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A Beacon-enabled Least-time and Energy Efficient With One-level Data Aggregation Routing Protocol for WSNs using IEEE 802.15.4

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Abstract: The Wireless Sensor Networks (WSNs) field of research is an interesting topic in the research community these days, because of its applicability in various fields such as civilian and medical research applications. Due to the resources and energy constraints in WSNs, routing can be considered as one of the most important issues in these networks. Every routing protocol designed for WSNs should be reliable, energy-efficient and prolong the network lifetime. This research proposes a beacon-enabled least-time and energy-efficient routing protocol with one-level data-aggregation using an IEEE 802.15.4 which is suitable for Low-Rate Wireless Personal Area Networks as WSNs, because of its low power consuming feature. The proposed protocol is compared to popular ad hoc and WSNs routing protocols i.e., *Ad hoc* On-Demand Distance Vector, Dynamic Source Routing, Destination-Sequenced Distance Vector routing, Directed Diffusion and Minimum Cost Forwarding. The propose work is simulated using network simulator 2. The simulation results show that the proposed protocol outperformed the routing protocols in the literature in terms of latency, throughput, average energy consumption and average network lifetime.

Key words: Wireless sensor networks, routing protocols, energy efficient, IEEE 802.15.4, Ns2

INTRODUCTION

A Wireless Sensor Network (WSN) is composed of distributed wireless sensor nodes which sense the environment and send the information gathered from the monitored area through wireless links to the desired destination. The sensor nodes create a non-permanent network and there is no need to have any established infrastructure or a centralized administration in this type of networks. This technology emerged in the early nineties and was considered as a substitute for Ad hoc networks. The easy deployment and low cost make these networks as one of the forthcoming technologies nowadays. Due to the high applicability of this technology in various fields such as military (Akyildiz *et al*., 2002), civilian (Liu *et al*., 2010), environmental monitoring (Kohvakka *et al.,* 2006), wild animals tracking, homeland security, health-monitoring, car park management (Benson *et al*., 2006) and also for smart homes (Xu *et al*., 2010), WSN is become known as a foremost research field over the last decade. For instance, thousands of sensors deployed inside and outside of an airplane to monitor the functionality of the different parts in a real-time manner and report the failure of any parts (Manjeshwar and Agrawal, 2001).

As a result of limitations in node's transmission range and resources it is required to involve other nodes for forwarding a packet from source to the destination which is usually the Base Station (BS). When the WSN is formed it should continue to work, without a replacement and maintenance of the energy sources.

BACKGROUND

In spite of the availability of a variety of routing protocols in WSN, there is still a gap in this field. The limited resources constraints and complexity in computations of the routing protocols is still an issue in designing the routing protocols for these networks.

Generally, routing protocols for WSNs can be classified according to a path selection, network structure and protocol operation. Figure 1 illustrates this classification in details.

Some of the most important characteristics of a routing protocol for WSNs are:

- **Simplicity:** The routing protocol should have less computational complexity
- **Energy efficiency:** The routing protocol should be efficient in power consumption which results in prolonging the network lifetime
- **Less delay:** It should have less delay in transmission of packets from node to the sink
- **Data aggregation:** Which is to combine the data from different sources which results in

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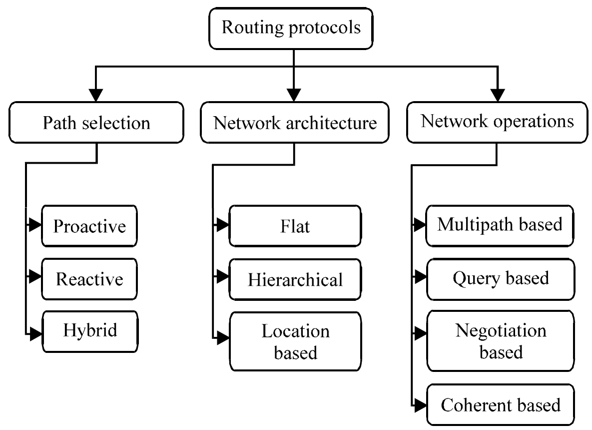

Fig. 1: Routing protocols taxonomy

eliminating duplicates and decreasing the number of transmissions, which lead to less energy consumption

- **Security:** That is to ensure the integrity of the information on the network and confidentiality of the data as well

The routing protocol designed in this work focuses on energy efficiency, less delay and enhancing the overall network lifetime.

Generally, each sensor node in a WSN consumes energy in three phases; sensing, processing the data and transmitting or receiving the processed data; therefore, a routing protocol should be designed to address two important issues. Firstly it is necessary to guarantee that the power consumption at each functionality level is as low as possible. The second one is the network lifetime, to ensure that connectivity in a network maintained for as long as possible.

In previous works as discussed by Jiang and Manivannan (2004), Sensor Protocol for Information via Negotiation (SPIN) (Perrig *et al*., 2002) and Directed Diffusion (DD) (Intanagonwiwat *et al*., 2000) which are in the category of flat routing protocols, load the network with noticeably large number of packets, since they use data diffusion. This decreases the throughput and also the network lifetime.

In the hierarchical routing protocols such as Low-Energy Adaptive Clustering Hierarchy (LEACH) (Handy *et al*., 2002) the routers will be grouped together based on their functionality into a hierarchy. These protocols have to intermittently select the cluster heads to meet the cluster architecture requirements, where the operation causes higher computational complexity. Therefore the cluster heads should have more resources and computational capacity.

A geographical information based protocol or a position-based routing such as Geographical and Energy Aware Routing protocol (GEAR) (Yu *et al*., 2001) is a routing protocol based on the geographic position information. In these protocols the message is sent to the geographic location of the destination as an alternative of using the network address. These protocols need additional equipment such as GPS that is costly and energy consuming, hence, they are not suitable for WSNs.

A wide range of routing protocols proposed for WSNs are currently used in many applications. According to Johnson and Maltz (1996), Dynamic Source Routing (DSR) protocol which is placed in the category of reactive, on-demand routing protocols is an energy efficient protocol with longer network lifetime. However, the latency of this protocol is high since routes are calculated on demand basis and the route maintenance phase does not repair a broken down link by itself. The advantage of using DSR is that its beaconless characteristic causes evasion of periodic packet transmission which results in better performance in static networks.

The *Ad Hoc* On-Demand Distance Vector Routing (AODV) protocol which was proposed by Perkins *et al*. (2003) is also one of the most famous routing protocols for ad-hoc and WSNs. It is a reactive, uni-cast routing protocol and only the information of active paths is necessary to be maintained in the routing tables but the routing information is stored in all nodes routing table. The advantage of this protocol is a reduction in the latency. On the other hand, the overhead due to the extreme number of route replies, increased memory requirement. A Destination Sequence Distance Vector (DSDV) (Perkins and Bhagwat, 1994) belongs to the category of proactive routing protocol, which is designed founded on the distance vector algorithm. The energy consumption of this protocol is higher than the previously mentioned ones. In order to avoid loops, DSDV uses the sequence numbers which are provided by the destination node. Nevertheless, for highly dynamic network topology, the drawback of proactive designs i.e., significant amount of resources need is still exists.

In the group of flat routing protocols DD, (Intanagonwiwat *et al*., 2000) is a Data-Centric (DC) and application specific protocol in which the data is being produced by sensor nodes, is named by attribute-value pairs. Data gathered from different sources are combined in DD protocol and results in redundancy elimination, number of transmission minimization, energy consumption reduction and the improvement of the network lifetime. However this protocol has some drawbacks. Firstly, the time synchronization technique is needed for data aggregation which is not easy to accomplish in WSNs. On the other hand, recording information leads to an increase in the cost of a sensor node.

The Minimum Cost Forwarding (MCF) (Ye *et al.*, 2001) algorithm is a data centric, flat and proactive routing protocol. The energy consumption of this protocol is lower, consequently the network lifetime becomes higher and the delay is not considerable. It is assumed that the direction of routing toward the BS is always known. However, each node needs to calculate the cost to reach its BS and also to check whether the residual cost is less than its cost or not. As the data packets are broadcasted, the routing overheads were high. Several copies of the data packet are in the network and multiple copies reach the BS.

In case of data aggregation, suppose that aggregation of all the data is carried out at each node; the amount of data would become very large. Consequently, there are chances of data being dropped or missed during the transmission. Therefore it is prudent to do data aggregation at one level only. In the schemes without data aggregation, sensor nodes are not aware of their neighbours. When an event occurs, each sensor attempts to send the gathered data, even in small quantity to the BS. Sensor nodes do not use any data aggregation mechanism and only forward the data packets to the BS (Vaidyanathan *et al.*, 2004). Such scheme faced many problems such as low bandwidth, high packet dropping ratio and energy limitations. Furthermore, the overall amount of useful information at the destination nodes would be less due to packet dropping. Nevertheless, such schemes can be used in scenarios in which events may move very fast such as battlefields and military surveillance.

There is a method which was proposed by Misra and Thomasinous (2010) that overcomes the mentioned issues. It was implemented in IEEE 802.11 which offers considerably higher data rates and required additional encoding; the power consumption by the radio also increased because the extra data required additional radio traffic (Veggeberg, 2011). Due to the fact that the IEEE 802.15.4 is the most suitable standard for WSNs in the state of the art, we use the advantage of this standard MAC layer to increase the network lifetime by proposed Beacon-enabled Least-time and Energy efficient with One-level data aggregation routing protocol using the IEEE 802.15.4.

METHODOLOGY

In this section, the existing routing protocol and the new proposed protocol are described. A Simple Least-Time Energy-Efficient Routing Protocol with One-Level Data Aggregation (LEO) (Misra and Thomasinous, 2010) is classified in the category of proactive routing protocols but the complete routes from source to BS is not crucial to be known by all the nodes. Each node only has the information about its neighbours, thus it reduced the need of large node's memory.

The new proposed routing protocol i.e., Beacon-Enabled, Least Time and Energy Efficient with One-level data aggregation routing protocol for WSNs using IEEE 802.15.4 (BLEO) is derived from the existing routing protocol, LEO; instead of using the IEEE 802.11 WLAN, the IEEE 802.15.4 is expected for this protocol which mostly used for WSNs.

The IEEE 802.15.4 offers two methods for channel access i.e., the non-beacon-enabled mode for low traffic and the beacon-enabled mode for medium and high traffic (Faridi *et al.*, 2010). In the beacon-enabled mode, all communications are performed in a superframe structure. A superframe is bounded by periodically transmitted beacon frames, which allow nodes to synchronize to the network (Kohvakka *et al.*, 2006).

Furthermore, by using beacon packets another important feature that can be integrated in the routing protocol, is mobility support. In order to make effective forwarding decisions, nodes need to be aware of the positions of their immediate neighbors. Since the beacon packet carries the information about the position of the nodes, the periodic broadcasting of beacon packets is a method which is used by most of routing protocols (Iwanicki and Van Steen, 2012).

DESIGN

The proposed protocol is based on the IEEE 802.15.4 and has three phases (1): Initialization, (2) Data forwarding and (3) Route maintenance.

The packet headers of BLEO are illustrated in Table 1 where amongst all the timetoreach_bstn and node_energy are the key parameters to calculate the routing paths.

Table 1: Packet header

Parameters	Description
pkt_src	Node which originated this packet.
pkt_dst	Destination node
pkt_acksrc	Node which originated the ack (for reliability)
pkt_type	Packet Type (init (beacon) /ack)
pkt_seq_num	Sequence number of the packet.
pkt_start_time (timestamp)	Packet start time at each node (emission time)
timetoreach_bstn	Time needed to reach the base station from the node
node_energy	Energy of the node
nodetrans_id	Node packet transmission ID
Aggregated_data	1 If the packet contains aggregated data else 0
beacon_posx	X position of beacon source
beacon_posy	Y position of beacon source

Initialization phase: Once the network is formed, a beacon packet will be broadcasted by the BS. A timer is set for this packet with a packet start time (pkt_start_time) of zero and also the node energy is set to an actual value i.e., initialize energy value which assumed 100nj in this work.

A lightweight scheme is used through the initialization phase, where the BS broadcasted beacons at the establishment. Receivers then take a timestamp from the beacon before the synchronization beacons propagate across the network.

As the packet received by the BS neighboring nodes, the algorithm in Fig. 2 was applied. The time needed for the packet to reach the BS is calculated from the information which the preceding node sent. So, the timetoreach_bstn, remaining energy after one transmission, node_energy, the position of the node (beacon_posx and beacon_posy) and route state (rt_state) will be updated as well. After that the packet will be broadcasted. The neighbor table will be renewed, i.e., node ID, timetoreach_bstn, node_energy and beacon position. This process being repeated till the whole network is covered and then each node acquainted all its neighbours that are located in its radio frequency range. After completion of this phase, each node directed the data packet using the stored data in the neighbor table. There is no need to create the route between the source and the sink (BS) since each node has the information of its neighbors.

Forwarding data packet phase: As the sensor node sensed an event which is application specific, the data packet is being sent out. At first when the data packet is being received by the node, the availability of the route is checked. If no route is available to the destination, the packet will be queued and wait for the route construction, If the route is available the packet will be forwarded through the route that was selected from the neighbor table of the node. The lookup() function will select the best route based on the least timetoreach_bstn and the highest node_energy. The priority of the received data packets highly depends on the application that being used. When the data packet is received at the node, the priority of the packets will be checked, if the packet is of "regular" type, the node searches for the neighbor with the highest node_energy in the neighbor table, then forward the packet through the selected route. But if the packet is of "priority" type, the node will search for the node with the least timetoreach_bstn value and then subsequently forward the packet. After forwarding the data packet, the neighbor table will be updated and the energy value of the node, which the data is forwarded from, is being reduced. This leads to a reduction in the need of periodically route maintenance which is initiated by the BS. This procedure repeats until the packet gets to the BS. By using a selection technique the increase of lifetime of the network and the least time for priority packets to reach to the BS is guaranteed. The algorithm for forwarding data packets is presented in Fig. 3.

```
If (packet type = Protocol Pkt)
        Protocol Packet();
Else if (packet type = Data Pkt)
        Forward Data Packet();
Else Drop the Packet;
Protocol Packet()
If (Packet type = Init)
    Update Neighbor Table();
    Broadcast of Initialization Packet();
Else if (Packet type = Ack)
    Update Neighbor Table();
    Broadcast of Ack Packet()
Add to neighbortable (Timetoreach_bstn of prev node, Node energy, Node ID)
Broadcast Beacon Packet() {
        Time = curt time-Pkt_start time;
        Timetoreach_bstn=Timetoreach_bstn
        of previous node + Time;
        Node energy= Node energy _ 1;
        Packet start time = Current time;
        x-position = beacon_posx;
        y-position = beacon_posy;
        rt_state = ROUTE_FRESH;
Broadcast Pkt  (Packet start time, Timetoreach_ bstn, Nodeenergy, Node position)}
Update Neighbor Table();
Modifyneighbor(Node energy);
```

Fig. 2: Initialization phase

```
Output
Forwarding data to the BS
Begin
//Check Route Availability
if (rt_availability == NULL) // There is no route for the destination
queue the packet and wait for the route construction;
elseif (rt_availability != ROUTE_FAILED) // if the route is not failed forward it
        Check Packet Priority();
         Forward Packet();
//Check Packet Priority
 If (Packet type == Regular)
Select neighbor with highest Node energy;
        Forward Packet;
 Else if (Packet == Priority)
Select the neighbor with least Timetoreach_bstn;
        Forward Packet;
End
```

Fig. 3: Data forwarding phase

Data aggregation process: From Patil and Patil (2010), point of view the primary goal of data aggregation techniques is to collect and aggregate data in an energy-efficient manner which results in an enhancement in the network lifetime. There is only one difference between data aggregation of the proposed routing protocol and previous ones. In this protocol data aggregation is not necessary to be done at all nodes; it should be done at one-level, which means data aggregation should be made by the node located immediately after the node sensing the event in the routing path. This function is energy efficient and reduced the computational overhead. Aggregation consists of two fundamental functionalities: first one is data redundancy removing and the second one is preserving simple consolidation of data, thus the number of transmissions will be reduced.

Route maintenance phase: Every time the BS received the data packet it sends an acknowledgment. The acknowledgement packet can be used for route maintenance. This technique benefits us by removing the need of periodical initiation of the route maintenance by the BS and by also improving the reliability of the network.

Implementation: The simulation is carried out by the latest version of the NS a (Breslau *et al*., 2000) i.e., NS-2.35 (released Nov. 4 2011). Simulation parameters that are used for configuration of the NS2 are listed in Table 2.

At first BLEO is compared with AODV that was implemented using the IEEE 802.15.4 designed by Ting *et al*. (2011) and Gowrishankar *et al*. (2009) respecting packet interval and number of nodes, respectively.

Table 2: Simulation parameters

Simulation parameters	Values
Terrain dimensions	2000×2000 m
Simulation time	100, 500, 900, 1800, 3600 Sec
Number of nodes	10, 16, 20, 30, 40, 50, 100
Mobility model	Random Way Point
Speed of the mobile nodes	0
Underlying MAC protocol	IEEE 802.15.4
Channel	/Wireless
Propagation	TwoRayGround
Network type	/WirelessPhy/802_15_4
Queue	DropTail/PriQueue
Antenna	OmniAntenna
Queue length	40
Traffic type	CBR
Traffic Loads	0.001, 0.01, 0.1, 0.3, 1, 3, 5

ASSUMPTIONS

Conventional sensor networks such as those being used in weather monitoring and battle fields have one BS. Instead of sending the data to the intermediate nodes, data is sent to the BS only, correspondingly, in this work we assume only one BS. The location of the BS is fixed. Consumed "transmission" and "reception" energy is equal for all nodes. It is assumed that the communication channel is error free and the MAC layer is responsible for error detection and correction.

Following is the performance of the protocol that is compared with the existing routing protocols in the literature, MCF, DSR, DSDV and DD. The performance metrics for evaluating this protocol are:

Average packet delivery ratio: As defined by Tsirigos and Haas (2004) is the ratio of the packets delivered to the destination successfully. PDR can be calculated based on the formula below. In this equation P_t is the total number of packets sent and P_r is the total number of packets received at the BS:

$$Adr = \frac{Pr}{Pt} \tag{1}$$

As it can be seen in Fig. 4a, PDR of BLEO is considerably higher than IEEE 802.15.4 based AODV from the traffic load of 0.1 to 5 pkts/sec with the average of 45.5%. Regarding Fig. 4b there is no significant difference between BLEO and AODV for 10 and 20 nodes but for 30, 40, 50 and 100 nodes BLEO performs 29.2, 31, 27.4 and 29.7% better than AODV respectively. As a result of the less number of packets in the network and the route updates in BLEO, the number of packets which are being successfully received at the BS during the simulation increased. Figure 4c shows the comparison between BLEO and existing protocols in the literature.

Average energy consumption: It is the consumption of energy measured in the unit of Joule (Ting *et al*., 2011). In order to estimate the energy consumption at each node, we have to consider the energy consumed during transmission of packets and reception and computation of data as well. On the other hand, the energy consumed for transmission is significantly greater than other phases. The energy consumption in this work is assumed to depend only on the transmission of the packets through the network.

The more the number of the packets are, the larger the energy consumption is. As DD and MCF transmit more number of packets for the same scenarios, they consumed more energy. Fig. 5a shows the results of comparison between BLEO and AODV and Fig. 5b demonstrates the energy consumed by BLEO, LEO, MCF and DD. As it can be observed BLEO outperforms AODV with the average of 1.04% regarding energy consumption.

Network lifetime: The lifetime of the network is the time until the depletion of all node's energy in the network. If we assume 0.02 nJ for each transmission and an average energy of 1 J in each node, then we can estimate the lifetime of the network by the following equation, E_{av} stands for the average energy consumption in this formula:

$$(100/E_{av})\ /86400/365 \text{ years} \tag{2}$$

It can be observed from Fig. 6 that, the network lifetime of the BLEO sharply differs from LEO, MCF and DD. This is because the energy consumption of BLEO is considerably less than others, so the lifetime will be decreased dramatically.

Average End-to-End delay: Average end to end delay covers all feasible delays caused by buffering throughout

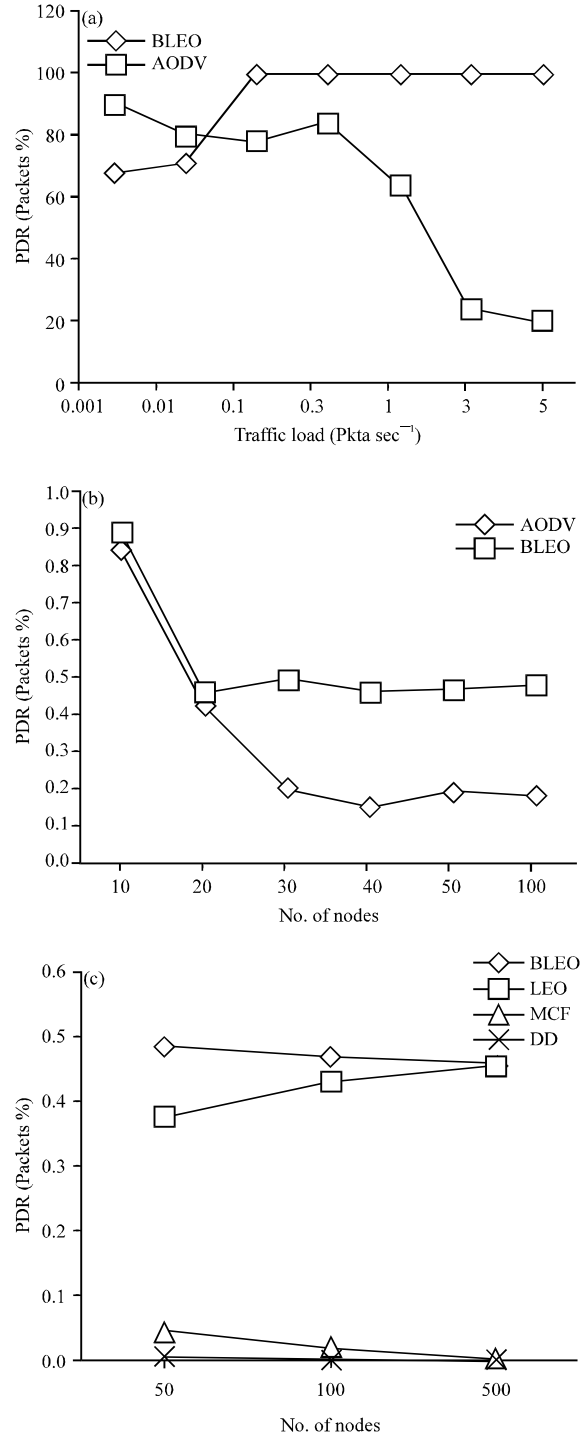

Fig. 4(a-c): Packet delivery ratio

route discovery, latency at the interface queue, latency of retransmissions at the MAC layer, in addition to the propagation and transfer of the data packets delays. The results presented in Fig,. 7a and b show the comparison

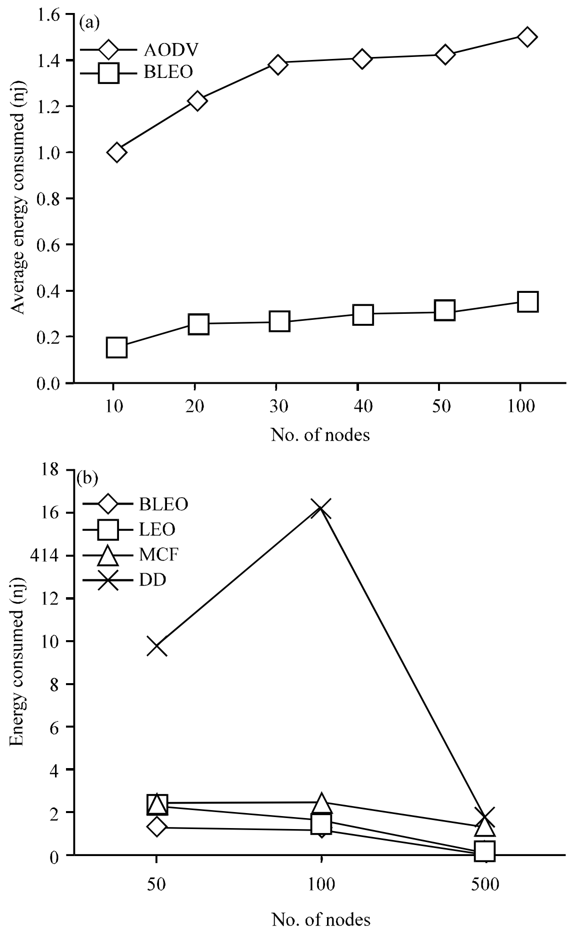

Fig. 5(a-b): Average energy consumption

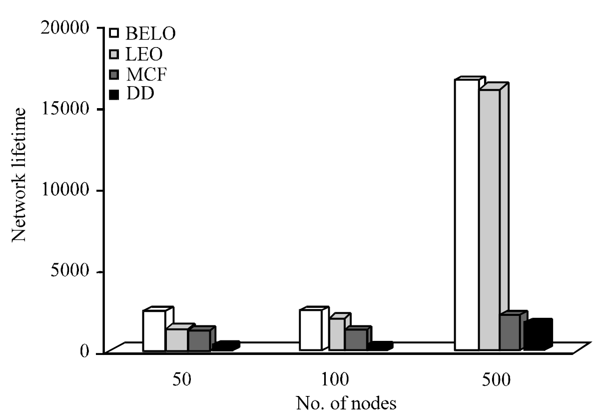

Fig. 6: Average network lifetime

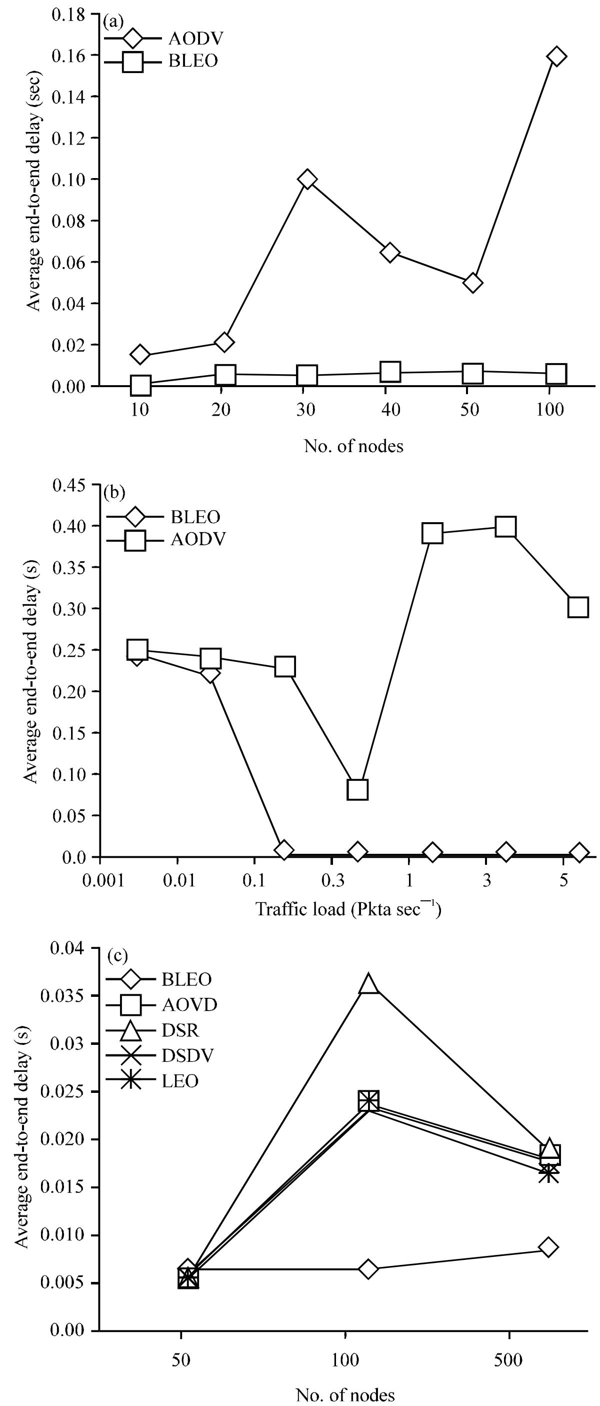

Fig. 7(a-c): Average end to end delay

of End-to-End delay between BLEO and AODV. It can be seen that the average end to end delay decreased by the average of 6.32 and 19.93% for BLEO in terms of increasing the number of nodes and packet intervals, respectively. As shown in the Fig. 7c the end-to-end delay of the new routing protocol is markedly less than the other routing protocols. This occurs because in this protocol the node with the least time to reach to the BS is selected from the neighbor table.

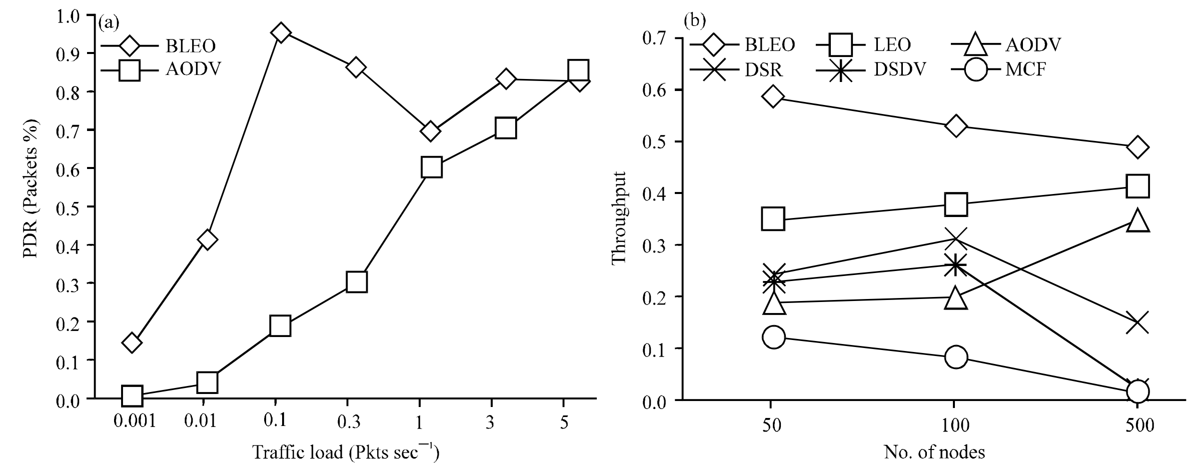

Fig. 8(a-b): Throughput

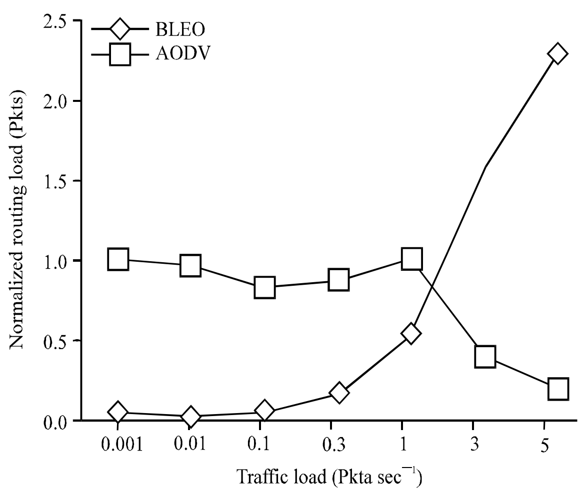

Fig. 9: Normalized routing load

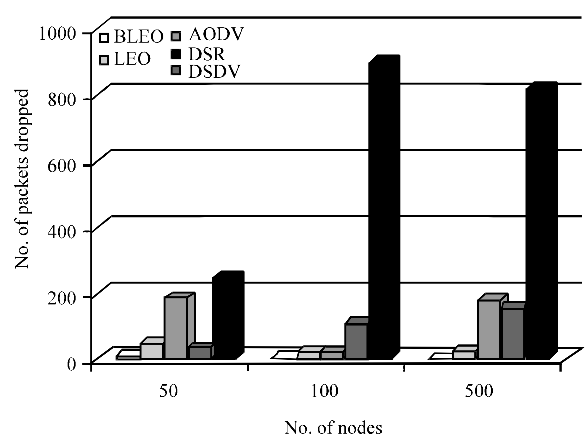

Fig. 10: Number of packets dropped

Throughput: Is defined as the rate of the successful received packets at the destination. The results for throughput can be exemplified in Fig. 8a and b for AODV and other routing protocols, respectively.

It is clear that BLEO has better performance in this case, since the number of packets in the network is less than AODV, D SR, DSDV and MCF. The results of the simulation show that BLEO surpass them in this case, for 50, 100 and 500 nodes the throughput increased by 23.38, 21 and 13.68%, respectively.

In terms of normalized routing load Fig. 9 BLEO shows better performance in comparison with the previous routing protocol with the average of 8.3%decrease. The number of packets dropped during simulation for BLEO Fig. 10 is less than other protocols in literature, since the routes are updated through routing.

CONCLUSION

In this work, we have proposed a least-time, energy efficient routing protocol with one-level data aggregation based on the LEO protocol using the IEEE 802.15.4. It takes less time, as the route with less time to reach to BS is selected each time. It is also energy-efficient, as no complex computation involved and also less energy consuming standard is used in this work. A single path is not always selected; instead, routing task is distributed depending upon the node energy, thereby increasing the network lifetime. One level of data aggregation refers to the fact that data aggregation needs not be carried out by all nodes, instead it needs to be done only at one node, immediately to the source node in the routing path. Proposed protocol has the potential for further improvement by taking mobility into consideration. By increasing the rate of beacon we can have mobility. Security is also an important and vital requirement for routing protocols. Introducing security features in LEO would be an interesting work to explore in the future. Improving the reliability and fault-tolerance in BLEO further is also a research problem that could be undertaken in the future. To develop a test-bed to fully investigate the impacts of this routing protocol in the performance of the network is a practical improvement regarding this work.

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