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Ant-based routing and QoS-effective data collection for mobile wireless sensor network

A. H. Fareen Farzana[1] · S. Nedunchelіyan[2]

Abstract Mobility management in mobile wireless sensor networks (MWSNs) is a complex problem that must be taken into account. In MWSN, nodes move in and out of the network randomly. Hence, a path formed between two distant nodes is highly susceptible to changes due to unpredictable node movement. Also, due to the limited resources in WSN, the paths used for data transmission must be tested for the link quality and time consumed for data forwarding. In order to solve these issues, in this paper, an ant-based routing protocol with QoS-effective data collection mechanism is proposed. In this protocol, the link quality and link delay are estimated for each pair of nodes. Link quality is estimated in terms of packet reception rate, received signal strength indicator, and link quality index. A reliable path is chosen from the source to the destination based on the paths traversed by forward ants and backward ants. Then, if the link is found to be defective during data transmission, a link reinforcement technique is used to deliver the data packet at the destination successfully. The mobile robots collect the information with high data utility. In addition, each mobile robot is equipped with multiple antennas, and space division multiple access technique is then applied for effective data collection from multiple mobile robots. Simulation results show that the proposed routing protocol provides reliability by reducing the packet drop and end-to-end delay when compared to the existing protocols.

Keywords Mobile wireless sensor networks · Packet reception rate (PRR) · Received signal strength indicator (RSSI) · Link quality index (LQI)

1 Introduction

A wireless sensor network (WSN) consists of several minute sensor nodes which perform functions like monitoring the network surrounding, handling the sensed information, and communicating with the destination node wirelessly. The sensor nodes in WSN have limited resources and are basically microelectronic devices. After the deployment of the sensors in WSN, these sensors work independently using batteries with limited energy. Hence, operations such as routing, duty-cycle scheduling, and medium access controlling must be performed efficiently in WSN [1, 2]. WSN can be used in home, military, science, transportation, health care, disaster relief, warfare, security, industrial and building automation, space discovery, and so forth. WSN is vastly used in phenomena monitoring [3–10].

Recently, mobile WSNs (MWSNs) are emerging as a new trend of WSN. They possess all the properties of static WSNs along with node mobility [11–13]. A major problem in MWSNs (i.e. designed for data gathering rather than for peer-to-peer sharing) is assessing the best path that a message should take for eventual delivery to a base station or exit point from the network. Thus, delivery is undertaken in a store and forward manner, with nodes exchanging packets on contact with one another. If the mobility patterns of nodes are highly dynamic and essentially unpredictable, determining the optimal path is impossible [5, 14–19].

Node mobility brings several challenges to large-scale sensor networking.

✉ A. H. Fareen Farzana
fareenfarzana0902@gmail.com

1 Aalim Muhammed Salegh College of Engineering, Chennai, India

2 Jaya Engineering College, Chennai, India

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- The preconstruction of message delivery network may not be useful since the topology may change too frequently due to node movement.
- The frequent location updates from a mobile node can lead to an excessive drain of limited battery power of sensors and increased collisions in wireless transmissions.
- The situation can get worse when the number of mobile nodes grows.
- *Self configuration*: Once deployed in an unknown area, mobile sensor nodes should configure to cover the area.
- *Agility*: As the phenomena of interest expand, shrink, or migrate to other places, MSN should adjust to the change of the dynamic sensing environment to maximize the sensing coverage.
- *Network connectivity*: MSNs should have access to a base station to report the current sensing readings. If only a subset of nodes have direct connectivity to the base station, the rest of nodes should have multihop paths to those that have that capability.
- *Energy efficiency*: Energy efficiency is critical to lengthen the network lifetime. Therefore, the traveling distance of mobile nodes and the communication overhead should be minimized.
- *Noise tolerance*: The sensing environment is subject to a high level of spatial and temporal noise as well as the sensor reading error. Regardless, the MSN should be able to find the optimal location of deployment [20–27].

Routing in MWSN is very challenging due to its constantly varying topology and regular link failures. Link failure causes delay in packet delivery and may also lead to packet loss. Thus, energy usage increases. Most of the ad hoc routing protocols such as Ad hoc On-Demand Distance Vector (AODV) Routing and On Demand Multi path Distance Vector Routing (AOMDV) perform effectively in traditional networks; however, these protocols work in a poor way in WSN since the resources are limited in the network nodes. Also, the recovery techniques used to overcome the repeated link failures consume high energy.

The conventional routing protocols of mobile ad hoc networks like AODV, DSR, OLSR, and LAR and energy-conserving protocols can be used for WSN. But, the continuous mobility is not taken into account as a network characteristic by these protocols for deciding the links to forward the data packets [28–34].

Mobility management in MWSNs is a complex problem that must be taken into account. In MWSN, nodes move in and out of the network randomly. Hence, a path formed between two distant nodes is highly susceptible to changes due to unpredictable node movement. Also, due to the limited resources in WSN, the paths used for data transmission must be tested for the link quality and time consumed for data forwarding. So in this paper, we propose to develop a routing technique which considers the node movement. Ant-based routing protocol along with QoS effective data collection is proposed using ant colony optimization (ACO) algorithm is proposed.

The paper is organized as follows. Section 2 describes the related works and Sect. 3 provides the detailed explanation of the proposed work. Section 4 explains the simulation results. Finally, Sect. 5 concludes the work.

2 Literature review

Sara et al. [35] have developed a hybrid multipath routing algorithm with an efficient clustering mechanism. A node with higher amount of energy, good communication range, and minimum mobility is chosen as the cluster head. The energy consumption during routing is handled efficiently by including the Energy Aware (EA) selection scheme and the Maximal Nodal Surplus Energy determination scheme. This technique includes the clustering and routing protocol which performs well in highly dynamic environment and also in energy-lacking network conditions.

Karim and Nasser [36] have presented a location-aware and fault tolerant clustering protocol for MWSN (LFCP-MWSN). At the time of cluster formation and movement of nodes between two clusters, the nodes are localized by the LFCP-MWSN technique by adding a range-free mechanism. The energy consumed by this protocol is around 30 % less when compared with the conventional protocols. The end-to-end transmission delay involved with this protocol is also low.

Awwad et al. [14] have proposed a technique in which the cluster head accepts the data packet from all the nodes in the network during the time slot assigned by TDMA. During free time slots, if a node enters a cluster, then every cluster head behaves like free cluster head one after the other. Based on the traffic and mobility features of the network, the TDMA scheduling is changed accordingly by the CBR MWSN. The protocol transmits the data towards the cluster head on the basis of the received signal strength.

Li et al. [37] have proposed a cluster-based data collection algorithm (ECDGA) for MWSNs. This network is made up of both mobile nodes as well as static nodes. The mobile nodes form a cluster by self-systemizing process which adjusts its position according to the distance between the static nodes. The cluster head is selected by the static nodes on the basis of the residual energy and mobile node position, which is important in transferring the data packet within the cluster. Data gathering as well as data fusion is the task of cluster head. This algorithm enhances the network lifetime and the network reliability.

Ba et al. [1] have proposed a mobile access resolution on the basis of the X-MAC protocol. This protocol follows several techniques which aids in minimizing the energy usage. The lifetime of the fixed nodes are assessed on the basis of the MoX MAC protocol and the reduction of the static nodes in the network due to the presence of the mobile nodes is also handled.

Van Le et al. [28] have proposed an ad hoc routing and relaying architecture called as Robots' Controllable Mobility Aided Routing (RoCoMAR). This routing is performed according to the robotic nodes controllable mobility. After the task is achieved or if there is no more use from the relay, then the robotic node stops functioning for the relay. When the relay position is determined, the robotic node places itself at a position by adjusting to the mobility of the network nodes to maintain the link.

Xiong et al. [38] have proposed a data-harvesting scheme for intermittently connecting mobile sensor network. Their approach took full advantage of storage resource and mobility pattern knowledge to improve the delivery ratio while minimizing the transmission overhead. Furthermore, their robust approach could be adaptive to the dynamic topology of network. An efficient forwarding mechanism and intelligent buffer management strategy were presented by them to route the data from mobile sensors towards a number of fixed or mobile sinks. In their scheme, every sensor was associated with a parameter delivery utility which signified the likelihood that it could deliver a message to a sink. Also, a message was forwarded in their scheme according to the random or utility-based strategy depending on whether the mobility pattern could be predicted to a certain extent.

Bijarbooneh et al. [39] have presented a novel quality-of-information (QoI)-aware data collection protocol (QoIACP) for WSNs with mobile users. The protocol is designed to optimize data utility, which measures the normalized QoI value of collected data per transmission. A hybrid methodology is used in the QoIACP protocol with a distributed neighborhood discovery protocol, but centralized clustering and data collection scheduling for coordination among multiple mobile users. The algorithm can significantly improve data utility at low communication overhead. However, the sensors in QoIACP may have slightly higher communication overhead.

Alayev et al. [40] have proposed to study a variant of TMP problem with adaptive transmission power and rate control. They have formulated the problem for joint scheduling with either power control or rate control or both. The data items are to be transmitted to mobile clients via the stationary data access points (APs). The scheduler dedicates sequences of consecutive timeslots of an AP to downloading a data item to a client. The APs controlled transmission power to tune its transmission range making sure that no interference occurs with neighbouring APs' transmissions. However, if two machine may interfere with one another, the power levels and their transmission rates may change.

Koucheryavy and Salim [11] have presented a prediction-based clustering algorithm for MWSNs. It applies necessary conditions for cluster head election along with heuristic predictors to generate steady and balanced clusters.

3 Ant based routing and QoS effective data collection mechanism

3.1 Ant colony optimization

Ant colony optimization (ACO) is a class of algorithms whose first member is called Ant System. The insects, like ants, bees, etc., acting as a community, even with very limited individual capability, can cooperatively perform many complex tasks necessary for their survival. This new heuristic is robust and versatile in handling a wide range of combinatorial optimization problems [84]. Here, the Forward Ant agent (FA) establishes the pheromone track to the source node, whereas the Backward Ant agent (BA) establishes the pheromone track to the destination node.

Ant algorithms duplicate the behavior of real ant with a certain number of virtual ants constructing solutions on a construction graph. Each edge in the construction graph is assigned an initial amount of pheromone in the pheromone matrix. After the construction, each solution is evaluated. The better the solution the more pheromone and the corresponding ant may deposit on the edges it traversed during the construction of the solution. This proves that the ants choose these edges in the next iteration of the algorithm (Fig. 1).

Once all ants have computed their tour, Ant System updates the pheromone trail using all the solutions produced by the ant colony. Each edge belonging to one of the computed solutions is modified by an amount of pheromone proportional to its solution value. At the end of this phase, the pheromone of the entire system evaporates, and the process of construction and update is iterated.

The functions of an ACO algorithm are as follows:

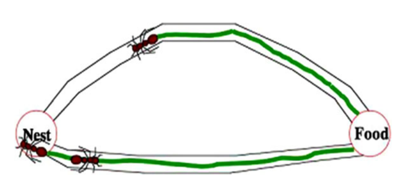

Fig. 1 Foraging behavior of ants

- A set of computational concurrent and asynchronous agents (a colony of ants) moves through states of the problem corresponding to partial solutions of the problem to solve.
- They move by applying a stochastic local decision policy based on two parameters, called trails and attractiveness.
- By moving, each ant incrementally constructs a solution to the problem.
- When an ant completes a solution, or during the construction phase, the ant evaluates the solution and modifies the trail value on the components used in its solution.
- This pheromone information will direct the search of the future ants.

Algorithm 1

Initialization
1. Initialize τιψ and ηιψ, V(ιψ).
Construction
2. For each ant k (currently in state ι) do
3. Choose in probability the state to move into
5. Append the chosen move to the k-th ant's set tabu k.
6. Repeat until ant k has completed its solution
7. End for
Trail update
8. For each ant move (ιψ) do
9. Compute Δτιψ
10. Update the trail matrix.
11. End for
Terminating condition
12. If not (end test)
13. Go to step 2

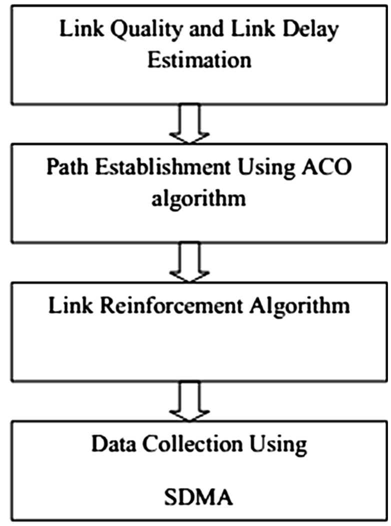

Fig. 2 Block diagram

3.2 Proposed contributions

In this paper, we propose to design Ant based mobility aided routing protocol for WSN. In this protocol, the link quality is estimated in terms of packet reception rate (PRR), received signal strength indicator (RSSI), and link quality index (LQI) [41]. In addition to the link quality, the link delay can also be added in the link reinforcement process [28]. In this protocol for route establishment, the Ant-based routing of ant colony optimization (ACO) is used. Here, the forward ants (FANT) and backward ants (BANT) can be used for route request and route reply process, respectively. Figure 2 shows the block diagram of the proposed routing protocol.

The mobile robots collect the information with high data utility [39]. In addition, we equip each mobile robot with multiple antennas and apply SDMA (Space Division Multiple Access) technique to data gathering [42] from multiple mobile robots. SDMA schedules data transmissions effectively so that we can minimize the total data gathering time by exploring the tradeoff between shortest moving tour of mobile robots and full utilization of SDMA.

3.3 Link quality and link delay estimation

The link quality is estimated in terms of packet reception rate (PRR), received signal strength indicator (RSSI), and link quality index (LQI) [41]. The LQI is estimated according to the Eq. (1) given below:

$$LQI = PRR \times normalized(RSSI_{mean})) \tag{1}$$

$$where\ normalized(RSSI_{mean}) = \frac{RSSI_{mean}}{60} + \frac{100}{60} \tag{2}$$

$$RSSI_{mean} \in [-100, -40]\,\text{dbm}$$
$$normalized(RSSI_{mean}) \in [0, 1]$$
$$PRR \in [0, 1]$$

The link delay, D_{link} is calculated according to Eq. (3) given below:

$$D_{link} = D_{proc} + D_{prop} \tag{3}$$

where D_{proc} is the processing delay involved with the forward ant/backward ant D_{prop} is the propagation delay between two nodes.

3.4 Path establishment for mobile robots using ACO algorithm

The path to transmit the data between the source and the destination is determined using the ACO algorithm. When

Table 1 Format of forward ant

Source address	Destination address	Intermediate nodes	LQI value	Link delay

Table 2 Format of backward ant

Source address	Destination address	Intermediate nodes	LQI value	Link delay

there is need to transmit data, the ant colony is used to discover all the possible paths towards the destination using forward ants and backward ants. The formats of the forward ant and backward ant are described in Tables 1 and 2.

These ants use pheromone to identify the path travelled. The forward ants distribute pheromone as it travels towards the destination. The pheromone aids the forward node to select links with lower delay and connect to nodes with good LQI. After the forward ants reach the destination, backward ant is created which traverses back to the source. The backward ants use the information recorded and pheromone distributed by the forward node to reach the source. The pheromone φ redistributed by backward node is given according to the Eq. (4) depicted below:

$$\varphi = \varphi + LQI - D_{link} \text{ (ms)} \tag{4}$$

Based on the LQI value and time used, the path is selected. The ACO technique is described in Algorithm 2.

Algorithm 2

1. When source (S) wants to transmit data to destination (D)
2. S launches the forward ant (F_{ant}) towards the D.
3. F_{ant} moves towards D through intermediate 1-hop nodes.
4. F_{ant} calculates the LQI value for every path towards all the 1 hop nodes according to Eq. (1).
5. Select the 1-hop nodes with path having higher link quality index (LQI) value.
6. Distribute pheromone at the node when F_{ant} passes a node,
7. As the F_{ant} passes each link, the link delay (D_{link}) is estimated according to Eq. (3).
8. The intermediate node details, link delay and the LQI value of every node traversed by the F_{ant} are recorded by it.
9. When the F_{ant} reaches D
10. Backward ant (B_{ant}) is created by D.
11. The B_{ant} moves towards the source by traversing the path selected by the F_{ant}.
12. During the backward travel, the B_{ant} distributes the pheromone at all the traversed node and records the link delay.
13. When the B_{ant} reaches S
14. S considers the path with best LQI value and lower link delay to transmit the data packet.

Thus, the path from the source to the destination node is determined based on the ACO algorithm which considers the quality of every link used for data transmission. Also, the selected path ensures lower delay in forwarding packets.

3.5 Link quality reinforcement algorithm

Link Quality reinforcement is performed to reinforce the link defects. This is necessary even though the path is determined efficiently using ACO due to the error prone nature of the wireless sensor network. Due to the dynamic network topology, there are possibilities of link compromise. So, link quality reinforcement is used.

Every node maintains a routing table. In the node's routing table, information about its neighboring nodes and surrounding robotic nodes is recorded. The path from the source to destination is selected based on the ACO algorithm, and the LQI at every route is estimated. In case of lower LQI, the link quality reinforcement algorithm is used. The link quality reinforcement algorithm is described in algorithm 3.

Algorithm 3

1. S: Source node
2. D: Destination node
3. ACO: ant colony optimization
4. LQI: link quality index
5. LQI_{ETE}: End To End LQI
6. LQI_{req}: required LQI
7. $REI_{Request}$: Reinforcement Request
8. REI_{node}: Reinforcement Node
9. REI_{reply}: Reinforcement Reply
10. RN_{node}: Robotic Node
11. M_{Req}: Move Request
12. PRE_{node}: Predecessor node
13. $next\_hop_{change}$: Next Hop Change

1. Source S transmits the data to the first intermediate node in the path that is determined previously.
2. When the intermediate node receives the data packet
3. Intermediate node estimates the LQI and appends it at the packet header along with the LQI values of the previous nodes across the path.

Algorithm 3 continued

4. When the data packet is received
5. D retrieves the LQI value at every link and estimates the LQI_{ETE}.
6. D compares the estimated LQI_{ETE} with the predefined LQI_{req}.
7. If $LQI_{ETE} > LQI_{req}$
8. Link quality is good.
9. Else
10. Link quality is poor.
11. End if
12. When the link quality is poor
13. D sends a $REI_{Request}$ to the node with lower LQI and it is considered as REI_{node}.
14. On receiving a $REI_{Request}$, the REI_{node} responds by sending an ACK to D to confirm the request reception.
15. If D receives the ACK
16. D waits for REI_{reply}.
17. End if
18. If D does not receive ACK within a predefined time interval,
19. D retransmits the $REI_{Request}$.
20. End if
21. After sending an ACK to D, the REI_{node} searches for a RN_{node} in its neighborhood and sends a M_{Req} to the closest RN_{node}.
22. On receiving the M_{Req} which consists of the address of the PRE_{node}, the RN_{node} sends an ACK to the REI_{node}.
23. Then the RN_{node} moves towards the assigned location and locates itself at the midpoint between the REI_{node} and PRE_{node}.
24. RN_{node} updates its routing table with its predecessor node as PRE_{node} and its successor node as REI_{node}.
25. RN_{node} then sends a $next\_hop_{change}$ message to the PRE_{node}, to update its routing table with its successor node as RN_{node}.
26. Now, the data packet is forwarded by the PRE_{node} to the RN_{node}, which in turn forwards the data packet to the REI_{node}.
27. On receiving the data packet from the RN_{node}, the REI_{node} sends a REI_{reply} to D to confirm the successful formation of a relay.

Thus, the robotic nodes are included in all the links with poor quality until the data is delivered at the destination. This increases the LQI value and thus stabilizes the path used for data transmission. So, data is delivered at the destination reliably.

3.6 Estimating data utility (D_u)

When a mobile robot enters a sensing field, it performs the function of collecting the data. But, for improved network operation, the data collected need to be of good quality, which is possible only if the data present at each node is of good quality.

Data utility [39] is a metric estimating the sum of qualities of information from the sensed data divided by communication overhead occurring the network in during data collection. Moreover, it maximizes gathered information without any increase in energy consumption.

In Algorithm 4, the process of collecting the data with high data utility is described.

Algorithm 4

Notations:

1. S_i: Sensor node
2. m: mobile robot
3. i: integer value
4. $U(S_i, m)$: data utility for communication between S_i and m
5. $D(S_i)$: Data size that is buffered at S_i
6. $Q(S_i)$: Data quality at node S_i
7. $B(S_i, m)$: Boolean Variable
8. $H(S_i, m)$: number of hops between S_i and m

Initialization: Every sensor node maintains two neighbor node sets; one its immediate neighbor nodes which is considered as the candidate sink nodes and the second node set is the immediate neighbor of its previous node.

1. If the candidate sink node in the node set of the sensor node differs from the candidate sink node of the previous sensor node set (in the sensing field)
2. Current sensor node requests its candidate sink node for a neighborhood discovery process
3. Sink node broadcasts a message that includes information such as node address, data size in the buffer, and data quality to the immediate neighbors (neighborhood discovery process)
4. The sensor nodes receiving the broadcast message responds by providing its information to the requesting node.
5. Based on the received information, the candidate node analyzes the surrounding sensor node's locations.
6. A cluster of sensor nodes is formed by considering the nodes with high data utility value.
7. The data utility value is estimated by the mobile robot according to (5):

$$U(S_i, m) = \frac{D(S_i) \cdot Q(S_i) \cdot B(S_i, m)}{H(S_i, m)} \tag{5}$$

8. The sensor with higher data utility value is selected as the data collecting point by the mobile robots.
9. In this way, a cluster of sensor nodes is formed with high data quality.

Thus, all the sensor nodes with higher data quality are selected by the mobile robots for better network performance.

3.7 Data collection using space division multiple access (SDMA)

Algorithm 5

Notations:

1. P: set of subsets of polling points
2. P_i': subset of polling points
3. S_i': sensor nodes
4. i: integer value

1. The polling points in the network are selected and grouped according to its current region, into a set of subsets of P denoted by P_1', P_2',…, P_n', such that
 $P_1' \cap P_2' \cap \cdots \cdots \cap P_n' = \emptyset$
 $P_1' \cup P_2' \cup \cdots \cdots \cup P_n' = P' \int P_i$
2. The sensor nodes in the network are grouped according to its current location and represented by $S_1', S_2', \ldots S_n'$, such that
 $S_1' \cap S_2' \cap \cdots \cdots \cap S_n' = \emptyset$
 $S_1' \cup S_2' \cup \cdots \cdots \cup S_n' = S' \int S_i$
3. The mobile robots visit the polling points in the sequence P_i' where i = 1, 2 …, n, such that maximum data gathering time among n regions is minimized. Thus, the overall latency involved in data collection from the sensor nodes is minimized.
4. The compatible pair among sensors is determined by connecting two sensors which lie within the coverage area of a single selected polling point.
5. The polling point ensures that the compatible pair of sensors is in a short moving tour.
6. If the sensor pair does not lie within the short moving tour path
7. This pair is ignored. This guarantees the latency involved in data uploading to be maintained at a minimum level.
8. End if
9. By connecting all the polling points, a minimum spanning tree is created, and values are allocated to each point of the tree.
10. Then, the spanning tree is divided into smaller trees, since the network range is usually too large to be considered a single tree.
11. After the tree size is optimized, the mobile robots traverse through the tree.
12. The mobile robots hop from one polling point to the next polling point, along the tree path.
13. At each polling point, the mobile robot collects data from every compatible sensor pair within the coverage area of the polling point.
14. After gathering data from one polling point, the mobile robot hops to the next polling point and so on.

4 Simulation results

4.1 Simulation parameters

We use NS-2 [39] to simulate our proposed Ant based Routing and QoS Effective Data Collection (ARQEDE) protocol. We use the IEEE 802.11 for Mobile Sensor Networks as the MAC layer protocol. It has the functionality to notify the network layer about link breakage. The sensor nodes are randomly deployed over an area of size 500 m × 500 m. In the simulated topology, there are 5 mobile robotic nodes and 95 mobile sensors with one static sink or base station, located at the top right corner. The mobile sensors are moving at an average speed of 2 m/s and the mobile robots are moving at the speed of 5 m/s.

The performance of AMAR is compared with RoCoMAR [28] and MoXMAC protocols, and the performance is evaluated in terms of average packet drop, packet delivery ratio, end-to-end delay, average residual energy, and routing overhead.

The simulation settings and parameters are summarized in Table 3.

4.2 Results and analysis

In this section, the performance evaluation of AMAR and RoCoMAR protocols are presented by varying the data sending rate and number of traffic flows.

4.2.1 Varying data sending rate

The data sending rate of CBR traffic is varied from 50 to 250 kb for 10 traffic flows and the performance is evaluated.

Figure 3 shows the results of delay for ARQEDE, MoXMAC, and RoCoMAR protocols, when the rate is varied. Since ARQEDE includes the link delay metric also in path establishment, the associated delay of ARQEDE is 73 % less when compared to RoCoMAR and 64 % less when compared to MoXMAC.

Table 3 Simulation parameters

Total number of nodes	101
Number of robotic nodes	5
Speed of mobile sensors	2 m/s
Speed of robotic nodes	5 m/s
Area size	500 × 500 m
MAC	802.11
Simulation time	50 s
Traffic source	CBR
Data sending rate	50, 100, 150, 200 and 250 kb
Number of flows	2–10
Propagation	TwoRayGround
Antenna	OmniAntenna
Initial energy	20.1 J
Transmission power	0.660
Receiving power	0.395

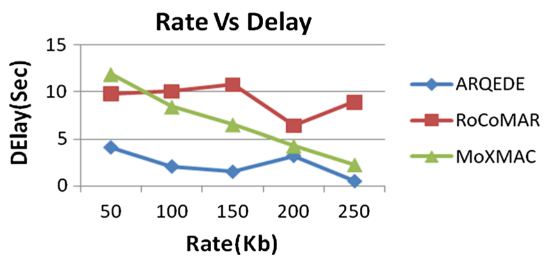

Fig. 3 Rate versus delay

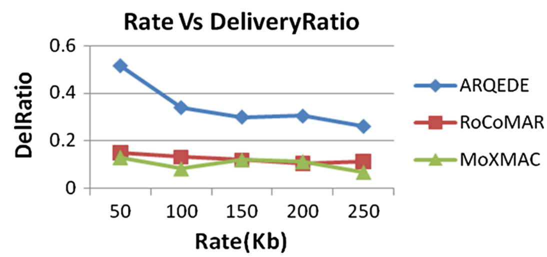

Fig. 4 Rate versus delivery ratio

Figures 4 and 5 show the results of packet delivery ratio and packet drop for ARQEDE, MoXMAC, and RoCoMAR protocols, when the rate is varied. As the volume of data traffic increases, there will be more packet drops. As depicted in Figs. 4 and 5, the packet drop linearly increases for RoCoMAR at higher data rates, whereas ARQEDE shows a steady packet drop and delivery ratio. Accurate estimation of link quality in ARQEDE yields 63 % higher delivery ratio and 90 % less packet drops, when compared to RoCoMAR and ARQEDE yields 70 % is higher delivery ratio and 88 % less packet drops than MoXMAC.

Figure 6 shows the results of overhead occurred for ARQEDE, MoXMAC, and RoCoMAR protocols, when the data sending rate is varied. The use of ACO technique in ARQEDE reduces the huge packet exchange involved in route discovery. Hence, the overhead of ARQEDE is 84 % less, when compared to RoCoMAR and 85 % less,when compared to MoXMAC.

Figure 7 shows the results of residual energy for ARQEDE and RoCoMAR protocols, when the rate is varied. When comparing the performance of the two protocols, we infer that ARQEDE has 21 % higher residual energy, than RoCoMAR, since the number of route disconnections is minimized in ARQEDE thereby reducing the energy involved in retransmission, and 18 % higher residual energy than MoXMAC.

4.2.2 *Varying the data flows*

The number of sources sending data to the sink are varied from 2 to 10 with a data sending rate of 50 kb, and the performance is evaluated (Fig. 8).

Figure 3 shows the results of delay for ARQEDE, MoXMAC, and RoCoMAR protocols, when the rate is varied. Since ARQEDE includes the link delay metric also in path establishment, the associated delay of ARQEDE is 63 % less when compared to RoCoMAR and 64 % less when compared to MoXMAC.

Figure 9 and 10 show the results of packet delivery ratio and packet drop for AMAR and RoCoMAR protocols, when the data flows are varied. As the volume of data

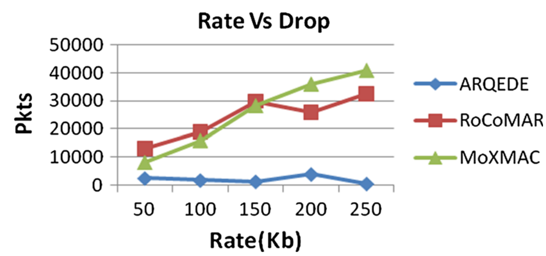

Fig. 5 Rate versus drop

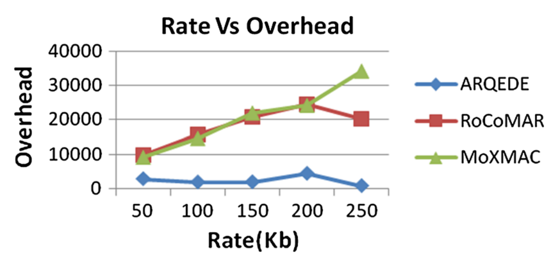

Fig. 6 Rate versus overhead

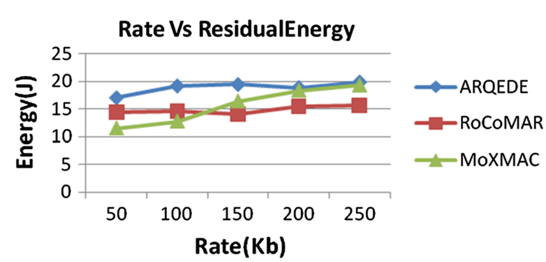

Fig. 7 Rate versus residual energy

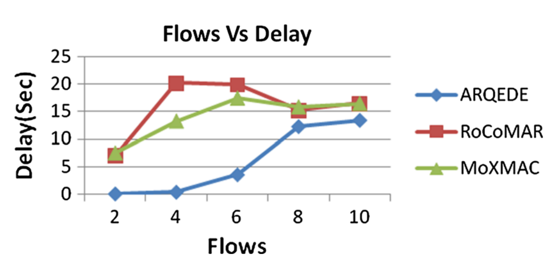

Fig. 8 Flows versus delay

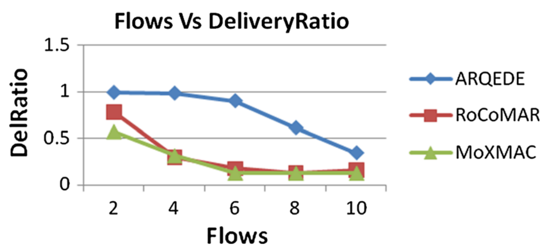

Fig. 9 Flows versus delivery ratio

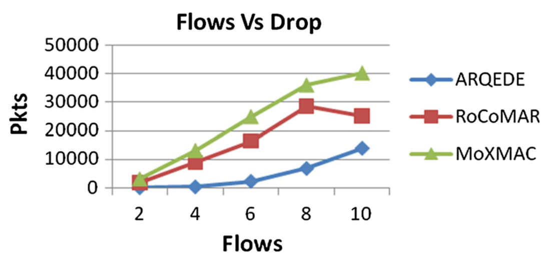

Fig. 10 Flows versus drop

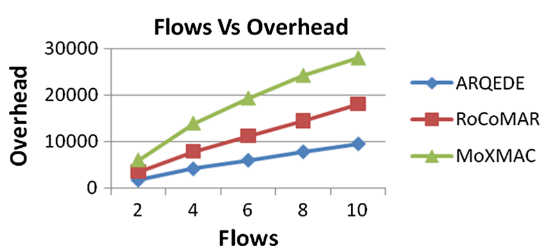

Fig. 11 Flows versus overhead

traffic increases, there will be more packet drops. As depicted in Fig. 4, the packet drop linearly increases for RoCoMAR and AMAR when the data flows are increased. Accurate estimation of link quality in AMAR yields 60 % higher delivery ratio and 67 % less packet drops, when compared to RoCoMAR.

Figure 11 shows the results of overhead occurred for ARQEDE,MoXMAC and RoCoMAR protocols, when the data sending rate is varied. The use of ACO technique in ARQEDE reduces the huge packet exchange involved in route discovery. Hence, the overhead of ARQEDE is 46 % less, when compared to RoCoMAR, and 68 % less, when compared to MoXMAC.

Figure 12 shows the results of residual energy for ARQEDE and RoCoMAR protocols, when the rate is varied. When comparing the performance of the two protocols, we infer that ARQEDE has 14 % higher residual energy, than RoCoMAR, since the number of route disconnections is minimized in ARQEDE there by reducing the energy involved in retransmission and 17 % higher residual energy then MoXMAC.

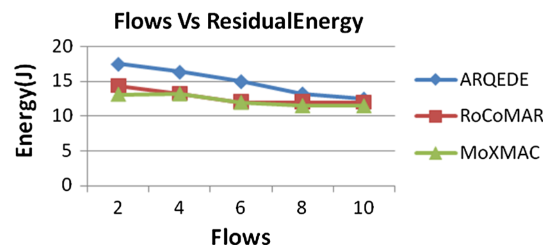

Fig. 12 Flows versus residual energy

5 Conclusion

In this paper, we have proposed ant-based mobility aided routing in WSN. Initially, the ant colony optimization technique is used to determine a reliable path. The forward ants and the backward ants use pheromone to avoid revisiting any node which may prolong the path. The link quality and delay involved are the important factors used for path selection by the ant colony. After the selection of a path, data packets are transmitted by the source towards the destination node. During data transmission, the link quality is again tested and compared with respect to a predefined value. If the link quality is determined to be poor, then robotic nodes are placed in the poor link in between the two consecutive intermediate nodes. This enhances the link quality and makes the link reliable. The data is then delivered at the destination by inserting robotic nodes whenever any link quality is determined to be poor. For QoS-effective data collection, each mobile robot is equipped with multiple antennas to apply SDMA technique to collect data with high utility. Simulation results show that this routing protocol provides reliability by reducing the packet drop and end-to-end delay when compared to existing protocols.

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A. H. Fareen Farzana received her Bachelor degree in Electronics and Communication engineering from Bharathiar University, Coimbatore, Tamil Nadu, India in 2002. She completed her M.E., in Applied Electronics from Anna University, Chennai, Tamil Nadu, India in 2009. She started her career as lecturer in August 2002. Presently she is working as Assistant Professor in the Department of Electronics and Communication Engineering at Aalim Muhammed Salegh College of Engineering. She is pursuing research in the field of Wireless Sensor Networks. Her research interests are in routing in MANET and Wireless Sensor Networks.

Dr. S. Neduncheliyan obtained his B.E. degree in Computer Science & Engineering from the University of Madras in 1989. He obtained his M.S. degree Specialized in Robotics Engineering from Universiti Sains Malaysia, Malaysia in 1999 and his Ph.D. in Faculty of Information and Communication Engineering from Anna University, Chennai in 2009. He started his professional career with a brief stint at Mohamed Sathak Engineering College during 1990–1992 as a Lecturer in the Department of Electronics and Communication Engineering. Later, he joined as lecturer in the Department of Electronics and Communication Engineering in the following institutions: Linton Institute of Technology (1992–1996), Kolej Premier Yayasan Perak (1996–1998), V.L.N. Institute of Technology (1998–2000), Ipoh, Malaysia. He has worked as Asst. Professor and Head of the department of Computer Science & Engineering in Mohamed Sathak Engineering College from 2000 to 2004. He has served as Asst. Professor, HOD (CSE) in Pavendar Bharathidasan College of Engineering and Technology, Jayaram College of Engineering and Technology, Trichy during 2004–2006. Later, he joined as professor and Head of the Department of Computer Science and Engineering at JJ College of Engineering and Technology, Trichy, during 2006–2009. During the period between December 2009 and November 2010, he worked as Principal of SCAD Engineering College, Cheranmahadevi, Tirunelveli. He joined as a Principal of Bajarang Engineering College Veappampatu, Thiruvallur. He has a total teaching experience of 25 years. He has published 20 research papers in International and National Journals. He has also presented 55 research papers in National and International conferences. He is currently guiding five students towards the award of Ph.D. degree in Anna University. His areas of interest are: Wireless Sensor Networks, Computer Networks, Interval Analysis and Robotics. He is having Ph.D. Guideship in Bharathiyar University as well as Vel's University.