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A Real-Time Routing Protocol along with new Reliability Approach in Wireless Sensor Network

[1]Maryam Norouzi, [2]Rabee Sharifi Rad and [2]Somayeh Khaje Hassani Rabori
[1]Shahid Behest University, Tehran, Iran
[2]Sirjan University of Technology, Kerman, Iran

Abstract: Reliable and real-time packet transmissions along with minimum energy consumption are main challenges in designing routing protocols to realize many applications of Wireless Sensor Networks (WSNs). With considering these challenges, we proposed a novel Geographical Reliable and Real-time routing Protocol (GRRP) which takes energy consumption into account. This protocol is based on two new approaches called geographical area divisions and efficient node selection function. GRRP makes use of these approaches to determine the best geographical angle and optimum nodes in the angle. In order to hit its goals, GRRP utilizes a novel multi-path routing algorithm. As the simulation results indicate, GRRP outperforms state-of-the-art protocols in terms of average end-to-end delay, throughput and reliability.

Keywords: Energy efficiency, real-time, reliability, routing protocol, trustability, wireless sensor networks

INTRODUCTION

Wireless Sensor Networks (WSNs), consisting of a large number of small size sensor nodes, have been received increasing attention by many researchers in recent years. These sensor nodes emerged by advances in Micro-Electro-Mechanical Systems (MEMS) technology, wireless communications and digital electronics have some constraints in resources such as power unit, processing capability, memory storage and wireless transceiver (Akyildiz *et al*., 2008). In spite of these constraints and simple functionality of sensor nodes, cooperation among them leads WSNs to be an appropriate platform for realizing many significant applications such as environmental surveillance and monitoring, military and battlefield situation awareness, advanced health care delivery and traffic control (Yick *et al*., 2008).

Taking advantage of routing protocols is one of the key techniques which can provide cooperation among WSNs' nodes. Therefore, many routing protocols regarding sensor nodes' constraints and applications' requirements have been proposed. Since power is one of the main constraints of sensor nodes, lots of proposed routing protocols focused on energy efficiency to prolong WSNs' lifetime (Liu *et al*., 2009; Mohanoor *et al*., 2009). Also, since Quality of Service requirements (QoS) such as real-time and reliable communication are important factors to satisfy many WSNs applications' requirements, there are many traditional routing protocols which have strived to achieve these QoS requirements. However, as far as we are aware, there are some chief drawbacks in these protocols. For instance some of them only concentrated on real-time and reliable communications while they haven't attended to energy consumption (Felemban *et al*., 2006), or some others efficiently support one of the QoS requirements (He *et al*., 2005; Biagioni and Chen, 2004).

In this study, a new routing protocol named Geographical Reliable and Real-time routing Protocol (GRRP) which utilizes nodes' position and aims to provide mentioned QoS requirements is proposed. The contribution of GRRP is providing both of reliable and real-time communications in WSNs while energy preservation considered as well. The proposed protocol hits its goals by relying on two innovative approaches and a multi-path routing algorithm with novel mechanism which takes advantage of these approaches.

The first novel approach emerged from geographical routing protocols' nature is based on selecting an angle from node's transmission radio range in the direction of Base-Station. In this approach the angle is divided into some equal arcs which are classified into two categories, positive and negative arcs. Finding best geographical data transmission angle along with its divisions and classification are described in section III-A. In the second approach which is related to selection of next hop nodes placed in chosen arcs a fitness function which determine nodes capability is required. Section III-B explains presented approach which is called Efficient Node Selection (ENS) function in details.

In order to provide real-time communications, a new multi-path routing algorithm which is in charge of providing reliability for GRRP is designed. To the best

Corresponding Author: Rabee Sharifi Rad, Sirjan University of Technology, Kerman, Iran

of our knowledge, although traditional multi-path routing protocols can provide reliable communications, they have not considered energy efficiency. With this in mind and by using new considered mechanisms, the optimum numbers of paths are created to yield energy efficiency in GRRP. This multi-path routing algorithm along with its mechanisms is investigated in section III-C.

The remainder of the study is organized as follows. At first related works are discussed in section II. Then section III describes the proposed Geographical Reliable and Real-time routing Protocol (GRRP). Next, simulation results are presented in section IV. At last section V concludes the study and brings future works.

LITERATURE REVIEW

Nodes' constraints along with numerous emerging applications with distinctive QoS requirements have resulted in proposing various routing protocols. According to the literature, the most important routing protocols, which achieve QoS requirements with considering nodes' limitations, are divided into two main categories: hierarchical and geographical (Chen *et al*., 2008; Mahapatra *et al*., 2006). However, lots of these protocols have efficiently achieved one of the QoS requirements, it means that when reliability has been improved, timeliness has dwindled and vice versa (Biagioni and Chen, 2004; Ahuja and Ramasubramanian, 2008; Peng *et al*., 2007). Both of QoS requirements were provided in the other protocols while energy efficiency was not attended (Felemban *et al*., 2006; He *et al*., 2005). In the following, some of the well known routing protocols are described.

Chen *et al*. (2008) have proposed Link Quality Estimation based routing Protocol (LQER), which can be classified in hierarchical category. In this protocol, path selection is based on historical status of link quality between nodes which are one hop closer than current node to the Base-Station. Although LQER is energy-aware and reliable, it cannot support real-time communications.

Hierarchical routing protocols based on clustering algorithms (Heinzelm *et al*., 2000; Muruganathan *et al*., 2005) are so sensitive about running out of power in cluster heads. Destructing these nodes results in uselessness of all nodes in relevant clusters, which affect the reliability of the network (Peng *et al*., 2007).

Qiao *et al*. (2010) proposed a simple geographical forwarding scheme with the ability of bypassing routing holes, called ABC. Although this protocol can provide good reliability, it suffers from data retransmission. Hence it is not appropriate to realize real-time applications in WSNs.

Felemban *et al*. (2006) extended SPEED (He *et al*., 2005) and proposed MMSPEED which appends multi-path mechanism to SPEED and belongs to geographical category. MMSPEED selects some paths according to required reliability called end-to-end reaching probability. If a sensor node insures that reaching probability is not achieved via total current paths, it produces more paths. In spite of QoS requirements provisioning by MMSPEED, it does not consider any mechanism for energy efficiency and prolonging network life time.

Real-Time routing protocol with Load Distribution (RTLD) is another kind of geographical routing protocol (Ahmed and Fisal, 2008). In RTLD each triggered node sends data to all neighbor nodes. Relay nodes which have received data, send it in a unicast. Regards to WSNs characteristics and RTLD operation it is obvious that the large numbers of paths will be created in this protocol. Although these amounts of paths provide reliable communications, they raise nodes' energy consumption and greatly reduce network lifetime. Another important drawback occurs when there is high traffic in the network. In this case, end-to-end delay increases due to high load injected to the network. Consequently, RTLD is not suitable for the multimedia applications where packet rate is high.

MATERIALS AND METHODS

GRRP tries to make multi paths from source node (triggered sensing node) to Base-Station with the aim of guarantying reliability and real-time communications, while energy preservation is considered too. Designed protocol is based on a multi-path routing algorithm with novel mechanism which exploits of two innovative approaches. The first approach, presented in section III-A, is related to optimal geographical area determination and division this area to some arcs. The second one presented in section III-B deals with selecting relay nodes from the chosen arcs by a new Efficient Node Selection (ENS) function. The novel multi-path routing algorithm which is based on the two mentioned approaches explained in section III-C.

Before introducing GRRP approaches and multi-path routing algorithm, it is worth mentioning that some assumption should be mentioned. At first, it is assumed that the sensor nodes are not mobile. In addition, based on the characteristics of geographical protocols it is assumed that each node is aware of geographical coordinates of itself and Base-Station through GPS (Hofmann *et al*., 1997) or some localization algorithms (Mao *et al*., 2007). As the last assumption, there is no void in the network.

Novel geographical divisions: Since transmitting data in maximum range consumes lots of energy, a high threshold (*High-Thr*) as nominal transmission range preventing node send packet far from has considered. Moreover it is an important factor that packets in next

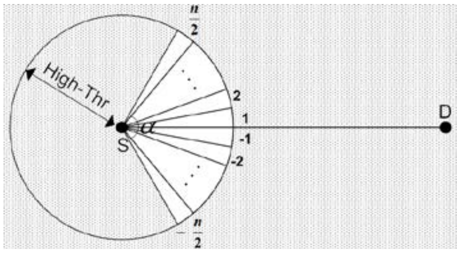

Fig. 1: High threshold along with α angle and its divisions

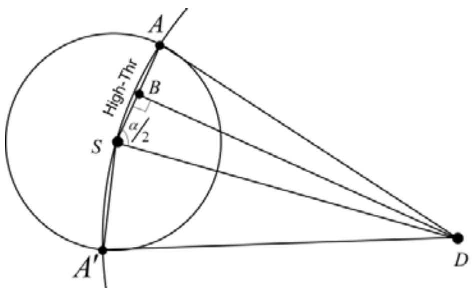

Fig. 2: Adjusting angle with α degree

hop nodes should be closer to the destination, therefore an angle of α degree in direction of the destination is chosen. Regarding this information, nodes locating in shaded area illustrated in Fig. 1, which are called black list nodes (Yick *et al*., 2008), must not be selected as next hop nodes. In the other words, only nodes closer than *High-Thr* and inside closest angle of *α* degree to the destination are inserted to neighbor table and can be selected as next hop nodes. After determining angle of *α* degree in the direction of the destination, source node divides it into *n* equal arcs (Fig. 1). The value of *n* can be considered based on the application.

In real-time communications, minimum end-to-end delay is required; therefore candidate nodes should be closer to the destination than source node. To obtain this, the angle with *α* degree should be adjusted correctly that all nodes located within this angle surely be closer to the destination than source node.

In order to calculate angle α with assumption that distance *SD* (Source to Destination) is more than *High-Thr*, as depicted in Fig. 2 a circle with center *D* and radius *DS* is drawn. This circle crosses the circle with center *S* and radius *High_Thr* in points *A* and *A'*. According to Fig. 2, the angle of α is obtained by Eq. (1). Where, D_{SD} and *High_Thr* in the equation are source to destination distance and sensing radius of source node, respectively. Since minimum D_{SD} is *High-Thr*, it can be concluded that minimum α angle is 120°. Therefore, if angle α is set less than or equal to 120°, next hop node will surely be closer to destination than source node. It is obvious that if D_{SD} is less than or equal to high threshold, determining the angle with *α* degree is

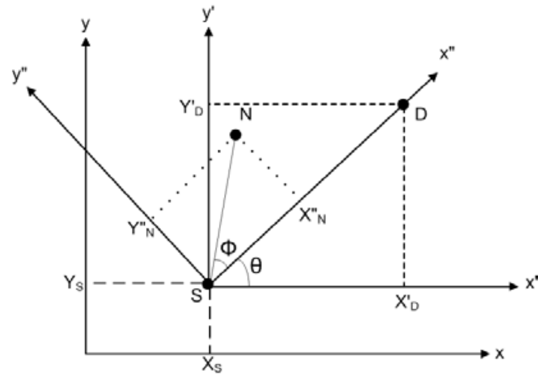

Fig. 3: Arc number calculation

meaningless. In this case source is able to send packets directly toward destination:

$$\alpha = 2ArcCos(\frac{High\_Thr}{2D_{SD}}) \quad (1)$$

After determining the angle of α, this angle is divided to *n* equal arcs which are numbered according to Fig. 1. After that, arc number of each neighbor node located in angle α should be calculated. In order to obtain neighbor nodes' arc number, one assumption is considered and some steps are followed. It is assumed that origin is in left lower corner of the network and nodes' positions are obtained according to this coordinates. Suppose that in Fig. 3, node *S* wants to calculate *arc-number* of node *N* while *D* is destination. Following steps are considered to obtain *arc-number*. At the first step, the origin should be transported to the co-ordinations of each node wanting to calculate neighbor's arc number. As shown in Fig. 3, origin has been transported to point (X_s, Y_s) and axis x'Sy' has been obtained.

After transportation, new co-ordinations of node *N* are equal to Eq. (2):

$$\begin{cases} X'_N = X_N - X_S \\ Y'_N = Y_N - Y_S \end{cases} \quad (2)$$

where, *(X_N, Y_N)* are co-ordinations of node *N* in axis xSy. In the second step, axis should be rotated with angle of rotation θ that has been calculated by Eq. (3):

$$\theta = arcTan(\frac{Y_D - Y_S}{X_D - X_S}) \quad (3)$$

where, *(X_D,Y_D)* are co-ordinations of the destination in axis xSy. After counter clockwise rotation, new co-ordinations of node *N* can be derived as follows:

$$\begin{cases} X''_N = X'_N .Cos(\theta) - Y'_N .Sin(\theta) \\ Y''_N = X'_N .Sin(\theta) + Y'_N .Cos(\theta) \end{cases} \quad (4)$$

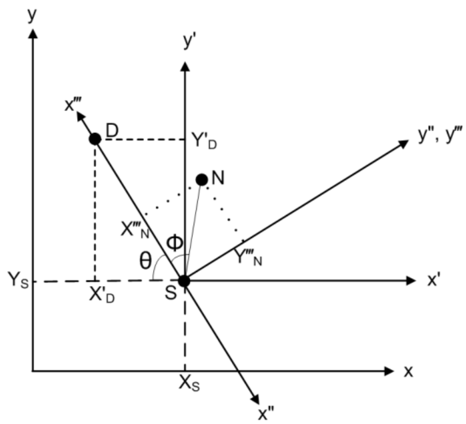

Fig. 4: Arc number calculation with reflection

Needless to say, by employing Eq. (4) when θ<0, axis rotates clockwise:

$$\phi = arcTan(\frac{Y''_N}{X''_N}) \quad while\ X''_N > 0 \tag{5}$$

In the third step, angle Φ which is the angle between lines *SD* and *SN* is calculated by Eq. (5). If Φ> (α/2), node *N* may be further than source to destination therefore it is added to black list, however in the case that Φ≤ (α/2), node *N* is certainly nearer to destination than source node (*S*). Therefore node *N* is added as neighbor of node *S* and at last its *arc-number* is calculated by Eq. (6):

$$arc - number = \left\lceil \frac{2\phi}{n} \right\rceil \tag{6}$$

In the second step, if X''_D is negative, one more stage should be considered too. Figure 4 mentions this condition that causes to have a reflection in the end of this step. Reflected co-ordinations are calculated across axis Y" therefore axis x‴Sy‴ is the result. And in the third step, with locating X'''_N and Y'''_N instead of X''_N and Y''_N in Eq. (5) respectively arc number is easily calculated by Eq. (6):

Hence co-ordinations of node *N* are calculated in Eq. (7):

$$\begin{cases} X'''_N = -X''_N = -X'_N.Cos(\theta) - Y'_N.Sin(\theta) \\ Y'''_N = Y''_N = -X'_N.Sin(\theta) + Y'_N.Cos(\theta) \end{cases} \tag{7}$$

After these steps for calculating nodes' *arc-number*, each node knows all candidate neighbor nodes along with their *arc-number*. This step is performed once for each node.

Efficient node selection function: In order to make multi-path routing, some arcs according to the average power of nodes are selected (see section III.C for more details). In each selected arcs, one optimum node must be chosen, hence GRRP uses an Efficient Node Selection (ENS) function for this purpose. Besides some neighbor node's parameters such as hop-by-hop delay and its distance to the destination which have been utilized in most traditional routing protocols to fulfill real-time communications and energy optimization, in this study one more parameter called trust ability added to ENS function to provide reliability. According to the mentioned parameters ENS function is presented at Eq. (8):

$$ENS = \lambda_1 T + \lambda_2 \frac{P_{cur}}{P_{\max}} + \lambda_3 \frac{d}{d_{\max}} + \lambda_4 \frac{D_{ND}}{D_{SD}} \tag{8}$$

where,

λ_i (i = 1, 2, 3, 4) = Coefficients
T = Trust ability
P_{cur} = Current remaining power
d = Hop-by-hop delay
D_{ND} = Distance between the node *N* and destination

Trust ability is a criterion to measure how the node is trustable to be chosen as next hop node. P_{max}, which is initial power of nodes, is fixed because all nodes in the beginning have same level of energy. D_{SD} is distance between source and destination. At last, d_{max} is maximum estimated latency that a packet can tolerate in each hop and reach to destination before its deadline. When there is moderate traffic all over the network, we can estimate that nodes located around center of gravity of angle α, have more chance to be selected. Whereas distance between the source and the center of gravity is ($\sqrt{2}$ /2 *High_Thr*), therefore there are approximately (($\sqrt{2}$ D_{SD}/*High_Thr*) hops from source to destination. If deadline of the packet is t_{dl}, maximum time that each packet can be postponed by each relay node (d_{max}) is presented in Eq. (9):

$$d_{\max} = \left\lceil \frac{t_{dl} * High\_Thr}{\sqrt{2} D_{SD}} \right\rceil \tag{9}$$

In Eq. (8) the values of coefficients differ from one application to another. For example in real-time applications λ_3 is better to be greater than λ_4 or in the application which energy has an important role, λ_1 should be less than λ_2. It is worth mentioning that in all applications both λ_3 and λ_4 must be negative.

In this study Eq. (10) considered to achieve the innovative parameter called trust ability:

$$T = c_1 B_1 + ... + c_i B_i + ... + c_k B_k \tag{10}$$

where, B_i is the parameter clarifying transmission status in i^{th} previous transmitted message so that if the message

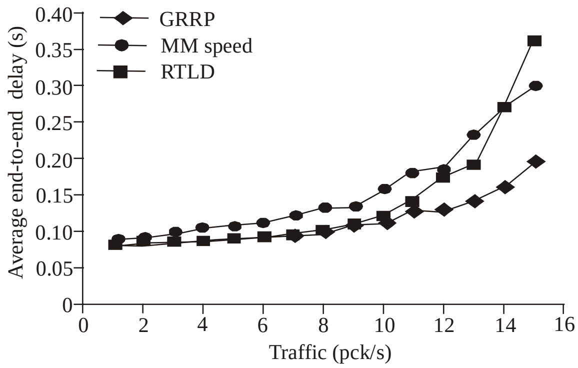

Fig. 5: Average end-to-end delay when traffic gradually increases from 1 to 10 packet per second

reached to the next hop node successfully, B_i is set to one and if message is lost due to congestion and errors on wireless channels it is set to zero, c_i is the coefficient determining the B_i importance and k is the number of latest considered messages. On the other work, B_1 is status of the most recent message and B_k is status of k^{th} previous message. Since each situation of a node is more important than previous situations, the value of c_i is greater than c_{i+1}. Eq. (11) derived from zipf's law (Tanenbaum, 2008) is utilized to attain c_i values so that satisfy required conditions:

$$\begin{cases} c_i = \frac{L}{i} \\ \sum_{i=1}^{k} c_i = 1 \qquad \forall i \in [1,2,...,k] \\ \frac{1}{L} = \sum_{i=1}^{k} \frac{1}{i} \end{cases} \tag{11}$$

where, L presents a constant value that makes sum of c_i exactly one.

In GRRP, node with more ENS value than other nodes in an arc can be chosen as next hop node. Needless to say, ENS parameters except distance to destination should be updated regularly by beacon messages. Once sending beacon message node starts delay timer till the answer is received. Whenever the answer is received the new delay is replaced in neighbor table and if not received, or timer expired, d_{max} is assigned to the node's delay.

Proposed geographical routing algorithm: In order to clarify the routing algorithm, as mentioned in the Fig. 5 several steps are considered for a source node which will deliver sensed data to the destination as following.

At first step, the source node, based on the novel geographical division in section III-A, selects the closest geographical *120°* angle to the destination and divides it to n equal arcs. Neighbor nodes are divided into two groups of neighbors, positive neighbors and negative ones .In all next steps nodes are considered into two completely independent groups and all estimations, calculations and actions are done with utilizing these groups of arcs separately. With this in mind, at second step the source node calculates average power of nodes in each arc then sorts arcs according to the average power values in descending order and produces a sorted list for each category.

In third step, the arc with highest average energy is selected from each sorted lists and their nodes are separately analyzed by new ENS function introduced in section III-B. The results of the algorithm leads to mark one optimum node in positive arcs and one other in negative arcs as next hop nodes.

In forth step, according to parameters of the selected nodes in positive and negative category, they are independently checked to determine they are capable of reaching sensed data to destination. Independently checking nodes' reliability in two separate categories makes the protocol more reliable and causes to increase probability of reaching packets to destination almost twice. In order to check nodes' capability, packet dropping probability of the selected nodes is estimated by Eq. (12):

$$e_N = \lambda_e (1 - T_N) \tag{12}$$

where, T_N is trust ability computed by Eq. (10); λ_e is a coefficient which makes the e_N flexible. Then with considering e_N and number of hops mentioned in section III-B, probability of reaching packet from source to destination through selected node named Path Reaching Probability (*PRP*) can be estimated by Eq. (13):

$$PRP_N = (1 - e_N)^{\left\lceil \frac{\sqrt{2} D_{SD}}{High\_Thr} \right\rceil} \tag{13}$$

In this equation (1-e_N) is probability of delivering packet to a selected node. It is worth mentioning that Eq. (13) assumes that packet dropping probability of other relay nodes which forms next hops to the destination are similar to e_N.

In order to clarify the algorithm, suppose that PRP_j are *PRP* of j^{th} path (path which reaches sink using j^{th} node selected by source node). After selecting first node in positive arcs, the estimated PRP_1 is compared to the ($\lambda_r \times P_{reach}$) which P_{reach} is set for sensed data packet based on application requirements and λ_r is a multiplied to make the protocol flexible. If the PRP_1 is more than $\lambda_r \times P_{reach}$, one path is enough to reach the required reliability, otherwise one path is not adequate for reaching packet to the destination with P_{reach}. Hence another path should be selected from positive arcs. To add new path, a new next node will be selected in next positive arc from sorted positive arcs. Adding new node from sorted list of arcs is continued until final probability of reaching data to destination get larger than $\lambda_r \times P_{reach}$. This probability is called Destination

Reaching Probability (*DRP*) and is calculated by Eq. (14). When *DRP* is larger than $\lambda_r \times P_{reach}$, it means that resulted paths are enough to have required reliability. This process is done in negative arcs to make reliability twice. The algorithm repeats steps 3 and 4 in order to select next nodes and then calculates *PRP* and *DRP*.

$$DRP = 1 - \left((1 - PRP_1) \ldots (1 - PRP_j) \ldots (1 - PRP_i) \right) \tag{14}$$

Sensed data are transmitted to all marked nodes in a multicast manner.

In this study multi-paths are created by source node. It means that only source node sends data in a multipath manner in positive and negative categories and next hop nodes send information in a unicast manner. On the other words, relay nodes select best node by ENS function from the arc with largest average power and send data to that selected node in a unicast manner.

RESULTS

OMNeT++ simulator, which is available on http://www.omnetpp.org, has been used to simulate and evaluate the performance of GRRP protocol. GRRP's efficiency was compared with MMSPEED (Felemban *et al*., 2006) and RTLD (Ahmed and Fisal, 2008) which have been simulated with OMNeT++ too. It is assumed that there is no void in the network; therefore void has not been considered in the simulations. We compared the three protocols in 3 metrics including average end-to-end delay, throughput and reliability. It is worth mentioning that all over the simulations we use simulation parameters listed in Table 1.

In the simulations, 225 nodes are placed in an area of 150 m×150 m covered uniformly. It is assumed the center node is destination and nodes in the middle of each side are source nodes which generate constant bit rate packets. Locating the source at the middle of each side helps to have enough nodes in the angle with 120° in direction of the destination. It is worth mentioning that in all simulations which packet rate varies from 1 to 10 packets per second, deadline was fixed at 100 ms.

In order to calculate nodes' power dissipation, we assumed the power consumption model mentioned in Heinzelman *et al*. (2002). This can be inferred from this model that amount of energy consumption for transmitting and receiving one message can be approximated the same.

Simulation results: In this section the three protocols named MMSPEED (Felemban *et al*., 2006), RTLDS (Ahmed and Fisal, 2008) and GRRP are compared in terms of mentioned metrics.

Table 1: Simulation parameters

Parameter	Value
Transmition rate	250 kbps
High threshold	34 m
Packet size	70 byte
Sensing range	5 m
Remaining energy	1 J
Arc numbers (n)	10
Packet reaching probability	0.8
λ_1,λ_2	0.25
λ_3, λ_4	-0.25
k	10
$T_{initial}$	1
λ_e	0.5
λ_r	1

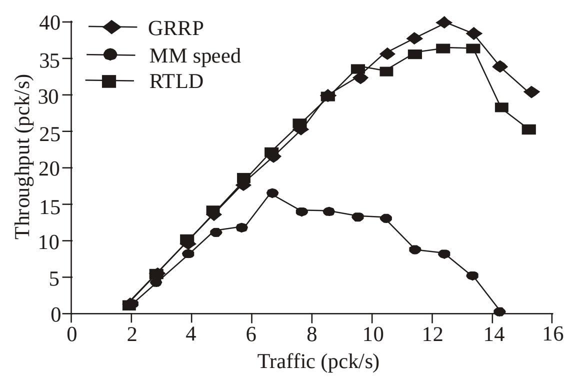

Fig. 6: Throughput in different packet rates

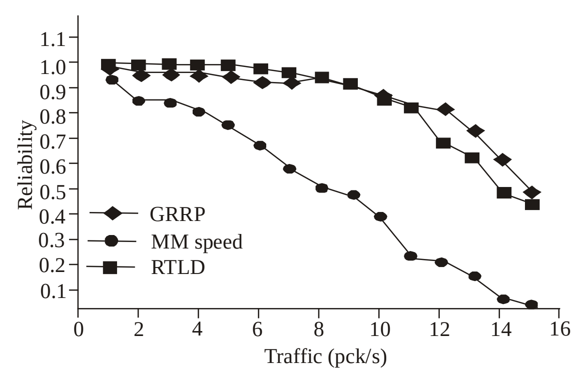

Fig. 7: Reliability with different traffic rate

- **Average end-to-end delay:** In real-time applications, packet delay from source to destination (end-to-end delay) is a crucial factor to design routing protocols. The simulation results in Fig. 5 show that GRRP can deliver data with minimum end-to-end delay in comparison with other protocols when packet rate gradually increases. In traffic with high packet rates, the average end-to-end delay of GRRP is 36 and 34% less than MMSPEED and RTLD, respectively. It is inferred that GRRP is an appropriate routing protocol for wireless multimedia sensor networks where the traffic is high besides traditional WSNs.
- **Throughput:** Although increasing packet rate results increasing the number of received messages to destination in time unit, but in heavy traffic when the network is not capable of route all

messages to destination, throughput gradually decreases. In spite of rising throughput with same trend in GRRP and RTLD till 9 packets per second, but Fig. 6 proves that GRRP is able to deliver more messages than RTLD in high traffic rates. It is on average about 13% improvement in throughput of the network in comparison with RTLD when traffic rate exceeds 11 packets per second.

- **Reliability:** Figure 7 displays reliability which is the proportion of received messages in destination to transmitted messages by sources. As mentioned before MMSPEED cannot act well in networks with high traffic also it has 12% lower reliability compared with GRRP in light traffic. Since RTLD always utilizes lots of paths, its reliability in low traffic rates is 2.6% more than GRRP. However GRRP outperforms RTLD in heavy traffic which is more similar to traffic in multimedia applications. It is about 19% improvement in reliability compared with RTLD.

Our simulation results confirm that GRRP is able to deliver packets with low end-to-end delay even in networks with high packet rate. In real-time applications, GRRP shows more throughput and reliability. Hence, it is a proper routing protocol for wireless multi-media sensor networks.

CONCLUSION AND FUTURE WORKS

This study proposed a protocol to actualize real-time applications with low energy consumption in WSNs. It is a simple and efficient geographical routing protocol to take Quality of Service requirements into consideration.

Simulation results proved that GRRP outperforms other protocols in term of average end-to-end delay. Moreover GRRP excels in throughput and reliability. As mentioned before there is about *19%* improvement in reliability compared with RTLD.

As future works, void can be considered in GRRP. In addition, in this study we tried to find neighbors which are surely closer than current node to the destination. It is worth evaluating performance of the protocol when relay node is closer than previous node to the destination, but rather it is further from source node in comparison with previous node.

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