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SAn Energy-efficient Opportunistic Multicast Routing Protocol in Mobile Wireless Sensor Networks

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Abstract: The study presents energy-efficiency Opportunistic Multicast Routing Protocol (E-OMRP) for the multicast energy consumption minimization problem in mobile wireless sensor networks. The protocol divides the network into grids, so each node determines their own coordinates according to the grid. The nodes only need to know the topology of their own grid, instead of the topology of the entire network. In order to better represent the impact of the movement on transmission, the nodes in the same grid determine the priority in light of the transmission delay factor and expected transmission cost, where the nodes speed as a parameter to calculate transmission delay factor. Then the relay nodes use the opportunistic routing to send messages to the next hop based on the order of priority. When the destinations receive a message from relay nodes, they select the optimal path in accordance with the transmission delay and links cost and transmission acknowledgement to source along the optimal path selected. If all nodes in the current grid transmission messages failure, the neighbor grids are in charge of retransmission. The results of simulation show that, compared with traditional multicast routing, E-OMRP is effective in reducing the consumption of links cost, so that it improves the link reliability and reduces the delay.

Key words: Wireless sensor network, energy consumption, multicast, opportunistic routing, cooperation

INTRODUCTION

Multicast has become an important means of communication in the Wireless Sensor Networks (WSNs), in terms of task allocation and target query (Akyildiz *et al*., 2002) which has more advantages than unicast and broadcast. Since the sensor nodes are deployed in remote, sparsely populated areas and energy constrained, so after the nodes are deployed, recharging more difficult, so improving the efficiency of each multicast transmission link to minimize the energy consumption of nodes in the network, which will not only extend the network work lifetime, but at the same time reduces the costs spent on the sensor hardware devices. So the research work on how to increase the energy efficiency (Anastasi *et al*., 2009) of wireless sensor networks is always a hot research area.

In general, there are many ways to improve the energy efficiency of nodes. One way is to decrease the total communication traffic by using the data aggregation, data compression, data prediction and duty cycling techniques (Ye *et al*., 2004; Xiao *et al*., 2006; Vuran and Akyildiz, 2006). The second solution is to design effective network protocols to increase the network lifetime. The first case from the hardware point of view to reduce energy consumption, while the second case from the viewpoint of software to improve the energy efficiency. In order to solve the reliable problem of wireless channel transmission, MIT has proposed a new routing scheme in recent years-opportunistic routing (Biswas and Morris, 2004). Traditional wireless ad hoc network routing protocol use pre-defined routing (Perkins and Royer, 1999; Intanagonwiwat *et al*., 2000): Before the end to end data transmission, the network establishes a transmission link between source and destinations and when each packet forwards, firstly it will select one next hop node and then forward packet. When the links quality is poor, the frequent data retransmission will consume a lot of bandwidth and energy of the relay nodes, at the same time, reduces the throughput of the network. The opportunistic routing can solve the problems mentioned above, which take advantage of the broadcast nature of wireless signals (Biswas and Morris, 2005; Zhong *et al*., 2006; Ke *et al*., 2010), through the competition of multiple potential relay nodes to select the optimal next hop relay. Literature (Gorce *et al*., 2010) describes the different opportunistic routing, each method design the routing protocol with different network metrics to ensure reliable transmission and reducing the links cost. In order to better achieve the purpose of energy efficiency, Bae and Stark (2008, 2009) uses mathematical methods between energy and delay, energy and

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bandwidth obtain the optimal value, to find the minimum energy value transmission required. Manimozhi and Santhi (2013) compares the different metrics in WSNs. Dubois-Ferriere *et al*. (2007) calculate the minimum links cost based on opportunistic routing to achieve the purpose of energy efficient.

In this study, we present Energy-efficiency Opportunistic Multicast Routing Protocol (E-OMRP) to minimize the transmission costs of each link. Firstly we divide the network into grids (Chakrabarty *et al*., 2002), each node can determine their coordinates based on the grid coordinate. Nodes only need to know the current grid topology, rather than the entire network topology. In order to make the data transmission more reliable, we use opportunistic routing to complete the transmission between links. In the mobile wireless sensor networks, when all the relay nodes in current grid transmission messages failure, the neighbor grids are responsible for retransmission and combined with opportunistic routing and coordination mechanisms (Kurth *et al*., 2008; Hu and Yang, 2009), it can be good to solve the problems of links interruption.

RELATED WORK AND PROBLEM DESCRIPTION

In WSNs and Mobile Ad hoc, multicast protocols proposed typically use the tree structure as the network topology (Lee *et al*., 2002). Tree-based routing protocols can reduce the total number of hops and save bandwidth, but when the network topology dynamically changes, protocols performance poorly in terms of throughput and robustness. In order to overcome the weakness of tree network, (Dhillon and Ngo, 2005 and Zeng *et al*., 2007) uses the idea of grids for multicast, the nodes in networks calculate the optimal path from source to destinations based on certain routing metrics (for example: bandwidth, throughput, jitter etc.,). However, in tree-based and grid protocols, the nodes need to create and maintain routing information in the relay nodes, which increase the links cost and network delay. In location-based multicast (Sanchez *et al*., 2007), the messages transmission is only based on the node location information. Each node in the network only knows the multicast nodes location and the local topology rather than the global topology, which can reduce the number of beacons transmission in network, at the same time, it also can reduce interference between signals. Literature (Yang *et al*., 2010; Khreishah *et al*., 2012) use opportunistic routing for multicast and combined with network coding, effectively improve network throughput, increasing the reliability of message transmission. Different multicast protocols complete the data transmission with different network topology and routing algorithm. Although they have their own advantages and disadvantages, in certain circumstances, can well satisfy the need of messages transmission. Now In this study we use the hop count to approximate the transmission delay minimizing the cost meanwhile in order to ensure that the hop count of path is least and vice versa.

ENERGY EFFICIENCY OPPORTUNISTIC MULTICAST ROUTING PROTOCOL

Network topology description: We use digraph G = (E, V, C (X, Y)) to simulate network, in which E represents the links between the grids, treating all the nodes in the single grid as a super node V, C (X, Y) is costs that the messages transmitted from the grid X to the next hop set Y. Assuming the grid $g_i \in M$, M represents the set of all the grids in network, the set of all nodes within the grid is expressed as v_{gi}, in g_i each node:

$$v_n^{g_i} \in v_{g_i}$$

The edge between v_n^{gi} within g_i and v_p^{gi+1} within g_{i+1} represents e (v_n^{gi}, v_p^{gi+1}) and any pair of nodes inside g_i and g_{i+1} constitute the set of edges that expressed as $E_{gi,gi+1}$, where e (v_n^{gi}, v_p^{gi+1})$\in E_{gi,gi+1}$. FL^{gi} is the set of forwarding nodes from the grid g_i to its one hop neighbor grids. If the current grid is g_i, then the neighbor set in its one hop transmission range represents N (g_i).

Selection of optimal forwarding set: We assume that there are two nodes (X, Y), on the path from s to one of destinations, where X is upstream node of Y. All nodes between X and Y, if they are closer to Y than X be selected as candidate forwarding set and constitute a candidate forwarding set with X and Y, also known as subgroup. Candidate forwarding set can be expressed as S_n, n_I and n_j are different nodes in set, where $n_i, n_j \in S_n$. If there is an edge between each pair of nodes, then it will have $|S_n|.(|S_n)-1/2$ in subgroup, the graph of subgroup structure called a complete graph. $X_{ni,\ nj}$ show whether there is a edge exist between n_i and n_j, if so, $x_{ni,nj}$ is1,otherwise is 0:

$$\sum_{n_i \in S_n} \sum_{n_j \in S_n} x_{n_i,n_j}$$

is the actual number of edges in subgroup. The subgroup cohesion degree δ can be expressed as:

$$\delta = \frac{\sum_{n_i \in S_n} \sum_{n_j \in S_n} x_{n_i,n_j}}{|S_n| \cdot (|S_n| - 1)/2} \quad (1)$$

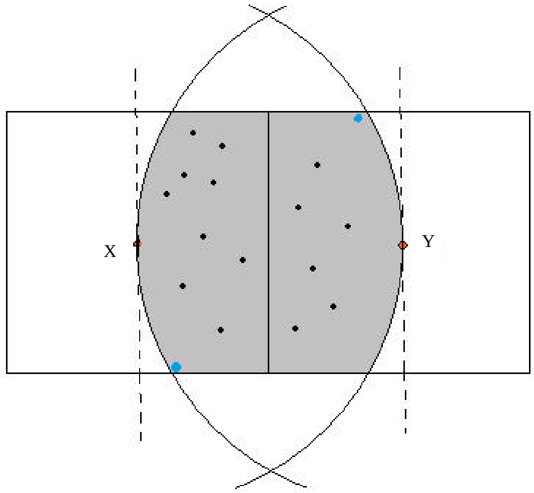

Fig. 1: Selection of the optimal forwarding set

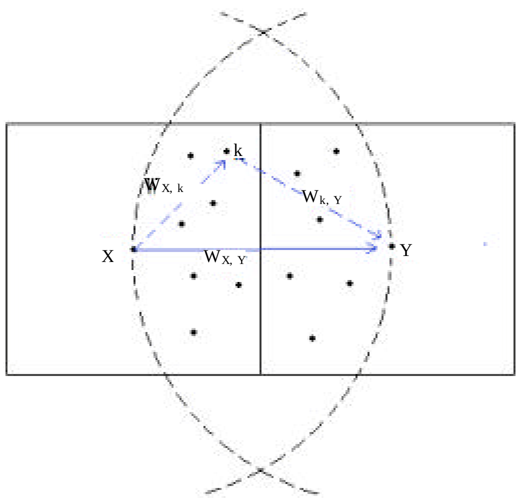

Fig. 2: Different nodes transmission cost in same forwarding set

When δ = 1, the selected set is optimal. S_{op} as the optimal set and is empty at the beginning time. We choose the node with closer to center region and add to set. Then select other node in S_n and judge whether exit a edge with every node in S_{op}. If the condition holds, so the node is available and add to S_{op}, this process can not end until S_n is empty. Figure 1 shows, the black are the nodes which meet the conditions, the nodes with green do not meet the conditions.

Optimal route selection

Energy model: According to the relationship between communication distance (d^2) and distance threshold (d^4), there are tow channel models as free space and multi-path fading respectively. If the communication distance is greater than the threshold ($d>d_0$), the system uses the multi-path fading channel model, otherwise adopts the free space model. Based on the nodes energy consumption and the communication model, the initial energy of each node is E_n ($E_n>0$), the energy consumption of nodes to send and receive k bit data are, respectively expressed as:

$$E_{Tx}(k,d) = \begin{cases} k * E_t + k * E_{amp} * d^2, d < d_0 \\ k * E_t + k * E_{amp} * d^4, d \geq d_0 \end{cases} \quad (2)$$

$$E_{rx}(k) = k*E_Y \quad (3)$$

where, E_t and E_r are the energy consumption of the circuit to transmit and receive per bit respectively, when the circuit is determined, E_t is a constant and E_{amp} is the power coefficient of the amplifier circuit, the energy consumption of amplifier relate to communication distance and bit error rate. d is the physical distance between the sending node and the receiving node. n is the channel loss index on the path, the value of which is generally 2 or 4, in this study we make n = 2, k is the bit rate of the wireless signals. From the Eq. 1 we can see, the energy consumption of transmission and receive is proportional to data size, sending more data, the more energy consumption.

Path metrics calculation: In order to simplify the problem, we use the energy consumption level of the nodes to approximate cost metric. When a node receives a message from its upstream node, the cost of nodes consume is equal to the energy of nodes to receive messages consume, the cost of transmitting nodes consumption is equal to the energy spent to send messages. As shown in Fig. 2, assuming that the central node X in the grid g_i transmits messages to the nodeY in the grid g_{i+1}, where the packet loss rate is e_X and the transmission cost is $w_{X,Y}$. The k th node of forwarding set receive messages from the upstream node X, where the packet loss rate is p_k and the transmission cost is $w_{X,k}$ and transmission messages to the downstream nodes from k node the packet loss rate is e_k and the cost is $w_{k,Y}$. The signal received power is proportional to distance d, therefore it can know that the links reliability is relation to distance, so we use distance parameter to represent the link volatility. The total cost of forwarding nodes in one transmission is:

$$C_k = w_{X,k}+w_{k,Y}+w_{sensor} \quad (4)$$

where, w_{sensor} is the consumption cost of node to sense.

We assume that n_{gi} is a candidate forwarding node in g_i and node Y in g_{i+1}, all nodes in the network at the same

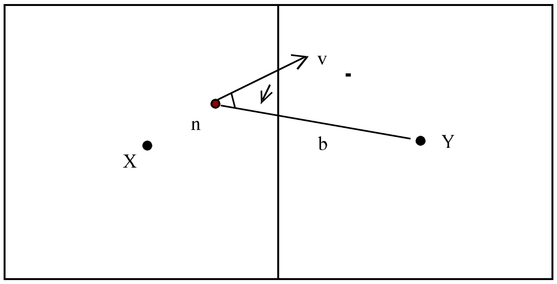

Fig. 3: The α express the direction vector from n to Y and b is the velocity vector of n,|×is the angle between the two vectors

speed v and the movement direction of nodes are uncertainty. As shown in Figure 3, α express the direction vector from n_{gi} to Y and b express the velocity vector of n_{gi}, **Ψ** is the angle between the two vectors. We can calculate cost**Ψ** as:

$$\cos\psi = \frac{a \cdot b}{|a \cdot b|} \quad (5)$$

The distance from n_{gi} to Y is d, after a unit of time, the distance is:

$$d_t = d\text{-}v.\ \text{Cos}\Psi \quad (6)$$

In order to calculate the nodes transmission cost more accurately, a speed factor is considered:

$$\varpi = \frac{d - v \cdot \cos\psi}{d} = \frac{d_t}{d} \quad (7)$$

We use the speed factor and expected transmission count [9], to calculate the priority of nodes in forwarding set, the expected cost is:

$$EC_k = \varpi \cdot \frac{C_k}{(1-p_k)\cdot(1-e_k)} \quad (8)$$

Ec_k is the priority parameter of forwarding nodes and the smaller the value, the higher the priority of nodes.

Then, we compute the expected transmission costs ETC_{gi} that node X transmit messages to Y. First calculate the cost of consumption of each node in forwarding set, the cost of consumption receive messages from node X and send it to Y:

$$ETC_{g_i} = (1-e_X)C_X + \sum_{k=2}^{FL}\left(\prod_{j=1}^{k-1} e_j\right).(1-e_k)C_k \quad (9)$$

The probability g_i transmit message to the next hop g_{i+1} is expressed as:

$$E_{g_i,g_{i+1}} = 1 - \prod_{j=1}^{FL} e_j \quad (10)$$

To simplify operation so:

$$\eta_{g_i} = \prod_{j=1}^{FL} e_j$$

supposing the neighbors set of g_I is N (g_i), the neighbors of which receive messages correctly is denoted as S∈N (g_i), through collaboration between the grids to transmit messages from g_I to g_{i+1} the probability and expected number of transmissions is, respectively:

$$E_t(g_i, g_{i+1}) = 1 - \prod_{g_n \in S}(1 - E_{g_n, N(g_n)}) \quad (11)$$

$$ETX(g_i, g_{i+1}) = \frac{1}{1 - \prod_{g_n \in S}(1-\eta_{g_n})} \quad (12)$$

According to Eq. 4 and 5 obtained the transmission cost (CTC) of g_i in collaboration with neighbors as follows:

$$CTC_{g_i} = E_{g_i,g_{i+1}} * ETC_{g_i} + \sum_{S \in N(g_i)} \prod_{g_k \in S}(1 - E_{g_{k-1},g_{i+1}}) * (E_{g_k,g_{i+1}}) * ETC_{g_k} \quad (13)$$

When k = 1, $(1\text{-}E_{gk\text{-}1,\, gi+1})$, indicates the probability of g_i transmit messages failure. When g_i transmit message to g_{i+1}, in the case of regional collaboration, by the (7) and (8) can calculate the total expected transmission cost expressed as:

$$ETC_t(g_i, g_{i+1}) = ETX(g_i, g_{i+1}) * CTC_{g_i} \quad (14)$$

Definition 1: Let P = (s, g_1, g_2, g_3,... g_i, d^k) is a path that one of the multicast routing set **σ**, g_i is *i*th path on the path, the costs of routing path P expressed as C (P|**σ**), where the sum of link cost and the expect link costs of the path P as follow:

$$C(P|\sigma) = \sum_{g_i \in P} c_{g_i,N(g_i)} = c_{g_1,N(g_1)} + c_{g_2,N(g_2)} + \ldots + c_{g_k,N(g_k)} \quad (15)$$

$$ETC(P|\sigma) = \sum_{g_i \in P} ETC_t(g_i, g_{i+1}) \quad (16)$$

Assuming there is a path P between the source and destination, when the data transmission rate is determined, the message transmission delay between g_i and g_{i+1} can be known. There are k bit data are delivered from g_i to g_{i+1} , the transmission delay can be expressed as D_i. On the basis of formulation (11), we can calculate the expected transmission delay and the total path delay:

$$D_{exp} = D_i \cdot ETX(g_i, g_{i+1}) \tag{17}$$

$$D_{tpd} = \sum_{g_i \in p} D_i \cdot ETX(g_i, g_{i+1}) \tag{18}$$

In the actual transmission, the delay of path P is D_T, γ is delay factor which use the expected transmission delay and actual transmission delay to calculate, with the following formula to express:

$$\gamma = \frac{D_T - D_{tpd}}{D_{tpd}} \tag{19}$$

When the source has multicast messages to send for the first time, the path of transmission multicast messages maybe not optimal for each destination. In order to minimize the costs of subsequent message transmission, we use the actual cost and expected transmission costs of the links to calculate the optimal path.

According to (14) and (15) to calculate λ, because the network is affected by many factors, the current status of links depends on the conditions of their environment. To simplify the equation, let:

$$\zeta = \frac{H_t}{H_{best}}$$

$$\lambda = \frac{C(P|\sigma) - ETC(P|\sigma) * \zeta}{ETC(P|\sigma)} \tag{20}$$

The first case indicates that the network link status is poor than the ideal state, in a real environment due to many factors, the volatility of the network link is relatively large, the volatility will decrease the transmission reliability of the hop-to-hop. Unreliable links will lead to more nodes or more areas are responsible for the task to deliver the message, when the number of nodes and areas reach a certain value, the total transmission cost will be greater than the sum of the expected transmission costs. In the normal case, it is more suitable for realistic scenario. The second condition for an ideal state, in this environment the links is stable, the reliability of message transmission is high, but this ideal state is incompatible with the actual situation.

In order to find the optimal transmission path, this study proposes a link metric functions, which include two parameters one of the parameters γ, the other parameters λ. F is expressed as follows:

$$F = f(\gamma, \lambda) \tag{21}$$

When the costs are same, the network may choose the path with fewer delay time as the subsequent messages transmission path.

Protocol description: In order to meet parameter metrics, we will modify several items in packet header. As the topology treated as the basic unit in grids in the study, the data packet is transmitted between grids, so the entries ForwardNum in the packet header is not suitable for the proposed protocol requirements and replaced as GridNum. In addition, the corresponding ForwardList entry will be replaced by GridList. In the data frame format, add expected transmission costs and the actual transmission costs of message transmission and extracted as ETCost and RTCost. After destination nodes have received the data packets from a plurality of neighbors, extract ETCost and RTCost using Eq. 18 to calculate γ. Then based on the coordinates of source and destinations, it would calculate expected transmission hops, using the message header TTL entries according to the Eq. 19 to calculate λ. Finally, using Eq. 20 to calculate F and select the path with the smallest path as the optimal path, transmission the acknowledgement to the source node along the reverse of the optimal path.

Assuming the grid of the highest priority node N located is g_i, the upstream region of which is defined as g_{i-1}, downstream region g_{i+1}, in g_{i-1} the highest priority node denoted by X, in g_{i+1} the highest priority node as Y. In the first data packet transmission, the network use flooding way for each grid to obtain the cost of the link has been consumed that when neighbors transmit messages to it, which can confirm the current location of the destinations according to the acknowledgement. When S transmits a packet to g_{i-1}, in g_{i-1} the forwarding node who listened to the message transmitted to decode data packet, if the region is included in GridList, then the forwarding nodes transmit data packet to the next hop grid. If the current grid is not in GridList, but is a neighbor of the grid g_n which is in GridList, then it saves the data packets received until g_n delivery successful. If the current grid does not detect that g_n delivered successfully in a certain time interval, it will take the responsibility to deliver the messages. If the current grid neither in GridList, nor a neighbor of grid in GridList, then the nodes in the current grid discard the data packets listened. After nodes decode the packet, extract ETCost and RTCost from the data frame and then use the Eq. 18, 19 to calculate F. When the destinations receive multicast messages from several different regions, they will have several values, then only store the link information with the smallest value. If P^k denotes kth paths, so:

$$P^k = \min(f(\gamma, \lambda)) \quad (22)$$

P^k will be responsible for the messages transmission. After destinations confirm the optimal path, which send an acknowledgment to the source node along the reverse direction of the data packets transmission.

EXPERIMENTAL RESULTS AND ANALYSIS

We simulate EOMR on the C++ platform, in networks a lot of nodes are randomly deployed in the area of 1000×1000 m, the transmission rate of nodes are the same as 1Mb sec^{-1}, the packet size is 512 kb, the wireless signal transmission range 147 m. In order to illustrate the performance of the EOMR protocol, the protocol compared with MAODV. We assume that the external interference effect on the link transmission reliability is small, the energy consumption of nodes monitoring is not included in the cost.

As shown from Fig. 4, E-OMRP protocol scales well with respect to the energy efficiency. When the number is small, the available relay nodes are less, the nodes which are responsible for transmission are not theoretically optimal, the energy consumption of two methods are more than the number of nodes is large. As the number of nodes increase, the cooperation chance among neighbors can be fully taken advantage of leading to the delivery ratio gain compared to the MAODV protocols. When the number of nodes changes, average energy consumption of the nodes in MAODV is more than the method we proposed. Because the method proposed in the study uses the opportunistic routing and cooperation mechanism. Figure 5 shows that the energy consumption of the nodes with different speeds, the movement of nodes may lead to links failure. In the beginning, the delivery ratios slightly decrease as the velocity increases, It is because nodes are more likely to outrun communication ranges. The links in MAODV are more sensitive to the moving speeds of nodes, the average energy consumption of nodes increase with the speeds. When the speed increases, E-OMRP performs better than MAODV. Because the speed as a parameter to calculate the priority of nodes, which can ensure the reliability of the transmission.

Figure 6 and 7 consider both the number and moving speeds of nodes, we compare E-OMRP and MAODV in terms of the average number of nodes per hop transmission. We can see from tow figures, when the nodes is less in the network, the two methods could not successfully transmission the message to the next hop with high probability, one side there are few relay nodes to select, on the other hand, in the transmission process, there are not suitable next hop to transmission messages. In this study, we use transmission delay and cost as the metrics to select the optimal path, the average number of

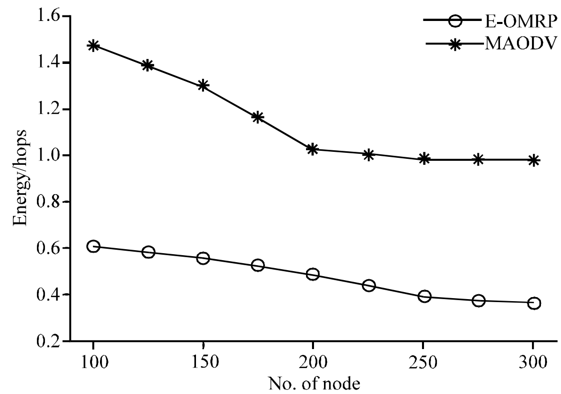

Fig. 4: Average energy consumption of nodes in case of the different number of nodes

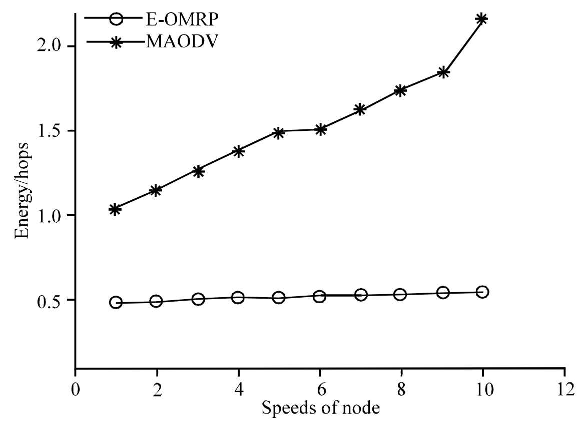

Fig. 5: Average energy consumption of nodes with different speeds

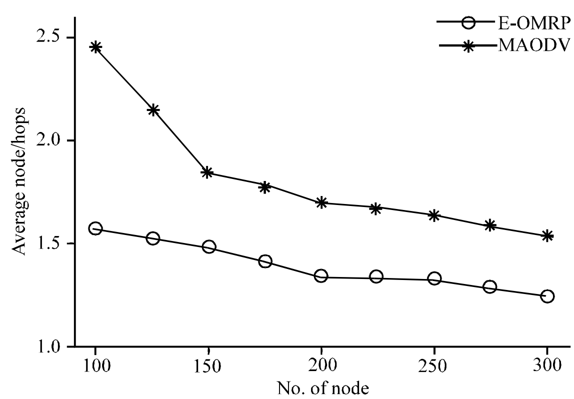

Fig. 6: Number of nodes per hops transmission need in case of the different number of nodes

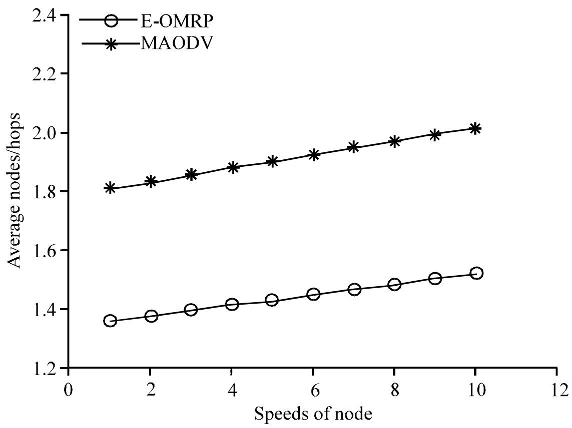

Fig. 7: Number of nodes per hops transmission need with different speeds

nodes per hop transmission can reflect the quality and reliability of links. As can be seen from the figures, when the number of nodes is less, E-OMRP uses opportunistic routing and select the optimal node set to transmit messages, which is better than MAODV in terms of transmission reliability without the use of opportunistic routing. When the MAODV protocols slightly perform poorly due to breakage of links resulting from the node mobility, the breakages may make nodes that are far away from the source difficult to receive the data packets. Our method perform well, because when the links dynamic are large, single grid transmission success rate is low, the cooperation mechanism will makes single hop transmission becomes more reliable.

CONCLUSION

In this study, we have proposed E-OMRP for the energy efficiency to illustrate the energy efficiency problem and use the opportunistic routing and cooperation to transmit the messages from source to the destinations. But the method only considers network layer and data link layer and physical layer are taken less consideration, the research of cross-layer protocol will be the focus of our future work. In the future work, we plan to design more efficient forwarding set selection algorithm and add the reliability to our E-OMRP protocol instead of using simple acknowledge along the optimal path selected.

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