An energy-efficient routing scheme by using GPS information for wireless sensor networks

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Abstract: A wireless sensor network (WSN) (or IoT network) is a collection of distributed nodes. These nodes gather data from various sensors and relay that information to a central point through a wireless network. Therefore, the data can be aggregated and have something useful done with it. These types of networks deal primarily with the transmission of small amounts of data that needs to be sent very efficiently. In this paper, we propose an energy-efficient routing algorithm based on the global positioning system (GPS) information. Proposed scheme track the destination's location based on the beacon messages of the main route nodes. Through the experiments, proposed scheme shows improvements in the data packet delivery ratio and reduces the amount of routing control message overhead compared with existing routing protocols such as energy-efficient ant-based routing algorithm (EEABR) and ladder diffusion.

Keywords: energy-efficient routing; GPS; global positioning system; energy efficiency; WSN; wireless sensor network.

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1 Introduction

Much is being made of the internet of things (IoTs) and the associated need for wireless connectivity for sensors. However, the networking needs of mobile devices and applications are distinct from the consumer world, with reliability (Behera et al., 2015; Boyle, 2014) and security (Riahi et al., 2013; Li and Tryfonas, 2015) high on the list. The advent of low-power processors, intelligent wireless networks and low-power sensors coupled with 'Big Data' analytics (Li et al., 2015) have led to the booming interest in the IoT. This combination of technologies enables a multitude of sensors to be put anywhere: not just where communications and power infrastructure exists, but anywhere there is valuable information to be gleaned about how, where or what a 'thing' is.

The concept of instrumenting 'things' such as machines, pumps, pipelines and rail cars with sensors is not new to the industrial world. Purpose-built sensors and networks already proliferate in industrial settings ranging from oil refineries to manufacturing lines. Historically, these operations technology (OT) systems have operated as separate networks, maintaining a high bar for network reliability and security that simply cannot be met with consumer technology. These high bar requirements filter the available technologies down to those best suited for business-critical Industrial IoT applications. In particular, the way these sensors are networked determines whether the sensors can be safely, securely and cost-effectively (Al-Turjman et al., 2012; Lazarescu, 2013) deployed in the harsh environments typical of industrial applications.

Energy availability is one of the most important considerations in any given wireless sensor network (WSN). Therefore, whenever possible, energy harvesting is used to provide an external energy supply to the nodes. Since this supply is unreliable, the WSN has to forecast it energy input to maximise the sensor network performance while minimising the number of nodes that are out of energy. A global solar power forecast is not enough, however, since nodes in a city have different orientations and locations (which correspond to different cast shadow patterns), and factors such as dust accumulation or solar panel ageing are highly variable among solar panels (Ramya et al., 2016; Kim and Noh, 2013). To make matters worse, the capacity of batteries is affected by environmental factors, and typically degrades significantly over the lifetime of the sensor network (Kim and Noh, 2013).

In this paper, we use the directional information to solve the additional energy consumption problem. In addition, the proposed algorithm can reduce routing overhead. The main route nodes broadcast beacon messages, which have the location of the destination, to their one-hop neighbours. This approach provides efficient tracking of a destination and reduces messages for routing. Experimental results show that proposed algorithm saves the energy up to 30% for routing compared with other routing protocols. This paper is organised as follows. In Section 2, we describe relevant studies, and Section 3 explains the detail of proposed algorithm. Section 4 evaluates the performance of proposed technique, and concludes the paper in Section 5.

2 Related work

2.1 Key challenging issues in WSN

2.1.1 Reliability

In OnWorld's global survey of industrial WSN users, reliability is the most important concerns cited. One general principle in designing a network for reliability is redundancy, where failover mechanisms for likely problems enable systems to recover without data loss. In a WSN, there are two basic opportunities to harness this redundancy. First is the concept of spatial redundancy, where every wireless node has at least two other nodes with which it can communicate, and a routing scheme that allows data to be relayed to either node, but still reach the intended final destination. A properly formed mesh network – one in which every node can communicate with two or more adjacent nodes – enjoys higher reliability than a point-to-point network by automatically sending data on an alternate path if the first path is unavailable.

The second level of redundancy can be achieved by using multiple channels available in the radio frequency (RF) spectrum. The concept of channel hopping (Chang et al., 2014) is that pairs of nodes can change channels on every transmission, thereby averting temporary issues with any given channel in the ever changing and harsh RF environment typical of industrial applications. Within the IEEE 802.15.4 2.4 GHz standard (Seo et al., 2015), there are 15 spread spectrum channels available for hopping, affording channel hopping systems much more resilience than single channel systems. There are several wireless mesh networking standards that include this dual spatial and channel redundancy known as time slotted channel hopping (TSCH), including IEC62591 (WirelessHART) (International Electrotechnical Commission, 2013) and the forthcoming IETF 6TiSCH standard (Accettura and Piro, 2014). These mesh networking standards, which utilise radios in the globally available unlicensed 2.4 GHz spectrum, evolved out of work by Linear Technology's Dust Networks group, who pioneered the use of TSCH protocols on low power, resource constrained devices starting in 2002 with SmartMesh products.

2.1.2 Cost

Cost is a major issue when it comes to WSNs, and often, it is tied to range. If someone has longer range and fewer gateways, then the cost of setting up your network may be lower. Another cost complexity comes with cellular networks. For example, 4G cellular networks are being phased out, which is causing big problems for some people. And even if your 4G cellular modems are working fine, then it will likely have to switch over to a different underlying technology very soon. This is difficult for many who do not need the extended capabilities of 5G/LTE + and cannot handle the extra cost.

2.1.3 Energy consumption

If the customer needs a wireless application to last 5–10 years, then they will need something very low power. But there will likely be a trade-off between latency and energy consumption. In other words, the number of times they transmit data in a given period may be affected in a low-power sensor network. If someone needs to gather data every 30 s instead of every 5 min, then they will have to deal with a system that uses more energy.

2.1.4 Sensors anywhere

For the IoT applications, the precise placement of a sensor or control point is critical. Wireless technology offers the promise of no-wires communication, However, if customer needs to power a wireless node by plugging it in, or recharge it every few hours or even months, the cost and impracticality of deployment become prohibitive. For example, adding sensors to rotating equipment to monitor conditions while the equipment is in service is not possible with wires. However, the knowledge gained from in-service monitoring can allow customers to predicatively maintain this critical equipment, thereby avoiding unwanted and expensive downtime.

To ensure flexible and cost-effective deployments, every node in an industrial WSN should be capable of running on batteries for at least five years, as this offers users the ultimate flexibility in coverage for Industrial IoT applications. As an example of an industrial TSCH-based WSN, Linear Technology's SmartMesh products typically operate at well under 50 μA, making it very feasible to operate for many years on 2 AA batteries. In environments where there is a good source of harvested energy, it is possible to run nodes perpetually on energy harvesting (Castagnetti et al., 2012).

2.2 Existing routing algorithms

2.2.1 Location-based protocols

In Yu et al. (2001), they proposed geographic and energy aware routing (GEAR) algorithm. It is an energy-efficient routing protocol for routing queries to target regions in a sensor field. In their algorithm, sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbours. They use recursive geographic forwarding algorithm to disseminate the packet inside the target region. In Nath and Niculescu (2003), they introduced a trajectory-based forwarding (TBF) protocol. This protocol requires a sufficiently dense network and the presence of a coordinate system. For example, a GPS, so that the sensors can position themselves and estimate distance to their neighbours. It can be used for implementing networking functions, for example, flooding, discovery, and network management. Minimum energy communication network (MECN) is proposed to achieve the minimum energy for randomly deployed ad hoc networks. It computes an optimal spanning tree rooted at the sink, called minimum power topology, which contains only the minimum power paths from each sensor to the sink (Rodoplu and Meng, 1999). In Li and Halpern (2001), they proposed small minimum energy communication network (SMECN). It improves the MECN, in which a minimal graph is characterised with regard to the minimum energy property. This property implies that of sensors.

2.2.2 Data centric protocols

In Directed Diffusion (Intanagonwiwat et al., 2000), they meet the main requirements of WSNs such as energy efficiency, scalability and robustness. Directed diffusion has several key elements, namely data naming, interests and gradients, data propagation and reinforcement. A sensing task can be described by a list of attribute-value pairs. At the beginning of the directed diffusion process, the sink specifies a low data rate for incoming events. After that, the sink can reinforce one particular sensor to send events with a higher data rate by resending the original interest message with a smaller interval. Likewise, if a neighbouring sensor receives this interest message and finds that the sender's interest has a higher data rate than before, and this data rate is higher than that of any existing gradient, it will reinforce one or more of its neighbours. In Braginsky and Estrin (2002), they proposed Rumour Routing algorithm. They use the logical compromise between query floods and event flooding app schemes is based on the concept of agent. It is a long-lived packet that traverses a network and informs each sensor it encounters about the events that it has learned during its network traverse. An agent will travel the network for a certain number of hops and then die.

2.2.3 Hierarchical protocols

In TEEN (Manjeshwar and Agrawal, 2001), they designed to be responsive to sudden changes in the sensed attributes such as temperature. Responsiveness is important for time critical applications, in which the network operated in a reactive mode. TEEN pursues a hierarchical approach along with the use of a data-centric mechanism. Hybrid, energy-efficient distributed clustering (HEED) (Younis and Fahmy, 2004) operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. HEED was proposed with four primary goals, namely

1 prolonging network lifetime by distributing energy consumption

2 terminating the clustering process within a constant number of iterations

3 minimising control overhead

4 producing well-distributed CHs and compact clusters.

In Lindsey and Raghavendra (2002), they proposed PEGASIS routing protocol. The power-efficient gathering in sensor information systems (PEGASIS) is an improvement of the LEACH protocol. Rather than forming multiple clusters, PEGASIS forms chains from sensor nodes so that each node transmits and receives from a neighbour and only one node is selected from that chain to transmit to the base station (sink). Gathered data moves from node to node, aggregated and eventually sent to the base station.

2.2.4 Multipath-based protocols

In Camilo et al. (2006), they proposed energy-efficient ant-based routing algorithm (EEABR). In their algorithm, they maximise the network lifetime of WSNs which is based on ant behaviour. EEABR aims to reduce the energy consumption while the communication related to the ants.

In E-D ANTS (Wen et al., 2008), they design to minimise the time delay in packet transfer for the purpose of energy constrained WSNs. This protocol adopts the energy × delay model based on ant algorithms. N-to-1 multipath discovery (Chu et al., 2002) is based on the simple flooding originated from the sink and is composed of two phases, namely, branch aware flooding (or phase 1) and multipath extension of flooding. In their algorithm, they use an active per-hop packet salvaging strategy can be adopted to handle sensor failures and enhance network reliability.

3 Proposed algorithm

In WSNs, energy efficiency is important because of the energy constrained sensor nodes. As explained in the previous section, many studies that sought to improve the data packet delivery ratio have been done, but these works leave a considerable number of routing overhead messages. This section describes a detailed scheme to improve the data packet delivery ratio while reducing the number of routing overhead messages via one-hop neighbour beaconing of the main route nodes.

3.1 Directional forwarding

Figure 1 shows the proposed directional forwarding algorithm (Kang and Ko, 2010). Each node recognises its location through the GPS module. A one-hop neighbour node, which is at a distance of one hop from the main route, recognises the location of the main route node through a 'Hello' message. In the figure, node A contains information about its location (Xa, Ya). In this situation, node A broadcasts its location information using a beacon message. Nodes B and C store the location of node A in each routing table. Four-directional forwarding, directions 1 to 4, is then applied. Direction 1 is (+, +), Direction 2 is (+, –), Direction 3 is (–, –) and Direction 4 is (–, +). In Figure 1, Node B locates direction 1 from node A, and node A sets the position of direction 3 from node B. In the same manner, node C locates direction 2 from node A and node A locates direction 4 from node C. Though 2-, 4-, 9- and 16-way directions can be applied, four-way direction shows the best performance with the least routing overhead. Using two-way direction, it causes many routing overhead as similar data packet delivery ratio. Furthermore, using 8- and 16-way direction, they result very low data packet delivery ratio because there are not enough control messages to trace the destination's location.

3.2 Basic operation of the algorithm

Table 1 shows the proposed local routing table, which has more fields than the general WSN routing table. The function of each field is described as below. The destID field stores the destination node ID using direction values that range from 1 to 4. The distance field stores the distance value between two neighbour nodes, from 1 to 50, as the transmission range of the WSN node. The HopCnt field indicates the hop count information to the destination node. SeqNo is given automatic sequential numbers, which specify a larger sequence number as newer route information. Lifetime is the lifetime of the route information; the information with a higher lifetime value remains in the routing table longer. Finally, the state field determines whether the route information is valid or not. If the lifetime field is 0 or if the state field reads INVALID, then the routing Table entry will be deleted (ignored).

Figure 1 Four-way directional forwarding (see online version for colours)

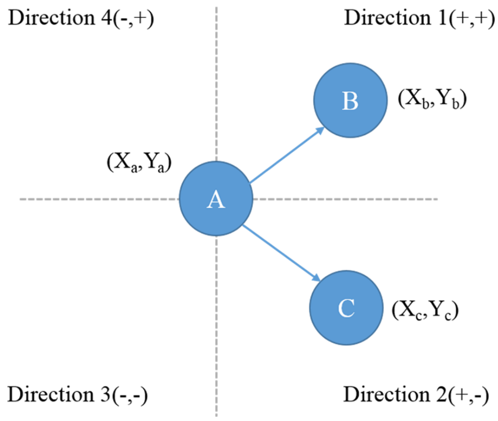


Table 1 Local routing table

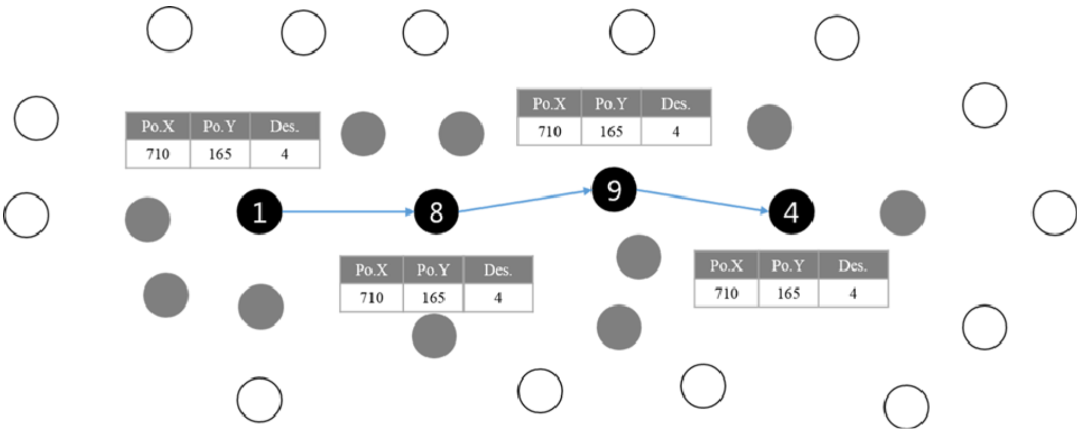
destID	*Direction*	*Next node*	*Distance*	*HopCnt*	*SeqNo*	*Lifetime*	*State*
Node 1	1	Node 5	20	4	345	10	VALID
Node 2	2	Node 6	30	5	347	0	INVALID
Node 3	3	Node 7	40	5	351	10	VALID
Node 4	4	Node 8	50	6	357	0	INVALID

Route maintenance and restoration are important factors in WSNs. In this subsection, the proposed route maintenance and restoration schemes are discussed. Figure 2 shows the route maintenance method between the source and the destination node. The black nodes are the main route nodes, the grey nodes are one-hop distance nodes from the main route node, and white nodes are two hops or more from the main route nodes. For instance, if a white node moves to a one-hop distance from the main nodes, then it will then change its status to a grey node. Under the same approach, if a grey node moves away from the main route node by more than two hops, then it will change its status to a white node. The difference between grey and white nodes is whether or not the node receives a beacon message from the one of the main route nodes.

In Figure 2, node 1 transmits the information of the location of the destination node to its one-hop neighbour node 8. This information is broadcast with a beacon message every second to its one-hop neighbour nodes by setting the TTL of beacon message to 1. Similarly, nodes 8, 9 and 4 broadcast beacon messages to their neighbours that have the location information and address of the destination node. Next, the one-hop-distant neighbour nodes from the main route nodes write the routing information on each routing table. The purpose of beaconing is to find the location of the destination immediately when route failure occurs along the main route nodes. This procedure is used as an effective type of local repair.

Regarding the local repair procedure of a proposed algorithm, it broadcasts an Route REQuest (RREQ) message to find the destination node set as TTL field = 2 when a node finds a link failure. If no destination node is found, it then sends a Route ERRor (RERR) message back to all active nodes that are dependent on the broken link. When every node receives the RERR message, those nodes delete the route of the broken link. Particularly for a source that receives such an RERR message, it can restart the route discovery procedure; a stale route is expired according to a timer-based technique. In the present scheme, when an upstream node detects a link failure, the node sends an RREQ message towards only the direction of the destination. These procedures contribute towards reducing the routing message overhead.

Figure 2 Route maintenance of proposed algorithm (see online version for colours)



3.3 *Packet forwarding*

Once a source node recognises the location of the destination, the source node selects one node from the routing table towards the destination direction. If many candidate nodes are selected, then the source node selects the node of the minimum hop count and the highest sequence number. Nevertheless, if it still has two or more candidate nodes, then it finally selects the one node with the longest distance value. The distance is determined from the distance field value of the routing table. If there is no suitable node for packet forwarding, then local repair procedures are executed.

Figure 3 Packet forwarding strategy (see online version for colours)

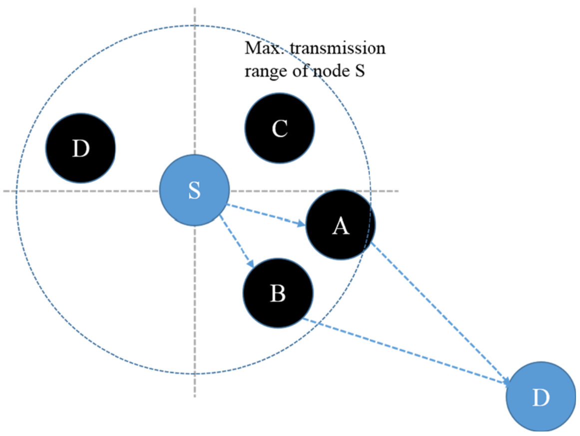


Figure 3 depicts source node S selecting one of the forwarding packets among nodes which locate in its transmission range. First, node S selects A and B nodes having the same direction (direction = 2) to the destination from its routing table. Subsequently, if they have the same hop count value and sequence number, node S then compares the distance field value of each node. As described in Figure 3, node A is finally selected as the packet forwarding node that has a larger distance value than node B.

4 Experimental results

In this section, we evaluate the proposed protocol and compare its performance with two other routing protocols based on ACO algorithm: the EEABR (Camilo et al., 2006) and ladder diffusion (Ho et al., 2012). The EEABR is well-known routing protocol for energy efficiency. Ladder diffusion is similar with our proposed protocol. These two protocols are proactive and aim the energy efficiency for WSNs. We used the following metrics to evaluate the performance.

- *Total energy consumption*: The total consumed energy of all sensor nodes at the end of simulation.
- *Average energy*: The average of energy of all sensor nodes at the end of simulation.
- *Minimum energy*: The lowest energy amount of all nodes.
- *Average hop distance*: The average hop distance of all data packets passed from a source node randomly chosen to the sink node in the simulation.

4.1 Simulation environment

The performance evaluation is achieved through simulations using the well-known simulator NS-3 v3.23. We implemented the three routing protocols as a module. In the simulation, sensor nodes are randomly deployed using Random Rectangle Position Allocator which is provided by NS-3. The sensor-deployed area is 400 × 400 m. The number of nodes increases from 200 to 400 with a fixed node number 20. For the each number of node, simulation is run more than 50 times and we average them to get the mean value. 1500 data packets are generated by random sensor node and sent to the sink node. The data packet size is 500 bytes. We used the standard energy model for WSNs (Heinzelman et al., 2002; Ray and De, 2011; Azharuddin et al., 2015). Table 2 summarises the parameters used in the simulation.

Table 2 Simulation parameter and its value

Parameter	*Values*
Area size	400 × 400 m
Number of sink nodes	1–10, Randomly generate
Number of nodes	200–400 with 25 increments
Node Distribution	Randomly distributed
Data packet size	500 byte
Number of data packets	1500
Transmission range (d_{TX})	50 m
Minimum waiting time (T_{min})	30 ms
Maximum waiting time (T_{max})	300 ms (Lee et al., 2015)
Initial energy of node (C)	2.0 J (Ray and De, 2011)
Electronics energy (E_{elec})	50 nJ/bit (Heinzelman et al., 2002; Ray and De, 2011; Azharuddin et al., 2015)
Amplifier factor for free-space model (ε_{fs})	10 pJ/bit/m^2 (Heinzelman et al., 2002; Ray and De, 2011; Azharuddin et al., 2015)

4.2 Simulation results

The results illustrated in Figure 4 are the total energy of all nodes consumed in the simulation. Our proposed protocol reduces total energy consumption more than 40%. The ladder diffusion adopted the concept of hop count to reduce the additional traffic of ants. In the EEABR case, the length of forward ant packet was decreased to address the energy consumption problem. Even they introduced their solution, there are still occurred the energy consumption problems from these results. As shown in Figure 4, it can be found that the additional traffics are increased by the number of nodes simultaneously. In our proposed protocol, we adopted the concept of relay nodes (one hop neighbours of the main route node). So our proposed protocol saves more energy because there is no additional traffic.

From Figure 5, the sensor nodes in our proposed protocol have more energy compared with the other protocols. In ladder diffusion and EEABR, every node generates additional traffic to find path towards sink node. The energy consumption is increased by the number of sensor nodes due to the nodes which participate in the data packet relay.

Figure 4 Total energy consumption (see online version for colours)

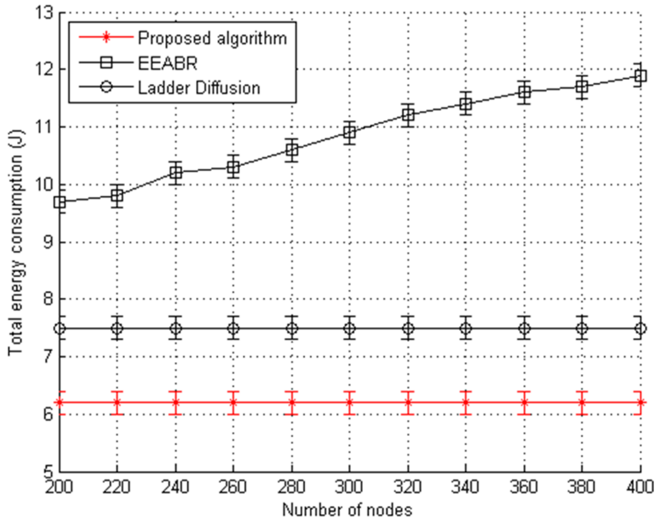


Figure 5 Average remaining energy of each node (see online version for colours)

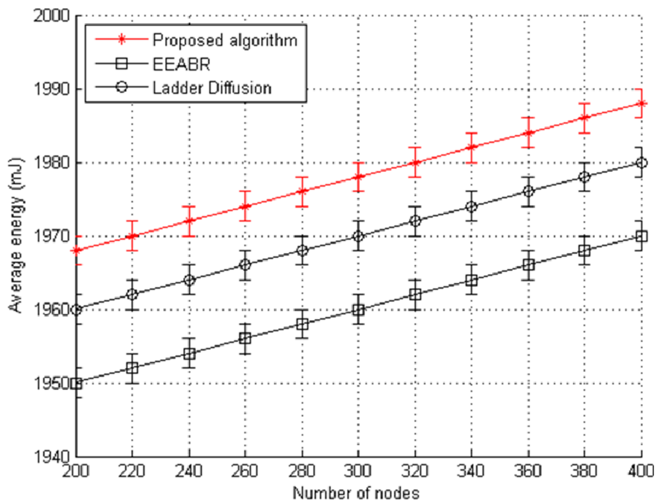


Figure 6 represents the minimum residual energy among the all nodes. As shown in Figure 6, minimum energy of proposed protocol is lower than other protocols. The reason is that the relay nodes are used to relay the data packets. In particularly, the nodes who consume energy more are the relay nodes near the sink node. This minimum energy problem can be solved using the directional forwarding and control the weight value of selection probability. In general, if the node is located near the sink node, then it has the minimum energy in the other protocols. Even the results show that our proposed algorithm has the lower energy than other protocols, it is reasonable and energy efficient from the entire network point of view.

Figure 6 Minimum remaining energy of all nodes (see online version for colours)

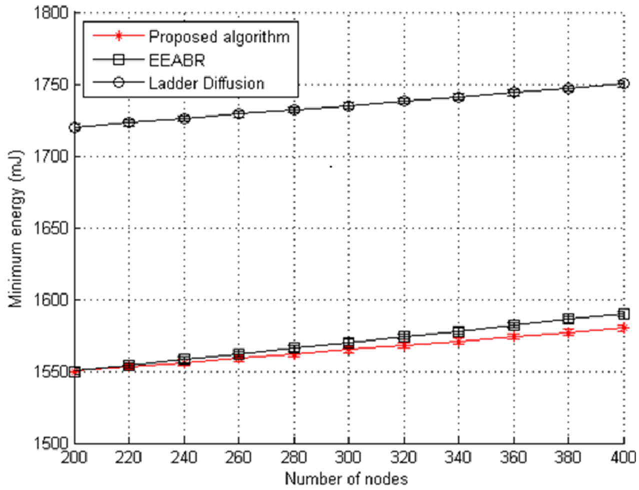
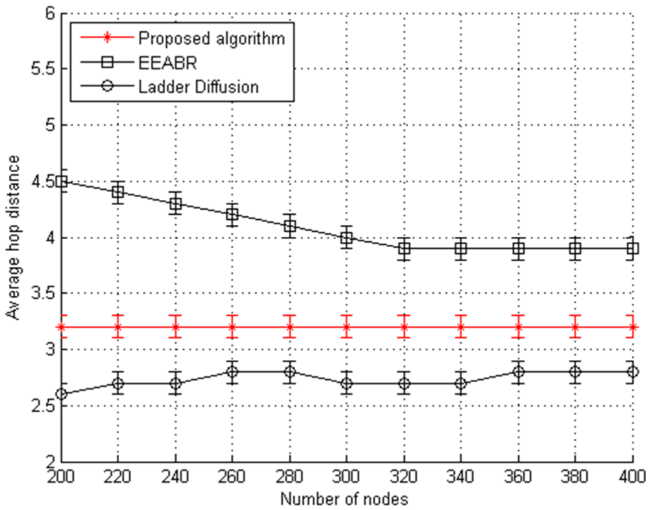


Figure 7 Average hop distance (see online version for colours)



The results illustrated in Figure 7 correspond to the hop distance which is required to reach the sink node. The hop distance is calculated by the data packet which is randomly generated in the random nodes. Ladder diffusion provides the direction to the sink node by adopting hop count calculation. Therefore, the average hop distance is lower than others. In the case of EEABR, the reason why the hop distance of EEABR is longer than others is that the protocol just considers energy and pheromone. Because of the relay node's selection in stochastic manner, the hop distance is depends on the selected relay nodes. Hence the hop distance is little higher than ladder diffusion has. The proposed algorithm generates small number of additional traffics for routing finding.

5 Conclusions

Recently, energy efficiency (Laitner, 2015; Kang and Choo, 2016; Sathyamoorthy et al., 2015) is the most importance challenging issues in the ICT, cloud computing and IoT environment. In this paper, we presented the energy-efficient routing protocol by using the GPS information for WSN. The proposed protocol aims for solving the additional traffic problem in the routing protocols based on directional forwarding and route restoration. Through the experimental results, proposed algorithm decreases the total energy consumption around 40% for routing, but also guarantees the maximisation of network lifetime.

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Conflict of interests

The author declares that there is no conflict of interest regarding the publication of this paper.

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