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ENERGY AWARE FAULT TOLERANCE TOPOLOGY CONTROL ALGORITHM

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ABSTRACT

Wireless sensors network (WSN) has emerged as one of the most common and widely spread wireless networks and is widely deployed in different fields and environments. Topology control algorithms aim to conserve energy and improve network capacity by choosing the right transmission power and neighbors so that the network is connected and has the desired properties. In WSN, topology nodes located away from sink node send the data of their messages over different long paths, which require higher amounts of energy than the near sink nodes. On the other hand, if any parent node in the topology fails due to technical error or energy depletion, nodes that send data over this failed node consume more energy and there is higher data loss due to selecting higher cost paths or failing to find an alternative one. In this paper, an energy-aware and fault tolerance topology control has been proposed which can built topology to minimize energy consumption and rebuild the affected parts of network topology in the case of parent nodes failure. WSN topology was built to minimize the maximum load of each topology node which can minimize power consumption and maximize the network lifetime. On the other hand, in the fault tolerance phase, the proposed mechanism monitored WSN nodes and in the case of node failure, the affected part of network topology was rebuilt and it can resume data collection immediately. Results showed that the proposed mechanism reduced the maximum load up to 35% compared to the AODV scenario. However, Packet delivery ratio and network throughput were increased up to 44% compared to energy based without the failure tolerance topology control mechanism in the case of node failure.

Keywords: *WSN, Topology control, fault tolerance, controlled sink*.

1. INTRODUCTION

WSNs are one of the most active and popular wireless networks which have gathered worldwide attention recently. An enhancement in Micro-Electro-Mechanical Systems (MEMS) technology has utilized the development in smart and small sensors production, which accordingly made WSN more popular. Smart sensor nodes are low powered devices equipped with one or more sensors, a processor, memory, a power supply, and an actuator with appropriate network services and protocols. A WSN mainly collects data from the monitored environment using sensors where it then delivers to the sink node via multi-hop wireless communications. WSN technology connects the physical world to the digital world. It has attracted tremendous attentions from both academia and the industry due to its great potential role in changing our ways to interact with the environment.

The standard architecture of WSNs is shown in Figure 1. [1] WSN mainly consists of sensor nodes, sink node and a remote user. All the data collected by the sensor nodes are forwarded to a sink node. Therefore, the placement of the sink node has a great impact on the energy consumption and lifetime of WSNs.

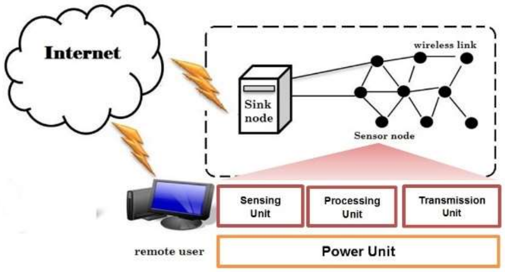

Figure 1 WSNs Architecture

Typically, a sensor node has four main components which are sensing, processing, transmission and power units. The sensing unit consists of a sensor and Analog to Digital Converters (ADCs) which convert the analog signal produced by a sensor to the digital signal. The sensor converts a physical phenomenon to the electrical signal. The processing unit constitutes a microprocessor or microcontroller which controls sensors, executing communication protocols and signal processing algorithms on the collected sensor data. Transmission unit collects the information from the processing unit and then transmits it to sink node. In the power unit, the main source of energy is the battery power. So, power unit supplies the battery power to the sensor node.

WSNs can be deployed to various environments where the users are concerned. Sensor nodes can be either simply distributed randomly in the field, or their locations are carefully planned. Such flexibility extends the feasibility of WSN. For example, they can be deployed in an area where people are hard to reach. In a WSN, there are typically many sensor nodes and one or more sink nodes. The sensor nodes are responsible for collecting information from the environment. The sink nodes are responsible for storing and processing information collected by the sensor nodes, and delivering the control messages to the sensor nodes. They also serve as the gateway between the users and the sensor network. A user can query the data generated by some sensor nodes via the sink nodes, or receive the reports of events detected by some sensor nodes via the sink nodes.

The importance of topology control lies in the fact that it critically affects the system performance in several ways. As shown in [2], the proposed mechanism determined the network spatial reuse and hence the traffic carrying capacity. Choosing a power level that is too large results in excessive interference, while choosing a power level that is too small may result in a disconnected network. Topology control also affects the energy usage of communication, and thus impacts the battery life. In addition, topology control also affects the contention for the medium. Contention and potential collision can be mitigated as much as possible by choosing the smallest transmission of power subject to maintain network connectivity [3], [4]. Topology control can guarantee network connectivity, improve the efficiency of wireless communications in sensor networks by mitigating interferences and collisions, and improve the efficiency of collaboration among sensor nodes [5]. This paper mainly focus on providing a reliable topology control which minimize the maximum relative load to maximize the lifetime of WSN, it also provides a reliable fault tolerance mechanism to overcome nodes energy depletion conditions and continue data delivery.

The rest of this paper is organized as follows: in the next section, the proposed mechanism for controlling WSN topology is presented. In section *3*, the proposed topology control and fault tolerance mechanism are discussed in details and evaluation metrics are defined. In section *4*, simulation scenarios and network topology are presented where simulation parameters are also defined. Results are presented and the discussion and investigation are illustrated. Section *5* concludes the proposed mechanism.

2. RELATED WORK

[6] proposed an energy-efficient topology control algorithm for maximizing network lifetime in wireless sensor networks with mobile sink which provided a predefined delay tolerance level. Each node did not need to send the data immediately as it became available. Instead, a node can store data temporarily and transmit it when the mobile sink arrived at the most favorable location for achieving extended network lifetime. However, the authors did not use grid architecture because data collection relied on anchor nodes. As a consequence, their solution cannot be applied in homogeneous WSNs.

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A novel scheme for energy enhancement in wireless sensor networks is proposed by [7] where data aggregation is done using Ant Colony Optimization. However, high energy consumption at the Cluster head (CH) caused a higher rate of data transmission which can minimize the network lifetime and causing data lose.

[8] mainly focused on finding Continuous and Optimal Trajectory (COT) in the network. However, the shortest path is not always used so in many cases higher energy consumption is done and minimize the network life time

[9] proposed a mathematical optimization approach for node distribution, activity schedule mobile sink, and data routing problem. Wrong movement and data routes of the sink mobility can result in longer path for data delivery and thus increase power consumption and decrease network lifetime.

[10] proposed a fault tolerance mechanism which depended on clusters formed at each round, where the number of exchange messages is increased so more energy can be utilised for maintaining fault tolerance. This study focused on faults that may occur in the cluster head, while sometimes faults may occur elsewhere.

[11] proposed a coordinated and controlled mobility of multiple sinks for maximizing the lifetime of wireless sensor and presented an MILP model to give a provable upper bound on the lifetime of the WSNs. However, the proposed solution restricted the latency of delivered packets.

[12] utilized a typical topological graphs algorithm. The results demonstrated that moving the sink always improves the lifetime of the network. However, data forwarding doesn't consider energy loads and energy consumption and multiple nodes energy depletion can occurs.

[13] proposed a controlled sink mobility for prolonging wireless sensor networks lifetime and presented a centralized MILP model which specified the duration and the order. However, the proposed solution restricted the latency of delivered packets.

3. ENERGY AWARE AND FAULT TOLERANCE TOPOLOGY CONTROL

A new WSN topology control algorithm which can increase the network lifetime is proposed in this paper. This energy aware and fault tolerance topology control algorithm (EAFTC) constructs the network topology at minimum power consumption and optimizes energy consumption. It is also designed to tolerate nodes failure related to energy depletion.

The EAFTC algorithm is similar to the Dijkstra shortest path algorithm [14]. Dijkstra algorithm is proposed to find the shortest paths between different graph nodes. This algorithm can be used to find the shortest path between any source node toward the destination node. The main difference between Dijkstra algorithm and EAFTC algorithm is that EAFTC selects the path from network node toward sink node to achieve minimized power consumption and distribute load among nodes.

The main goal of the EAFTC algorithm is to extend the lifetime of the wireless sensor network by achieving optimum power consumption and tolerate node failure. EAFTC has two main phases. The first phase is to achieve optimum power consumption by preventing communication with maximum power and replacing it with collaborative architecture based on determining communication power of network nodes. This collaborative architecture minimizes the rate of power consumption for nodes with small remaining power by minimizing communication burden of forwarded data and information.

The second phase task mainly re-forms the connections in case of node failure, removes depleted nodes and prevents network collapse to tolerate node energy failure.

3.1 EAFTC Algorithm Assumptions:

The WSN includes different scenarios, which are different data delivery mechanisms that mainly depend on the status of the sink node, node power consumption and node remaining energy. In the proposed algorithm for controlling the network topology, the following assumption is assumed.

1- Controllable sink mobility path which means that the path is not random.
2- Consumed power is directly proportional with communication distance, where farther nodes require more power to send data to them.
3- All nodes have identical power consumption for sending a single unit of data to the same distance.
4- Predefined remaining energy threshold which indicates node depletion when the remaining energy is lower than it.
5- Sink node has unlimited power.

3.2 EAFTC Algorithm Architecture:

EAFTC algorithm controlled the network topology by selecting the parent or next hop for all network nodes to achieve minimum power consumption and increase network lifetime. The consumed communication power of nodes mainly depends on three factors:
1- The number of neighbor nodes that it communicates with.
2- The distance between nodes.
3- The remaining node power.
EAFTC mainly has two phases: the first phase involves building the network topology based on the power consumption and maximizing network lifetime, and the second phase involves monitoring network nodes for node energy depletion and rebuilding the affected part of the network topology.

Phase 1: Building energy aware network topology

Suppose that a network contains N nodes and M links, where $L\ (n\ n_2)$ is the link between node n_1 to node n_2, $G(n_1)$ is the set of neighbor nodes that n_1 communicates with to retrieve and forward information. $P\ (n_1,\ n_2)$ is power required to transmit one unit of data from n_1 to n_2, and $R(n_1)$ is the remaining power of node n_1.
So, we can define the maximum load of the node $n1$ as $O(n_1)$ [6], where :

$$O(n_1) = \frac{(\text{number of members of } G(n_1) \text{ x } Max(P(n_1, G(n_1))))}{R(n_1)} \quad (1)$$

The concept of EATC Algorithm is to control the network topology to achieve minimum $O(n)$. The root of the network topology, where all network nodes will forward data to, will be the location of the sink. This mobile sink is assumed to have unlimited power and it is connected to the master nodes which are directly connected to the nodes to collect data in links with minimum distance. Each non-master node joins the topology and the link between this new node with existing nodes will be selected to achieve minimum load.
To illustrate the EAFTC Algorithm methodology, consider the network in **Error! Reference source not found.**. Node S is the mobile sink node, where nodes $n_1,\ n2,\ n3$ are the master nodes directly connected to the sink node. In this example, we assume that the remaining power of all nodes $R(n)$ is equal to 1. Node 13 is the new node which is added to the network. The parent node of node 13 is required to be specified. The load for the parent node candidates which are nodes $n11$, $n10$ and $n12$ is calculated. The new node n13 is connected to it and the first parent candidate is node 11. Substituting in equation 1,

we have $O(n11)$ =6 x 2= 12. If the parent node candidate is node 10, the load is $O(n10)$ =3 x 3 = 9; however, if the parent node candidate is node 12, the load is $O(n12)$ = 4 x 2 = 8. So, to minimize the maximum load the best parent node of node 13 is to connect it to $n12$.
The proposed algorithm can minimize the power consumption and extend the network lifetime due

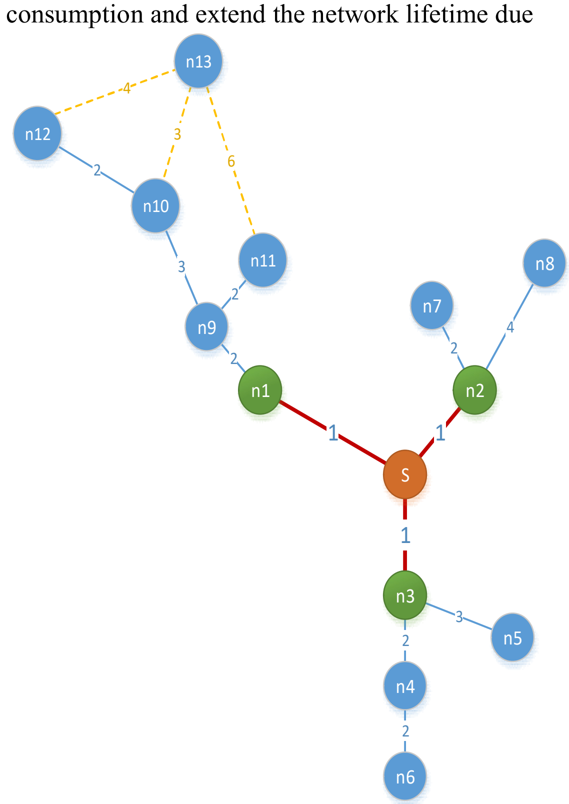

Figure 2 Example of the energy aware topology generated by EAFTC Algorithm methodology

its ability to minimize the communication overhead and distribute it among capable network nodes.

```
Retrieve new WSN node ( N_new )

Retrieve all Nodes located at the coverage of  N_new  ( NS_coverage ).

Set O(n_temp)   = Maximum load of node_1 in NS_coverage.

Set Node_Candidate = node_1

For reach node_i  in NS_coverage

If (node_i-energy > threshold)

       Calculate Maximum load of the node_i  as O(n_i)  as shown in
equation before

If (O(n_i) < O(n_temp)   )
Node_Candidate = node_i
O(n_temp)   = O(n_i)
End IF
End IF

End For loop

Set N_new Parent  =  Node_Candidate
```

Figure 3 Pseudo code of Network topology building

```
Retrieve all Topology Nodes N_all  .

For each node_i  in N_all

If ( node_i-energy  < energy_threshold )

      Retrieve all childs of node_i  (node_i-childs)

             For each node_m in node_i-childs

                    Add node_m to topology

             End For loop
End IF
End For loop
```

Figure 4 Pseudo code of Energy depletion and fault tolerance mechanism

Phase 2: Tolerate energy depleted nodes

The proposed algorithm monitored the energy level of each node if any data forwarding or sending operation was performed. A predefined value of energy threshold was 3 joules. If the node energy was decreased lower than the predefined threshold value, an energy depletion alert was raised. When energy depletion alert was raised, the algorithm started to specify the affected nodes. If the energy depleted node was an edge node where no communication can pass through it, nothing was implemented. On other hand, if the energy depleted node was a parent node, the EAFTC algorithm specified the affected nodes which passed their data through the depleted node and then retrieved all the nodes which had

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common coverage with these nodes. Then EATC algorithm reconstructed the part of the network topology including these nodes and ignored the depleted node. Energy depletion and fault tolerance mechanism is as shown in **Error! Reference source not found.**.

3.3 Performance evaluation

The proposed algorithm performance was evaluated against two main scenarios: Ad Hoc On-Demand Distance Vector(AODV) scenario and the algorithm of Joint sink mobility and routing to maximize the lifetime of wireless sensor networks which is proposed in [6]. These two scenarios were designed with constrained or predefined path sink mobility assumption.
Evaluation experiments were performed using networks which have a predefined number of nodes. The overall load of the network and the evaluation metrics were measured.
Multiple evaluation metrics have been measured. These metrics represent the network performance and how it behaves with different simulation circumstances. The evaluation metrics include:

1. Maximum relative loads.
2. Network throughput.
3. Packet delivery ratio.
4. End-to-end delay.

4. METHODOLOGY AND PERFORMANCE EVALUATION

To simulate the proposed mechanism against the latest proposed research of topology control, a simulation topology network has been built as shown in Figure . The simulation network includes 12 nodes. Node 0 represents the sink node, with nodes 1,2 and 3 connected directly to the sink node. The neighbors of each node and the link weight which represents the power required to transmit a unit of data which is directly proportional to the distance between two connected nodes are shown for each node at the network.

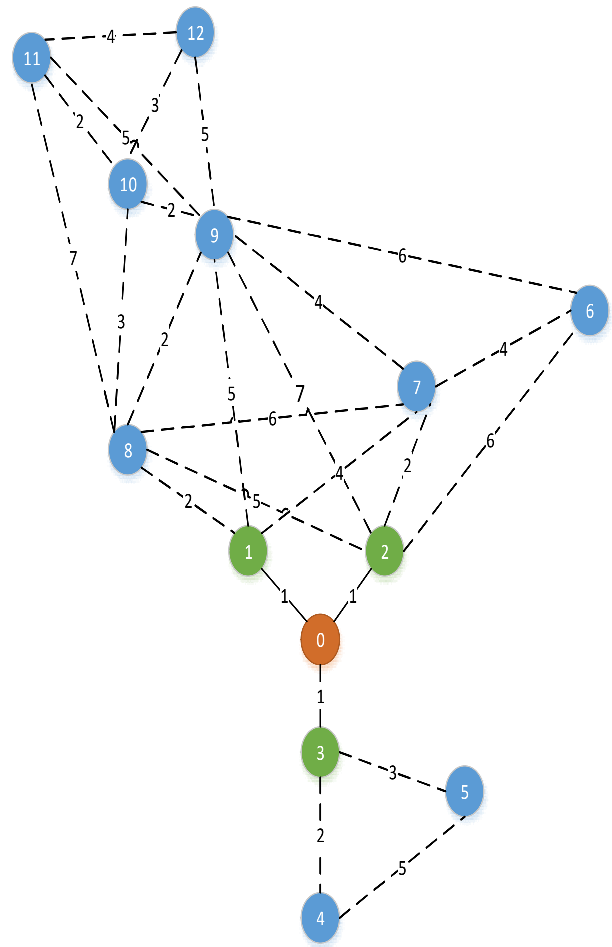

Figure 5 Simulation topology

4.1 Network Simulator

To implement and evaluate the proposed algorithm, a reliable network simulator is required. The Network Simulator 2 (NS2) [15] was used which is a powerful network simulator used in different network scenarios. NS2 has been used in simulating different protocols related to Wireless Sensor Network, VANET and MANET.

4.2 Simulation Parameters

The network simulation is shown in Table 1. 13 nodes were selected with default energy model values in a 1000 * 1000 square meter area. Simulation time was set to 100 seconds and simulated traffic was at a constant bit rate.

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Table 1 Network simulation parameters

PARAMETER	VALUE
Channel type	*Wireless Channel*
Radio-propagation model	*Two Ray Ground*
Network Interface Type	*Wireless Phy*
Antenna type	*Omni Antenna*
Interface queue type	*Drop Tail/Pri Queue*
Maximum packet in Queue	*50*
Network interface type	*Phy/Wireless Phy*
MAC type	*802_11*
Topographical Area	*1000 x 1000 sq. m*
Sending Power	*0.744W*
Receiving Power	*0.0648W*
Power consuming when node is idle	*0.05W*
Initial energy of a Node	*(20.0 Joules for 4-12) (100 Joules for 0-3)*
Routing protocols	*AODV*
Number of nodes	*13*
Simulation Time	*100 seconds*
Traffic Type	*Constant bit rate (CBR)*
Packet size	*512 KB*
Traffic rate	*20 Kbps*

4.3 Simulation Scenarios

Two main scenarios were simulated. The first scenario included no nodes failure during the simulation time. In the second scenario, a node failure was simulated. Node 8 was set to consume high power at the idle state which can reflect a node's misbehavior condition. Three main mechanisms were simulated and the first mechanism did not include any topology control mechanism. AODV specified the best route among the available neighbors as shown in the topology. In the second mechanism, an [6]Energy-efficient topology control algorithm was implemented where topology was controlled in a specific way which worked on minimizing the maximum relative load of each node at the simulation network. The mechanism scenario included the proposed EAFTC mechanism where topology was built to minimize the maximum load and monitored against node energy depletion or failure.

4.3.1 Scenario 1: No Node Failure Scenario

The first scenario included normal network behavior where node failure was assumed and all nodes were working properly and did not reach energy depletion levels. Three network topology handling mechanisms were simulated including no topology control, energy based topology control and EAFTC mechanisms.

Mechanism 1: AODV Scenario

When the simulation topology was run without any topology control, AODV protocol selected the data path for all nodes toward the sink node as shown in **Error! Reference source not found.**. Topology nodes were connected based on the shortest path where the minimum number of hops on the bath from the source node to the sink node was selected. As illustrated, no energy level or power consumption estimation was considered and high energy paths can be selected.

Mechanism 2: Energy-efficient topology control algorithm

When Energy-efficient topology control algorithm was applied in the simulation topology, the topology was built as shown in **Error! Reference source not found.** to minimize the maximum load which reduced the power consumption at each topology node. Topology shown in the figure did not include node failure.

Mechanism 3: Energy aware and fault tolerance topology control -EAFTC

The proposed mechanism of the topology structure was built in the same way as the Energy-efficient topology control algorithm as shown in **Error! Reference source not found.**. If there was no node error or fault, the topology behaved in the same way and the results were the same as the Energy-efficient topology control algorithm.

4.3.2 Scenario 2: Node Failure Handling

To evaluate the performances of AODV scenario, Energy-efficient topology control algorithm and EAFTC mechanism for handling nodes failure, node 8 was selected as the failed node and to simulate node failure, we have assigned high power consumption values of power for a node Idle state which can represent a real power leakage problem. Initial power was the same for all nodes to prevent any topology building decision which mainly depends on the remaining energy.

Table 2 node failure energy parameters

Parameter	Value
Sending Power	*0.744W*
Receiving Power	*0.0648W*
Power consuming when node is idle	*5.05W*
Initial energy of a Node	*20.0 Joules*
Threshold energy value	*3.0 Joules*

Mechanism 1: AODV scenario

When node 8 failed, AODV recalculated the path based on the nodes' neighbors and the new path was built as shown in the **Error! Reference source not found.**. Node 11 was affected and its path was redirected to node 12 as shown in the figure.

Mechanism 2: Energy-efficient topology control algorithm

For the topology based network, when node 8 failed, no handling mechanism was applied and all child nodes of the failed node also failed as shown in **Error! Reference source not found.**. Nodes 10, 11, and 12 all failed to forward their collected data.

Mechanism 3: Energy aware and fault tolerance topology control algorithm

For the proposed EAFTC, when node 8 reached the energy threshold, a handling mechanism was applied and all child nodes of the failed node were re-added to the topology based on the neighborhood table as shown **Error! Reference source not found.**. Connections of nodes 10, 11, and 12 were resumed based on the minimum values of the calculated maximum load. Proposed mechanism require investigation in real environment and network topology. Also building more intense topologies can result in more clear results where higher number of nodes and paths can be found and real data estimation can be achieved.

5. EVALUATION RESULTS

This section includes the results for both simulation scenarios of the three different mechanisms. Evaluation metrics as defined in the previous chapter were estimated using the corresponding equation. These evaluation metrics are: node maximum relative load, packet delivery ratio, network throughput and end to end delay.

5.1 Maximum Relative Load

For AODV scenario mechanism and based on equation 1 for calculating the maximum relative load of each node including remaining power, number of links and maximum link load, the maximum relative load was calculated. Based on the estimated maximum relative load for topology nodes, the average maximum relative load for all nodes was 0.611 watt.

On the other hand, for both energy based topology control and EAFTC mechanism, the maximum relative load was calculated based on the built topology where remaining power, maximum links and maximum link load can be estimated. The average maximum relative load for all nodes was 0.398. Based on the result, the maximum relative node load has been reduced up to 35%.

As shown in the results of three simulated mechanisms in Figure below, both energy based and proposed EAFTC mechanisms have minimized the maximum network load to extend the lifetime of the network where energy consuming was minimized. On the other hand, the AODV scenario approach had higher maximum load values.

Based on the result, the maximum relative node load has been reduced up to 35% compared to the AODV scenario control approach. However, the values were the same as the Energy-efficient topology control algorithm.

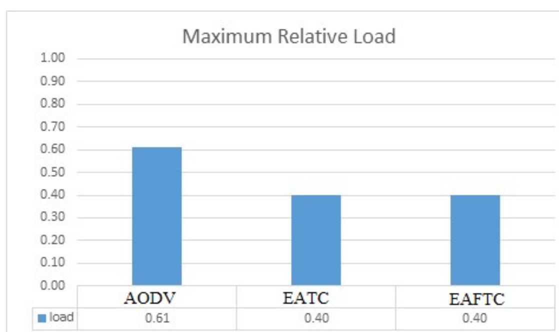

Figure 6 Maximum relative load for three mechanisms

5.2 Packet Delivery Ratio – PDR

As shown in **Error! Reference source not found.**, in the scenario where there was no node failure, all three mechanisms provided equivalent

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packet delivery and the number of dropped packets was minimized.

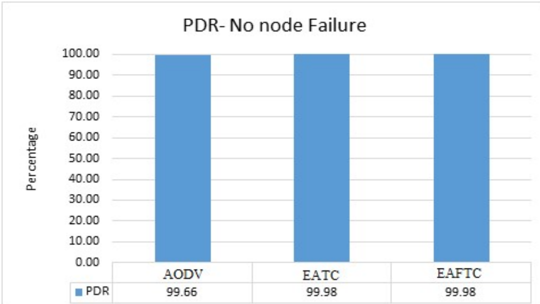

Figure 7 Packet Delivery Ratio for no node failure scenario

However, when node 8 failed in the AODV scenario, PDR was decreased. PDR decreased due to the increasing number of dropped packet when node 8 failed and until a new path was found.

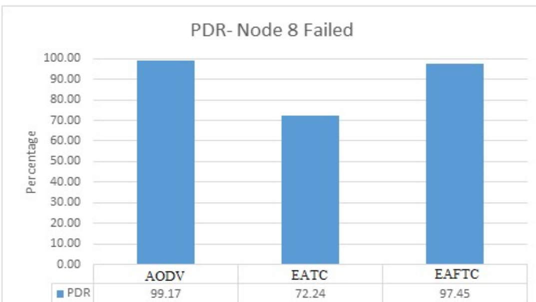

Figure 8 Packet Delivery Ratio for node failure scenario

On the other hand, in the energy based topology scenario, PDR was significantly decreased where all child nodes of the failed node could not deliver their data. Finally, the proposed mechanism was able to avoid node failure and detect new path where data can continue to deliver successfully.

5.3 Throughput

The network throughput reflects the amount of successfully delivered data, where high throughput values indicate better performance. In the case of node failure, the three mechanisms provided the same network throughput as shown in Figure .

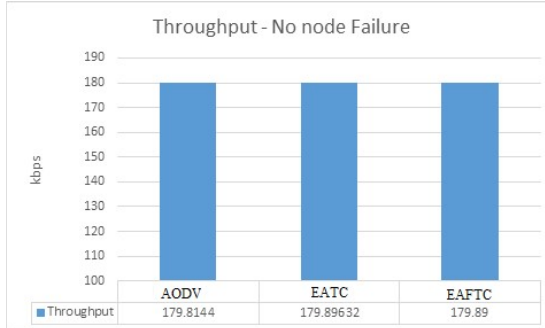

Figure 9 Network throughput for no failure scenario

However, when a single node failed, the energy based mechanism decreased the network throughput significantly where a new path was not established. On the other hand, network throughput was lightly affected for both AODV scenario and the proposed energy and fault tolerance energy mechanisms, where a new path was re-established.

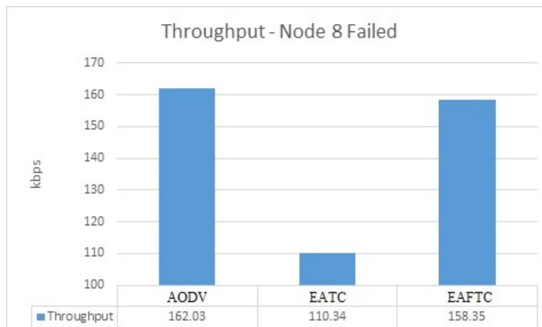

Figure 10 Network throughput for node failure scenario

As shown in Figure , the network throughput for energy based topology control has been dropped significantly where the edge node cannot deliver its data correctly; however, the EAFTC mechanism provided better network throughput which was very close to the AODV scenario throughput.

5.4 End to end Delay

End to end delay represents the average time for data delivery from source nodes toward sink nodes as shown in Figure . End to end delay was decreased for both energy based and EAFTC mechanisms where shorter and less load paths and optimized paths were selected; However, higher end to end delay was achieved by the AODV scenario mechanism where random paths were selected.

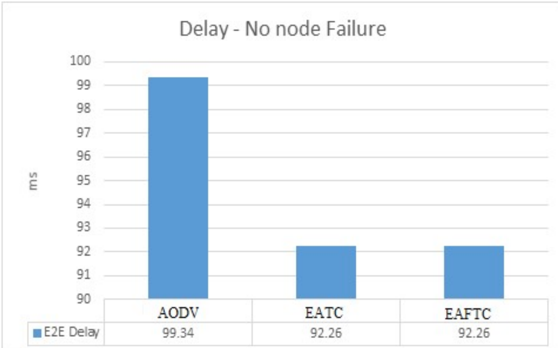

Figure 11 Network average end to end delay for no node failure scenario

On the other hand, end to end delay has been increased with AODV scenario where higher load paths were selected where AODV selects paths based on the shortest path only regardless to the link load or nodes load, in case of node failure. EATC provided less end to end delay for delivered packets where no new path was selected for the child nodes of the failed nodes. EAFTC provided the best end to end delay in case of node failure for all data packets delivery as shown in Figure 1 below.

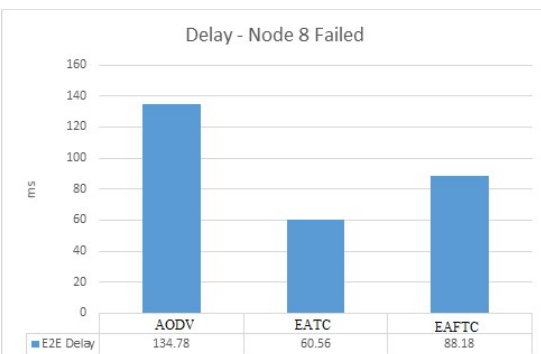

Figure 1 Network average end to end delay for node failure scenario

5.5 Results Analysis and Discussion

As illustrated in the results, when AODV scenario was applied, wireless sensor networks data was forwarded based on the used routing protocol which was AODV in our scenarios. So, paths which provided a minimum number of hops were used without concerning the remaining energy or required power to the forwarded data. As a result, power consumption loads were not equally distributed among nodes where different nodes can be energy exhausted rather than others.

In the energy aware topology control, wireless sensor network was built on the basis of remaining energy, power consumption and nodes power loads. The topology was built to provide even load of energy consumption among all network nodes to maximize the network lifetime. Results showed that when no topology was applied, the average maximum relative load of network nodes was 0.61, However when energy based topology control was applied in both energy based mechanism and EAFTC mechanism, the average maximum relative load was decreased to 0.4 which indicated that the average maximum load was decreased up to 35%.

When network node failure happened, AODV scenario depended on the routing protocols to discover s new route toward sink nodes without depending on any topology control. On the other hand, energy based control mechanism did not provide any failure handling mechanism which resulted in data packets dropping. Meanwhile, EAFTC handled node failure based on the energy approach where new paths were selected for all nodes affected by the failed node. In case of energy depletion, a new path was selected before complete node energy exhaustion. A threshold value of 3 joules was defined.

As illustrated in the results, the Packet delivery ratio for AODV scenario and EAFTC mechanism were very close which was about 98%, where PDR for energy based topology control has been decreased down to 72.24%. So, the results showed that EAFTC has increased network PDR up to 25% compared to energy based topology control.

Because of the increased number of packet dropping, network throughput was decreased using energy based topology control. However, the EAFTC mechanism has enhanced the network throughput up to 44% compared to energy based topology control mechanism.

EAFTC mechanism handled node failure and rebuilt the affected part of the network topology based on the nodes neighborhood. However, using the AODV scenario, routing protocol started a new path discovery process which can result in higher delay and select longer alternative paths. For energy based topology control mechanism, measured values of delay were related to all packets before node failure so its value was lower than the EAFTC and AODV scenario. Results showed that EAFTC has enhanced end to end delay up to 34% compared to the AODV scenario.

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6. CONCLUSION

In this paper, we presented a fault tolerance and energy based topology control mechanism. The EAFTC algorithm has two main phases: topology building phase and topology monitoring a fault tolerance phase. In the first phase, the topology control built the network connection to minimize the maximum relative load among nodes which can result in maximizing the network lifetime. In the second phase, the proposed mechanism monitored the network status for node failure or energy depletion. A predefined remaining energy threshold was defined to avoid node exhausting, and when this threshold was reached, the affected part of the network was rebuilt to guarantee continuous data delivery. The proposed mechanism has achieved the defined objectives where a network was built based on the node power consumption level and load has been minimized for low power nodes to prevent network dis-connectivity. Fault tolerance mechanism was defined to help the network to recover after any energy depletion node failure and continue data delivery.

Different evaluation metrics were defined to evaluate the performance of the proposed mechanism against AODV scenario and energy based topology control mechanism. These metrics include: maximum relative load, packet delivery ration, end to end delay and network throughput. Two main scenarios have been built to simulate normal network condition and node failure network condition. EAFTC has reduced the maximum relative load among nodes and tolerated energy depletion failures which maximized the network lifetime.

Defining a suitable threshold values in one of the most critical constrains and limitation where defining a threshold value to fit different topology require nodes status investigation and data generation statistics.

As Future work, we suggest proposing the procedure for calculating optimized threshold value which can depends on the network status, and how nodes behaves, and consume energy for the remaining energy level which requires further investigation where it can be variable, depending on the network status, and the remaining energy levels of that network, and to estimate the best value to consider node energy depletion. Calculating the suitable value based on network condition can provide better energy based fault tolerance handling and maximize network lifetime.

Moreover, the proposed mechanism enhanced data delivery in case of node failure and continue data delivery based on minimizing maximum load mechanism. However, defined threshold value which is used for considereing energy depletion node require more calculation and investigation to meet the requirements of the network status.

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