Real-Time, Fault Tolerance and Energy-Efficiency (REFER) Enhancement in Wireless Sensor Actuator Networks

Shama Ali[1], Hanumanthappa S N[2]

[1]*M.Tech Student Dept. Of ECE, UBTCE, Davangere, Karnataka, India*
[2]*Assistant Professor, Dept. Of ECE, UBTCE, Davangere, Karnataka, India*

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Abstract - *Wireless sensor and actuator networks (WSANs) are composed of sensors and actuators to perform distributed sensing and actuating tasks. Most WSAN applications (e.g., fire detection) demand that actuators rapidly respond to observed events. Therefore, real-time (i.e., fast) and fault-tolerant transmission is a critical requirement in WSAN's to enable sensed data to reach actuators reliably and quickly. Due to limited power resources, energy-efficiency is another crucial requirement. Such requirements become formidably challenging in large-scale WSANs. However, existing WSANs fall short in meeting these requirements. To this end, we first theoretically study the Kautz graph for its applicability in WSANs to meet these requirements.*

We then propose a Kautz-based REal-time, Fault-tolerant and EneRgy-efficient WSAN (REFER). REFER embeds Kautz graphs into the physical topology of a WSAN for real-time communication and connects the Kautz graphs using distributed hash table (DHT) for high scalability. We also theoretically study routing paths in the Kautz graph, based on which we develop an efficient fault-tolerant routing protocol. It enables a relay node to quickly and efficiently identify the next shortest path from itself to the destination based only on node IDs upon routing failure, rather than relying on retransmission from the source.

Key Words: WSAN, Fault Detection, Fault Diagnosis, Fault Recovery, Network Measurements.

I. INTRODUCTION

A wireless sensor network (WSN) is a collection of low-cost, low-power and multi-functionality wireless sensing devices that can be densely deployed for surveillance purpose. Traditionally, it is used for data gathering by sampling surroundings and reporting to predefined data sinks. As hardware technology advances, it is now evolving toward service-oriented wireless sensor and actuator networks (WSANs) [1]. A WSAN consists of sensor nodes capable of measuring stimuli in the environment and actuator nodes capable of affecting their local environment. Similar to WSNs, WSAN sensors usually are low-cost and low power devices with a short transmission range that are used for the sensing a physical phenomenon. WSAN actuators are resource-rich devices characterized by higher processing and transmission capabilities and a longer battery life.

When sensors detect events, they process and transmit the event data to their nearby actuators, which take action on the events. WSANs can potentially be used in applications such as real-time target tracking and surveillance, homeland security, chemical attack detection and environment monitoring in battlefields, factories, buildings and cities. For example, smoke detectors (i.e., sensors) deployed in a building report detected fire events to sprinklers (i.e., actuators); Sensors deployed in a battlefield report their detected malicious objects to actuators, which immediately takes action accordingly. Since sensors are densely deployed to ensure the coverage and topology connectivity usually, the scenario we considered in this paper is a highly dense and mobile WSAN which consists of densely populated and possibly mobile sensors.

Actuators need to quickly and reliably respond to nearby sensed events. Delay response may lead to disastrous consequences such as a large loss of life. Therefore, real-time (i.e., very fast) communication is of great importance in guaranteeing the timely actions. Because of node mobility and resultant routing failures, fault-tolerance is crucial to ensure reliable node communication. In addition, energy-efficiency is also a critical requirement for WSANs due to limited resources of sensors. Such requirements become formidably challenging in large-scale WSANs (e.g., battlefield monitoring applications) where the number of sensors is in the order of hundreds or thousands [2].

Most of the routing protocols for mobile ad hoc networks (MANETs) and WSNs treat every node equally and fail to leverage the capabilities of resource-rich devices to reduce the communication burden on low-resource sensors. These protocols are suboptimal for WSANs. Recently, mesh-based [3], [4] and tree-based [5], [6] systems have been proposed for data transmission in WSANs. In the mesh-based methods, physically close sensors form a cluster and the cluster head reports their sensed events to the closest actuator through a multi-hop path. In the tree-based methods, physically close sensors form a tree for data transmission. In both methods, a source node must retransmit a message upon a routing failure.

When one node can no longer operate it offers in redundancy and network is termed as reliable network, the remaining nodes can still responds with one another in between nodes or it connects directly. Self forming and Self healing are few more characteristics of a Mesh Network.

Over a specific coverage area network architecture provides cost effective and dynamic high bandwidths. Series of short hops are used to crack the distances, mesh infrastructure carries data over large distances. When it performs routing in between nodes not only to enhances the signal but considerately transfer data from successive points by looking over forwarding decisions in a network.

Over the coverage area, architecture with cautious design presents high bandwidth, spectral efficiency and economic advantages. Except in occasional failures of nodes or addition of new nodes these networks are considerable to have stable topology. The traffic path collected from huge number of terminal devices forwards the traffic path to or from gateway. Whereas in Ad-hoc networks or client mesh networks traffic flows in between pair of nodes hence traffic path changes infrequently.

Infrastructure management is said to be as centrally managed or decentralized both are inexpensive and very reliable and resilient, as each node needs only forwards as far as the next node. In a single hop network node acts as routers to transmit information over nearby nodes to peers that are far away to reach resulting in span of larger distances. As each node is associated with several other nodes, a mesh network topology is said to have reliable network. If in case of any hardware failure or network fault or any node drops out of network then its neighbor can quickly find another route using a routing protocol.

With the capability of self-organization and self configuration in a wireless network, The nodes in a network are deploy incrementally, one node at a time, as needed. As number of node mount increases, users experience with increase in reliability and connectivity issues accordingly. It is intended to do rather for reliability and affords access networks in smaller regions.

It is desirable to provide Self reconfigurable Fault Tolerance for any large-scale network supporting many users and a diverse set of applications. Reconfigurable fault management aims to automate many of the fault tolerance task by continuously monitoring network condition for self-awareness, analyzing the fault after it is detected for self-diagnosis, and taking adaptation actions for self-recovery. Thus it potentially reduces human efforts and responds to the faults faster.

Fault Management is a fairly young research field, in this paper we discuss on faults, fault recovery, Extensive experimental results demonstrate the superior performance of REFER in comparison with existing WSAN systems in terms of real-time communication, energy-efficiency, fault-tolerance and scalability.

The rest of the paper is organized as follows: Section II presents Related work on WSAN's, Fault Diagnosis and Fault Recovery is described in section III. Section IV includes Methodology and Sections V and VI presents Simulation setup and Results. and in Section VII Conclusions were drawn.

II. RELATED WORK

WSNs can be regarded as a subcategory of MANETs with additional constraints of security and energy-efficiency. WSANs are a subcategory of WSNs with higher requirements on real-time, energy-efficient and fault-tolerant transmission.

MANETs use either topological routing [8], [9], [20] or geographic routing [7]. AODV [8] and DSR [20] are reactive routing protocols, in which a source node broadcasts a query to find a path to the destination. DSDV [9] is a proactive routing algorithm, in which each node maintains and periodically updates a routing table by message flooding. Keeping a complete routing table reduces route acquisition latency for data transmission. However, its correct operation depends on its periodical global dissemination of connectivity information, leading to low scalability. Further, the limited battery power of the sensors makes such routing unsuitable for WSANs. Geographical routing always chooses the node closest to the destination by relying on the position information generated by GPS or a virtual coordination method [10], [11], [12], both consume a considerable amount of energy, which are also not suitable for WSANs.

Many routing algorithms have been proposed for WSNs.

Pottner et al. [21] introduced a heuristic to calculate a schedule that can support the given application requirements in terms of data delivery latency and reliability and described methods and tools to collect the data necessary as input for schedule calculation.

He et al. [22] investigated the on demand scenario where data collection requests arrive at the mobile element progressively, and modelled the data collection process as a queuing system. Based on this model, the authors evaluated the performance of data collection through both theoretical analysis and extensive simulation.

Ji et al. [23] introduced a more reasonable model, probabilistic network model, for the network capacity of data collection. They proposed a cell-based path scheduling (CPS) algorithm for snapshot data collection, and proposed a zone based pipeline scheduling (ZPS) algorithm for continuous data collection.

Vazifehdan et al. [28] proposed two energy-aware routing algorithms for WANET, called reliable minimum energy cost routing (RMECR) and **r**eliable minimum energy routing (RMER). However, the above methods need to retransmit a message from the source to the destination upon a routing failure, generating a certain delay. Also, most of these methods are not energy efficient due to their flooding based topological or geographical routing components. REFER is superior to the previous WSAN routing protocols because it can simultaneously meet the requirements of real-time communication, fault-tolerance and energy-efficiency. Most previous research on Kautz graphs focus on exploiting the Kautz graph in the application layer of P2P networks [14], [15], [16].

Zuo et al. [17] proposed to build a Kautz graph overlay on the application layer of a MANET in order to enhance the routing performance. However, due to the topology inconsistency, the method uses MANET multi-hop routing for the communication between two neighboring Kautz nodes.

Ravikumar et al. [29] and Li et al. [16] studied the shortest and longest path routing. In BAKE [15] and DFTR [18], a node uses the next shortest path when it fails to forward the message along the shortest path. However, a node needs to use a routing generation algorithm (equivalent to the process of building a tree) to find different routes to a destination node and calculate their lengths, which generate high energy consumption.

Imase et al. [30] identified the bounds of the three possible path lengths in the worst case, but they did not indicate all disjoint paths, the precise path length and the corresponding conditions, which are identified in REFER.

III. FAULT DIAGNOSIS

A. Sources of Faults

Mesh routers helps to connect mesh networks with different wireless networks. Hence WMNs are termed as standalone devices. It provides greater range of data transfer rates in the networks. In wireless communication, protocols used for communication are at small cost. So, there are more chances of packet losses and node failures. Information transmission generally starts from source node to specified destination node.

There are a numerous faults occur in a mesh topology, which are categorized as follows.

- Transmission link fault: noise by external source, fading of multi-path, interferences which are strong, and client's misbehavior are some of the reasons included, to show why fault occurs. Link in these networks experiences higher loss rate or long delays.
- Network element fault: Reasons for fault to occur because of failing in single mesh devices, hardware failures, power supply fails, and software crashes.
- Mesh protocol fault: black hole and route loops are created by routing protocol under some circumstances. Extremely quick decrease is observed in network throughput and flapping route, which are reasons of routing protocols. Protocols of Mesh routing are developed in order to reclaim faults from failure in path, and it can still give few un-preferred complications.
- Traffic congestion. As network quantity exceeds the link capacity, a network can experience important profusion or even disintegrate if not managed correctly.

B. Taxonomy of Fault tolerant Techniques

Recent research has developed several techniques that deal with different types of faults at different layers of network stack. To assist in understanding the assumptions, focus and intuitions behind the design and development of these techniques. We borrow the taxonomy of different fault tolerant techniques used in traditional distributed systems.

- Fault Prevention: This is to avoid or prevent faults.
- Fault Detection: This is to use different metrics to collect symptoms of possible faults.
- Fault Isolation: This is to correlate different types of fault indications received from the network, and propose various fault hypotheses.
- Fault Identification: This is to test each of the proposed hypotheses in order to precisely localize and identify faults.
- Fault Recovery: This is to treat faults, i.e., reverse their adverse effects.

Note that there do exist some techniques that address a combination of all these aspects. In fact, these techniques operate at different layers of the network protocol stack. Most

Fault avoidance techniques operate in the network layer, adding redundancy in routing paths; a majority of fault detection and recovery techniques operate at the transport layer; and a few fault recovery techniques perform at the application layer, concealing faults during off-line data processing. In this paper, we use the above taxonomy to systematically summarize and compare the fault tolerant techniques that are potentially useful.

Isolation of faults that is checking location of faults, identification of faults, that is detection of fault type are present in Fault diagnosis. Locating the faults and even determining links faults or failure in nodes is relatively easy by sufficient measurement. Pinpointing will be a challenge for faults in route cause, where faults will be corrected making recovery decisions automatically by the system. In-accurate adaptations are made and route cause assumptions are made by some of existing solutions. Packet loss is caused always by assumption of TCP by congestion and then avoiding congestion will be by sender getting slows down, where over error-prone wireless links may give bad performance.

By selecting the different links if there is any failure detected in link for repairing the paths by several routing protocols. Opportunity for fault recovery quickly with less cost by reacting to the root cause by uninformed fault recovery, which would be. Level of transmission power gets increased by a mesh node and if any obstacles are present the a link will get degraded, or if channel is very busy or strong noise is present in current channel, then with neighbors, channel switching can be done.

To repair the faults, automation action should be performed by system, and bring the network to a desirable state Once a fault has been detected and diagnosed. Without using the global impact in some cases, repairing of faults can be taken place in generalized fashion. In face of excessive contention, conditions of bad channel can be held by adapting transmission rate of transmitter. Nodes are made to be blacklist it from routing in the case mesh nodes are not forwards any packets as expected. Relocation of traffic should be taken place if that node is determined to be narrow. Methods which provides better recovery can be attained in these scenarios, if reorganization of root source of the faults are done.

The reconfiguration fault recovery approaches need to address three significant challenges. First the network measurements must allow accurate reconstructions of network models, otherwise the computed recovery actions could be misleading. Another challenge is that finding a suitable configuration in a large solution space must be fast enough, otherwise the network dynamics may render the returned solution no longer applicable. Finally, a Fault management must support human understanding by providing logs and explanation on its reasoning logic of fault diagnosis and recovery process. This will increase the user confidence for better adoption.

IV. METHODOLOGY

To achieve the consistency between overlay and physical topology, we rely on node communication to determine node ID since the real node communication distance reflects node physical distances. The process of embedding Kautz graph to a cell is actually the process of Kautz ID assignment. It involves two steps: actuator ID assignment and sensor ID assignment. We present the details of each step below.

Actuator ID Assignment

The actuator ID assignment process detects triangles among the neighboring actuators and sequentially assigns IDs to the actuators. For this purpose, we first introduce a distributed method for a large-scale network and then introduce a centralized method for a small-scale network.

Sensor ID Assignment

After the actuators in each cell receive their IDs, they select active sensors in the cell to be Kautz nodes to form a complete K graph.

REFER Routing Protocol

The REFER routing protocol consists of intra-cell communication and inter-cell communication. The intra-cell communication is developed. This enables a node to quickly and efficiently determine the different successors of the d-disjoint paths from itself to the destination node and corresponding path lengths simply based on node IDs without relying on an energy-consuming method. The fault-tolerant routing algorithm in a Kautz graph in the intra-cell communication. When node U initiates or receives a message destined to node V, it initially chooses its successor in the shortest path to V (as in the greedy shortest protocol). If the successor is congested failed or the link to the successor is broken down. Without the need to notify the source node, U locally chooses the second shortest path, third shortest path, and so on until a successor capable of forwarding data is found. If a number of paths with the same path length exist, U randomly chooses a successor among these paths. To forward the message to the successor, the node chooses a path with the lowest delay [8], which could be either a multi-hop path or direct path. After a node receives U's message, it repeat the same process in choosing its successor for message routing.

V. SIMULATION SETUP

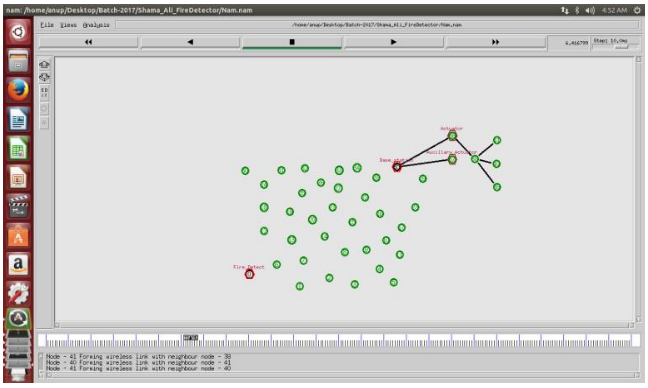
In WSA Networks, there is no one-for-all scheme that works well in scenarios with different network sizes, traffic overloads, and node mobility patterns. Ns-2 is a discrete event simulator using in networking research. NS-2 used for wired and wireless network to provides significant support for simulation of TCP, routing and multicast protocols. It is combination of two simulation tools. The network simulator (ns) contains all commonly used IP protocols. The network animator (nam), which is use to visualize the simulations. Ns-2 can fully simulates a layered network from the physical radio transmission channel to high-level applications.

Table: 1 Simulation Parameters

Simulation Parameters	Value
Simulator	Ns-2 (2.35)
Topology	1200*1000
Propagation Model	TwoRayGround
No. of Nodes	0- 40
Bandwidth	3 Mbps
Queue length	340
Packet Size	512 bytes
Simulation Time	20 s
Initial Energy	100 Joules
Routing Protocols	DSR
Actuators	2 (36 & 37) nodes
LAN	3 (38,39 &40) nodes

VI. RESULTS AND DISCUSSION

Simulation of the network was performed to detect fire and to inform to the LAN Network with considering Fault-Tolerant, Reliable, and Energy Efficient



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Node - 41 Forming wireless link with neighbour node - 38
Node - 40 Forming wireless link with neighbour node - 41
Node - 41 Forming wireless link with neighbour node - 40
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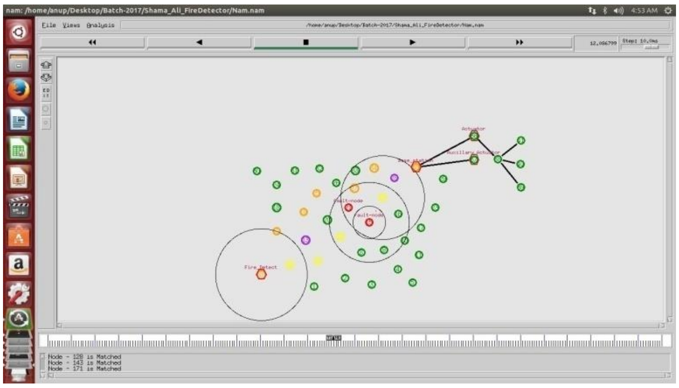
Fig.1 Deployment of random nodes

Fig 1 shows the Forming a Wireless Mesh link with nodes, The Environment has dimension of 1200 * 1000. Number of nodes considered here is 40 and initial energy on each node was set to 100 joules. Also in this work we considered Source node as Node 0 and destination node as Node 35. It is clearly shown in above fig. Node 36 & 37 are considered as Actuators. Lan Network is associated with nodes 38 39 and 40 respectively.

After that, It checks for fault in the path. If fault is detected, it searches for the alternate path by using multi-hop communication. If Path associated with any faults, then it is detected using fault diagnosis algorithm.



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Node - 128 is Matched
Node - 143 is Matched
Node - 171 is Matched
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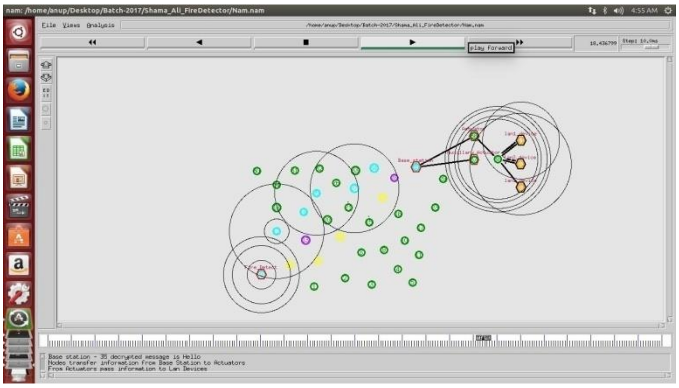
Fig.2 Fault detection

When Base station (BS) receives message from Detectors, **it** has to circulate with any one of the Actuators within the network. These actuators take necessary action based on the type of application required. Here in this work we propose LAN Network, After collecting information, The primary actuators/Auxiliary actuators forward those Traffics to the LAN network.


nam: /home/anup/Desktop/Batch-2017/Shama_Ali_FireDetector/Nam.nam
File Views Analysis
play forward
Base_station
Fire_Detect

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Base station - 35 decrypted message is Hello
Nodes transfer information from Base Station to Actuators
From Actuators pass information to Lan Devices
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Fig.3 Fault recovery and Actuators circulates Detection to LAN

Before Simulation time expires, Faulty Recovery actions took place for those fault nodes by selecting a parameter from configuration Parameters.

In this Section simulation results are presented. Here, simulations are carried out for 36 wireless mesh nodes. The performance evaluated by using the following metrics.

1. *Packet Delivery Ratio:* Packet Delivery Ratio (PDR) is defined as the total no of packets successfully received by the destination to the no of packets sent by the source.

PDR= Number of Packets Received (ACK)/ Number of Packets Sent (TCP).

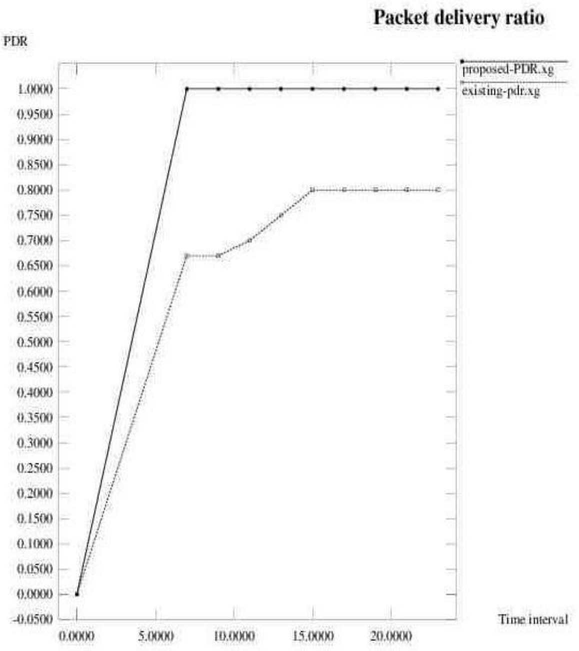

Fig. 4 Packet delivery ratio (%)

The PDR specifies the performance of network that how successfully the packets have been transferred. Larger values give better results.

2. *Throughput:* It is defined as Average rate of packets successfully transferred to their final destination per unit time.

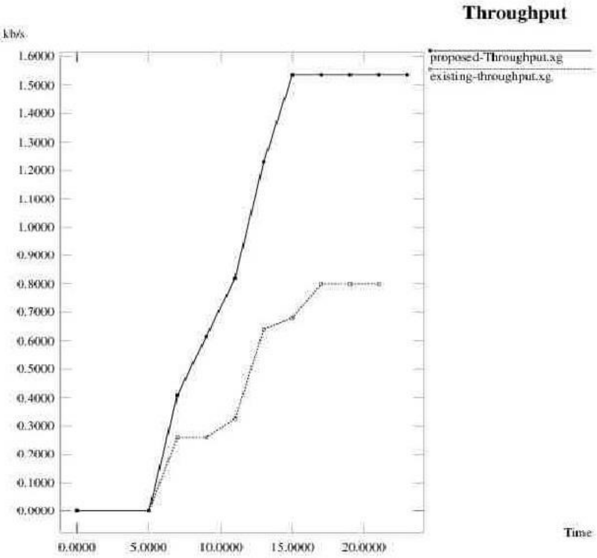

Fig. 5 Throughput (Kb/S)

3. *Energy Consumption:* The average energy consumed for the mesh network.

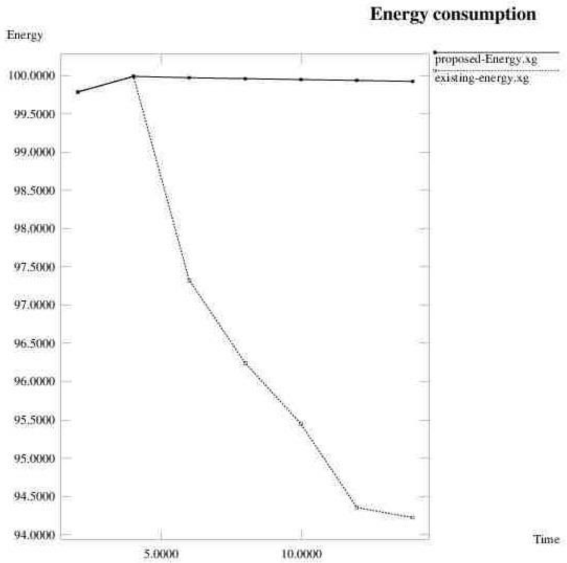

Fig. 6 Energy Consumption (J).

VII. CONCLUSION

Real-time, energy-efficiency and fault-tolerance are critical requirements for WSAN applications. Current routing protocols proposed for WSANs fall short in meeting these requirements. In this paper, we theoretically studied the properties of the Kautz graph, which shows that it is an optimal topology for WSANs to meet the requirements. Thus, we propose REFER, which incorporates a Kautz graph embedding protocol and an efficient fault-tolerant routing protocol. REFER's embedded Kautz topology is consistent with the physical topology, facilitating realtime communication. Further, REFER leverages DHT for the communication between Kautz-based cells for high scalability.

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BIOGRAPHIES

H Shama Ali after graduating in the field of Electronics and Communication from BIET Davangere, right now doing Masters in the Field of **Digital Communication and Networking** in UBDT College of Engineering, Davangere. Further aiming to undertake my specialized studies on the real time concepts of wireless technology so that the ease of exploring the technology increases among all the starta of people.

Sri **Hanumanthappa S N**, did Engineering in the field of Electronics and Communication in SJMIT Chitradurga under Kuvempu University, Further did masters in Digital Communications in BEC Bagalkot. Currently working with a **Experience of 16 Years** in the teaching field. Presently working in **UBDTCE of Davangere** as a permanent faculty. I have completed the course work on the subject of Wireless Sensor Networks and Currently Doing PH.D