Agent Based Multipath Routing in Wireless Sensor Networks

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Abstract—**recently, mobile agents have been used to solve many problems in wireless sensor networks. Agents are usually transferred from a node to another to aggregate the sensed data and simplify the complexity of the routing algorithms. Intelligent agents can reduce the communication cost over a very low bandwidth links among the sensors. However, agents are still new to sensor networks. Small numbers of the research papers have been published in such area. In this paper, we propose an Agent Based Multipath Routing (ABMR) algorithm for wireless sensor network. The algorithm considers many of the sensors and the monitored field parameters such as energy, reliability, and number of hops, as well as the data importance. The algorithm builds a reliable multiple paths from the source to the destination. The number of paths is selected based on the importance of the sensed data. Intelligent agents are designed to construct the multipath as well as to send the sensed data to its destination. To show the effectiveness of the proposed algorithm, ABMR is compared to non-agent based algorithm (NABMR) as well as to one of the recent multipath routing algorithm through an extensive set of experiments.**

Keywords-sensor netorks; routing, Multipath , reliable

I. Introduction

Recently, sensor networks have gained a lot of attention from academia and industry alike. Sensor networks are formed from a combination of homogenous or heterogeneous sensors. Sensors cooperate to form an ad hoc network and report their sensed data to usually more powerful node(s) named sink node. The sink node could also query the sensors for specific information. Therefore, sensor networks could be classified from this prospective into event-based and query-based. However, some applications might require the reporting and the query features at the same time. In addition, sensors suffer from a severe shortage of energy, computation, memory, and storage. Nevertheless, once sensors are deployed, they are unattended and required to survive for long time.

The first phase of forming a sensor network is the deployment. During this phase, sensors are either arranged manually or deployed randomly using for example flying robot or helicopter [2]. The deployment greatly affects the next phase which is the routing phase. For instance, the network topology and the connectivity of the nodes are formed based on the sensors locations in the monitored field. Sensors connectivity is identified by the communication range of each sensor which might be different in case of heterogeneous sensor network. Consequently, a multi-hop network might be constructed. During the routing phase, the sensed data, query, and control messages are traveled from a node to another to reach their destination. This transfer consumes a considerable amount of sensors energy; in fact, the communication is the most energy consuming in sensor networks. Therefore, many routing protocols are proposed mainly to save the sensors energy and prolong their lifetime.

Agents have been used in many applications to reduce the number of message that need to be send from one node to another. We propose using agents in routing in sensor networks to reduce the number of data and control messages and prolong the sensors lifetime. Agents are also great tools in case of communication with low bandwidth which is one of the main features of sensor networks.

Sensors could be used in many emergency scenarios such as fire rescue and battle field monitoring. For instance, sensors in a fire rescue operation are either pre-deployed or “deployed on the fly” by the firefighters. These sensors not only detect the hot spots in the fire place but also guide the firefighters through the fire as well as report their position to the control center. Messages are usually send from the control center to the firefighter to warn or direct him/her through the fire. On the other hand the firefighter may send messages to ask for help or report his/her status. In such scenarios, reliable reporting protocol will play a key role in a successful fire rescue operation; otherwise, firefighters as well as people in fire will be exposed to danger. Our work in this paper considers establishing multipath routing for reliable transition.

At the same time, there are many parameters that need to be considered in routing. For instance, it is not desirable to send the sensed data to a node with low energy, or through unreliable links. In addition, sensors might be surrounded by hazards such as fire. Routing through nodes in fire might not be the best choice. Therefore, we believe considering parameters such as sensors energy, reliability, hazard will enhance the sensor network operations and can save lives and prevent disasters.

This paper is organized as follows; it starts by the related work in section 2, the used network model and our assumptions are presented in section 3, NABMR is introduced in section 4, section 5 presents the performance evaluation experiments, finally, the paper concludes in section 6.

II. Related Work

Although mobile agents are new to sensor networks, they have been proposed to solve many problems wireless networks. For instance, agents are utilized to solve the data dissemination [14] [17], Node coverage [18], and routing problems [16] in sensor networks. In [14] and [17], agents transferred to the data sources and aggregate the collected data instead of moving the data to a centralized node for processing. Manik el at. in [18], studied the coverage problem using mobile agents. Agents are used to identify the faulty nodes for further redeployment. In [16], the authors studied the usage of mobile agents in Directed diffusion routing algorithm [4]. The problem with this agent based routing algorithm is that it is used only with a specific scenario where multiple agents need to be initiated for different image processing. In addition, the directed diffusion utilizes the query based sensor networks and is not suitable for reporting/event-based networks. Our routing algorithm on the other hand can be utilized in both types of networks and it is not related to specific application.

Many routing protocols have been proposed for wireless sensor networks. These protocols could be categorized based on the used techniques to flooding, gradient, clustering, and geographic routing protocols. Flooding algorithms such as SPIN [3] is based on a controlled flooding to the messages where traditional flooding problems like implosion, overlap, and resource blindness are handled. The protocol uses meta-data instead of full data-packet which is much shorter than actual data packets transmitted. SPIN authors reported that it delivers 60% more data per unit energy than blind flooding protocol. However, nodes have to be active all the time and this might consume a large amount of sensors' energy.

Gradient algorithms such as Directed Diffusion [4], GRAB[5], and GEAR[6] are data centric communication protocols where all communication is for named data (attribute-value pair). The Next hop along the route is decided by matching the data with established gradients in the network. The disadvantages of such protocols are that they are not energy aware as well as the gradient setup phase is expensive.

Another set of protocols are the clustering protocols such as LEACH [7] and TTDD [8]where random cluster head selection is done each round with rotation to spread the workload. The communication completed with cluster head via TDMA MAC (a fixed schedule for communicating with non cluster nodes) and data aggregation is done at the cluster head. The problems with such routing protocols are: 1) failure of cluster head might cause many of the routing problems, 2) cluster head selection is a difficult process to optimize, and 3) they are based on expensive assumption for all nodes to be capable of long range communication.

The final category of the routing protocols is geographical routing such as GPSR[9] and GAF [6]where they make use of the geographical information for efficient routing. Such protocols are application dependent and need tuning for parameters like estimated node active time, time for discovery, and active and sleep. The readers are referred to [10] , [11], [12] , and [13] for more details on the routing protocols and their taxonomy.

The most related routing algorithm to our work is the one proposed in [1] which could be classified as gradient algorithm. The authors proposed a multipath routing algorithm that considers sensors energy level and signal strength. The authors claimed that their routing algorithm outperforms both directed diffusion and flooding algorithms. However, the authors neglected many of the parameters that might affect the routing such as number of hops and data importance. In addition, the algorithm considers only homogenous sensors; such assumption might not fit a wide range of sensor networks applications.

A common problem with all of the previous protocols is the lack of adaption to the monitored area conditions. None of the previous protocols considered for example the hazard level of subareas in the monitored field. They did not consider the hazards that might be generated around the nodes due to the environment condition. For instance, some high energy nodes might be surrounded by a fire that might destroy the nodes. Selecting such node to be part of a path might disconnect such path. Also, sometimes the sensed information might have different importance level. For example, data sensed by a node that is deployed in a strategic place is more important than data sensed from nodes deployed in non strategic areas.

We introduce NABMR as Non-Agent-Based routing protocol that considers many of the sensors as well as the monitored field parameters. NABMR , for instance, selects the next hop node in a route based on the hazard level of the surrounding subareas in the monitored field. In addition, it takes into consideration the next hop sensors residual energy, number of hops, and channel reliability. Moreover, it is a disjoint multi paths protocol where the number of paths to be constructed are selected based on the importance of the sensed data. Routing the message to a neighbor with the highest energy might guarantee delivering it to another hop. In addition, sending a message to a shortest distance using sensor's low energy node might save its energy. On the other hand, this might affect the overall distance that a message has to transfer. Therefore, combining the distance with the number of hops is expected to optimize the overall distance that a node has to travel.

Another parameter that any reliable algorithms should consider is the channel reliability. Channel reliability could be measured based on the signal strength between the nodes or from the previous history dealing with the neighbors. Moreover, for a reliable message delivery, a disjoint multi path might be used. We believe that selecting the number of paths based on the message importance may safe the overall network energy as well prolong the network lifetime. We also believe that considering all of these parameters during the routing will guarantee the reliable delivery of the messages.

III. Network Model and Assumptions

Given a set of sensors *S* to monitor a field *F*, sensors form a wireless ad hoc network in which they cooperate to send a message from any node to the sink or vice versa. A sensor node $s \in S$ may act as a sensor, router, or both. In addition, sensors are assumed heterogeneous in terms of their energy, communication range, and sensing range. Some of the sensors might be mobile in which they can move from one place to another while some others are stationary. In fact, heterogeneous networks are proven to be more efficient in terms of their lifetime and efficiency where homogenous sensor networks suffer from poor scalability [14].

Nodes report their sensed data based on the monitored field activities as well as according to the sink node requirements. The sink node is responsible of setting the reporting rate during the configuration phase where it is not part of our discussion in this paper. Nevertheless, nodes are assumed to have enough storage and capabilities to discover their neighbors.

At the same time, the monitored field is assumed to have differentiated monitoring requirements. Some areas in the monitored field might be considered more important in terms of monitoring than other areas. This certainly will affect the message routing in the network.

We assume smart sensors that can measure the required parameters such as channels reliability and current residual energy. Generating such data is out of the scope of this paper. However, this data is used to select the next best hop. A threshold value is set for each parameter where a node $s \in S$ reports the changed parameter(s) to its neighbors if the parameter(s) value increased more than the threshold(s). Nevertheless, nodes are assumed having the store and forward capabilities in case of any message transfer failure or there is a need for retransmission.

Although our protocol in this paper is inspired by data driven protocols, it can be used in data driven or query-based sensor networks. In data driven network, sensors send their data when an event occurs or periodically. While in a query network the sink node initiates the process by sending an interest on the network and a node that has data about this interest will reply.

IV. NABMR: Non Agent Based Multipath Routing in Wireless Sensor Networks

In this section, we introduce our proposed routing protocol; it is designed to have multiple paths between the source and the destination. These paths consider many of the network parameters as well as organize the routes in a way that they work as backup to each others. NABMR works in two phases as follows:

Phase 1: Nodes' Routing Tables Initialization

In this phase, nodes collect information about their neighbors. However, each node needs to know the most basic information such as its neighbors' energy level, channel reliability, and the hazard level around it. The hazard level is used as one of the measures to discard some of the nodes from joining any of the created paths. A threshold is set in each node either before the deployment or sent in a message from the sink to all nodes after deployment. If the hazard level of a node is greater than this threshold, the source node discards the sender node from the path creation phase. This information is updated if any of these sensors parameters dropped or increased severely.

Figure 1 shows the control message format that is sent by each node to its neighbors. As shown in the figure, three fields along with the message header (*Msg Header*) and message type (*MsgType*) are included in the message. The message type (MsgType) field is used to differentiate between the control and data messages. The Energy level field E_s is used to hold the node's current energy level. In addition, H_s and C_{is} fields are used for Node's hazard level and channel reliability between nodes *i* and *s* respectively. Each node is assumed to have a table that keeps such neighbors information.

MsgHeader	*MsgType*	E_s	H_s	C_{is}

Figure 1: Nodes' control message

Phase 2: Multi-paths Creation

In the first phase, each node collects information about its neighbors. Now, if a node (source node) needs to send its data to the sink or any other node (destination node), it has to go through the paths creation process. In this process, the number of paths to be created depends on the information importance level. We adapted the US emergency level for both the information importance as well as the hazard level of each node. Therefore, the importance of the information is divided into five levels which are severe, high, elevated, guarded, and low. Corresponding to each level a number of paths are configured.

The source node starts by selecting the best number of nodes based on the neighbors' energy and channels' reliability after normalization as in equation (1). (E_s / C_{is}) represents the ratio between the sensor's energy and the channel's reliability which they are quite related. α and β are constants that are chosen to prioritize the node based on the energy channel reliability ratio and hazard level H_s.

Node Priority = $\alpha(E_s / C_{is}) + \beta H_s$ (1)

It is obvious from the previous equation that there is a tradeoff in selecting the best values for α and β. Selecting high value of β, avoids the highly hazard areas while high value of α chooses the reliable and high energy nodes. In addition, the number of paths N_s is defined based on the importance of the information to be sent. The source node sends a path request message formatted as shown in Figure 2. Again, the *MsgType* represents the type of the messages to be sent; in this case, it is a path request type. *PN* is concatenated node identifiers along the path including the source node while *PHC* is the accumulated hope count along the path. In addition, *PD* is the accumulated path distance where the distance between the nodes are added.

Msg header	*MsgType*	*PN*	*PHC*	*PD*

Figure 2: Nodes' control message

To form a multi disjoint paths from the source to the destination, a reserved flag is assigned to the visited nodes. If a path request is sent to a node that is already joined a path, it returns a "*Reserved*" message to the sender. The path request message is propagated through the network until it reaches the destination node. Once, this information is arrived at the destination node, it priotrizes the paths based on equation (2) which contains only two parameters *PD* and *PHD*. We did not consider all of the other parameters during selecting the main and backup paths to avoid all sensors parameters along all of the selected paths to the sink node.

Path Priority = (PD /PHC) (2)
, where PD is the path total distance and PHC is the path hop count.

Consequently, the sink node returns the paths along with their priorities through the highest important path to the source node. Once paths are received by the source node, it starts to send its data through the main path till it finishes. If a path is down for any reason, one of the backup paths is activated. In sensor networks, nodes might be scheduled to go sleep mode; therefore, in order to keep the selected routes alive without any disconnectivity, a selected node is notified to stay awake till the end of the sending period. However, a path reconfiguration procedure is initiated if a path node has to be out of the path due to for example energy depletion or node capturing.

Once the source node is done with its data, it sends a control message to all nodes that joined the paths to free them. Nodes may go to sleep mode in such case unless they are reserved by another source node.

V. ABMR: Agent Based Multipath Routing in Wireless Sensor Networks

In this section, we explain our agent based routing (ABMR) algorithm. The main idea behind using a mobile agent in the routing is to avoid broadcasting the sensors data such as residual energy and reliability periodically to the neighbors. Sending such data consumes a lot of the sensors energy especially if we are dealing with mobile nodes. Instead, an intelligent mobile agent will collect such data and take the appropriate decision.

ABMR considers two types of agents which are *Node_Selection* and *Path_Fusion* agents. *Node_Selection* agent is a mobile agent that is responsible of visiting the source node neighbors and collecting their information. In addition, it is responsible of choosing the required number of nodes for paths selections. *Path_Fusion* agent is stationary agent that is usually initiated by the destination node. It prioritizes the paths returned by *Node_Selection* agent according to the paths parameters.

i. *Node_Selection* Agent Packet Format

The *Node_Selection* mobile agent packet format is shown in Figure 3. As can be seen, two fields *Src* and *Dest* are reserved to the addresses of the source and destination nodes, respectively. Both fields are used as unique identifier to *Node_Selection* agent. The next *NextHop* field is used to hold the selected next node address. The payload consists of the processing code and the collected data. The collected data includes the visited and their information.

Src	*Dest*	*NextHop*	*Agent Code*	*Data*

Figure 3: *Node_Selection* agent packet format

ii. ABMR Algorithm Details

ABMR works in two phases; in the first phase the *Node_Selection* mobile agents travel from the source node to its neighbors to collect the required information. The required information includes sensor's residual energy, distance, and channel reliability. The agents return back to their sender to decide the best number of nodes to select from among the neighbors. As can be seen from such scenario, agents are not initialized unless there is a data to be sent from the source node. Sensors in such case do not have to periodically send their status (parameters) to their neighbors. Equation *(1)* is used to sort the number of nodes according to their parameters. Therefore, the required number of nodes based on the sensed information importance is selected.

Once the agent decides on the neighbors to be selected to join the paths, it spawns other agents to those neighbors to do the same tasks. However, each agent needs to choose only the best node from all the neighbors. Those agents will travel through the network holding the overall path and nodes information up to the destination node.

As noticed from the collected information at the destination node, they are contradicting. For instance, the residual energy and channel reliability need to be maximized while hazard, the path hope count, and distance need to be minimized. Therefore, the *Path-Fusion* agent is spawned on the sink node to perform such job. The agent uses a simple genetic algorithm to solve such optimization problem. Since the sink node is usually a powerful node, running such algorithm will not affect the performance of the overall sensor network. The multi objective evaluation functions are stated in the following equations:

$$Obj\_1 = Max \sum_{s=1}^{n}(E_s + C_{is}) \quad (3)$$
$$Obj\_2 = Min \sum_{s=1}^{n}(d_{is}/PHC + H_s) \quad (4)$$

Where E_s is the sensors residual energy, C_{is} is the channel reliability between the sensors i and s, d_{is} is the distance between the sensor i and its neighbor s, n is the number of nodes in each path, and PHC is the Path Hop Count.

The chromosome is a binary string that depends on the number of the source neighbors. Each field could be 0 or 1 where 0 means that the neighbor is considered during the routing, otherwise it is not considered. For instance, if a sensor $s \in S$ needs to send its sensed data to the sink node through four paths and it has six neighbors, the chromosome may look like the one in Figure 4. The Figure shows a chromosome that includes sensors with identifiers 2,3,5, and 6. Each chromosome is evaluated using the previous two objective functions stated in equations (1) and (2). Therefore, each chromosome produces two values.

0	1	1	0	1	1

Figure 4: Chromosome example

The initial population could be any number of chromosomes. However, only two chromosomes are used throughout this paper for simplicity and to reduce the required processing. At the same time, two pools are reserved for chromosomes with the best chromosomes produced from equations (1) and (2) respectively. The crossover operation is done by merging the two chromosomes together. Figure 5 shows a sample crossover between two of the chromosomes. The crossover operation is followed by mutation operation which randomly changes some of the bits from ones to zeros and vice versa provided that the number of ones in each chromosome stays the same.

1	1	1	0	0	1

1	0	1	0	1	0

(a) Before crossover operation

1	1	1	0	1	1

(b) After crossover operation

Figure 5: Crossover operation example

The resulted chromosome is evaluated and compared to the two chromosomes in the pools and replaces one of them. If the value of new obj1 and obj2 are not better than the ones in the pools, the crossover and mutation operations are performed again on the chromosomes at the pools and the new chromosome is discarded. The stopping criteria could be based on a number of iterations or number of iterations without any change in the objective functions.

VI. EXPERIMENTAL RESULTS

In this section, we evaluate NABMR and ABMR through a number of experiments. In the first set of experiments, the effect of the number of messages on the network dissipated energy is studied. The effect of the hazard level on the messages delivery rate is presented in the second set of experiments. The hazard in these experiments is modeled by Gaussian distribution function for the purpose of simulation. Finally, another set of experiments are conducted to study the network delay due to hazard distribution.

NABMR in these experiments are compared to the multipath routing algorithm proposed in [1]. As mentioned, the authors compared their algorithm to the directed diffusion and flooding algorithms. Therefore, comparing our algorithm to it will be sufficient to prove its efficiency. We use SENSE simulator to simulate both algorithms. SENSE parameters are adjusted to use linear battery and IEEE 802.11 as MAC layer with only one sink node. In our experiments, we use heterogeneous set of nodes with different sensing and communication ranges as well as the initial energy. The running time for any experiment is assumed open till the network is disconnected. In addition, the values of α *and* β are set to 50% each. Therefore, they will have equal effect on the routing conditions. These values are application specific and might vary accordingly.

A. *Effect of Number of Messages on the Average Dissipated Energy*

In this set of experiments, we study the effect of number of message on the average dissipated energy for NABMR, multipath, and ABMR algorithms. 100 nodes are uniformly distributed in an area of 400 X 400m. The number of messages changes from 100 to 500 messages, as shown in Figure 6, and the number of paths generated are changed from single path to five paths with each experiment for all algorithms.

Figure 6a shows the average dissipated energy in case of no hazard is found in the network. As shown, NABMR and multipath algorithms almost have the same average dissipation energy. However, in some cases, the multipath algorithm shows less energy dissipation rate due to less computation in taking the routing decision. On the other hand, ABMR is taken less energy from the sensors due to the huge reduction in the parameters update messages send from each node to its neighbors. For instance, in case of 500 messages that are sent from different source nodes to the sink node, ABMR consumes on average 35% , NABMR consumes 50% , and multipath consumes 48% of the sensors energy.

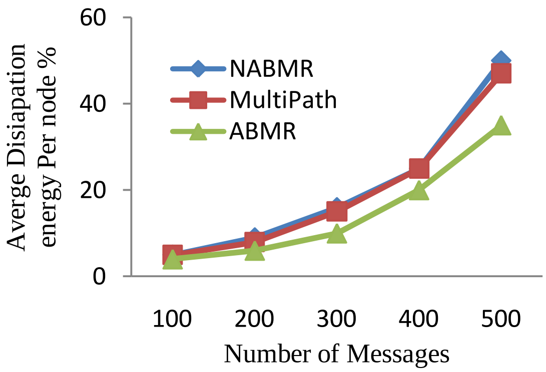
On the other hand, Figure 6b shows a big difference in the consumed energy among the three algorithms when hazard are applied. Based on our experiments, NABMR consumes on average 10% less energy than the multipath algorithm. This 10% is consumed in retransmitting the messages that are dropped due to hazard areas. It is obvious from such scenario that as hazard around the nodes increases, more messages will be dropped by the multipath algorithm and more energy will be consumed by the nodes. At the same time, ABMR consumes almost 15% less than NABMR algorithm. Again, ABMR performance comes from eliminated the update messages from the network. However, based on our experiments, we came across another problem which is in order for agent to collect the sensors parameters; it has to go through hazard nodes. Those agents might not come back to the source node. Therefore, we set a time to live (TTL) for each agent to be killed.

B. *Effect of the Hazard on the Delivery Rate*

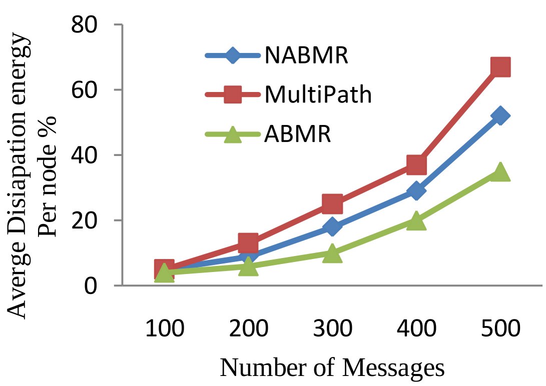
In the previous set of experiments we deliberated the effect of the hazard level on the dissipated energy in all algorithms. However, hazard seems to affect the multipath routing more than NABMR and ABMR since it is not hazard aware. In this section, we conducted different set of experiments to compare NABMR, ABMR , and multipath algorithms in terms of message delivery rate with no hazard and when hazard is introduced in the network. We start by looking at the delivery rate when there is no hazard is generated. We use the same network configuration presented in the previous section.

As shown in Figure 7a, the delivery rate of both algorithms, on average, is almost the same. However, at some points such as 300, NABMR and ABMR over performed the multipath algorithm due to selecting of large number of paths condition based on the information importance. On the other hand, ABMR seems to outperform NABMR in terms of the message delivery rate. Based on our observations, in NABMR some of nodes might die because of energy depletion due to large number of messages required to be sent.

On the other hand, when hazard is introduced in the network, the delivery rate of multipath algorithm is reduced sharply due to high message loss. As shown in Figure 7b, on average almost 25% of the messages are dropped due to the hazard. However, NABMR and ABMR well performed in such cases where the delivery rate is almost 98% and 99%, respectively. The 2% and 1% loss, as we noticed, is due to high hazard areas that are distributed for some periods of time and prevents NABMR and ABMR from finding any alternative paths.

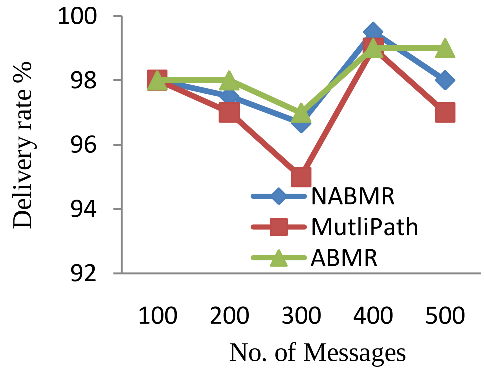


(a)

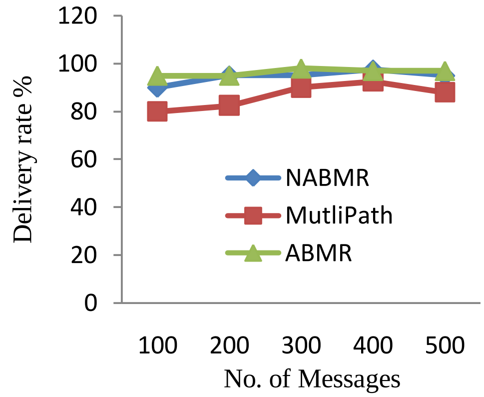


(b)

Figure 6: Average dissipation energy percentage per node (a) without applying hazard; (b) with hazard



(a)



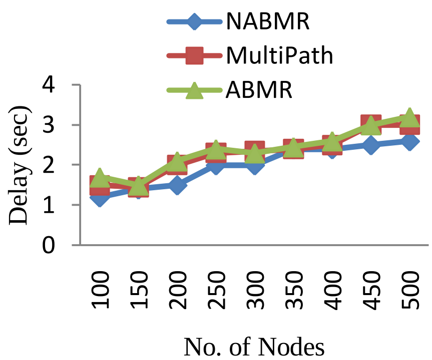
(b)

Figure 7: Message delivery rate (a) without hazard , (b) with hazard

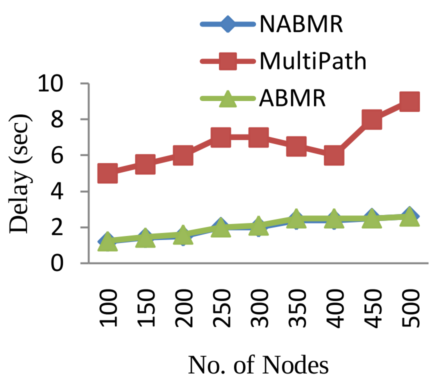
C. *Effect of Number of Nodes on the Message Delay*

In this final set of experiments, we study the effect of increasing the number of nodes on the average message transmission delay. As shown in Figure 8a, we measured the delay when no hazards are generated in the network. NABMR seems to slightly outperform the multipath algorithm in most of the cases. On the other hand, AMBR and NABMR are performing almost the same with a little delay in ABMR due to the initial step in collecting the neighbor's information.

At the same time, when hazard are introduced in the network, as shown in Figure 8b, the multipath suffers from high delay while NABMR and ABMR have only few millisecond difference from the previous case. For instance, NABMR has a delay of 2 seconds when 500 nodes are used while multipath algorithm needs 8 seconds average to deliver same number of messages. In addition, as mentioned, some messages will never be delivered due the hazard distribution. ABMR and NABMR are performing almost the same with few milliseconds more delay in ABMR. Overall ABMR and NABMR are adapting to the network conditions.



(a)



(b)

Figure 8: Average delay in seconds (a) without hazard, (b) with hazard

VII. Conclusion

In this paper, we proposed NABMR as a new hazard aware multipath reliable routing algorithm. The algorithm considered many of the sensors as well the environment parameters such as sensors' energy, reliability, and hazard. In addition, we introduced ABMR algorithm to study the usage of mobile agents in the routing. We compared the performance of NABMR, ABMR and multipath algorithms through a set of experiments. Our experiments show the effectiveness of NABMR and ABMR in terms of energy dissipation, delivery rate, and delay.

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