

# ENERGY EFFICIENT FAULT-TOLERANT ROUTING IN GRID BASED WIRELESS SENSOR NETWORK

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**Abstract**— A wireless sensor network is made up of tiny size sensor nodes having the limited computation capability, bandwidth, power supply and storage. These networks are generally deployed in inaccessible tough terrains and hence network failures either due to physical damage or energy depletion are quite inevitable. Also, in the absence of manual intervention, these networks must operate autonomously for which the network must have auto-configuration and self healing capability. In this paper, we propose an Energy Efficient Fault-tolerant Routing (EEFR) in grid based wireless sensor network, which is a node failure detection and recovery strategy. This scheme organizes the randomly deployed sensor nodes into clusters of suitable size cells by constructing a virtual grid over entire sensor field, where grid nodes also perform the data aggregation to eliminate the redundant data. One of the other main reasons for constructing a grid structure is to handle the network topology of the network that is changing dynamically due to node failure. The Grid Nodes (GNs) are used to forward the data from source to sink. Each grid node creates a local zone comprising some sensor nodes that can act as representative of GN when it fails. In this scheme, the shortest path is used for main data delivery and when a GN fails, an alternate node with maximum residual energy within local zone is selected as new GN. The simulation study reveals significant improvement in term of fault tolerance and energy conservation in comparison to existing schemes.

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**Index Terms**— Energy-efficient, Wireless sensor networks, EEFR, Fault-tolerance, Node failure.

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## I. INTRODUCTION

Recent advances in micro-electro-mechanical systems, and low power and highly integrated digital electronics have led to the development of micro-sensors that enabled a new generation of massive-scale sensor networks suitable for a wide variety of applications ranging from large scale habitat monitoring, battlefield surveillance, and disaster relief operations to small health care, process monitoring and control etc. A wireless sensor network (WSN) is usually composed of large numbers of such micro-sensor nodes. These sensors nodes continuously sense the external environment and send the stimulus data to the sinks through multi-hop communication [1] [2]. Since sensor nodes have limited resources and generally deployed in inaccessible tough terrains and hence network failures either due to physical damage or energy depletion are quite inevitable.

Thus the abrupt failure of nodes or links may cause network partition, data loss, path failure, dynamic change in network topology and more failure to deliver important data in the network can hurt the applications' objective [3][4]. The routing protocols of such networks should thus be designed to provide fault tolerance with the aims as follows. First, in most scenarios data delivery must be continuous and any faults arising must be auto-recovered efficiently with minimum data loss. Second, with the dynamic changes of topological structures of the networks, WSNs should have the abilities of self-adjusting and reconstructing. Third, a node failure must be detected and/or averted during network operation to achieve a high reliability and availability in a sensor network [3].

Different types of fault detection and fault tolerant routing technique have been summarized [5][6]; that help us to understand the challenges in designing fault tolerant protocols for distributed sensor applications. Some existing major routing protocols for WSN such as Directed Diffusion [7], Braided [8], MESH [9] etc are the multi-path routing. In multi-path routing multiple copies of one packet are transmitted in parallel along different paths to the same destination. Whereas, Energy Aware Routing [10], Rumor [11] etc are single-path routing. The single path routing is simple and consumes less energy, but path/node failure will cause a break of transmission and hence completely ruin the delivery.

Other multipath fault tolerant routing protocol MERP[12] based on the load balancing and constructs path between different nodes. This protocol diagnoses node failures along any individual path and increase the network persistence. Yang Y. et al. proposed a network coding base reliable disjoint and braided multipath routing for sensor networks NC-RMR[13]. This protocol creates multipath by hop-by-hop method and only maintains local path information of each node without establishing end-to-end paths. In this protocol, network reliability is increase by constructing a disjoint and braided multipath. Karim L. et al. proposed a Fault Tolerant Clustering Protocol for Mobile WSN (FTCP-MWSN) [14], which a reliable and energy efficient routing protocol. This protocol introduced the fault tolerance mechanism to detect the failure of sensor nodes. Challal Y. et al., proposed secure and efficient disjoint multipath construction for fault tolerant routing in wireless sensor networks SMRP/SEIF[15]. In this scheme, a fault tolerant, multipath selection

scheme is employed to enhance the tolerance of the network and conserve the energy of sensors. Chanak P. and Banerjee I., proposed a energy efficient fault-tolerant multipath routing scheme for wireless sensor networks EEFTMR [16]. The scheme is based on multipath data routing, which recovers node fault and transmission fault. In this scheme shortest path is used for main data routing and other two backup paths are used as alternative path for faulty network and to handle the overloaded traffic on main channel.

In this paper, we propose an Energy Efficient Fault-tolerant Routing (EEFR) in grid based wireless sensor network which is an energy efficient node fault detection and recovery strategy. In this scheme, the grid is constructed by the sink appearing first in the sensor field or when no valid grid exists. The Grid Nodes (GNs) are used to forward the data/query between source-sink pair. Every grid node on data path creates a local zone comprising some sensor nodes that can act as representative of GN when it fails. In this scheme, the shortest path is used for main data delivery and when a GN fails, a node within local zone with highest residual energy is selected as new GN. Simulation study reveals significant improvement in term of fault tolerance and energy conservation in comparison to existing schemes. Rest of the paper is organized as follows. Section II describes the virtual grid construction, creating local zones, and handling node or link failure in the proposed work. In section III, performance of the EEFR is evaluated. Section IV concludes the work.

## II. ENERGY EFFICIENT FAULT-TOLERANT ROUTING (EEFR) SCHEME

In this section, we describe EEFR scheme for wireless sensor network in detail. The basic network model is based on the following assumptions:

- Sensor field is represented as a two-dimensional plane and is divided into equal square sized cells.
- The sensor nodes are randomly deployed and are stationary.
- Each sensor node is aware of its geographical location using global positioning system (GPS).
- Single-hop communication is used for data transmission between neighboring nodes and long distant data delivery is accomplished by multi-hop communication.
- The sensor nodes are homogeneous and wireless channels are bidirectional.
- Each sensor node is aware of its available energy.

## III. GRID CONSTRUCTION AND CELL SIZE DETERMINATION

The EEFR scheme uses location information to divide the two dimensional sensing field into virtual grid when all the sensors nodes are deployed. Each sensor

node knows its location as well as location of its 1-hop neighbor node using GPS System. The grid construction process is initiated by the sink that appears first in the sensor field or when no valid grid is present. The sink divides the sensor field into a grid of cells. Each cell is  $\alpha \times \alpha$  square field. The sink considers itself at one of the grid point (GP) of the grid and its coordinates  $(X_s, Y_s)$  become the starting point for formation of the grid as shown in figure 1. All other grid points (GPs) located at  $P = (X_p, Y_p)$  are calculated from sink starting point  $(X_s, Y_s)$  and cell size  $\alpha$  as:

$$\begin{aligned} \{X_p = X_s + i * \alpha, Y_p = Y_s + j * \alpha\} \\ \text{where } \{i, j = \pm 0, \pm 1, \pm 2, \pm 3, \dots\} \end{aligned} \quad (1)$$

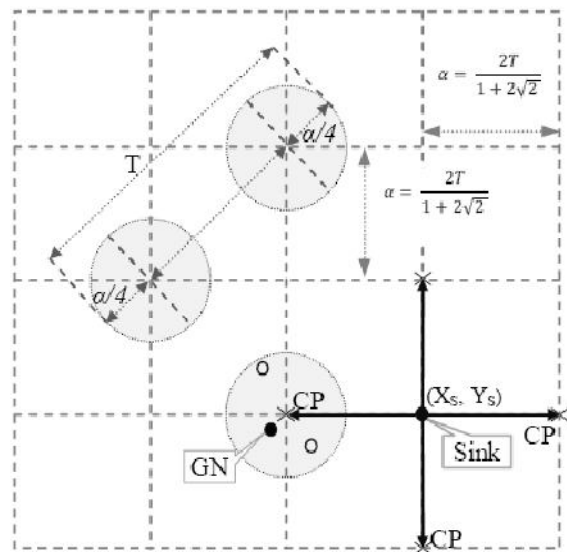


Figure 1: Grid construction and cell size determination

In this paper, the procedure described in SLDD [17] is used for grid construction process and termination of grid construction process at boundaries or void regions of WSN.

## IV. PATH SETUP AND CREATION OF LOCAL FORWARDING ZONE (LFZ).

In the proposed scheme, the grid is constructed by the sink; therefore, all GNs in the sensor field know the location of the sink. When an event is detected by a sensor node it becomes the source node (SN). This SN broadcasts a data announcement message to find the nearest GN. As all the GNs of the cell in which SN lying are at one hop distance, therefore, the message reaches to these GNs in single transmission. All these GNs reply back to SN along with their coordinates. The SN selects the GN that is closer to sink and called as source agent (SA). The SA is responsible for setting up path, data announcements, data aggregation and data delivery. SA aggregates data if it receives common data from multiple SNs and hence reduces the redundancy. This will help to reduce the transmissions and conserve network energy.

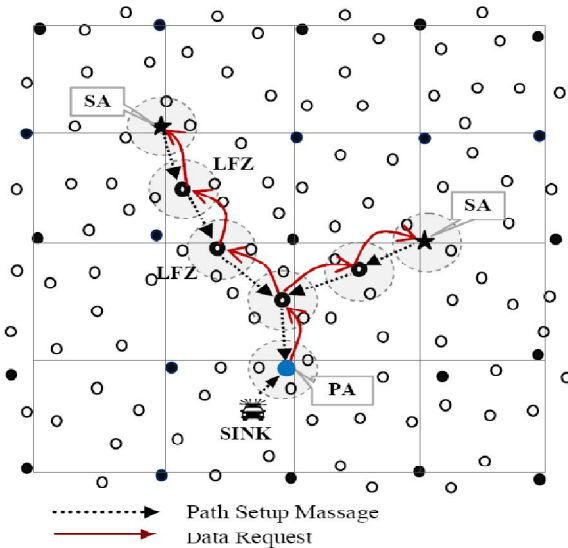


Figure 2: Path Setup and Local Forwarding Zone (LFZ) Creation

Once a GN is selected as SA, it initiates the path setup ( $M_{Pathsetup}$ ) process. SA selects a neighboring GN that is closer to sink as its upstream node (called as forwarding node) and forwards  $M_{Pathsetup}$  to it. This forwarding node (FN) further forwards  $M_{Pathsetup}$  to its upstream GN closer to sink. This process continues till message reaches at the sink. Upon receiving the  $M_{Pathsetup}$  message, sink sends back the data request message through the reverse path as shown in figure 2. When, SA receives the data request from sink, it builds a data packet and disseminates it through the establish path.

During the path setup process, all the FNs on the data path including SA create LFZ within the radius of  $l$  (where  $l = \alpha/4$ ), which comprises some sensor nodes. If FN fails, any SN with maximum residual energy within LFZ can act as next representative of failed FN. Once a node is selected as FN, it starts polling to create a list of nodes that can act as alternate FN by broadcasting a message within the radius  $l$ . Each node within LFZ broadcasts a tuple comprising their coordinate and remaining residual energy. Every node within LFZ including FN creates an indexed list of nodes in descending order of their residual energy. Whenever, the residual energy of FN falls below a threshold value or when FN fails, the new FN is selected from the indexed list in sequence from top. The entries of failed FN are removed from the indexed list. Therefore, the proposed scheme supports the reliable data delivery by selecting an alternate FN within LFZ for continuous data delivery.

## V. NODE FAILURE DETECTION AND RECOVERY

The SNs are generally deployed in inaccessible tough terrains and thus, may fail due to depletion of batteries or destruction by an external event. The failure of a FN causes the halt of data delivery and

loss of data. Thus, the need is to select a node within LFZ as new FN to resume the data delivery and to avoid the data loss.

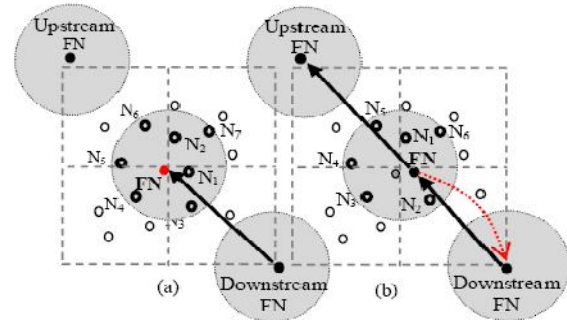


Figure 3(a): FN fails within LFZ Fig. 3(b): Selecting alternate FN within LFZ

In the proposed scheme, all the SNs within LFZ are one hop distance from their neighboring LFZ. Thus, when a FN receives broadcasting from its downstream FN, the same broadcasting also heard by all the SNs within the same LFZ. After receiving the broadcasting, the FN forwards the same to its upstream FN, which is also listen by all the SNs in the LFZ as well as SNs in the neighboring LFZs. This assures that the FN is live and message is transmitted successfully. The proposed scheme explores the overhearing of FN broadcasting as the acknowledgement and successful functioning of network. In case, the SNs within LFZ listen the downstream FN broadcasting, but does not overhear the forwarding from the FN in their LFZ within a specific time period, then the FN within LFZ is assumed fail. Also, downstream FN does not overhear the forwarding of FN, therefore, it stops data transmission till it receives a live message from upstream LFZ. This helps to avoid the loss of data. At this point process of selecting a SN as new FN is initiated. When, the SNs in the LFZ of failed FN, do not listen the forwarding of their FN within specific time, the node that is top in the index list, elects itself as new FN and broadcasts the live message. The entry of the old FN is deleted from the index list. The downstream FN resumes the data delivery as soon it receives the live message from the upstream LFZ. Thus, within the LFZ, load-balancing or FN failure is handled by selecting a node as FN for reliable and continuous data delivery.

## VI. PERFORMANCE ANALYSIS

In this section, we evaluate the performance of the EEFR and compare it with EEFTMR[16] and SWR[19] schemes under different scenarios such as varying node density, node failure ratio. In performance evaluation, we use an energy model as describe in [18] for WSNs. The key energy parameters are the energy needed to sense a bit ( $E_{sense}$ ), receive a bit ( $E_{rx}$ ) and transmit a bit over a

distance  $d$  (Etx). Assuming path loss in energy model is  $\frac{1}{d^n}$ .

These parameters take the form as below:

$$E_{tx} = \alpha_{11} + \alpha_2 d^n \quad (2)$$

$$E_{rx} = \alpha_{12} \quad (3)$$

$$E_{sense} = \alpha_3 \quad (4)$$

Where  $\alpha_{11}$  is the energy/bit consumed by the transmitter electronics (including energy costs of imperfect duty cycling due to finite start-up time),  $\alpha_2$  accounts for energy dissipated in the transmit op-amp (including op-amp in-efficiencies),  $\alpha_{12}$  is the energy/bit consumed by the receiver electronics and  $\alpha_3$  is the energy cost of sensing a bit. Hence, energy consumed per second (i.e. power) by a node acting as a relay that receives data ( $r$  bits) and then transmits it  $d$  meters onward is:

$$P_{relay}(d) = (\alpha_{11} + \alpha_2 d^n + \alpha_{12})r \quad (5)$$

$$= (\alpha_1 + \alpha_2 d^n)r \quad (6)$$

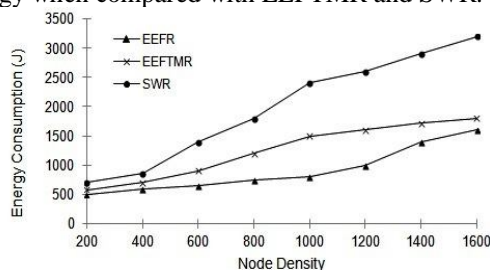
The default simulation setting has a square sensor field of size  $2000 \times 2000 \text{ m}^2$  in which 200 sensor nodes are uniformly distributed. Some of these sensor nodes act as sources and generate data packets. Simulation model is run 100 times and the observation is based on the nodes density and percentage of node failure. The size of control/query packet is 36 bytes and data packets are 64 bytes. Path loss is set as  $\eta = 2$ . The transmission range  $T$  of each sensor is 100m. Table 1 summarizes various simulation parameters.

**Table 1: Simulation parameters**

Parameters	Values
Size of Sensor Network	2000 X 2000 $\text{m}^2$
$\alpha_1$ ( $\alpha_1 = \alpha_{11} + \alpha_{12}$ )	180mJ/bit,
$\alpha_2$	10pJ/bit/ $\text{m}^2$
Data Packet Size	64 Bytes
Query/Control Message Size	36 Bytes
Transmission Range (T)	100 m
Number of Sensor nodes	200
Numbers of Sinks	4
Distribution Type of Sensor Nodes	Uniform

#### • Energy consumption vs. node density

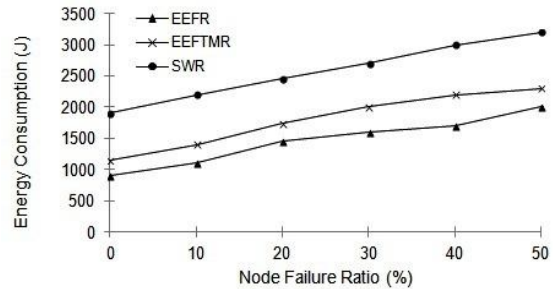
The figure 4 shows that the total energy consumptions of all the schemes with varying node density. Assuming the node failure ratio is 10%. Energy consumption of all the schemes increases with node density. However EEFR consume less energy when compared with EEFTMR and SWR. The EEFR scheme consumes an average of 26% and 46% less energy when compared with EEFTMR and SWR.



**Figure 4: Energy consumption vs. node density**

#### • Energy consumption vs. node failure ratio

The figure 5 shows the total energy consumption with varying node failure ratio. The EEFR consumes less energy when compared to EEFTMR and SWR. This is because, in EEFR, when a FN fails within LFZ, an alternate node within same LFZ is selected as new FN, whereas, EEFTMR constructs and maintains alternative additional paths to handle failures. The energy consumption in case of SWR gradually increases it takes an active strategy against broken paths and always tries to repair them. On an average EEFR consumes 17% and 51% less energy when compared to EEFTMR and SWR.



**Figure 5: Energy consumption vs. node failure ratio**

## CONCLUSION

Proposed Energy Efficient Fault-tolerant Routing (EEFR) in grid based wireless sensor network is node failure detection and recovery scheme. In EEFR, grid nodes that disseminate data are called as forwarding nodes (FNs). Each FN on data path creates a local forwarding zone (LFZ) comprising some nodes. When a FN fails, an alternate node within LFZ is selected as new FN and data delivery continues through same path. In the propose scheme nodes within LFZ overhears the broadcasting and exploits it as acknowledgement. The EEFR efficiently detects the node failure and has the self healing capability against such failure. The simulation results show significant improvement in term of overall energy consumption under different network scenarios such as node density, node failure ratio. The performance of proposed scheme EEFR is better when compared with EEFTMR and SWR.

## REFERENCES

- [1] R. Verdone, D. Dardari, G. Mazzini and Andrea Conti, "Wireless Sensor and Actuator Networks: Technologies Analysis & Design," Elsevier: London UK, March 2008.
- [2] Jamal N. Al-Karaki, Ahmed E. Kamal, "Routing Techniques in Wireless Sensor Network," IEEE wireless Communication, December 2004.
- [3] Hai Jin and Wenbin Jiang, "Handbook of Research on Developments and Trends in Wireless Sensor Networks: From Principle to Practice", Information Science Reference, Hershey, PA, 2010.
- [4] J. H. Lee et al., "Speedy Routing Recovery Protocol for Large Failure Tolerance in Wireless Sensor Networks",

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- [5] Li Paradis and Qi Han; "A Survey of Fault Management in Wireless Sensor Networks"; Springer, Journal of Network and Systems Management, 2007, Volume 15, Issue 2, pp. 171-190.
- [6] Yu M., Mokhar H., and Merabti M.; "A Survey on Fault Management in Wireless Sensor Networks"; IEEE Wireless Communications 14(6), pp. 13 – 19, December 2007.
- [7] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed diffusion: a scalable and robust communication paradigm for sensor networks"; Proceedings of ACM MobiCom '00, Boston, MA, 2000, pp. 56-67
- [8] D. Ganesan, R.Govindan, S.Shenker, and D.Estrin; "Highly-Resilient, Energy-Efficient Multipath Routing in Wireless Sensor Networks" ACM Mobile Computing and Communications Review, Vol. 5, No.4, October 2001.
- [9] F. Ye, S. Lu, and L.Zhang, "Gradient Broadcast: A Robust, Longlived Sensor Network". <http://irl.cs.ucla.edu/papers/grab-techreports.ps>, 2001
- [10] Shah R. C. and Rabaey H. M.; "Energy Aware Routing for Low Energy AdHoc Sensor Networks"; IEEE Wireless Communications and Networking Conference (WCNC.) March 2002, Vol 1, pp 350 – 355.
- [11] Braginsky D., Estrin. D. "Rumor Routing Algorithm for sensor Networks." In Proc. of the First ACM International workshop on Wireless Sensor Networks & Applications, September 2002, page 22-29.
- [12] Kim M., Jeong E., Bang Y. C., Hwang S., Kim B.; "Multipath energy-aware routing protocol in wireless sensor network"; IEEE Proceedings of the 5th International Conference on Networked Sensing Systems (INSS'08), June 17–19, 2008, pp 127–130.
- [13] Yang Y., Zhong C., Sun Y., Yang J.; "Network coding based reliable disjoint and braided multipath routing for sensor networks"; Elsevier, Journal of Network and Computer Applications, Vol. 33, No. 4, pp 422–432; July 2010
- [14] Karil L., Nasser N.; "Energy Efficient and Fault Tolerant Clustering Protocol for Mobile Sensor Networks"; IEEE ICC 2011 proceedings, June 2011.
- [15] Challal Y, Ouadjaout A, Lasla N, et al. Secure and efficient disjoint multipath construction for fault tolerant routing in wireless sensor networks. Journal of Network and Computer Applications, 2011, 34(4): 1380–1397.
- [16] Chanak P., Banerjee I., "Energy efficient fault-tolerant multipath routing scheme for wireless sensor networks", Elsevier ScienceDirect, The Journal of China Universities of Posts and Telecommunications, Volume 20, Issue 6, pp 42–48, December 2013.
- [17] Singh K., Sharma T.P.; "Sink Location-oriented Data Dissemination using Grid in Wireless Sensor Networks"; Elsevier Int. Conf. on Advances in Information Technology and Mobile Communication AIM 2013, pp 346-353, April 2013.
- [18] M. Bhardwaj, T. Garnett, A. P. Chandrakasan, "Upper bounds on the Lifetime of Sensor Networks," IEEE Conference on Communications (ICC 2001), Finland, vol. 3, pp 785 – 890, June 2001.
- [19] Di Tian , Georganas, Nicolas D. "Energy efficient routing with guaranteed delivery in wireless sensor networks" IEEE Wireless Communications and Networking, Vol 3, pp. 1923 – 1929, 2003.

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