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Layer Based Energy Efficient Routing Protocol for Heterogeneous Wireless Sensor Networks

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Abstract: Due to heterogeneity in the power of nodes, asymmetric link is commonly encountered phenomena in wireless sensor networks (WSN). Most of the routing protocols in WSN are proposed to work on bidirectional links which render the use of asymmetric links infeasible. In this study, we propose LEERP: A layer based energy efficient routing protocol for wireless heterogeneous sensor networks (WHSN) that makes use of asymmetric link to provide better energy efficiency and higher delivery rate. The LEERP protocol first identifies the asymmetric link and provides bidirectional for those links by reverse path algorithm. Then, it uses level values and energy threshold value to select next forwarding nodes in the neighbor list of each node. Simulation results show that our protocol significantly outperforms the other existing methods in WHSN.

Key words: Heterogeneous, wirelss heterogeneous sensor networks, asymmetric link, energy efficient, protocol

INTRODUCTION

Wireless sensor network (WSN) consisting of mini embedded part which are usually called "motes" that is equipped with a microcontroller, radio transceiver, battery, and an interfacing unit. WSN have been commonly applied to in-door monitoring, health care, security, habitat monitoring, etc. Each node collects data from their surroundings and transmits all collected sensed data to Base Station (BS). Wireless Heterogeneous Sensor Network (WHSN) is a kind of sensor network where each Sensor Node (SN) has different sensing characteristics (Chen *et al.*, 2013; Prakash and Paramasivan, 2015; Du and Lin 2005; Brahim *et al.*, 2009). For example, Mica2 mote is a common product equipped with various sensing units such as humidity, pressure, light sensors. Different applications may have diverse transmission characteristics in terms of transmission range, computational power, storage capacity, etc. Different transmission ranges causes asymmetric links in the network (Chen *et al.*, 2013b; Ramasubramanian and Mosse, 2008; Gagneja *et al.*, 2009; Wang *et al.*, 2012). For example, in the Fig 1, if node P has the ability to cover the node Q, but Q cannot cover P. Here the upstream node is P and downstream node is Q. So the conventional routing protocol is unsuitable for heterogeneous networks (Chen *et al.*, 2013a; Ramasubramanian and Mosse 2008).

The conventional routing protocol in WHSN suffers from at least three reasons:

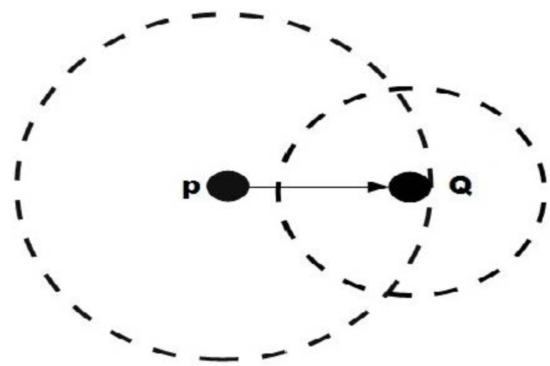

Fig. 1: Asymmetric link

- Due to the asymmetric link, the nodes which have bidirectional link can only be involved in the data transfer which causes the unacceptable overhead and significant energy expenditure to those particular nodes
- A suitable Neighbor node may lose a chance to be selected as relay node
- The significant energy efficient causes the lifetime of the network to become critical (Prakash and Paramasivan, 2015)

In this study, we address the problem of providing routing scheme for WHSN where nodes have asymmetric link. LEERP is a layer based protocol whose layer

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information is used to find the shortest path between source and BS. By establishing reverse path, LEERP takes advantage of asymmetric link. It has mainly two phases. The Setup Phase which includes the identification of asymmetric link to find reverse path and initializing layers and the Routing Phase which includes the source node chooses the forward nodes based on its level value i.e. layer number and available energy which should be greater than or equal to Eth. The level value is calculated only once before routing, whenever there is a change, the node locally adjusts its level value.

Literature review: Most of the conventional routing protocols address the sensor with the same battery power, transmission ranges, etc. Protocols like AODV, DSR uses RREQ and RREP to discover the routes for the destination. But, due to the asymmetric link, RREP could not use the original path to reach the source. So, AODV avoids the asymmetric link and DSR supports asymmetric link, but it causes an additional route discovery.

Only few routing protocols are proposed for heterogeneous sensor networks where the nodes are partitioned into powerful and powerless (Alla *et al*., 2011; Chen *et al*., 2008; Du and Lin 2005; Brahim *et al*., 2009). The nodes whose transmission range is high, considered as powerful nodes which act as Cluster Head (CH) and the remaining nodes are considered as powerless which act as data collection centers. These methods uses intra cluster and inter cluster protocol. Intra-cluster protocol handles the transmission between data centers and CH. Inter cluster protocol takes care of transmission between CH and BS. However asymmetric link is not fully utilized in these protocols. BRA (Ramasubramanian and Mosse, 2008) has the benefit of using asymmetric link in the network by establishing reverse paths for asymmetric link.

ProHet used asymmetric link to achieve assured delivery rate by finding reverse path within 3 hops. It selects the relay node only by historical statistics which does not consider energy of the nodes. Each time selecting the same node causes the nodes to run out of energy. Our goal is to design an energy efficient routing protocol for heterogeneity nature of sensor networks

MATERIALS AND METHODS

LEERP protocol: In this study, we propose LEERP protocol which has two phases. The first phase is Setup Phase which includes the identification of asymmetric link, reverse path for unidirectional link and initializing layers and the second phase is routing phase which includes the selecting nodes, relaying message and acknowledgement.

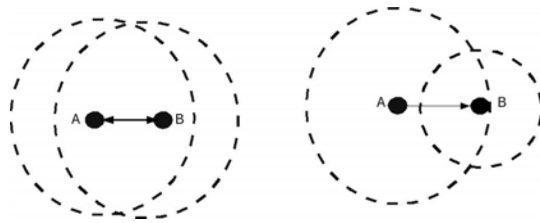

Fig. 2: Coverage area of nodes A and B

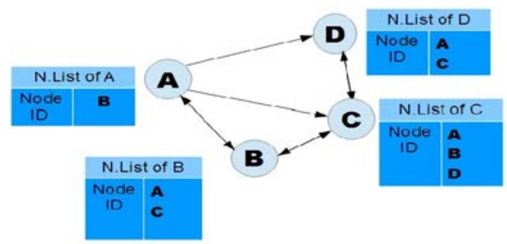

Fig. 3: Each node built neighbor list from the hello packet of neighbors

Setup phase: First step is to identify the bidirectional nodes, upstream nodes and downstream nodes by broadcasting Hello packet in the network. By using neighbor list of others, the node identifies the asymmetric link. In Fig. 2a, A and B links are bidirectional. So, both can transmit and receive from each other. In Fig 2b, A has the ability to cover the node B but B cannot cover A. Node A is an upstream node for node B and Node B is an downstream node for node A.

Identifying asymmetric link in the network

Initialization:

- Each SN broadcast Hello packets in the network
- When a node receives the Hello packet, it adds the source node of the Hello Packet to its Neighbor List (NL)
- After adding the nodes to its neighbor list, each node broadcast its neighbor list with their current energy level
- Once the node receives the Neighbor list of other nodes, it compares that with its own neighbor list
- If its node Id has been recorded in the list it adds that node as bidirectional in its NL, otherwise, it confirms that the link is unidirectional

Let us consider Fig. 3 to explain this method. After broadcasting Hello packet, the node adds the node id to its neighbor list whose Hello packet been received. For example node C receive Hello packet from nodes A, B, D and add these node Ids to its neighbor list. Similarly, every node updates their neighbor list based on Hello packet which shown in Fig. 3. Each node broadcast their neighbor list in the network. When node C receives neighbor list from node A, it compares its neighbor list with A's list. It couldn't find its own node Id but it has already recorded node A as a neighbor node in its own. Node C confirms that the link between node C and node A is unidirectional and add node A as upstream node in its routing table. Now, the node C tries to find the reverse link to reach node A which is explained below.

Reverse path for unidirectional link: Once the node classified the link, it will try to find the reverse link for the upstream nodes in its neighbor list. There are two cases to find the reverse link. In first case, since the downstream node knows neighbor list of its neighboring nodes, it checks that anyone of its neighbors has bidirectional link with the upstream node. If so, the downstream node send FIND message with its own Id and upstream node Id to that relay node and FIND message reaches the upstream node within two hops. If more than one node has the bidirectional link with upstream node in its NL, it selects the relay node based on its available energy. Once the upstream node receives the FIND message, it updates its neighbor table with node Id as downstream node. Now, the upstream node directly sends LINK message to the downstream node with the node Ids throughout the FIND message travels.

In second case, if the downstream node does not have any neighbor node with bidirectional link with upstream node, it broadcast FIND message with the Hop limit set with 3. When the relay node receives the FIND message, it checks the neighbor list with the Upstream Id. If anyone of its neighbor has bidirectional link with the upstream node, it append its own Id and reduce the hop limit by one and send the FIND message to that neighbor and at last the find message reaches the upstream node. Otherwise, if the hop limit reaches0or the node doesn't have link, the node just discards the FIND message. If the upstream node receives more than one FIND message, it chooses the optimal path.

For example consider Fig. 4, the node D tries to find reverse link to reach node A. Node D has already received the neighbor list of node C. D checks the neighbor list of node C whether C has bidirectional link connection with node A. It finds that C doesn't have. So, D broadcasts FIND message with its own Id, Upstream Id, and hop limit is set with 3 (D,A,3). When node C receives FIND message, it checks the upstream node Id in its neighbor list. C doesn't have bidirectional link with node A. So, it reduces the hop limit to 2 and append its own Id and rebroadcast the FIND message (D,C,A,2). Now, the node

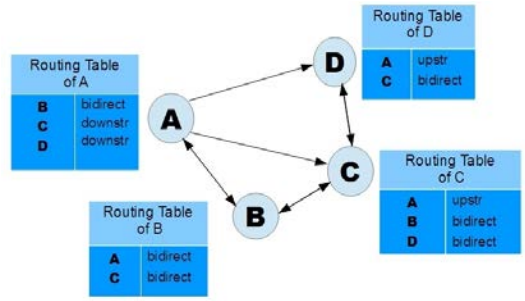

Fig. 4: Link status of neighbor node is identified

B has the bidirectional link to node A. So, it append its own Id and reduce the hop limit to 1 and send the FIND message to A (D,C,B,A,1). Then, node A adds D in its neighbor list as a downstream node and send the reverse path details i.e. LINK message to node D (D, C, B, A). Now node A confirms that it can directly send any data to node D. Similarly, all the downstream nodes make the connection with the upstream node

Assigning levels to SN: The BS broadcast 'PING' packet along with its level value. This level value indicates the hop distance of a node from BS. The level value for BS is zero. Those nodes which receive PING message is aware that it can directly communicate with BS without any intermediate nodes. Thus, these nodes become level 1 node and it updates its neighbor table with the Sink ID as well as its level number. This procedure continues until all nodes discover each other. Figure 5 shows the level value of each node in the network.

Algorithm: assighning level value:

1. BS broadcast PING message with its level value. The level value L = 0 for BS.
2. If a node receives PING message from BS, it adds one to the level value L = 1 and update its routing table. Then rebroadcast the PING message with its own Id level L = 1.
3. If a node receives PING message from more than one node, it waits until it receives PING message from all the neighbors.
4. Then searches the neighbor table with the lowest level and add one to this level. Now, the node rebroadcast with its own Id and updated level value in the network.
5. This process continues until all the nodes set their level value. The layer number is dynamically updated during the whole lifetime of the node due to lossy links.

Routing phase: The routing phase of this protocol is based on four parts selecting nodes, relaying message, acknowledgement and energy model. The conventional routing protocols omit the asymmetric links in their routing. But when we consider the asymmetric link for routing, it will increase the network performance.

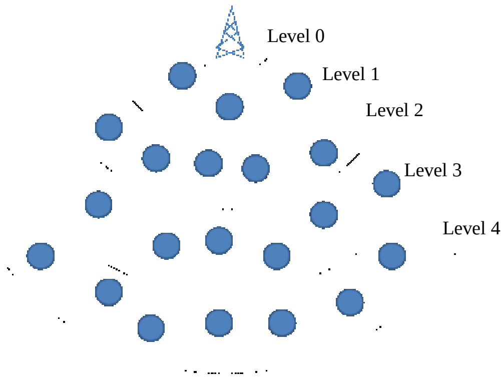

Fig. 5: Level value of each node is identified

Selecting nodes: The source node selects the relay node based on its level value and available energy of the nodes. When a node needs to send data to BS, it searches in its routing table whether it has direct link to BS. If so, it sends data directly to BS. Otherwise, the source node search in its routing table and find the neighbor nodes whose level value is lower and their available energy is equal to or greater than the E_{th}. E_{th} is calculated in the section IV (Fig. 5).

Algorithm: selecting nodes:

a) Source node checks its NL about nodes with lower level value. For example if the source node A's level L = 4, it searches the node with level L = 3.
b) Node A chooses the nodes in NL whose link is bidirectional or downlink with lower level
c) Otherwise it chooses the nodes with the same level.
d) Among the chosen nodes, source node selects forwarding nodes whose available energy level is greater than or equal to E_{th}.

Relaying message: When a node receives message to forward, it checks the nodes in the NL whose link is bidirectional or downlink with lower level and whose energy consumption is greater than or equal to E_{th}. Otherwise, it selects the nodes with the same level. Once the forwarding nodes are selected, it adds its ID in the header and transmits the message to the intended nodes. This process continues until the node reaches the BS. $E_N$is the energy of a node and FN is the forwarding node.

Algorithm: relaying messages:

a) The current node (B) checks the Neighbor list to find the nodes with lower level. (L_B>L_{FN})
b) If the link between the lower level node is bidirectional or downstream (B→FN or B → FN)
c) It chooses those nodes and checks their energy level.
d) Forwarding nodes are selected whose energy levels are greater than the threshold level E_{FN}= E_{th}.
e) else it chooses the nodes with the same level and repeats the above process.
f) After selecting the optimal nodes, the current node adds its own Id in the message header and transmits the message.

Acknowledgement: When BS receives the message, it replies back with the ACK to all the forwarding nodes. The later arrives copies of same message will be discarded. When a forwarding node receives ACK, it checks the previous node link is upstream or bidirectional. If it is bidirectional, then directly send the ACK to that node. Otherwise the node uses the reverse path to reach the previous node. If the node doesn't have any reverse path to that node, it just drops that ACK packet.

Algorithm: acknowledgement:

a) After receiving message from forwarding nodes BS replies back with ACK. The latter arrived of the same messages will be discarded.
b) When a FN receives ACK, **if** its previous node in the list is bidirectional
c) It directly sends the ACK
d) else if it is upstream then
e) Use reverse path to send ACK to that node
f) else
g) Simply drop the ACK.
h) End if
d) Energy Model

According to study (Yuan *et al*., 2007), a node's energy consumption for transmission and reception formula for WSN is given below:

$$E_{TX}(n,d) = \begin{cases} nE_{ele} + n\varepsilon_{fs}d^2, & d < d_0 \\ nE_{ele} + n\varepsilon_{fs}d^4, & d \geq d_0 \end{cases} \quad (1)$$

$$Erx(n) = ERx - ele(n) = n\ Eele \quad (2)$$

When a node transmits n bit data over a distance d, the energy consumed by the node is given above. Where, E_{ele} is energy spent per bit by a transmitter. $\varepsilon_{fs}d^2$, ε_{mp} are the amplifier energy in the free space and multipath fading channel model. n is the message bit. d, d_0 are transmission distance and distance threshold respectively. d<$d_0$energy model is used here for densely deployed networks.The energy consumption by a relay node in the network is defined as:

$$E(n)=ETx(n,d)+ERx(n) \quad (3)$$

Substitute Eq. 1 and 2 in Eq. 3:

$$E(n) = 2n\ E_{ele} + n\ \varepsilon fsd^2 + n\ Eele \quad (4)$$

Consider Fig. 6, if node G transmits packet to J node in level L = 2 , then the energy consumption is:

$$E_{G1}(n)=n\ Eele + n\ \varepsilon fsd^2(GJ) \quad (5)$$

Energy consumption to receive message by node G is:

$$E_{G2}(n)=nE_{ele} \quad (6)$$

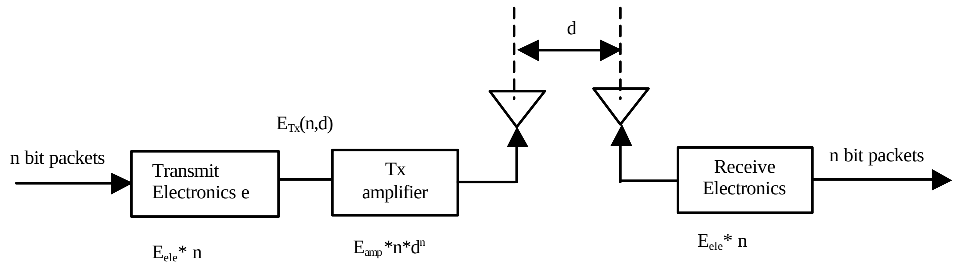

Fig. 6: Energy distribution model

Energy consumption to transmit packet from P to G is:

$$E_{G3}(n)=n\,E_{ele}+n\,\varepsilon fsd^2(PG) \tag{7}$$

Finally, the total energy consumption to relay packet to G is $E_{total}(G) = E_{G1}(n)+E_{G2}(n)+E_{G3}(n)$

$$E_{total}(G)=3n\,E_{ele}+n\,\varepsilon fsd^2(GJ)+n\,\varepsilon fsd^2(PG) \tag{8}$$

Similarly, the total energy consumption to relay packet from P to F is:

$$E_{total}(F)=3n\,E_{ele}+n\,\varepsilon fsd^2(FJ)+n\,\varepsilon fsd^2(PF) \tag{9}$$

The total energy of node is frequently calculated. If $E_{total}(F)$ and $E_{total}(G)>E_{th}$, the source node selects these nodes as their forwarding node. E_{th} value is set at least one node's energy level in the neighbor list will come under that.

Performance analysis:

Simulation settings: In this study, we compare the performance of LEERP with ProHet, AODV and Flooding using Network Simulator-2 (NS-2). Number of nodes in the network is increased from 100-350 and nodes are randomly distributed in an area of 1000×000 m 30 randomly chosen source nodes send data to the BS during the simulation. The BS which is provided with infinite power supply is placed at the center of the area. FIND message size is 25 bytes. Packet size is 50 bytes. Asymmetric topology is generated by using D-model.

In D-model, three types of transmission ranges are used: Maximal (70m), Minimal (30m) and Normal (50m). Transmission diversity of a node is the difference between maximal and minimal ranges. In this simulation, 20 diverse deployments of heterogeneous sensors are randomly generated. IEEE 802.11 MAC is used with some changes and the total simulation time is 40 min. In this simulation, all sensor nodes have the capable to receive and send beacon or HELLO/FIND message.

RESULTS AND DISCUSSION

Figure 7a shows the percentage of asymmetric links in the network. It shows that 40 % links are asymmetric in the network when a node's transmission diversity is set to 20 m. Figure 7b shows that 96% of asymmetric links are able to find reverse path within three hops which justifies those 3 hops is well enough to make a reverse path Fig.7.

Since the nodes are selected based on level values, the average hops are required to transfer a message from source to BS is reduced when compared to ProHet which shown in Fig. 7c.

When the number of nodes increases, the delivery ratio also gets increased which shown in Fig. 7d. This is due to the fact that the denser WHSN supports data to get more chances to be delivered to the BS. Here, we compared the delivery ratio of ProHet, AODV and Flooding with LEERP. AODV is a symmetric link routing protocol and it avoids asymmetric link in the network during routing. So, it couldn't guarantee the delivery ratio compared to LEERP and ProHet. Flooding offers the highest delivery ratio. LEERP provides higher delivery ratio, since the nodes available energy is also one of the consideration to select forwarding node, but ProHet didn't consider nodes energy as one of the parameters while selecting next node. LEERP and ProHet are getting nearer delivery ratio when the numbers of active nodes are >300. Due to the layer arrangement during initialization, LEERP causes overhead.

However, the arrangement is made only at the beginning, whenever there is a change, the node locally adjusts its level value. Unlike ProHet which looking for the route in each relay, the LEERP need not require to put more efforts to choose next relay due to layer arrangement. Flooding causes the highest overhead in the network. The comparison is shown in Fig. 7e.

During our simulation, number of nodes in the network is varied from 100-350. Initial energy is set as 4J. During the process of selecting relay nodes, LEERP consider energy as one of the main parameter. Figure 7 shows when the E_{th} is increased from 50-85 %, the delivery ratio also

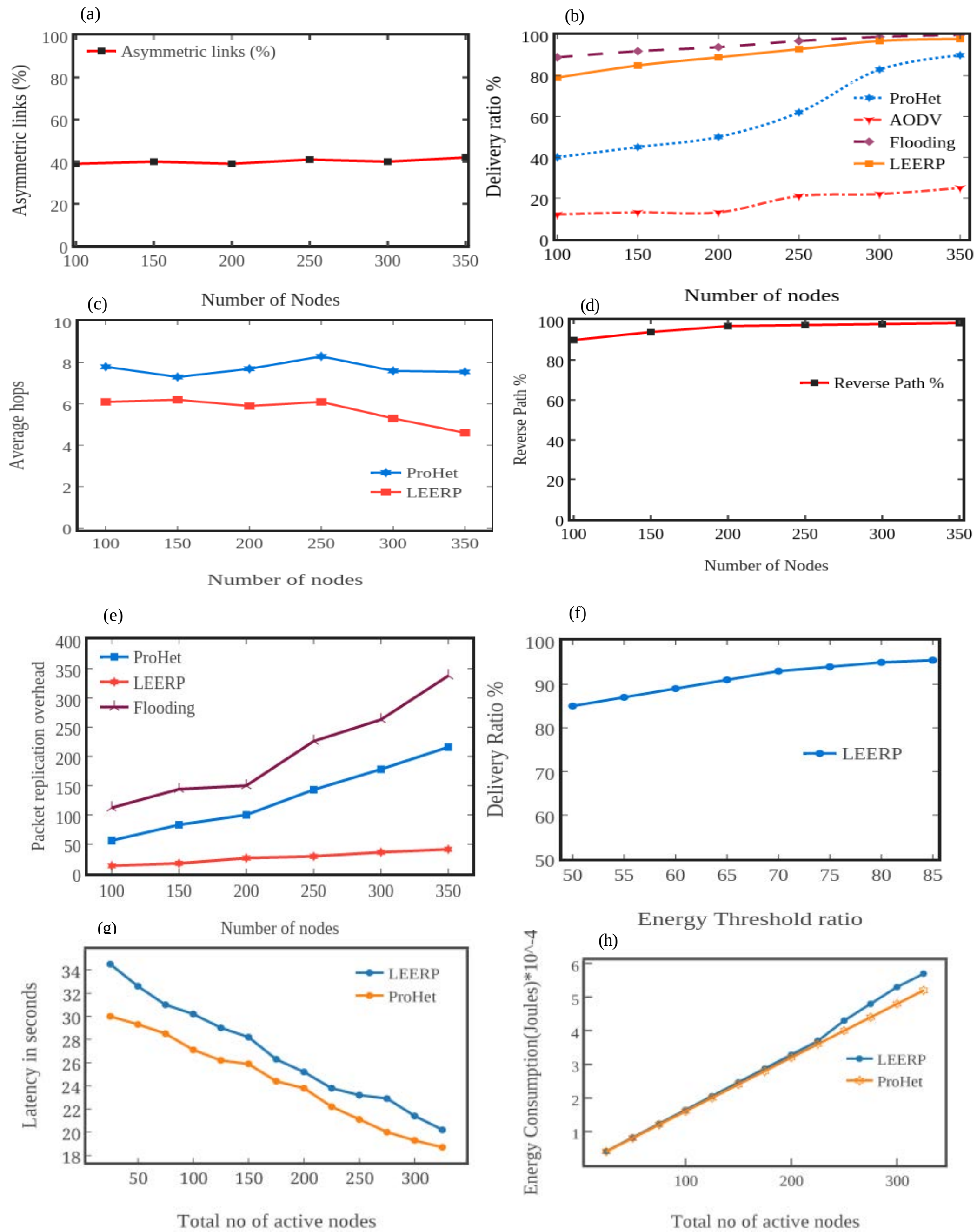

Fig. 7: a) Percentage of asymmetric links: b) Percentage of reverse path; c) Average hops to reach destination; d) Reverse path; e) Average packet replication overhead; f) Delivery ratio for different eth; g) Latency of ProHet and LEERP; h) Energy consumption in seconds

gets increased, shown in Fig.7f. When we set threshold without any upper bound, we cannot obtain higher delivery ratio. Figure 7g shows the latency of ProHet and LEERP. is inversely connected with number of active nodes. ProHet gives lower latency than our protocol. It is mainly because of two reasons.

So, it saves time for selecting next forwarding nodes. Second is, whenever the number of active nodes is increased, source nodes get next forwarding nodes easily. But LEERP selects next forwarding nodes only based on their available energy level which causes few delays. Figure 7h shows the total number of energy spent by each node in the network. Both LEERP and ProHet choose their forwarding decision only based on their network topology and energy consumption of both protocol increases, when the number of active node in the network gets increased. ProHet looses more energy while selecting two hop receivers and there is a great possibility of higher duplication of packets which consumes more energy. But LEERP selects forwarding nodes based on their level value and available energy and saves more energy.

CONCLUSION

In this study, we proposed a layer based energy efficient routing protocol LEERP which deals the asymmetric links in WHSN. It identifies the asymmetric link and provides bidirectional for those links by reverse path algorithm. LEERP used layer based routing and selects next relay node based on level value and E_{th} value. We showed that LEERP can provides better performance than existing routing protocols in terms of delivery ratio, energy efficiency and overhead through our simulation results. In our future work, we would like to design more number of routing protocols to address the further issues in WHSN routing.

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