GBFTS: Group Based Fault Tolerant Scheme in Wireless Sensor Networks

Indrajit Banerjee, Prasenjit Chanak, Hafizur Rahaman, and Nachiketa Das

***Abstract*—In wireless sensor network probability of fault occurrences are very high mainly for physical deployment and wireless communication policy. Faulty sensors node and transmission fault decreases the network quality. It is most important to tolerate the faults which occur in network to improve the network quality. In wireless sensor network, energy is most considerable thing because each sensor node has a constant power supply. In this paper, we propose group based fault tolerant scheme (GBFTS) for fault tolerant and energy efficient routing in wireless sensor networks. In this technique sensor nodes are organized into some levels and groups. Each node communicates to other node on the basis of level and group. The GBFTS technique recovers data transmission failure, sensor node failure and data transmission delay with the help of alternative node connection in different network levels with minimum energy loss. The simulation result shows that the GBFTS recovers maximum number of sensor node failures or transmission failures. The result shows that the GBFTS technique transmits data very fast in normal and faulty environment.**

***Index Terms*—Fault tolerant (FT), wireless sensor network (WSN), base station (BS), group head.**

I. Introduction

A wireless ad-hoc network is collection of hundreds or thousands of autonomous nodes/terminals [1]. They are forming a multi-hop radio network that can be used in wide spectrum of application. The fault tolerant techniques in WSN can be divided into two parts, one is retransmission another is data replication. The retransmission based techniques are based on acknowledgement transmitting. In retransmission technique main disadvantage is large amount of energy and time wastes for data retransmission; therefore, this is not suitable for WSN. In replication technique multiple copies of data are transmitted over multiple way/path in the networks. If any fault occurs in network then the duplicate transmitted data reaches to the base station or cluster head using alternative way. If large numbers of way/paths are selected for duplicate data transmission then huge amount of energy is lost for multiple data transmission. Other hand multiple data packets create traffic congestion problem in the networks. In this scenario, we propose an energy efficient fault tolerant routing protocol referred to as the GBFTS to suit for the WSN large number application. The GBFTS technique divided whole network into some groups. Group members are connected to group head via multi-hop connection. The connections are maid according to their level value and membership value. In GBFTS, sensing data is moved implicitly towards the base station by multiple ways with minimum node involvement through the group head. Group head is selected from the group member's node. In GBFTS technique, nodes consume small energy to transmit data to their base station and able to recover maximum number of faults. In this paper we have compared the performance of our proposed scheme GBFTS with other fault tolerant algorithm like query-base protocol (PEQ) [2] and directed diffusion (DD) [3] technique.

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The authors are with the Bengal Engineering and Science University, Shibpur, Howrah. India. (e-mail: ibanerjee@it.becs.ac.in; e-mail: prasenjit.chanak@gmail.com; e-mail: rahaman_h@it.becs.ac.in; e-mail: nachiketad@gmail.com).

II. Group Base Fault Tolerant Scheme

This section proposes a fault tolerant technique, referred to as GBFTS. The GBFTS targets fault tolerant data routing with energy efficient manner in sensor networks. GBFTS also control traffic delay, when sensor node transmit there data to base station. The work is motivated by the idea of Application Level Framework (ALF) [4] and SPIN Family Protocol [5], [6].

The GBFTS is based on the following ideas-

1) Before data transmission, the sensor nodes should make small groups according to their level value and membership number. Every group select a group head in lower level of the groups. Group head collect data from group member's nodes and transmits to upper groups.
2) The sensor nodes should be resource adaptive. They should monitor their resources and change their operation accordingly at each time interval [7].
3) Data should move towards destination through shortest path. The involvement of minimum number of nodes in data transmission extends the network lifetime and also ensures the data security.
4) Sensing data reach to group head or base station with multiple paths but group head or base station receive only one data packet, negotiate other duplicate data packet. If one data is loss by any fault of network then other duplicate data reach to group head or base station.

A GBFTS node handles five types of messages for communication:

LVL: level determination: After deploying all the sensor nodes. Base station (BS) would help to determine the level of sensor node as it has been done in previous work [1].

MSN: membership number determination: After level determination, base station (BS) would help to determine the member ship number with respect to level vales of the nodes.

ADV: new data advertisement: When nearest level nodes of group head wants to dissipate a data, it advertises this fact by broadcasting ADV message (containing the meta-data).

REQ: request for data: A group head send a REQ message with respect to ADV message.

DATA: a DATA message contains useful sensor data: This message is used in original data transmission.

Meta-data contains a brief and complete description of the data that is to be sent. It is described as

$$MDx = F\ (Dx) \quad (1)$$

Dx refers to the actual data. The size of meta-data (*MDx*) must be much shorter than the *Dx*. For the current work, ‘F’ is considered as defined in [1], [9]. The GBFTS nodes are resource-aware as well as resource adaptive. The nodes can find out the energy available at any moment of time and can also calculate the data transmission and computations cost in terms of energy. This information allows a GBFTS node to take decision with the target of proper resource utilization.

III. Mathematical Model

In this section we are describe mathematical formula which are used to data transmission and data receiving purpose. We also describe GBFTS routing delay.

Energy dispatch by the sensor node is calculated through a linear function. In radio communication data transmission energy loss is represented by E_t:

$$E_t = (\alpha_1 + \alpha_2 \gamma^n)\beta \quad (2)$$

where α_1 represent energy consumed by the transmitter electronics circuit. And α_2 represent dissipated energy in the transmit op-amp. The both parameter are properties of the transmitter which is use by the sensor nodes, γ represent transmission range. The parameter ‘n’ is the power index for the channel path loss of the using antenna. The β represent bits rate which is transmitted by the sensor nodes.

Energy dispatch for receiving purpose is represented by the E_r. If α_3 is the energy/bit which is consumed by the receiver electronics circuit used by sensor node and receiving bit is βthen:

$$E_r = \alpha_3 \beta \quad (3)$$

In GBFTS technique sensor node divided into some groups according to network size. Every group content a group head, group head collect data from its group member nodes. After data collection group head aggregate data and send it to next group for sending data to base station. Each group’s member nodes send their data to next lower level nodes. Group head present upper level of the next group. Group head nearest upper level nodes content multiple copies of the data but group head collects only one nodes data from nearest level nodes. Other duplicate data packets are negotiated by the group head. With the help of *lemma 1* we are calculating packet routing delay in GBFTS.

Lemma 1: Let M be the collection of path, which are used for packets transmission to the network. If m is non-repeating path for them, then the delay suffered by any packet σ is not more than the number of distinct packets that overlap with σ. A set of paths ‘m’ is said to be non-repeating if any two paths in ‘m’ that meets, shares some successive links, and diverge never meets again. Two packets will be overlap if they share at least one link in their paths.

Proof: Let σbe an arbitrary packet. If $\sigma$is delayed by each of the packets that overlap with no more than once, the lemma is proven. Else, if a packet (call it n) overlapping with σdelay σ twice, then n has been delayed by another packet which also overlaps with $\sigma$and which never gets to delay σ. Let $M_i$be the link that σ traverses in level i, for$1 \le i \le d$, d represent level. To compute the maximum delay that σ can ever suffer, it suffices to compute the number of distinct packets that overlap with σ. If $n_i$is the number of packets that have the link M_i in their paths, then $D\sum_{i=1}^{d} n_i$ is an upper bound on the number of packets that overlap with σ.

The number of packets that can potentially go through the link M_i is 2^{i-1}since there are only 2^{i-1}sensors at level one. Each such packet has a probability $\frac{1}{2^i}$ to going through M_i. This is because a packet starting at level one can take either the direct link or the cross link, each with a probability of $\frac{1}{2}$. Once it reaches a sensor at level two, it can again take either a cross link or a direct link with probability $\frac{1}{2}$, and so on. If the packet has to go through M_i, it should pick the right link at each level and there are i such links. Therefore, the number $n_i$of packets that go through $M_i$is a binomial $B(2^{i-1}, \frac{1}{2^i})$. The expected value of this is $\frac{1}{2}$. Since the expectation of a sum is the sum of expectations, the expected value of $\sum_{i=1}^{d} n_i\ is\ \frac{d}{2}$. The total delay is O(d) with high probability.

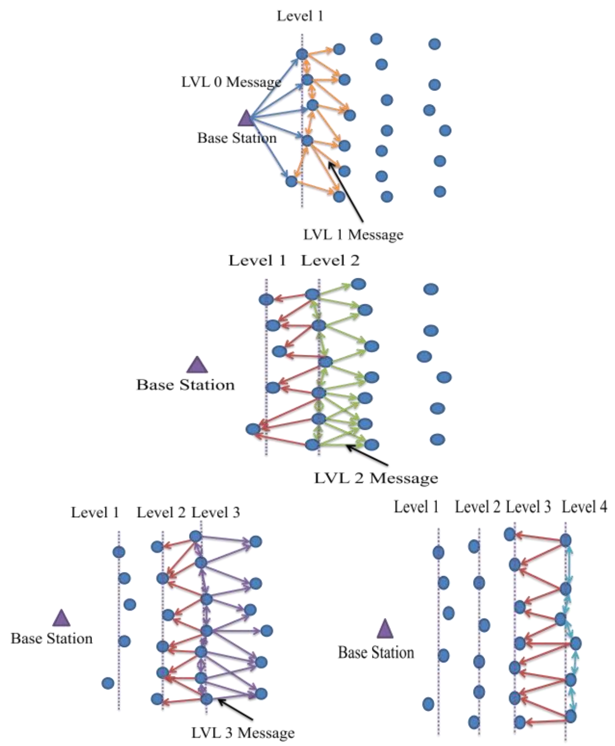

Fig. 1 Level detection protocol a) base station send LVL 0 message nearest sensor nodes, nearest sensor nodes set their level 1 and broadcast LVL 1 message b) LVL 1 nearest nodes receiver sending message and check their level value if receiving level value is less then present level value then set their level receiving level value add 1 and broadcast LVL message to nearest nodes.

IV. Implementation of GBFTS

In this section, we present the details of GBFTS that follows the philosophy outlined in section II and III. The GBFTS works in four phases: *a)* Level determination of each node. *b)* Member ship number determination of each node. *c)*

Generate connection oriented grouping between the sensor nodes. *d)* Data transmission from sensor nodes to group head or base station. At the time of sensor nodes deployment in WSN, the level of each sensor node is set as infinite (LVL = ∞). The LVL message is used to determine the level, as our previous work in [1] (Fig. 1). After fixing level for all the sensor nodes, the GBFTS divides the whole network in different levels. When a new node N is added to an existing network, it determines level with broadcasting an LVL message to its neighbors. The level of any sensor node can compute its LVL value as min (LVL of neighbors) +1. After level detection phase connection establishment phase start.

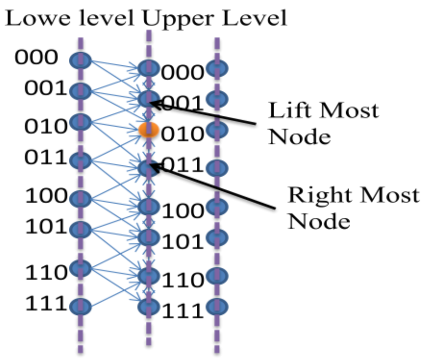

Fig. 2a. Upper level nodes set their membership value according to neighbour nodes information.

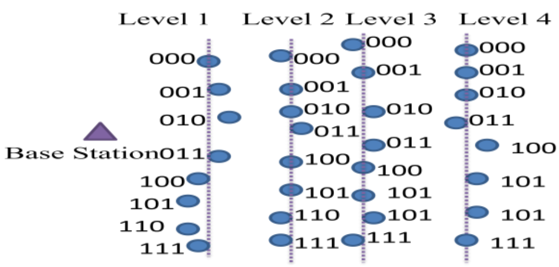

Fig. 2b. Sensor nodes set their memberships value in WSN.

In connection establishment phase each node set own member ship number with the help of base station (BS) (Shows in Fig. 2a and Fig. 2b). At the time of deployment every sensor nodes set their member ship number as ∞ . Base stations only provide nearest level sensor nodes member ship value by broadcasting MSN message into LVL 1. The LVL 1 sensor nodes receive MSN message from base station and check her member ship number and its left or right neighbour's member ship number. If MSN less then member ship number then set own member ship number MSN less then right neighbour and grater then left neighbour *($MSN_{left\text{-}neighbour} < MSN_{owner} < MSN_{right\text{-}neighbour}$)* . After set its membership value it further broadcasts MSN message to set the membership number of its neighbour nodes. Upper Level member nodes sets own membership value according to the receiving MSN message. This process continues until each node gets a MSN value less than ∞. When a new node N is added to an existing network, it determines membership number with broadcasting an MSN message to its neighbour nodes.

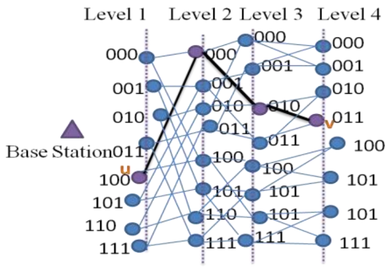

Fig. 3. Connection establishments between different level nodes.

After setting the member ship number, sensor nodes are arranging into different groups. The group size depends on the total size of the networks. The groups are made with 2^n number of nodes where, $n = 2,3,4, \dots$. In a single group each member node of upper level nodes directly transmits their data to lower level (Fig.3). Group content a group head, which is present in the upper group's lower level (Fig. 4). The group head collects all the data from its own group members then aggregates and send it to upper group; finally it reaches to base station. The definitions 1 describe how group's members are connection in networks.

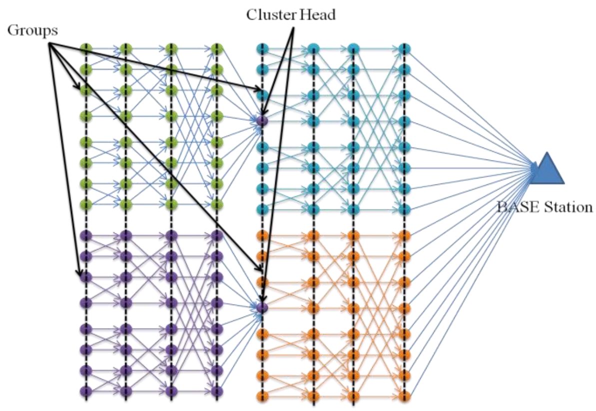

Fig. 4. Groups nodes connection in GBFTS.

Definition 1: Group denoted by G_L. Each node in G_L can be represented as a tuple $< r, l >$. the variable r is MSN of the nodes and l represents the level of the node. A node $u = < r, l >$ in G_L is connected with two nodes in upper level. These two nodes are $v = < r, l+1 >$ and $w = < r(l+1), l+1 >$. The MSN number of v is the same as that of u and the MSN number of w differ from r only in the $(l+1)th$ bit. Both v and w are in level $l+1$. The link (u, v) is known as the direct link and the link (u, w) is known as the cross link. Both of these links are present in level$(l+1)$.

Example: in Fig 3 the node $< 011,1 >$ is connected to the nodes $< 011,2 >$ and $< 001,2 >$ in this case group size is 2^5. Since upper level node transmit their data to group head with the help of at most four nodes. If u is any nodes in level 1 and v is any node in level k, there is a unique path between u and v of length d. Let $u = < r, 0 >$ and $v = < r', d >$. The unique path is $< r, 0 >, < r_1, 1 >, < r_2, 2 >, \dots \dots, < r', d >$, where r_1 has the same first membership number node as r', r_2 has the same first and second member ship number node as r', and so on. This path exits in the definition 1.

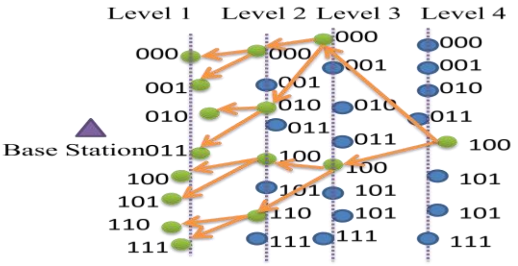

Fig. 5. Data transmission from source node to base station.

In data transmission phase when any node sense data from surrounding environment, first check whether this data is new data or not. If this data is new then it is to be transmitted to group head. The group head collect all group members data and transmitting to next upper group head. In a group, upper level sensor nodes transmit their data next two lower level sensor nodes according to their connection path. In Fig. 5 the node '100' level 4 sends it data to next lower level 3's member node '100' and '000'. After receiving this data node '100' and '000' checks whether the data is new or not. If received data is new then transmit it to next lower level 2 member nodes {000, 010, 100, 110} and level 2 sensor nodes {000, 010, 100, 110} check those data in similar manner and send the receiving data to level 1 member nodes {000,001,010,011,100,101,110,111}. Finally, in a group every lower level member nodes get data from upper level nodes. In group nodes send their data into multiple paths because if any data is loss by the environmental noise or other physical component then duplicate data packet reaches to group head. When data is transmitted from upper level to lower level then data packet duplication is increased into 2^n ratio. In lower level data cost is very high because in a group if fault occurs between lower level sensor nodes then again data is retransmitted from upper level this process very time and energy consuming. In GBFTS lower level fault tolerant percentage is very high compare to upper level. If any fault occurred in lower level sensor nodes that will not affect in data transmission into base station because these faults are recovers by the other sensor nodes. In level 2 fault tolerant percentage is low compare to level 1 i.e. half of level 1 because in this level four sensor nodes takes receiving data which is transmitted by the upper level 3. In level 3 fault tolerant percentage is half of the level 2 i.e. in this level two sensor nodes receive data which is send by level 4 source nodes.

When group head nearest level nodes are receiving data from upper level or sensing new data from environment. They produce a meta-data according to original data. The size of meta-data is very small compare to original data. Meta-data send to group head by ADV message. The group head maintain a queue and store meta-data information. According to meta-data information group head replay with REQ message on first come first serve (FCFS) basis for sending original data. If requesting node unable to send original data to group head. Group sent REQ message to next node. If meta-data sending nodes are not receiving any REQ they are not send their original data. They are deleting the original data after some interval of time.

V. GBFTS SIMULATION

In this section, we evaluated the performance of the GBFTS technique. The network simulation model is built using MATLAB. Table 1 summarizes the important simulation parameters value. The sensor nodes have following attributes: a unique identification number (node MSN), a level number (node LVL), and node status which indicate whether a node is in alive state or dead with respect to nodes remaining energy reading. *Average delay:* Average delay is latency time, from the moment when a packet is transmitted by source node to the moment it is received at the base station. *Average packet delivery ratio:* Ratio of the number of distinct received packet to the number of originally sent packet.

TABLE I: SIMULATION PARAMETERS

Sensor Deployment Area	100×100
Number of nodes	100 to 600
Data Packet Size	800bit
Initial Energy	0.5J
$\alpha_1\alpha_3$ energy loss by transmitter electronics circuit and receiver energy loss circuit	50 nJ/bit
$\alpha_2$dissipated energy by transmit op-amp	10 pJ/bit/ m^2
Data aggregation energy loss	5nJ/bit/message

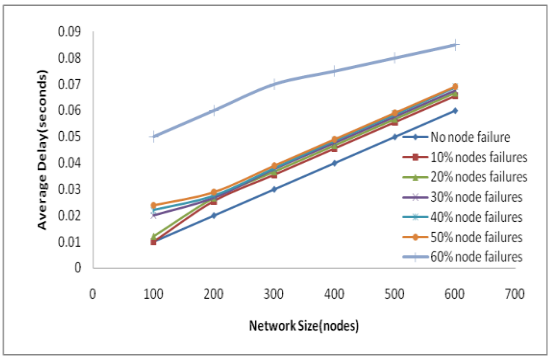

Fig. 6. Average delay with nodes failures.

In GBFTS if any fault is occurs in the networks then average delay for data transmission is very small (Fig. 6). In the GBFTS technique if number of nodes or transition fault is increased then the data transmission delay is increased slowly. The GBFTS tolerate 53% nodes failure of total network size. The average delay for data transmission is increased for more than 53% nodes failure.

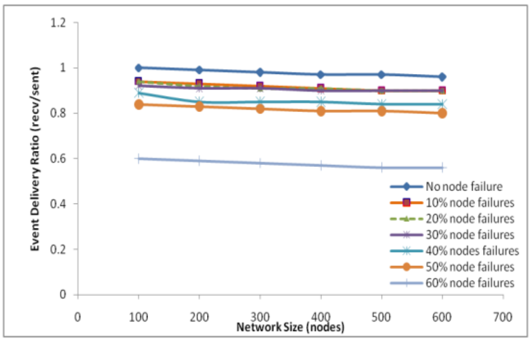

Fig. 7. Average packets delivery ratio with nodes failures.

Fig. 7 shows that the GBFTS is able to maintain a reasonable packet delivery rate even at high percentage of node failures. The GBFTS techniques recover 55% nodes failure. When 55% nodes fault occurs in whole network then event delivery are affected in very small scale but after 55% nodes failure, delivery ratio is affected in very high scale.

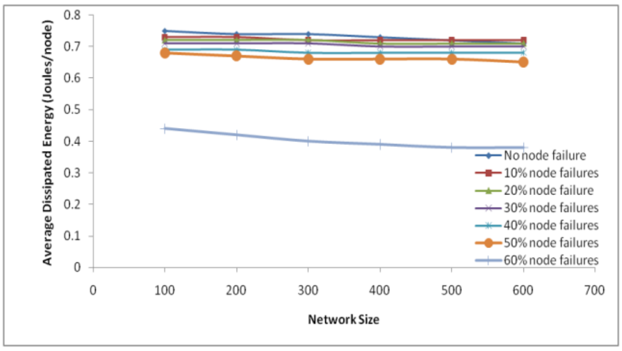

Fig. 8. Average dissipated energy with node failures.

Fig. 8 shows that the average energy loss of the network in different percentage of nodes failure. In GBFTS the energy loss decreases slowly up to 55% nodes failure, because in this case maximum amount of sensing data is delivered to base station. However, when the nodes failure reaches 55% then energy loss of the network decreases very fast, because the number of data delivery to base station is decreased.

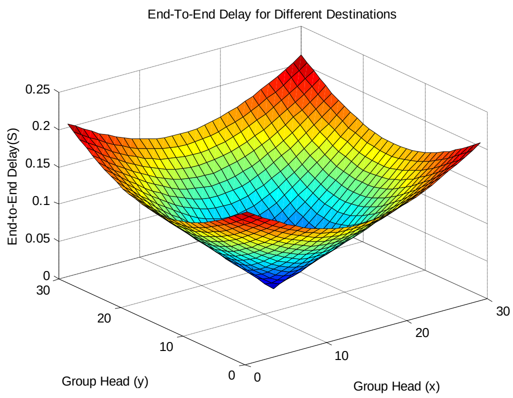

Fig. 9. End-To-End Delay for different group head location in GBFTS.

The data transmission delay from different group head location to base station is shown in Fig. 9. In this case we consider total number of nodes in the network is 250 and base station is located at the middle of the network. When group head distance from base station is increased then data transmission delay is increased.

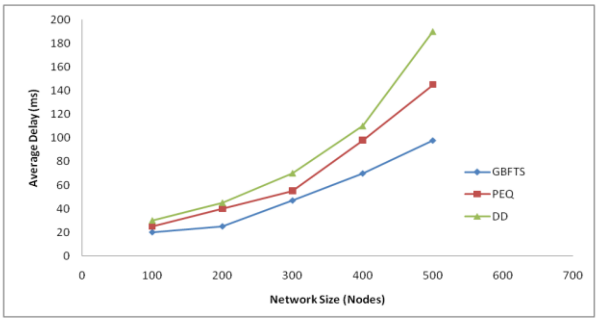

Fig. 10. Average packets delivery delay.

The Fig. 10 shows the comparison result of the packet delivery time to base station among GBFTS, PEQ and DD algorithm. If network size is increased then DD and PEQ data delivery time is also very highly increased compare to GBFTS technique. GBFTS delivers data to base station 28.37% faster than PEQ and 41.58% faster than DD.

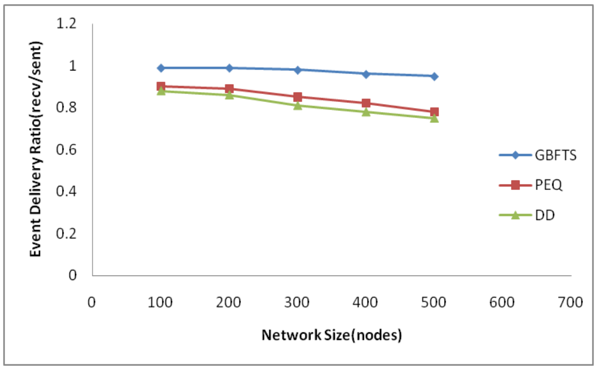

Fig. 11. Packets delivery ratio.

The Fig.11 shows the comparison result of packet delivery ratio to base station. GBFTS is more efficient to avoid data collision within network compare to PEQ and DD techniques and deliver maximum number of packets.

VI. Conclusions

In this paper we propose GBFTS fault tolerant technique. The GBFTS improves the fault tolerant capability of the WSNs compare to other exiting fault tolerant techniques with minimum energy loss and time delay. In GBFTS technique, nodes are connected to the base station or group head on the basis of membership number and level value. In this technique, if source node sends any data to base station then fault tolerant probability is increased in lower level comparison to upper level. The valuation of data is increased in lower level comparison to upper level. The GBFTS technique tolerates 55% nodes failure with energy efficient manner.

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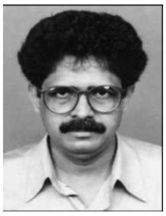
Indrajit Banerjee is an assistant professor in the Information Technology Department at Bengal Engineering and Science University, Shibpur, India. He got the bachelor degree in mechanical engineering from Institute of Engineers, India. He received his masters in Information Technology from Bengal Engineering and Science University in 2004. He is currently pursuing his Ph. D. in Information Technology in Bengal Engineering & Science University. His main research interests are cellular automata, wireless ad hoc and sensor network.

Prasenjit Chanak received his B.Tech degree in Information Technology from Institute of Engineering and Technology, U.P., India in 2007. He is currently pursuing his master's degree in Information Technology from Bengal Engineering and Science University. His main research interest is wireless ad hoc sensor network.



Hafizur Rahaman received the B.E. degree in electrical engineering from Bengal Engineering College, Calcutta University, Calcutta, India, in 1982 and the M.E. degree in electrical engineering and Ph.D. degree in computer science and engineering from Jadavpur University, Calcutta, in 1988 and 2003, respectively. During 2006–2007, he visited the Department of Computer Science, Bristol University, Bristol, U.K., as Postdoctoral Research Fellow. He is currently chairing the Department of Information Technology, Bengal Engineering and Science University, Howrah, India. His research interests include logic synthesis and testing of VLSI circuits, fault-tolerant computing, Galois-field-based arithmetic circuits, and quantum computing. Dr. Rahaman has served on the Organizing Committees of the International Conference on VLSI Design in 2000 and 2005 and as the Registration Chair for the 2005 Asian Test Symposium, which was held in Calcutta.

Nachiketa Das is a research scholar in School of VLSI Technology at Bengal Engineering and Science University, Shibpur, India. He got the bachelor degree in electronics and communication engineering from Institute of Electronics and Telecommunication Engineers, India. He received his masters in Digital electronics and advanced communication in 2005. His main area of research is fault detection and synthesis of FPGA.