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Gravitational Search Algorithm based Fault Tolerance in Wireless Sensor Network

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Abstract— **In this paper, we propose Gravitational search algorithm (GSA) based fault tolerance in wireless sensor network. Based on the residual energy and sponsored coverage of the sensor nodes cluster head is selected. To monitor the activity of the cluster head, a backup node is selected in each cluster. This backup node is selected using our proposed Gravitational search algorithm (GSA). Using this selected backup node, faulty cluster head is identified. In the same way, activity of the cluster members are also monitored by using the selected CHs. Simulation results show that performance of the proposed approach outperforms our previous work.**

Keywords— Gravitational search algorithm (GSA), cluster head, backup node, faulty cluster head

1.INTRODUCTION

Wireless Sensor Networks (WSNs) have been broadly taken in account as a standout amongst the most vital advancements for the twenty first century [1] [2]. Empowered by late advances in remote communication advances, little, modest, and shrewd sensors sent in a physical range and organized through remote connections and the Internet give extraordinary chances to an assortment of non military personnel and military applications, for instance, natural supervision, war zone observation and control of industrial process [3] [4]. Recognized from conventional remote communication systems, for instance, cell frameworks and mobile ad hoc networks (MANET), WSNs have one of a kind qualities, for instance, denser level of hub organization, higher lack of quality of sensor hubs and extreme energy, calculation, and capacity imperatives [5] [6], which display numerous new difficulties in the improvement and use of wireless sensor networks. In the previous decade, wireless sensor networks have gotten gigantic consideration from both scholarly world and industry everywhere throughout the world. A lot of research exercises have been completed to investigate and settle different plan and application issues and huge advances have been made in the improvement and deployment of wireless sensor networks. It is imagined that sooner rather than later wireless sensor networks will be broadly utilized as a part of various regular citizen and military fields and alter the way we live, work, and collaborate with the physical world [7].

However, sensor nodes in the network often face node failure because of hardware failures, exhaustion of power or malicious attack. Once some sensors failed, networks may be split into multiple isolated parts, preventing the sensor transmitting data, even worse leading to network failure. Since it is unrealistic to remove or repair the faulty nodes in the network, research on the fault-tolerant and reliability characteristics of wireless sensor networks is becoming a popular issue recently. So this work focused on fault tolerant of the sensors in wireless sensor network. Contribution of this work is described below.

- Based on the residual energy and sponsored coverage of the sensor nodes, cluster head (CH) is selected.
- In each cluster, backup node (BN) is selected using our proposed Gravitational search algorithm (GSA).
- Using the selected BNs, inactive CHs are identified. In the same way, inactive cluster members are identified using CHs.

Rest of this paper is organized as follows. Section 2 surveys some previous literatures. Section 3 presents our proposed approach. Section 4 discusses results of our proposed approach. This paper is concluded with section 5.

2. RELATED WORKS

In this section, some previous literatures are reviewed that focused on the fault tolerance challenges in wireless sensor network. Indrajit Banerjee *et al* [8] have presented efficient fault detection and routing (EFDR) method. They have detected the faulty nodes using neighbor node's temporal and spatial correlation of sensing information. Deepali Virmani, Savneet Kaur and Satbir Jain [9] have proposed Secure and Fault Tolerant Dynamic Cluster Head (SFDCH) Selection algorithm. Based on the maximum available energy, maximum throughput and minimum distance, they have selected the cluster head. M. Yuvaraja1 and M. Sabrigiriraj [10] have presented a fault detection and recovery method where the sink makes an agent packet and the Agent establishes a query path towards the dead or faulty node. Arunanshu Mahapatro and Ajit Kumar Panda [11] have proposed multiobjective swarm optimization (2LB-MOPSO) algorithm to find an optimum trade-off between detection accuracy and detection latency. They also have used Time redundancy to detect intermittent faults since an intermittent fault does not occur consistently.

Kumar Nitesh, Md Azharuddin and Prasanta K. Jana [12] have presented a distributed algorithm to design an energy efficient cluster base WSN. They also have proposed a local recovery method for the abandoned sensor nodes, which are formed due to the failure of any cluster head. Yao Lin *et al* [13] have proposed fault-tolerant protocol. Their proposed fault-tolerant algorithm has searched faulty node in the path and revise the path furthermore. This algorithm has resisted malicious attack and node losses. T. Panigrahi, Meenakshi Panda and G. Panda [14] have presented a fault tolerant distributed estimation in WSNs. They also have presented block adaptive diffusion adaptive algorithm to make the robust estimation algorithm energy efficient. Md Azharuddin, Pratyay Kuila and Prasanta K. Jana [15] have presented distributed clustering and routing algorithms jointly referred as DFCR. They also have used distributed run time recovery of the sensor nodes to prevent the CHs from the sudden failure.

3. GRAVITATIONAL SEARCH ALGORITHM BASED FAULT TOLERANT

A. Residual energy

The residual energy (RE_i) of each node(N_i) after performing one data communication is estimated using the following formula:

$$O_1 = RE_i = E_i - (E_{tx} + E_{rx}) \tag{1}$$

Where, E_i is the initial energy of the node; E_{tx} and E_{rx} are the energy utilized at the time of transmission and reception of data.

B. Sponsored coverage (Ci)

Sponsored coverage is defined as the sector shaped region in the sensing area of a node covered by its neighbor node. Consider two nodes X and Y at a distance c. The sponsored coverage of Y for X is represented using the central angle 2ω where ω can be calculated as follows:

$$Cos\,\omega = \frac{d^2 + X^2 - Y^2}{2Xd} \tag{2}$$

$$\therefore O_2 = \omega = arc\cos\left(\frac{d^2 + X^2 - Y^2}{2Xd}\right) \tag{3}$$

C. Cluster formation

Among the sensor nodes, node with maximum residual energy and coverage is selected as cluster head (CH). Based on the weight of the cluster head, each sensor node in the sensing area joins to corresponding CH, thus the cluster is formed. Weight of the cluster head is calculated based on the following equation.

$$W\,(SN_j, CH_i) = \alpha \frac{E_{res}(CH_i)}{d(SN_j, CH_i) \times d(CH_i, BS)} \tag{4}$$

Where, $E_{res}(CH_i)$ - denotes the residual energy of CH. Sensor nodes join to the CH with higher residual energy.

$\frac{1}{d(SN_j, CH_i)}$ - defines reciprocal of distance between sensor node SN_j and cluster head CH_i. The sensor node SN_j joins to the nearest CH_i in its communication range.

$\frac{1}{d(CH_i, BS)}$ - defines the reciprocal of distance between cluster head CH_i and base Station BS. The sensor node SN_j joins to the CH_i which is closer to the base station BS.

α - represents a constant value.

During this cluster formation, each sensor node calculates this weight value using the above equation (4). Then the sensor node joins to the cluster head CH with the highest weight value.

D. Backup node selection using Gravitational Search Algorithm

To monitor the activity of each cluster head in a cluster, a backup node (BN) is to be selected. For backup node selection, Gravitational Search Algorithm (GSA) is presented in this section. Gravitational Search Algorithm performs based on the law of gravity. In GSA, objects (candidate solutions) are considered as the agents (masses). Because of the gravity force the agents attract each other. This force results in a worldwide movement of all agents towards the agents with heavier masses. Henceforth, masses cooperate with the help of a direct form of communication through gravitational force. The heavy masses (that correspond to optimal solutions) move more slowly than lighter ones. The position of the mass or agent corresponds to the solution of the issue. With the help of a fitness function gravitational and inertial masses are estimated. The solution with heavy mass is measured as an optimal solution in the search arena.

Solution of this algorithm is the position of the BNs which are to be selected. Now, let us assume a scheme with $i\,th$ agents (masses) i.e.,

$$A_i = \lfloor X_{i,1}(t), X_{i,2}(t), \ldots\ldots, X_{i,D}(t) \rfloor \quad (5)$$

Where $X_{i,d}(t)$ denotes the position of the $i\,th$ agent or BNs in the $d\,th$ dimension. This is also represented as,

$$X_{i,d}(t) = (x_{i,d}(t), y_{i,d}(t)),\ 1 \le i \le N_P,\ 1 \le d \le D \quad (6)$$

The force on the $i\,th$ mass from the $j\,th$ mass at time t is well-defined

$$F_{ij}^d(t) = G(t) \times \frac{Mass_{PG_i}(t) \times Mass_{AG_j}(t)}{R_{ij}(t) + \varepsilon} \times \left(x_i^d(t) - x_j^d(t)\right) \quad (7)$$

Where $Mass_{AG_j}(t)$ represents the active gravitational mass associated with the $j\,th$ agent at time t. $Mass_{PG_i}(t)$ denotes the passive gravitational mass associated with the $i\,th$ agent at time t. ε and $G(t)$ represent a small constant and gravitational constant correspondingly. $G(t)$ is well-defined as follows

$$G(t) = G_0 \times \exp\left(-\gamma \times iter / \max iter\right) \quad (8)$$

Where, G_0 and γ are signified as initial value and descending coefficient correspondingly. Current iteration is signified as $iter$ and maximum number of iteration is signified as $\max iter$. $R_{ij}(t)$ is the Euclidian distance within the agents i and j. The total force on agent i for each iteration is assessed with the help of the subsequent equation.

$$F_i^d = \sum_{j \in Kbest,\, j \ne i} ran_j F_{ij}^d(t) \quad (9)$$

Where, Kbest signifies the set of K agents with the best fitness values and the biggest masses. ran_j is a random number in the interval [0, 1]. By mapping the fitness, the inertial mass of each agent is designed as follows

$$mass_i(t) = \frac{Fit_i(t) - worst(t)}{best(t) - worst(t)} \quad (10)$$

$$Mass_{in_i}(t) = \frac{mass_i(t)}{\sum_{j=1}^{N} m_j(t)} \quad (11)$$

Where, $Fit_i(t)$ signifies the fitness value of the ith agent at time *t*. In this work, the fitness value is calculated using the parameters sponsored coverage and residual energy. Using equations (1) and (3), the fitness value is derived as,

$$Fit_i(t) = o_1 \times \beta + o_2 \times (1 - \beta), \qquad 0 < \beta < 1 \quad (12)$$

An agent with maximum fitness value has heavier mass and has better position, i.e., the better is selected as the backup node.

The values *best (t)* and *worst (t)* are well-defined as

$$best(t) = \max_{j \in \{1,\ldots,N\}} Fit_j(t) \quad (13)$$

$$worst(t) = \min_{j \in \{1,\ldots,N\}} Fit_j(t) \quad (14)$$

Henceforth, the acceleration of ith agent at time *t* is intended with the help of equations (9) and (11). $a_i^d(t)$ is well-defined as follows

$$a_i^d(t) = \frac{F_i^d(t)}{Mass_i(t)} \quad (15)$$

Velocity and position of an agent are designed with the help of the subsequent equations (16) and (17) correspondingly.

$$V_i^d(t+1) = ran_i \times V_i^d(t) + a_i^d(t) \quad (16)$$

$$X_i^d(t+1) = X_i^d(t) + V_i^d(t+1) \quad (17)$$

Where, ran_m represents a uniform random variable in [0, 1].This random number gives randomized characteristic to the search. The iteration counter is augmented until we get the optimal solution.

Algorithm

1.Initialize the Agents i.e., m number of BNs.
2.Calculate the fitness function for each agent using (12).
3.Update G (t), best (t) and worst (t) using (8), (13) and (14) respectively.
4.Calculate the total force using (9).
5.Calculate inertial mass and acceleration using (11) and (15) respectively.
6.Update velocity and position using (16) and (17) respectively.
7.Process continued until get the optimal solution.
The agent with optimal solution is selected as a number of BNs.

E. Faults detection using the selected BNs and CHs

1.Backup node monitors the corresponding CH and decides whether it is alive or not.
2.Periodically, BN sends alive message (AL_Mes) to the CH.
3. If the BN receives reply message from the CH, then it decides CH is alive. Otherwise CH is declared as defective and the selected BN cares the role of CH.
4.Similarly, cluster members in a cluster are monitored by their corresponding CH.
5.Each cluster head in a cluster receives information from the cluster members periodically.
6.If CH does not receive the information for a pre-determined interval, then the corresponding member is assumed as failed and it will be removed from the routing table.

4. RESULTS AND DISCUSSIONS

Our proposed approach GSA-FT (Gravitational Search Algorithm based Fault tolerant) is implemented in network simulator NS2. In this simulator, 500 sensor nodes are performed in the region 1000m×1000m. Each sensor node in the region is executed with the transmission power of and also the receiving power of. Transmission range of each sensor node is. DSDV routing protocol is used in this work. Each sensor node is included with Omni directional antenna radiates radio wave power uniformly in all directions. Also Two ray ground radio propagation model is considered, which used to predict the received signal power of each packet. Table 1 shows the simulation parameter and its value of our proposed approach.

Parameter	**Value**
Area size	1000m×1000m
Routing protocol	AODV
MAC	802_11
Antenna	Omni Antenna
Radio propagation model	Two Ray Ground
Packet size	512bytes
Initial transmitting power	0.660W
Initial receiving power	0.395W
Initial energy	10.3J
Simulation time	100secs
Rate	500kb

Table 1: Simulation parameters and its values

4.1. Performance metrics

Performance of our proposed approach is evaluated using the following metrics. Performance metrics of our proposed approach GAFSA-FCR are compared with that of our previous work GAFTC [16].
Delivery ratio: It is the ratio of the number of packets received successfully and the total number of packets transmitted.

$$Delivery\ ratio = \frac{Number\ of\ packets\ received}{Number\ of\ packets\ transmitted} \quad (18)$$

Packet drop: It is the number of packets dropped during the data transmission.
Packet delay: The delay of network describes how long the network takes to transmit a bit to the destination. Unit of this parameter is seconds (s).
Throughput: It is the amount of data that can be sent from the sources to the destination per second. Unit of this parameter is kb/s.

$$Throughput = \frac{Amount\ of\ transmitted\ data\,(kb)}{Transmitted\ time\,(s)} \quad (19)$$

Overhead: Number of extra bytes added to the data packet to transmit the data.
Energy consumption: Amount of energy consumed by each node during the transmission. Also it is defined as the difference between the initial energy and current energy of a node. Unit of this parameter is Joule (J).

$$Energy\ consumption = Initial\ energy - current\ energy \quad (20)$$

Network lifetime: It is defined as the time of network disconnection due to the failure of one or more sensor nodes. Unit of this parameter is seconds (s).

B Performance based on nodes

Performance metrics of our proposed approach GSA-FT are evaluated for varying nodes 100, 200, 300, 400 and 500 nodes. Figures 1-6 show the comparison of the performance metrics of our proposed approach GSA-FT with the previous work GAFTC. Figure 1 shows the comparison of delivery ratio of our proposed approach with the previous work for varying nodes. Delivery ratio of GSA-FT is increased to 67% than that of previous GAFTC.

Figure 2 shows the comparison of packet drop of our proposed approach with the previous work for varying nodes. Compared with GAFTC, packet drop of our proposed approach is reduced to 16% and 34% respectively. Comparison of end-to-end delay of our proposed approach with the previous work for varying nodes is shown in figure 3. Packet delay of our proposed approach is reduced to 21% than that of previous GAFTC.

Figure 4 shows the comparison of throughput of our proposed approach with the previous work for varying nodes. Compared with the previous GAFTC, throughput of our proposed approach is increased to 20%. Comparison of overhead of our proposed approach with the previous work for varying nodes is shown in figure 5. Overhead of our proposed approach GSA-FT is reduced to 17% than that of GAFTC. Compared to the previous GAFTC, energy consumption of GSA-FT is reduced to 93% as shown in figure 6.

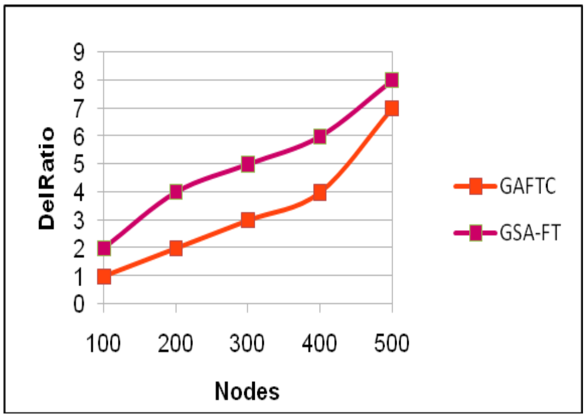

Figure 1: Nodes Vs Delivery ratio

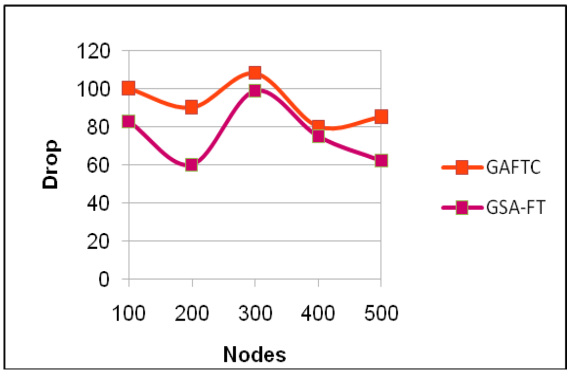

Figure 2: Nodes Vs Drop

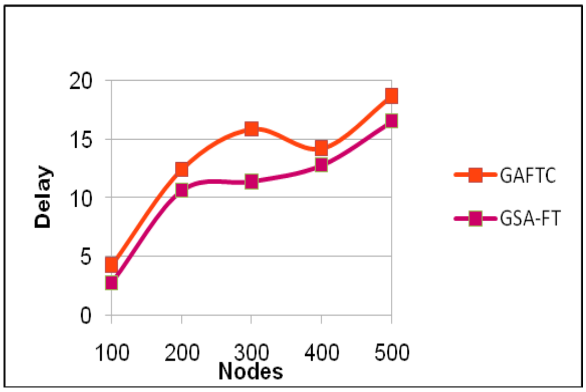

Figure 3: Nodes Vs Delay

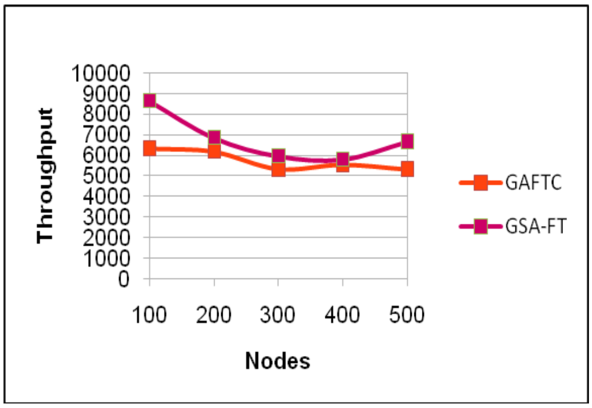

Figure 4: Nodes Vs Throughput

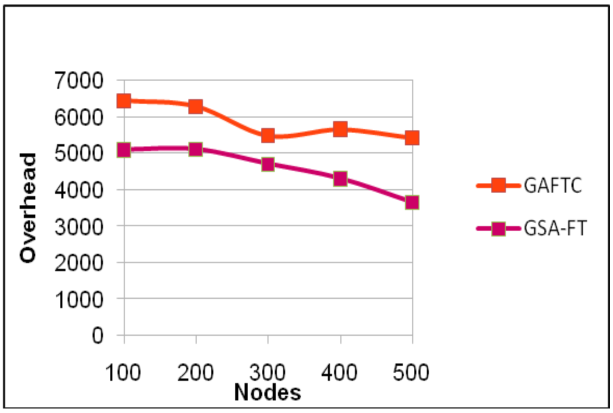

Figure 5: Nodes Vs Overhead

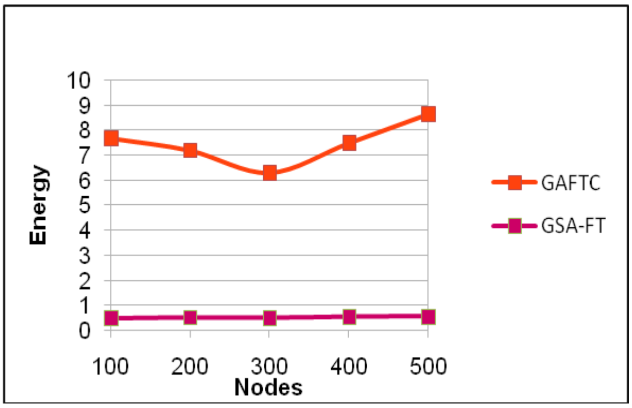

Figure 6: Nodes Vs Energy consumption

5. CONCLUSION

In this paper, we have proposed Gravitational search algorithm (GSA) based fault tolerant in wireless sensor network and the proposed approach has been simulated in the network simulator. Based on the residual energy and sponsored coverage of the sensor nodes cluster head has been selected. Activity of the cluster head has been activated using a backup node which has been selected in each cluster. This backup node has been selected using our proposed Gravitational search algorithm (GSA). Using this selected backup node, faulty cluster head has been identified. In the same way, activity of the cluster members has been also monitored by using the selected CHs. Simulation results showed that performance of the proposed approach outperformed our previous work.

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