International Journal of Computer Information Systems and Industrial Management Applications.
ISSN 2150-7988 Volume 4 (2012) pp. 522–529

Energy Aware Hybrid PUSH-PULL with Fault Tolerant Approach in Sensor Networks

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Abstract— **Wireless sensor networks (WSNs) have wide variety of applications and provide limitless future potentials. Nodes in WSNs are prone to be failure due to energy depletion, hardware failure, communication link errors, malicious attack, and so on. Therefore, fault tolerance is one of the critical issues in WSNs. Directed diffusion is a classic data-centric routing protocol in Wireless Sensor Networks (WSNs). However, the communication cost and energy balance over the whole WSNs have not been paid enough attention. Hybrid PUSH-PULL data Diffusion (LOHD) is a data dissemination algorithm for data-centric sensor networks. LOHD works well in a wide range of networks and source/sink settings. It adaptively selects an ultra-node through a well-controlled flooding and the ultra-node maintains the gradients from sources to sinks. In this paper we intend to improve energy consumption and data delivery ratio. In former we use the hybrid Push-Pull and in the latter we use the fault tolerant mechanisms. The most commonly used technique for fault recovery is replication or redundancy of components that are prone to be failure. In this paper we improve the LOHD with considering energy parameter in order to extend the lifetime of the sensor network, and we introduce fault tolerant method in order to increase the reliability and data delivery ratio. Simulation results show that our proposed protocols are outperforms directed diffusion in energy efficiency, energy balance over WSNs, and delivery ratio.**

Keywords: Wireless Sensor Networks, Fault tolerant, Directed diffusion, Energy efficient.

I. INTRODUCTION

Wireless sensor networks are envisioned to consist of many small devices that can sense the environment and communicate the data as required [1].

The sensor network is one of the multi-hop networks similar to the ad hoc networks. Therefore, each sensor node forwards the data if it receives the data from another sensor node. In ad hoc networks, researchers focus on the communication performance like as the throughput and other factors. However, the most critical requirement for widespread sensor networks is power efficiency since battery replacement is not viable [2].

Sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime. In a multi-hop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

In a sensor network a node communicates with other nodes that lie within the transmittable range to accomplish the given tasks. Due to the constraints of sensors, the sensor network routing protocols are much simpler than any other network routing protocols. Routing protocols for wireless sensor networks are responsible for maintaining the routes in the network and have to ensure reliable multi-hop communication under the energy limitation.

We think that a more useful metric for routing protocol performance is *network survivability* [3]. By this we mean that the protocol should ensure that connectivity in a network is maintained for as long as possible, and that the energy health of the entire network should be of the same order. This is in contrast to energy optimizing protocols that find optimal paths and then burn the energy of the nodes along those paths, leaving the network with a wide disparity in the energy levels of the nodes, and eventually disconnected subnets. If nodes in the network burn energy more equitably, then the nodes in the center of the network continue to provide connectivity for longer, and the time to network partition increases. However, the routing protocol for wireless sensor networks should be fault tolerant and should bypass the hole and prevent the hole enlarging. There are several research works that analyze and propose fault-tolerance mechanisms for wireless sensor networks. A first type of faults is related to software problems (e.g. bugs in the embedded programs) in the nodes, that prevent them from functioning correctly. In reference [4], the authors have analyzed and presented a mechanism to correct them. A second type of errors is the erroneous estimation of the sensed parameter (e.g. the node seems to work properly, but the values returned by sensor are incorrect). Reference [5] has examined this behavior and proposed a solution based on the computation of a correlation value between the different sensed values.

A number of routing protocols have been proposed for sensor networks [6] [7] [8] [9] [10][11]. However, these protocols normal only focus on achieving one goal so that they are not general enough for WSN applications. Data-centric routing is normally neither load-balanced nor fault-tolerant. We discuss that a good routing protocol for WSN should be designed by considering the characteristics of the sensor network and satisfying the primary requirements of a good routing protocol. In this paper, we focus on designing an *energy*-efficient, load balanced and fault-tolerant, routing protocol.

From the simulation results, we evaluate the performance of the algorithm and clarify the effect of that on the sensor networks.

The rest of paper is organized as follow: In section II, related works has been described, In section III, we abstract the requirements of a good routing protocol for WSN. Review of directed diffusion algorithm in section IV. In section V we described the LOHD algorithm. We present our algorithm in section VI. A fault tolerant approach on proposed algorithm has been presented in section VII. Simulation results are presented in Section VIII; finally we proposed the conclusion in Section IX.

II. RELATED WORK

Y. Yu, R. Govindan, and D. Estrin [10] discussed an energy-efficient routing protocol for routing queries to target regions in a sensor field. The protocol, called Geographic and Energy Aware Routing (GEAR). In GEAR, the sensors are supposed to have localization hardware equipped, for example, a GPS unit or a localization system so that they know their current positions. Furthermore, the sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbors. GEAR uses energy aware heuristics that are based on geographical information to select sensors to route a packet toward its destination region.

Rahul Shah et al.[3] proposed using sub-optimal paths occasionally to increase the lifetime of the network substantially. This protocol is a destination initiated reactive protocol like Directed Diffusion with the difference being that instead of maintaining one optimal path, a set of good paths are maintained and chosen by means of a probability which depends on how low the energy consumption of each path is. Thus any single path does not get its energy depleted because different paths are chosen at different times. This ensures the graceful degradation of the network in low-energy networks because energy is burnt more equally in all nodes.

Schurgers et al. [11] have proposed a slightly changed version of Directed Diffusion, called Gradient-based routing (GBR). The idea is to keep the number of hops when the interest is diffused through the network. Hence, each node can discover the minimum number of hops to the sink, which is called height of the node. The difference between a node's height and that of its neighbor is considered the gradient on that link. A packet is forwarded on a link with the largest gradient.

Xu Cheng, Feng Wang, and Jiangchuan Liu[9] introduced a novel Location-Oblivious Hybrid PUSH-PULL data Diffusion (LOHD) algorithm, which suits a wide range of networks and source/sink settings. We discuss this in greater detail in section V.

III. PRIYMARY REQUIREMENTS OF ROUTING PROTOCOLS

Due to the severe energy constraints of large number of densely deployed sensor nodes, it requires a suite of network protocols. The traditional routing protocols have several shortcomings when applied to WSNs. First, it is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Therefore, classical IP-based protocols cannot be applied to sensor networks. Second, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management. In this section we define some requirements of routing protocols in WSNs.

- **Energy efficient**
  Since sensor nodes are battery powered, they have limited energy capacity. Routing protocols designed for sensors should be as energy efficient as possible to extend their lifetime, and hence prolong the network lifetime while guaranteeing good performance overall. Many conventional routing metrics such as the shortest path algorithm may not be suitable. Instead, the reasons for energy consumption should be carefully investigated and new energy-efficient routing metrics developed for WSNs.
- **Load balanced**
  Traffic can also be distributed in such a way as to maximize the life of the network. A path should not be used continuously to forward packets regardless of how much energy is saved because this depletes the energy of the nodes on this path and there is a breach in the connectivity of the network. It is better that the load of the traffic be distributed more uniformly throughout the network. So a good routing protocol should have a feature of load balance to extend the lifetime of the sensor network.
- **Fault tolerant**
  Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. Thus, the routing protocol for wireless sensor networks must accommodate formation of new links and routes to the data collection base stations.

IV. DIRECTED DIFFUSION

Directed diffusion consists of several elements: interests, data messages, gradients and reinforcements [7]. The base station floods the sensor network with a query about the interested events. The 'interest' query specifies the sensing task. The data messages are the events generated by a single or a group of nodes in response to the query sent by the base station. The interest queries are disseminated throughout the sensor network as an interest for named data. This dissemination sets up the "gradients" within the network to draw events. A gradient is a direction state created in each node that receives an interest [7]. The node, which generates the events, sends the events back to the base station along multiple gradient paths. The directed diffusion algorithm assumes that each node knows its location once deployed. A key feature of directed diffusion is that every sensor node can be application-aware, which means that nodes store and interpret interest packets, rather than merely forwarding them along the route. Each sensor node that receives an interest packet maintains a table that contains which neighbor(s) sent that interest. To such a neighbor, it sets up a gradient. A gradient is used to evaluate the eligibility of a neighbor node as a next-hop node for data dissemination. After setting up a gradient, the sensor node redistributes the interest packet by broadcasting. In [13], original DD is extended to a DD protocol family, which includes: a) two-phase pull diffusion, b) push diffusion, c) one-phase pull diffusion, each of which are summarized hereafter.

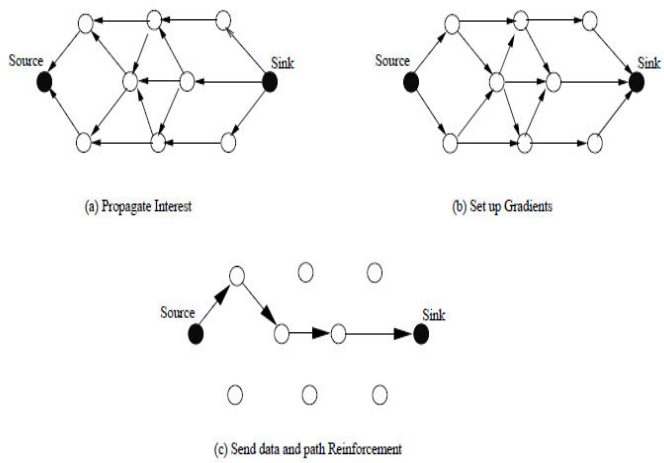

Fig. 1. Directed diffusion Scheme

A. Two-Phase Pull Diffusion

Two-phase pull diffusion is the original directed diffusion. In two-phase pull diffusion a sinks sends interest to find sources. After receiving the interest, sources forwards exploratory data messages to maintain paths toward the sink. When exploratory data reaches the sink, the sink *reinforces* its preferred neighbor, establishing a reinforced gradient towards the sink. The reinforced neighbor reinforces its neighbor in turn, all the way back to the data source or sources, resulting in a chain of reinforced gradients from all sources to all sinks. Subsequent data messages are sent only on reinforced gradients rather than to all neighbors.

Moreover, using reinforcement, the data routes can be dynamically changed according to the changes in the WSN. In this case, the sink sends reinforcement messages through a new path other than the current path. Furthermore, negative reinforcement messages are sent through the current path to suppress data transfer through that path.

B. Push Diffusion

The two-phase pull diffusion works well when there are a few numbers of sinks. In one-phase push diffusion, the roles of the source and sink are reversed. Sinks become passive, with interest information kept local to the node subscribing to data. Sources become active; exploratory data is sent throughout the network without interest created gradients. An advantage of push diffusion compared to two-phase pull is that it omits interest propagation where information is sent throughout the network rather than two phases .Push is optimized for a different class of applications, but where sources produce data only occasionally. Push is not a good match for applications with many sources continuously generating data since such data would be sent trough the network even when not needed.

C. One-Phase Pull Diffusion

A benefit of push diffusion compared with two-phase pull diffusion is that it minimized flooding that can be a significant benefit in large networks .In one-phase pull, when an interest arrives at a source, it does not send exploratory message to establish gradient from source to sink, but instead sends data only on the preferred gradient. The preferred gradient is determined by the neighbor who first sends the matching interest, thus suggesting the lowest latency path. Thus one-phase pull does not require reinforcement messages, and the lowest latency path is implicitly reinforced. One-phase pull has two disadvantages compared to two-phase pull. First, it assumes symmetric communication between nodes since the data path (source-to-sink) is determined by lowest latency in the interest path (sink-to-source). Two-phase pull reduces the penalty of asymmetric communication since choice of data path is determined by lowest-latency exploratory messages, both in the source-to-sink direction [13]. Second, one-phase pull requires interest messages to carry a flow-id, this requirement makes interest size grow with number of sinks.

V. THE LOCATION-OBLIVIOUS HYBRID PUSH-PULL DATA DIFFUSION ALGORITHM (LOHD)

The pull and push work well when there are a few sinks or sources, respectively. When the number of both sources and sinks increases, neither Push nor Pull can avoid the significant overhead increase. [12] Proposed a novel Location-Oblivious Hybrid PUSH-PULL data Diffusion algorithm (*LOHD*).

LOHD first finds a rendezvous node called ultra-node, which is selected by the intersection of local flooding respectively from the sources and sinks. In this stage all the sources broadcast the identical messages called SOS (SOurce Searching) and all the sinks broadcast the identical messages called SIS (SInk Searching).

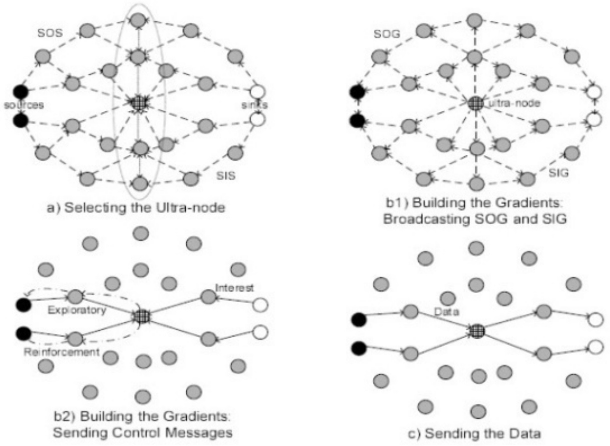

Fig. 2. Data Sending Steps in LOHD

Node's distance to its nearest sink is defined as dSI and its distance to its nearest source as dSO. After the SOS/SIS flooding is done, each node with
|dSO− dSI| < R will then randomly generate an integer number. By setting *R* to 1, the selected ultra-node will be exactly in the middle of the sources and sinks.

When the ultra-node is determined, the field is divided into two parts (sinks to ultra-node and sources to ultra-node). The ultra-node then broadcasts SOG (SOurce Gradients) towards the first part and SIG (SInk Gradients) towards the second part. When the sources (sinks) receive the SOG (SIG) messages, the gradients from the sources (sinks) to the ultra-node are established. Then the sources send the exploratory data and the sinks send the interests to the ultra-node through the established gradients instead of flooding. Therefore, the required gradients between sources and sinks are built.

VI. THE PROPOSED ALGORITHM

Using the shortest path without considering the residual energy of nodes, it is may leads to fail the intermediate nodes and in the worst case it is possible that network partition. To counteract this problem, we propose a new mechanism that we call ELOHD. The basic idea is that to increase the performance of LOHD algorithm by using the energy aware mechanism.

Unlike location centric algorithm each sensor node in LOHD needs not to know its position information, all its decisions about data transmission are based on its knowledge about the neighbor nodes, so that it eliminates the extra requirement for additional hardware and the overhead for complicated localization computation. Each node chooses that neighbor from whom it first received, without considering other parameters, such as energy level.

On relaying the messages, all the nodes record the previous sender. But due to energy limitation maybe intermediate nodes fail to forward incoming packet, thus, in ELOHD each sensor node checks a remaining power capacity of its neighbors and determines the activity of route construction process.

Since the location information is unavailable, gradients are necessary for relaying the data. Our goal is to build the gradients between sources and sinks efficiently.

ELOHD has two stages: First, we select proper ultra-node candidate. By increasing *R* in original algorithm (LOHD) more nodes can be as the ultra-node candidate; therefore we can choose the one has the maximum energy. As a result, the energy of the ultra-node would last more because all data is sent through the ultra-node, thus the energy of the ultra-node maybe consumed rapidly.

Second, we choose appropriate path (source to ultra-nod and ultra-node to sink) depend on node's energy remaining. Each of the intermediate nodes forwards the exploratory (interest) message to a neighbor with maximum energy. This is continued till the exploratory (interest) packet reaches the ultra-node. At the same time, the energy differences between different nodes are reduced. As a result we try to choose one path with maximum energy connecting the source to the destination

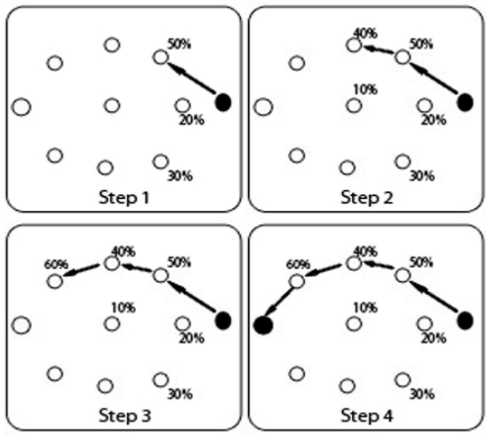

Fig. 3. ELOHD Work Flow

It is interesting to note that the shortest path (shortest in hop count) is not the most preferred path in terms of splitting probability.

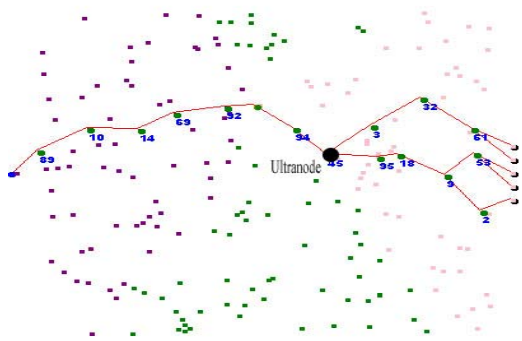

Fig. 4. LOHD Path Finding

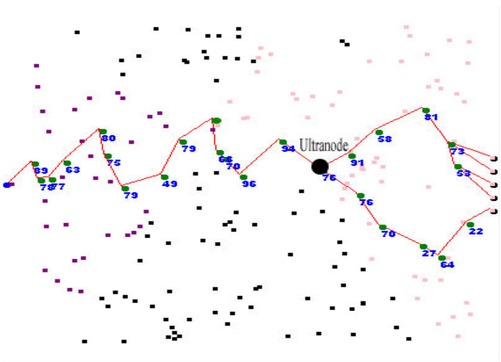

Fig. 5. ELOHD Path Finding

VII. FAULT TOLERANT APPROCH BASE ON PROPOSED ALGORITHM

One of the key prerequisites for effective and efficient embedded sensor systems is development of low cost, low overhead, high resilient fault-tolerance techniques.

Fault-tolerance is the ability of a system to deliver a desired level of functionality in the presence of faults. Fault-tolerance is crucial for many systems and is becoming vitally important for computing and communication based systems as they become intimately connected to the world around them, using sensors and actuators to monitor and shape their physical surroundings.

We focus our attention on how to back-up one type of sensor with another. There are two main reasons for this decision. The first is that we can save the discovered path for long time and the second is that we can save the energy of nodes without need to determine the new path. In this section, we introduce fault tolerant energy aware data diffusion (FELOHD) which is a modified version of the well known LOHD method.

FELOHD proposes vital solutions to some shortcomings of the pure LOHD and ELOHD methods that we proposed in previous sections.

There are several reasons for a communication link or a node to fail. Fault-tolerance mechanisms tackle these abnormal situations. Generally there is a trade-off between the reliability improvement obtained by a fault tolerance mechanism and the performance of the network.

The power supply on each node is relatively limited, and frequent replacement of the batteries is often not practical due to the large number of the nodes in the network. Therefore, energy is the most constraining factor on the functionality of such networks. In order to save energy, nodes only use the short range communications which is proven to be much less energy consuming than the long range. The short range communication between the nodes implies localized interaction in the network.

As we showed in previous section, by determining the suitable intermediate node we can improve the pure LOHD algorithm performance to send data toward the sink. Dropping the intermediate node causes to destroy the path over the network, so the aggregated data can't be send from the nodes to sink through the same route. In this situation we have to build a new route between nods and sink, thus we have to consume more energy to find a new path for sending data in the network. Therefore we use one alternative ultra-node that has more energy than other intermediate nodes in the network.

Figure (6) shows this method clearly, how designing the fault tolerant in data diffusion.

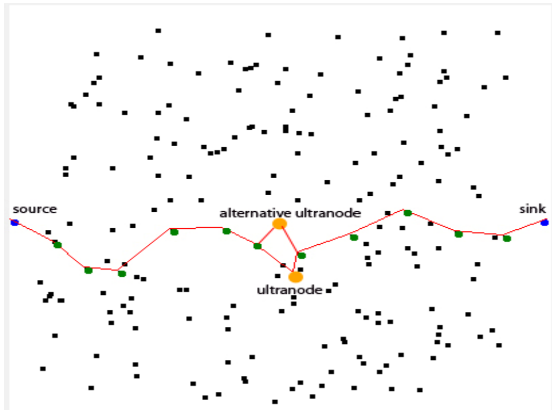

Fig. 6. Alternative ultra-node (FELOHD)

We can use the ultra-nodes periodically to save their energy or we can use alternative ultra-node when the primary ultra node fails. In latter the delivery ratio will increase. We examined the effect of this method with pure LOHD and ELOHD in next section but there are many interesting questions remain open and it would be premature to claim that this method has proven the data diffusion and network life under any circumstance.

VIII. SIMULATION RESULTS

In this section we compare the proposed algorithm with LOHD. We consider square fields, in which sources and sinks are clustered in the two diagonal corners and we assume that 100 nodes are randomly dispersed into a field with dimensions 50 m^2. The nodes are fixed and the radio transmission rate is 12 m. A sensor node's transmitting and receiving power consumption are 0.650 W, 360 W, respectively. The size of data packet is 200 byte. The initial power of each node is given randomly.

A. *Energy consumption*

Energy consumption is a metrics to measure the efficiency and the lifetime of WSN. Figure 7,8 and 9 shows a snapshot of energy consumption by using three different routing protocols. The x-axis is the value of the average energy of nodes and the y-axis depicts the value of lifetime of the sensor network.

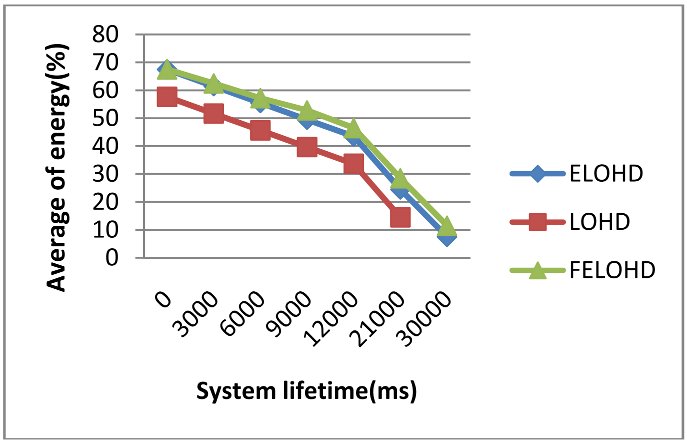

Fig. 7. Wireless Sensor Network's lifetime with one source and one sink

Figure 7 shows the average energy as function of network lifetime in WSN. This simulation shows how node's energy affects the performance of the network lifetime. As can be seen ELOHD increases lifetime of the network by selecting the energy aware path. FELOHD has better result than ELOHD because of the node that is considered as alternative ultra-node. In FELOHD when ultra-node fail due to its function second ultra-node will be used and there is no need to reconstruct the path. FELOHD saves the process of reconstructing the path and has a little longer life time than ELOHD.

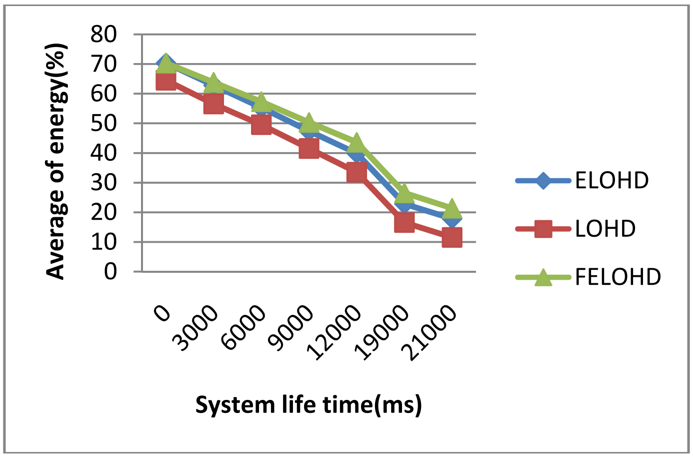

Fig. 8. Wireless Sensor Network's lifetime with one source and five sinks

Figure 8 and 9 compare the average energy of nodes among LOHD, ELOHD and FELOHD. As can be seen in figures, the average energy of nodes in ELOHD and FELOHD are better than the original algorithm and the lifetime of the sensor network increases.

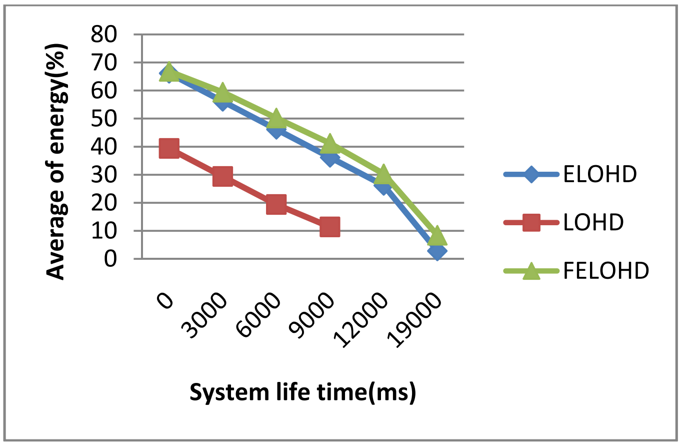

Fig . 9. Wireless Sensor Network's lifetime with one source and 10 sinks

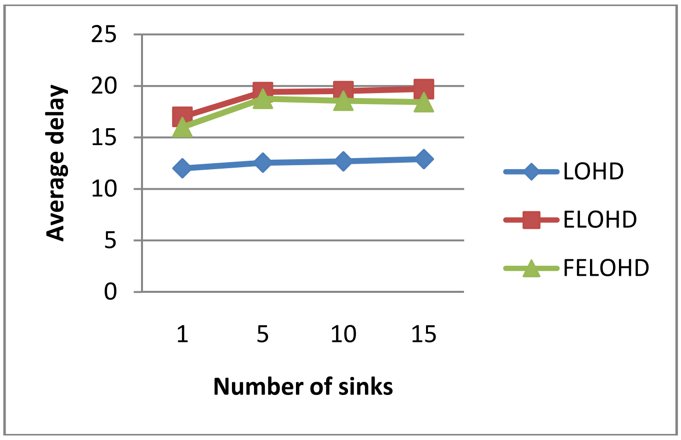

Fig. 10. Wireless Sensor Network's delay

We can find that ELOHD and FELOHD take longer length path than LOHD due to their mechanism to balance the load and avoid holes, thus the average delay of the network increases.

A. Packet delivery

We use packet successful delivery rate to measure the fault tolerance of the three routing protocols. We find that FELOHD provide better packet successful delivery rate as shown in Figure 14 and Figure 15. In both figures, the x-axis is the number of successful delivered packets and y-axis represents the simulation time. FELOHD has a high successful delivery rate and LOHD has the lowest successful delivery rate.

From above sections, we conclude that FELOHD extends the lifetime of the sensor network, decreases the load imbalance factor, increases the message successful delivery rate, and controls the number of the failed sensor and the hole enlargement at a cost of extending the path length a little bit.

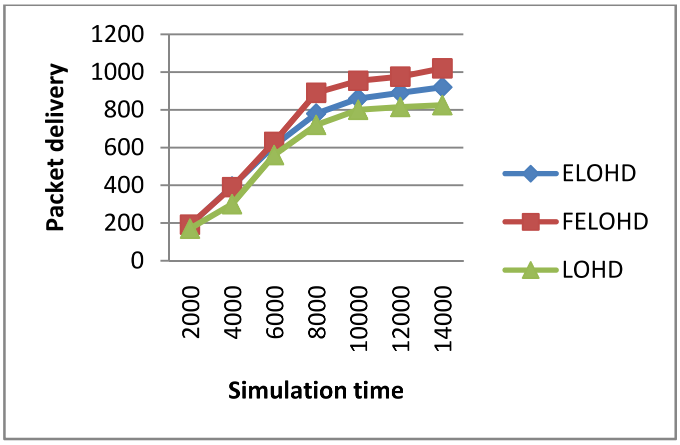

Fig. 11. Packet delivery with one source and five sinks

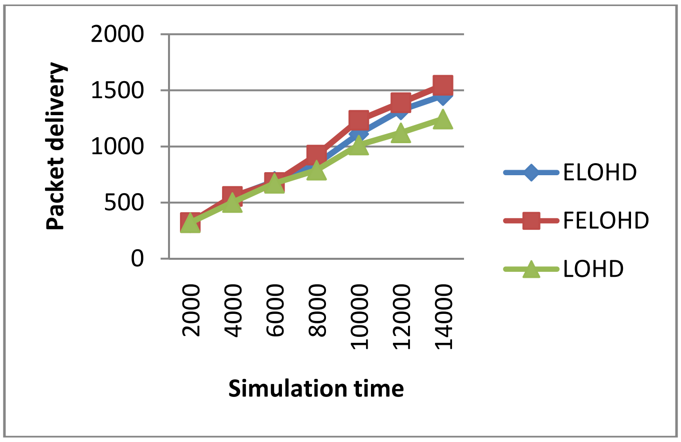

Fig. 12. Packet delivery with one source and ten sinks

IX. CONCLUSION

The shortest path is not always necessarily good for the network life time. Thus we used energy aware mechanism to choose intermediate nodes with higher amount of energy between several candidate nodes.

In this paper we introduce a well known protocol for wireless sensor networks which is Location-Oblivious Hybrid PUSH-PULL data Diffusion algorithm (*LOHD*) protocol. We mentioned the most shortcomings in this protocol and we proposed new versions of LOHD which is attempting to solve its shortcomings; the proposed protocols are called Energy Efficient and Fault Tolerant LOHD.

We presented a new mechanism to select the intermediate nodes base on energy aware mechanisms and Fault tolerant approaches, which considers the remaining energy of node to achieve the balance of energy consumption in network, then the probability of each node to be selected to perform transmission task is increased. Also we have developed a new approach to design low overhead fault-tolerant sensor networks. The key idea is to use one type of sensor to back-up sensors of different types by exploiting flexibility during multimodal sensor data fusion.

Since the proposed protocols consume less energy, the network has a longer lifetime. In addition, the proposed protocols have a slightly higher delivery fraction than the original PULL-PUSH directed diffusion. By doing this network lifetime increased and the nodes energy balanced in the network.

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