmitter's local cost, and it compares the transmitter's cost to its own. Since the cost must always decrease, the transmitter's topology information is stale and there may be a routing loop if a transmitter's advertised cost is not greater than the receiver's. Adaptive beaconing, which extends Trickle [16], reduces a long loop time and improves efficiency in bandwidth and energy. It also dynamically controls beaconing time interval according to specific situation such as detecting a loop, a new node's network join, and channel state change. In addition, CTP effectively reduces the packet dropping probability by tuning data plane. Instead of dropping, CTP combines a retransmit delay with proactive topology repair to increase the chances of delivering the current packet. As a result, CTP offers 90-99.9% packet delivery in the highly dynamic link topology. Thus, CTP is globally valued as high performance routing protocols, and currently implemented in TinyOS. Even though all the above collection based protocols provide efficient link discovery scheme using a variety of useful features, they are not intended for mobile WSN environment.

2.2 Link Estimation

Link estimation is essential for reliable transmission in wireless networks. It also affects to organize robust topology and reduce packet retransmission over lossy links, thereby improving network throughput as well as other network performance. The most common metric used by existing ad hoc routing protocols is a minimum hop-count. However, the minimum hop-count might be not an optimal metric in dense wireless environment because there may be many nodes that have equal cost. In other word, each node has higher packet loss probability by interference between each other in dense space. MinteRoute have examined a reception probability to analyze the variation of wireless links through various experiments. It is obvious that both link quality and data reception ratio have a correlation, but some exceptions were also found by this experiments. The cases are such that very distant nodes occasionally transfer packets successfully. The experiment in a grid environment also validated the fact that a neighbor with a minimum hop-count is not necessarily an optimal link. Such problem has led to a variety of research on finding more reliable links in wireless network, where a reliable link can define a link having good link quality. Nodes can estimate the link quality of an in-bound link from a neighbor and the link quality is usually measured by the delivery ratio or the link quality indicator such as LQI (Link Quality Indicator) and RSSI (Received Signal Strength Indicator). The link quality between a directed node pair (*A*, *B*) is the probability that a packet transmitted by node *A* will be successfully received by *B*. In wireless links, the link quality between a node pair (*A*, *B*) is asymmetry. In other words, the link quality of (*A*, *B*) and (*B*, *A*) are different because each node has different local interference and noise. Therefore, each node can have two link qualities as follows.

- **In-Bound Link Quality:** In a node pair (*A*, *B*), the in-bound link quality of node *B* is a receiving link quality for the other node *A*, and derived by node *B* by counting the successfully received packets among all the transmitted packets from node *A* or using LQI and RSSI provided by the radio on node *B*.
- **Out-bound Link Quality:** In a node pair (*A*, *B*), the out-bound link quality of node *A* is a transmitting link quality for the other node *B*. Node *A* can derive its own out-bound link quality by listening to the advertisement of the in-bound link quality from node *B*.

As aforementioned, MinteRoute proposes a new estimator, WMEWMA. WMEWMA(t, α) computes an average success rate over a time period as $\frac{Packets\ Received\ in\ \boldsymbol{t}}{\mathbf{max}(Packets\ Expected\ in\ \boldsymbol{t}, Packets\ Received\ in\ \boldsymbol{t})}$ and smoothens the average with the EWMA. The tuning parameters are t and α, where t is the time window represented in the number of message opportunities and $\alpha \in [0, 1]$ controls the history of the estimator. Similarly, [14] also proposed a new metric which accounts for lossy links: *expected transmission count* (ETX). The goal of ETX is to choose routes with high end-to-end throughput. Although ETX does not ensure the reliability of end-to-end packet delivery ratio, it surely has good performance in terms of end-to-end throughput because it enables a transmitter to forward packets to the most reliable link of all neighbor lossy links, thereby increasing the packet delivery ratio between one hop nodes as well as reducing energy consumption by decreasing retransmission probability. ETX is calculated by the delivery ratio of exchanging probe packets between a transmitter and a recipient. It also appropriately handles the asymmetry of each direction by considering both of in-bound and out-bound link qualities. More specifically, ETX is a link quality metric based on Bernoulli trial that is derived as follows.

$$\mathrm{ETX} = \frac{1}{d_f \times d_r} \quad \textbf{(1)}$$

where d_f is the probability that a data packet reaches the recipient successfully, and d_r is the probability that an ACK packet is received successfully at the transmitter. Each probability is calculated by

$$r(t) = \frac{count(t-w,t)}{w/\tau} \quad \textbf{(2)}$$

Each node broadcasts a fixed size of probe packets at an average period τ, and every node receives it during the window size w. $count(t-w, t)$ is the number of probes received during the widow w, and w/τ is the number of probes that should have been received. In case of the link $A \rightarrow B$, A (d_r) and B (d_f) are easily derived by this calculation. Because node B knows that it should receive a probe from node A every τ second, node B can correctly calculate the current loss ratio even if no probes arrive from node A. Since ETX requires both d_f and d_r, each probe sent by node A contains the number of probe packets received by node A from each of its neighbors during the last w seconds. This allows each neighbor to calculate the d_f for node A whenever it receives a probe from node A.

CTP Noe [17] improved the previous CTP [15] by using a four-bit estimator which uses four bits of information from the three layers. This is a hybrid estimator that combines the information provided by the three layers with periodic beacon in order to provide accurate, responsive and useful link estimation. As shown in Figure 1, a four-bit estimator appropriately handles valuable information provided by the layers including physical, link, and network to archive the goal that a link estimator should be accurate and efficient. The four bit is composed of a *white bit*, an *ack bit*, a *pin bit*, and a *compare bit*. The white bit is set when the channel state recorded by a received packet is clear. The ack bit is set when receiving an acknowledgement in the link layer for the transmitted packet. The pin bit and the compare bit are provided by the network layer. The pin bit applies to the link table entry. When the network layer sets the pin bit on an entry, the link estimator cannot remove it from the link table until the bit is cleared. The compare bit is set if the route provided by the sender of the packet is better than the route provided by one or more of the entries in the link table. The four-bit estimation is a hybrid method where the estimation method follows the method used in MintRoute, separately calculating the ETX value tuned by combining both WMEWMA and ETX. As a result, the four-bit estimator shows significant improvements on cost and delivery ratio over current approaches. However, the above link estimation method focuses on how to measure the link quality precisely, rather than considering mobile environment. In our scheme, we propose the weighted link estimation using the node type in order to support mobility efficiently.

3 Dynamic Tree Organizing for Mobility Support

In this section, we introduce a collection based routing protocol, called dynamic tree organizing routing (DTOR), for mobility support in WSNs. The motivation by which we design the protocol includes the following four goals.

- **Reliability:** A protocol should have delivery ratio of at least 90% of end-to-end packets.
- **Robustness:** It should be operated normally without tuning or control even if the topology or network environment is changed.
- **Efficiency:** A network is operated with low cost by reducing overhead and eliminating unnecessary operations for the network maintenance.
- **Mobility:** To ensure the mobility of sensor node, the session is maintained normally even if sensor node moves to another area.

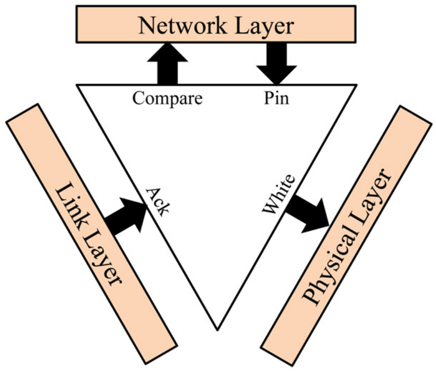


Figure 1. A four-bit link estimator, represented by the triangle in the center, interacts with three layers

To accomplish these goals, we propose a topology organization scheme and a link selection method in the protocol. Overall procedures of DTOR are exemplified in Figure 3 and Figure 4. The gateway bigins to establish topology by broadcasting a beacon message and each sensor node selects their one-hop neighbor based on the weighted link estimation. It is worth noting that the gateway uses adaptive beaconing for energy saving. When a mobile node moves after topology organization, the mobile node can find a new link promptly by listening to an advertisement message from neighbors.

3.1 Basic Topology Organization

Network topology is organized by two types of messages. The first is a beacon message of the GW. Initially, the GW broadcasts a beacon to build a topology where we call this beacon message a *Routing* (*Rout*) packet. Un-joined nodes perform link estimation, association, and registration when they receive the *Rout*. The *Rout* is periodically broadcasted by the GW, and flooded into the entire network through the periodic routing update. Each of nodes connected to the GW also periodically broadcasts an advertisement packet called an *Adv* packet to notify new nodes, which join the network, of the information about the associated GW. The nodes overhearing this *Adv* associates with the GW after estimating link if they have not joined the network yet. It is important to note that the *Adv* is only transmitted to one-hop neighbors, and not flooded. The reason of dividing two types of messages for routing is to avoid the overhead of energy and traffic caused by periodic flooding, and support real-time mobility for mobile nodes. In designing of this routing protocol, we assume that each of nodes tries to find good quality links, and this greedy tendency can be an important factor to find an optimal path in WSNs with dynamic topology. Consequently, we have attempted topology optimization using self-link quality estimation with this greedy characteristic.

Figure 2 shows an example of network topology organized by this scenario. In this scenario, we assume that mobile nodes and fixed node are co-existed in the network, distinguished by the different cost which is one of factors in estimating link quality. In addition, each of nodes sends its own data to the GW through the best link, and all nodes are able to have one or more links including reserved links which are other neighbor links, except for the best link, for fast retransmission in case the transmission fails. The best link has higher cost than any other links, and the cost is valued by link estimation. In Figure 2, the best link is presented by a bold line, and the reserved link is denoted by a dotted line. It is important to note that a link with higher cost means a better link. The example of topology organization is depicted in Figure 3 where a gateway broadcasts a beacon message to its neighboring nodes, which broadcast a beacon message and select a link based on the following link selection scheme. In the following subsection, we describe a link selection scheme for reliable data transmission and dynamic topology configuration.

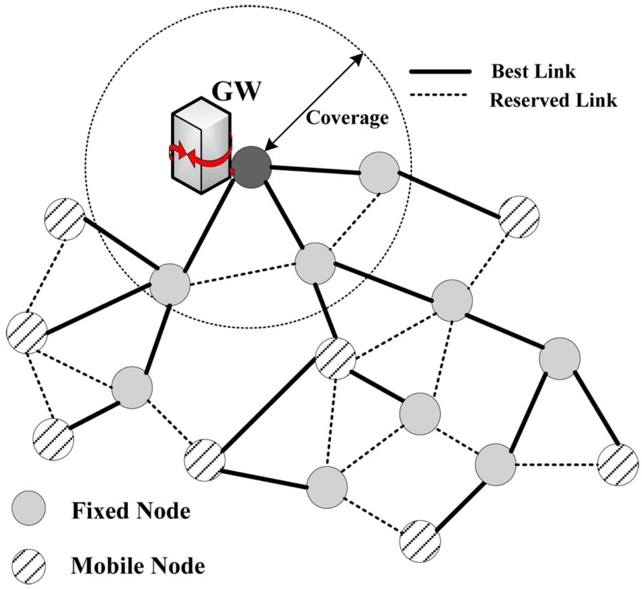


Figure 2. An example of topology organization

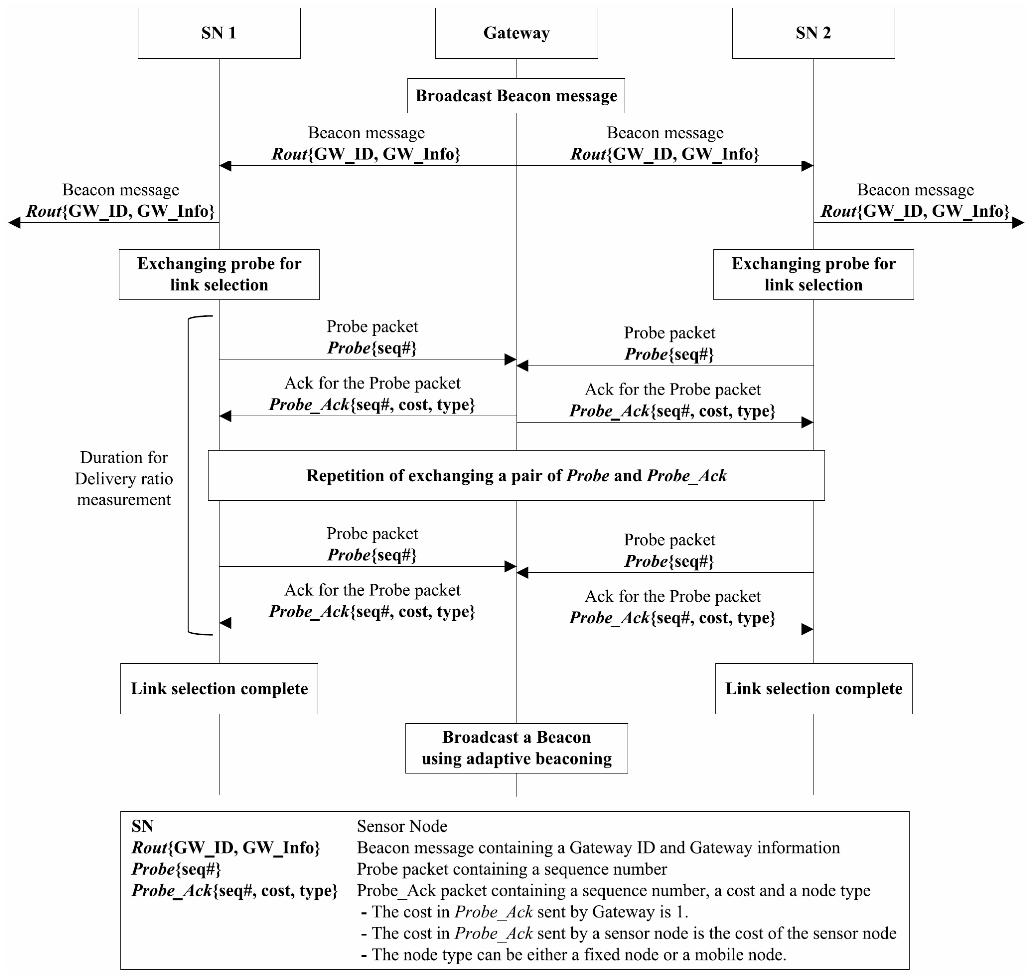
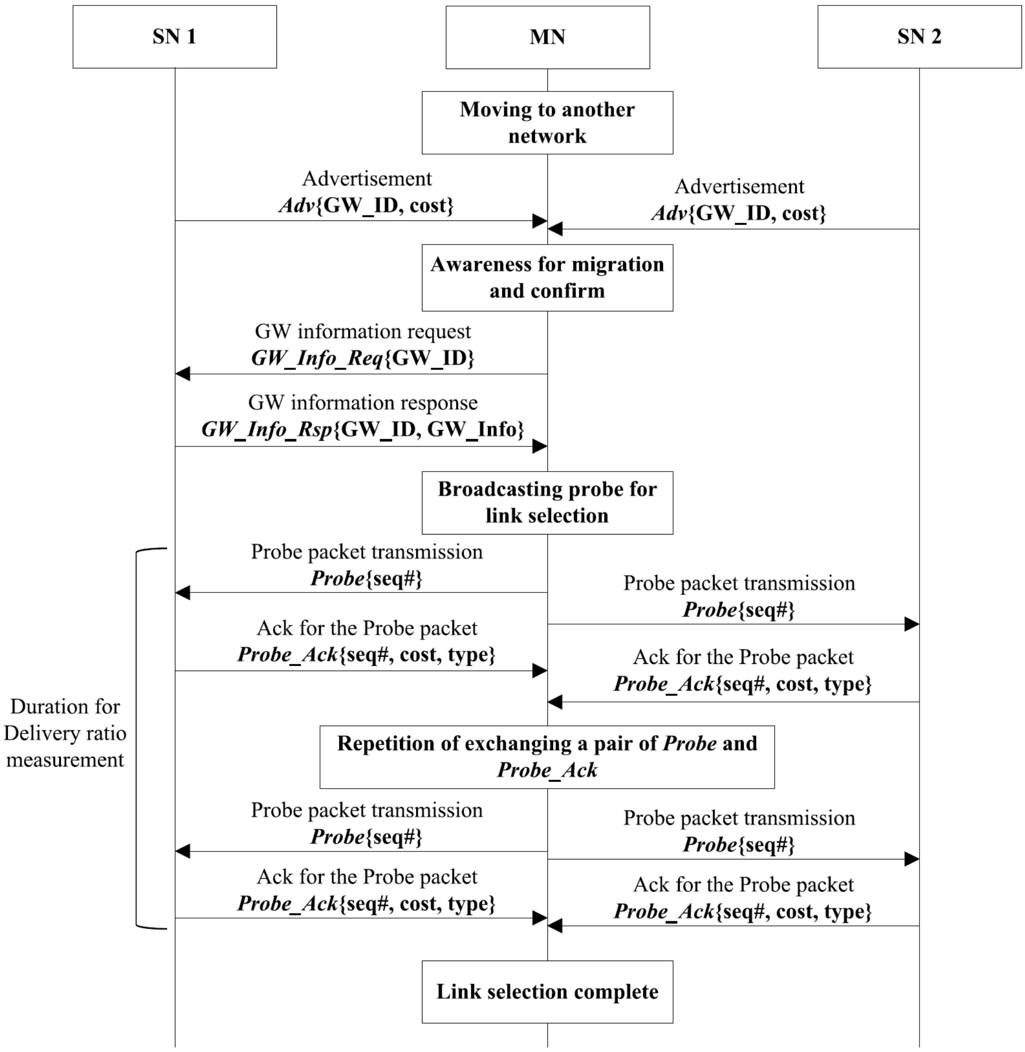


Figure 3. The procedure of topology organization



SN	Sensor Node
MN	Mobile Node
***Adv*{GW_ID, cost}**	Advertisement message containing a Gateway ID and a cost
***GW_Info_Req*{GW_ID}**	Gateway information request message containing a Gateway ID
***GW_Info_Rsp*{GW_ID, GW_Info}**	Gateway information response message containing a Gateway ID and Gateway information
***Probe*{seq#}**	Probe packet containing a sequence number
***Probe_Ack*{seq#, cost, type}**	Probe Ack packet containing a sequence number, a cost and a node type

Figure 4. The procedure for mobility support

3.2 Link Selection Scheme

Since the data in WSNs is mainly transmitted in the uplink direction, we focus on estimating link quality for uplink only in order to increase throughput and save energy by reducing transmission failures and the number of retransmission. The link estimation can be conducted in the following three cases.

- **Case 1:** The link estimation is performed when the un-joined node receives a *Rout* from a GW. The node decides the best link through link estimation after the network association.
- **Case 2:** It is conducted when the un-joined mobile node hears *Adv*s from adjacent nodes in a new network. The node attempts to find the best link for sending data to a new GW.
- **Case 3:** Even if a node successfully transmits data to the neighbor with the best link, the transmission can be failed. The node tries to re-transmits the data to neighbors in the order listed in its own neighbor table until the transmission succeeds or no more neighbor is in the table. The node then performs link estimation again.

The link estimation is calculated by the delivery ratio because the hop count based method cannot accurately reflect the degree of link reliability, and the method using the LQI of the physical layer is not stable to be employed in link estimation. The delivery ratio is measured by exchanging probe packets, and it is similar to previous methods [13, 15]. The delivery ratio of each link is derived by a simple metric of $r = \frac{Acks\ received\ in\ \boldsymbol{t}}{Packets\ sent\ in\ \boldsymbol{t}}$, where t is the elapsed time for calculating the delivery ratio.

We consider the link, which is from each node to the GW, which is denoted by the bold red line in Figure 5. Each link from the GW to node *D* via node *A* and *B* has the delivery ratio of 1, 0.9 and 0.8, respectively. In addition, each delivery ratio from the GW to node *D* via node *C* is 0.7 and 0.6. Although the shortest path from the GW to node *D* is GW→*C*→*D*, the reliable path could be GW→*A*→*B*→*D* by the Bernoulli loss process. In other words, each link cost for the neighbor node $i \in \{neighbor\ nodes\ of\ the\ estimating\ node\}$ is defined by the product of the delivery ratio and the cost (C_i) of the node *i*, and thus each node takes the maximum cost for all neighbor nodes as its own cost. Consequently, the cost for the end-to-end path from node *k* to the GW can be denoted by as follows.

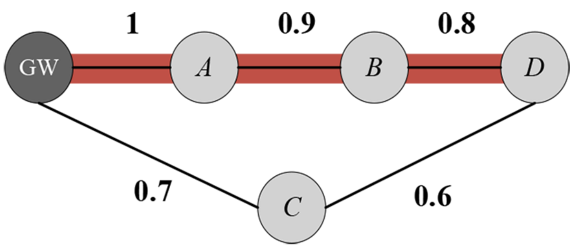


Figure 5. Link cost of each node by delivery ratio measurement

$$C_k = \mathbf{max}(C_i \cdot r_{i,k}) \qquad \text{for } \forall i \in N_k \qquad (3)$$

where $r_{i,k}$ is the delivery ratio between node *i* and node *k*, and N_k denotes the set of all neighbor nodes of node *k*. In Figure 5, node *D* has two costs of 0.72 and 0.42 for two different links, and selects the path via node *A* and *B* whose cost is higher than that of the path via node *C*. Nevertheless, node *D* does not discard the path via the node *C* because it could be the alternative path when the node *B* moves out of the network or is broken. Consequently, node *D* caches the route for node *C* in its own neighbor table as one of reserved links, and immediately re-transmits the data to node *C* when the response from node *B* has not arrived. This method can also improve the network performance in terms of throughput and latency. After successful retransmission, node *D* executes the link estimation again to tune the topology and find a robust link in the changed environment.

As aforementioned, we have assumed that there co-exists fixed nodes and mobile nodes in the network. In our scheme, the classification of each node is as follows.

- **Fixed Node:** Once it is deployed, it does not move to another network. Therefore, its *Adv* information is very trustworthy.
- **Mobile Node:** It is able to go anywhere in anytime. Therefore, its *Adv* could be a rumor if it is not fresh or has been modified.

Such classification for nodes can be used for finding more reliable links and, more specifically, it can be a clue which instructs new nodes to make a correct decision. Assuming that a traveler is finding a way in the strange place, he will ask locals instead of strangers to obtain more accurate information. In our scheme, a new node is a traveler, and the fixed and mobile nodes are corresponding to the locals and the strangers, respectively. In other words, the information from the fixed node is more trustworthy than from the mobile node. Thus, we allocate different weights to each node according to the node type. Firstly, value 1 is given to the fixed node as the weight. In addition, weights for the mobile nodes are differently given from 0.95 to 0.8 according to how long they stay in the network. This weight is used for calculating the cost and deciding handover. How to use the weight in deciding handover is dealt with in the subsequent subsection, and thus we only present how to calculate the cost using the weight. As mentioned above, the cost is determined by simply using the Bernoulli loss process and the weight is reflected in calculating weighted cost. Thus, the weighted cost for the end-to-end path from node *k* to the GW can be derived as follows.

$$C_k^W = \mathbf{max}(w_i \cdot C_i^W \cdot r_{i,k}) \qquad \text{for } \forall i \in N_k \qquad (4)$$

where C_k^W is the weighted cost of node *k*, w_i is the allocated weight for the neighbor node *i*, and N_k denotes the set of all neighbor nodes of node *k*. It is important to note that from now on, the cost means the weighted cost in this paper.

3.3 Protocol for Mobility Support

The GW should periodically broadcast a beacon to help the mobile node to be aware of handover without support of any devices which provide location information. Since the time over which the mobile node recognizes movement is dependent on the beacon interval, the GW should broadcast a beacon with a short interval for fast recognition. However, the network consumes the energy as much as $\sum(E_{rx(i)} + E_{tx(i)})$, where $E_{rx(i)}$ and $E_{tx(i)}$ is the energy consumption of the *i*-th node to receive and forward a beacon, respectively, whenever a beacon is flooded. It is obvious that the amount of energy consumption per unit time increases, as the interval becomes shorter. To mitigate this phenomenon, we employ an adaptive beaconing scheme from Trickle [16]. However, having a maximum window size for the GW means that the network has reached the saturated state, and beaconing is no more needed. In this case, the beaconing is occurred with long interval, and thus the probability, for which the mobile nodes detect their own handover, will be significantly reduced. To resolve this problem, we make each of nodes to notify one-hop neighbor nodes of the network information using the *Adv*. This method increases opportunistic probability for which the mobile node recognizes its own handover into another network.

Figure 4 shows the example of the procedure for mobility support. If a mobile node has moved to another network, it can recognize its own handover by the *Adv* of the neighbor nodes. The mobile then requests the GW information to confirm whether the *Adv* is correct or not, but this step is skipped if the *Adv* came from the fixed node. After confirmation, the mobile node tries association to join the network and then it exchanges probe packets with the neighbor nodes to measure the delivery ratio. In Figure 4, the mobile node can know the cost for each of links from each *Probe_Ack* packet, the mobile node selects the link with the highest cost which is calculated from Eq. (4).

4 Performance Evaluation

In this section, we describe the simulation environment and the scenarios for evaluating the proposed DTOR, and then evaluate its performance and discuss the results. We first compare DTOR with beaconing-only scheme during topology organization in terms of energy consumption. We then analyse our proposed scheme in terms of packet delivery ratio and network lifetime under different number of nodes and data generation rates.

4.1 Simulation Environment

Our simulation is conducted in the log normal shadowing radio environment where the size is 100×100 m^2, there are 50 mobile nodes and 50 fixed nodes, and the transmission range of each node is 20 m. Each node has the same initial energy of 5 J and transmits one packet of 20 bytes every second. Mobile nodes move in the network according to the random waypoint mobility model with a maximum speed of 10 m/s [18]. Figure 6 shows the organized topology by the proposed link quality estimation. The dotted red line is the link which is connected by only the *Rout* messages of the GW, which is located in 0 in Figure 6, and the black line presents the topology by the proposed link selection after initial topology organization. Through this topology, we can intuitionally know that traffic load would be relatively distributed compared to the method by the *Rout* message, which is presented by the dotted red line. Since most nodes select the link of the first *Rout* in the topology of the dotted red line, the possibility to choose the same parent is higher and thus the traffic overhead of the parent would be increased. On the other hand, each node in the topology of the black line is highly likely to comparatively select different parents in the topology by the link estimation because the link selection is determined by the delivery ratio with each parent. It means that the selected parent by our proposed scheme is much less likely to have obstacles such as concentration of traffic or transmission collision between nodes.

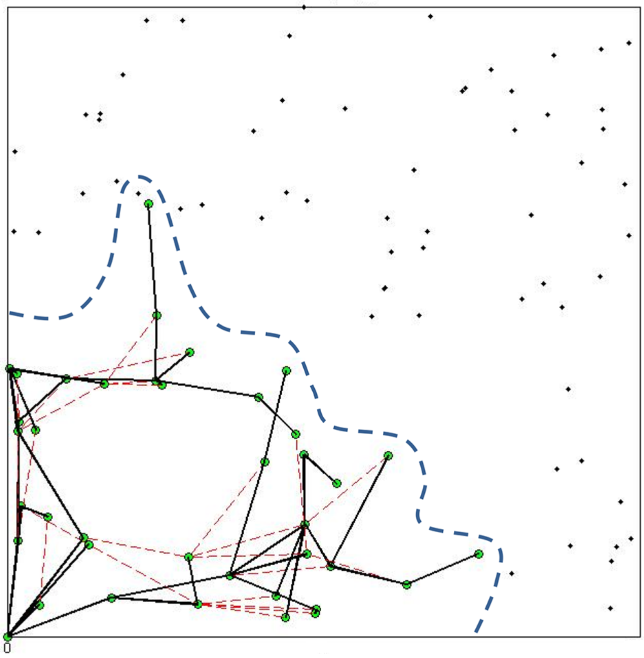


Figure 6. Topology configuration by the link quality estimation: lognormal shadowing radio environment, 100×100 m^2, 100 nodes, and 20 m transmission range. The bold dotted blue line shows the edge of the network. In this scenario, the network edge is formed by the number of maximum hop, limited by 5 hop in this experiment. The maximum hop is criteria of partitioning each network. Consequently, each GW organizes its own covering zone formed by the edge, and manages the nodes inside the edge

4.2 Simulation Results

In this section, we present the results of the simulation in aforementioned environment. The consumed energy shown as simulation results is calculated by Table 1 [19] where we have assumed that the transmission power is set to 0 dBm and the radio chip is a CC2420 radio transceiver.

Table 1. Operating modes for transmission and reception of CC1000 and CC2420

Radio chip	CC1000		CC2420	
	Current	Energy/Bit	Current	Energy/Bit
Listening/Rx	74mA	88nJ/b	19.7mA	236.4pJ/b
Polling (1/100)	74uA	N/A	197uA	N/A
Tx at -25 dBm	N/A	N/A	8.5mA	102nJ/b
Tx at -20 dBm	5.3mA	414nJ/b	9.2mA	110.4nJ/b
Tx at -15 dBm	7.4mA	578nJ/b	9.9mA	118.8nJ/b
Tx at -10 dBm	7.9mA	617nJ/b	11.2mA	137.4nJ/b
Tx at -5 dBm	8.9mA	695nJ/b	13.9mA	166.8nJ/b
Tx at -0 dBm	10.4mA	812.4nJ/b	17.4mA	208.8nJ/b
Tx at 5 dBm	14.8mA	1156nJ/b	N/A	N/A
Tx at 10 dBm	26.7mA	2086nJ/b	N/A	N/A

Figure 7 shows the consumed energy by the end-to-end data transmission of each node in the network. The left figure is the consumed energy of each node in the network by only beaconing, and the right figure shows the consumed energy of each node in the network by the proposed DTOR. As indicated by Figure 7, the consumed energy has been clearly different between two schemes. Periodic beaconing and consequent flooding make the entire network to consume more excessive energy by approximately 40% on average, compared to the proposed DTOR. This shows that both the advertisement of each node for mobility and adaptive beaconing support dynamic topology configuration while conserving the energy of the network. Furthermore, it is worth noting that the energy consumption of each node in our proposed DTOR is more uniform than another one, which prolongs the lifetime of the network. Figure 8 presents the ratio of the consumed energy for control packets used by each node, where we can find that the nodes are mostly consuming the energy in beaconing, compared to others. Even if our proposed DTOR spends more energy for sending additional messages such as the *Adv*, *Probe* and *Probe_Ack*, DTOR is more energy-efficient than the previous scheme with only beaconing as shown in Figure 8. Furthermore, Figure 9 shows that the end-to-end average latency of each node in the network has been reduced by approximately 10%, compared to the previous scheme with only beaconing.

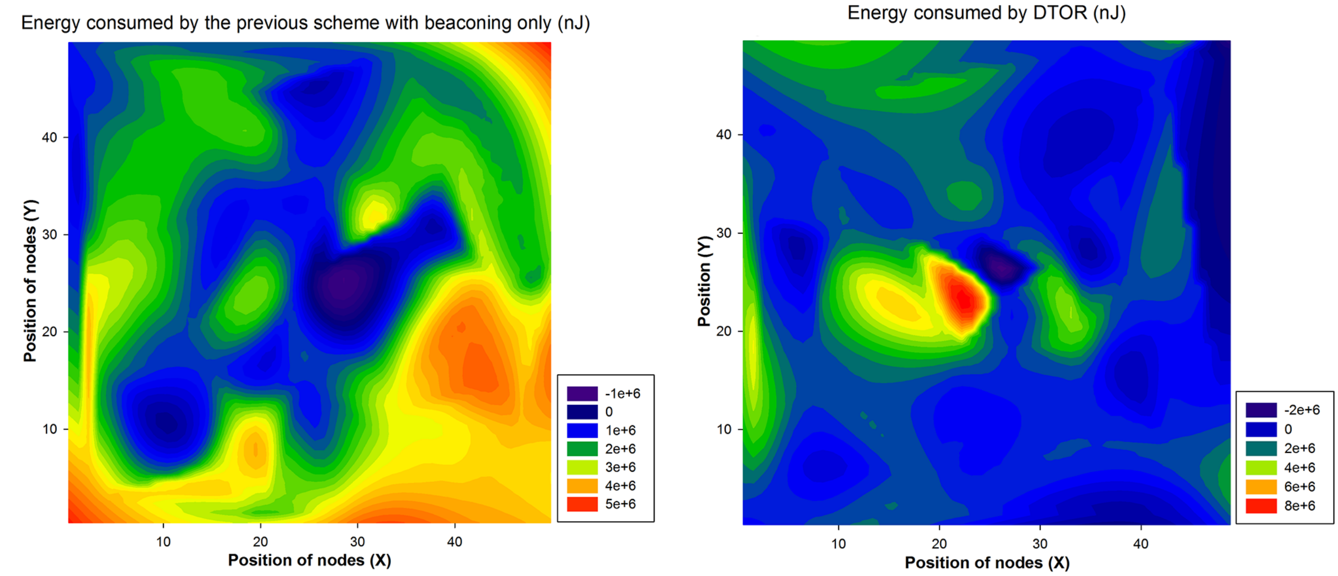


Figure 7. The consumed energy of each node in the network: the left figure shows the consumed energy of each node by only beaconing, and the right figure shows the consumed energy of each node by the proposed DTOR

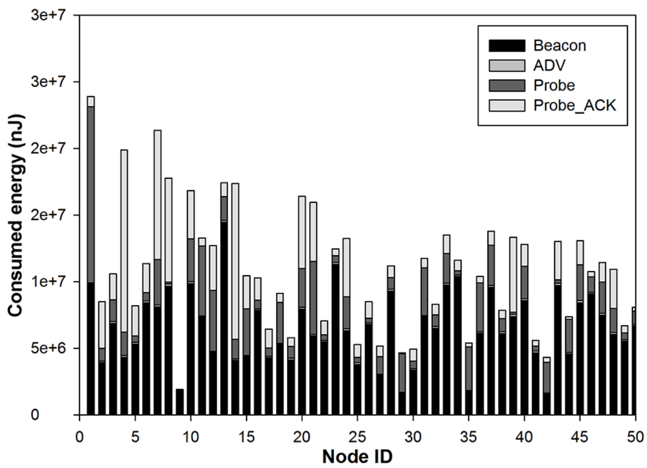


Figure 8. The ratio of the consumed energy for each of packets: it shows the ratio of energy of control packets used by each node

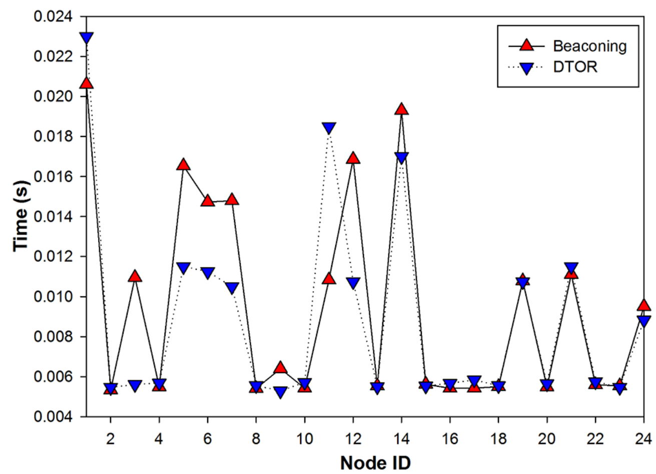
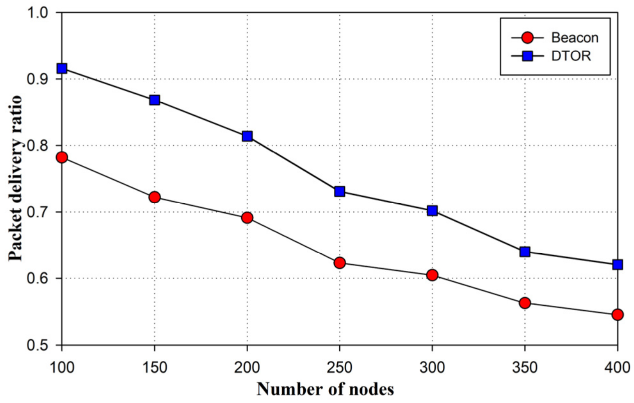
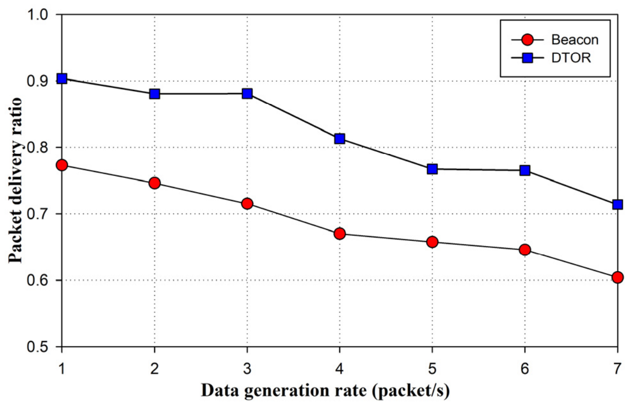


Figure 9. The end-to-end average latency of each node in the network

Figure 10 shows the packet delivery ratio according to the number of nodes and the data generation rate. DTOR outperforms the scheme with only beaconing by 17.8% since DTOR detects the movement of mobile nodes quickly and uses reliable links based on the weighted link estimation.



(a) effectiveness of the number of nodes



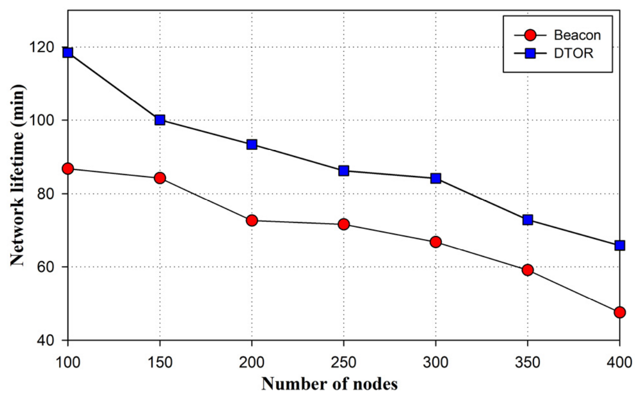
(b) effectiveness of the data generation rates

Figure 10. Packet delivery ratios

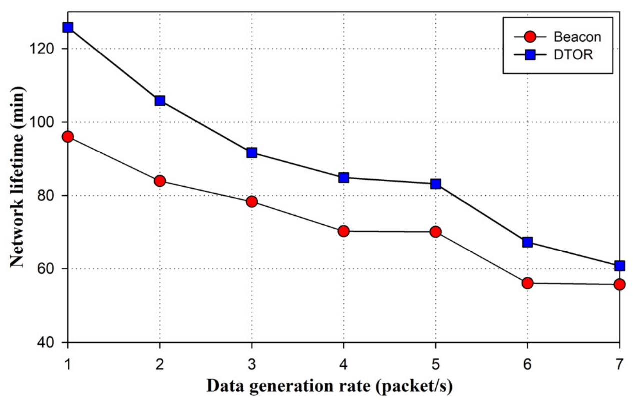
Impact of different number of nodes and data generation rates on the network lifetime is depicted in Figure 11. The simulation results show that our proposed scheme achieves higher network lifetime than the beaconing-only scheme by 23.9%. The reason is that DTOR uses adaptive beaconing and advertisement messages to reduce energy consumption. Furthermore, the weighted link estimation scheme helps to save energy by reducing data retransmission.

5 Conclusion

In this paper, we proposed an efficient dynamic tree organizing routing for mobility in WSNs named DTOR. By taking advantage of the node advertisement, the efficient weighted link estimation and the adaptive beaconing, DTOR could support mobility, dynamic topology configuration and low energy consumption. Our performance evaluation proved that DTOR is highly energy-efficient and has low end-to-end latency.



(a) effectiveness of the number of nodes



(b) effectiveness of the data generation rates

Figure 11. Network lifetime

Furthermore, DTOR achieved higher packet delivery ratio and network lifetime by 17.8% and 23.9% respectively.

Our future work is to validate performance of the proposed scheme by comparing with CTP and other related works. Consequently, we must tune other schemes including CTP so that they are analyzed in the same condition and environment. Furthermore, we have a plan to add new ideas such as the network edge decision method and the real-time neighbor table tuning which is not reflected in the proposed scheme.

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References

[1] B. P. Santos, M. A. M. Vieira, L. F. M. Vieira, eXtend Collection Tree Protocol, *2015 IEEE Wireless Communications and Networking Conference (WCNC)*, New Orleans, LA,

2015, pp. 1512-1517.
[2] S. P. Singh, S. C. Sharma, A Survey on Cluster Based Routing Protocols in Wireless Sensor Networks, *Procedia Computer Science*, Vol. 45, pp. 687-695, March, 2015.
[3] N. Sabor, S. Sasaki, M. Abo-Zahhad, S. M. Ahmed, A Comprehensive Survey on Hierarchical-Based Routing Protocols for Mobile Wireless Sensor Networks: Review, Taxonomy, and Future Directions, *Wireless Communications and Mobile Computing*, Vol. 2017, Article ID 2818542, pp. 1-23, January, 2017.
[4] H. Huang, A. V. Savkin, M. Ding, C. Huang, Mobile Robots in Wireless Sensor Networks: A Survey on Tasks, *Computer Networks*, Vol. 148, pp. 1-19, January, 2019.
[5] N. A. Pantazis, S. A. Nikolidakis, D. D. Vergados, Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey, *IEEE Communications Surveys & Tutorials*, Vol. 15, No. 2, pp. 551-591, April, 2013.
[6] J. Shen, H. W. Tan, J. Wang, J. W. Wang, S. Y. Lee, A Novel Routing Protocol Providing Good Transmission Reliability in Underwater Sensor Networks, *Journal of Internet Technology*, Vol. 16, No. 1, pp. 171-178, January, 2015.
[7] J. S. Pan, L. Kong, T. W. Sung, P. W. Tsai, V. Snášel, A Clustering Scheme for Wireless Sensor Networks Based on Genetic Algorithm and Dominating Set, *Journal of Internet Technology*, Vol. 19, No. 4, pp. 1111-1118, July, 2018.
[8] M. S. Gharajeh, S. Khanmohammadi, DFRTP: Dynamic 3D Fuzzy Routing Based on Traffic Probability in Wireless Sensor Networks, *IET Wireless Sensor Systems*, Vol. 6, No. 6, pp. 211-219, December, 2016.
[9] S. Khanmohammadi, M. S. Gharajeh, A Routing Protocol for Data Transferring in Wireless Sensor Networks Using Predictive Fuzzy Inference System and Neural Node, *Ad Hoc & Sensor Wireless Networks*, Vol. 38, No. 1-4, pp. 103-124, 2017.
[10] S. Khanmohammadi, M. S. Gharajeh, An Intelligent and Knowledge-Based Overlapping Clustering Protocol for Wireless Sensor Networks, *International Journal of Communication Systems*, Vol. 31, No. 10, pp. 1-22, July, 2018.
[11] M. S. Gharajeh, FSB-System: A Detection System for Fire, Suffocation, and Burn Based on Fuzzy Decision Making, MCDM, and RGB Model in Wireless Sensor Networks, *Wireless Personal Communications*, Vol. 105, No. 4, pp. 1171-1213, April, 2019.
[12] C. Perkins, E. Belding-Royer, S. Das, *Ad Hoc On-demand Distance Vector (AODV) Routing*, RFC 3561, July, 2003.
[13] K. Kim, M. Baek, Performance Evaluation of MINTRoute Protocol at Different Scenarios, *International Conference on Hybrid Information Technology*, Daejeon, Korea, 2011, pp. 9-15.
[14] D. S. J. D. Couto, D. Aguayo, J. Bicket, R. Morris, A High-throughput Path Metric for Multi-hop Wireless Routing, *Wireless Networks*, Vol. 11, No. 4, pp. 419-434, July, 2005.
[15] O. Gnawali, R. Fonseca, K. Jamieson, D. Moss, P. Levis, Collection Tree Protocol, *7th ACM Conference on Embedded Networked Sensor Systems (SenSys)*, Berkeley, CA, 2009, pp. 1-14.
[16] P. Levis, T. Clausen, J. Hui, O. Gnawali, J. Ko, *The Trickle Algorithm*, RFC 6206, March, 2011.
[17] O. Gnawali, R. Fonseca, K. Jamieson, M. Kazandjieva, D. Moss, P. Levis, Ctp: An Efficient, Robust, and Reliable Collection Tree Protocol for Wireless Sensor Networks, *ACM Transactions on Sensor Networks*, Vol. 10, No. 1, pp. 1-49, November, 2013.
[18] C. Bettstetter, H. Hartenstein, X. Pérez-Costa, Stochastic Properties of the Random Waypoint Mobility Model, *Wireless Networks*, Vol. 10, No. 5, pp. 555-567, September, 2004.
[19] N. Chohan, *Hardware Assisted Compression in Wireless Sensor Networks*, Dept. of Computer Engineering and Computer Science, University of California, Santa Barbara, June, 2007.

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