International Journal of Computer Applications Technology and Research
Volume 3– Issue 7, 434 - 438, 2014

A Fault tolerant system based on Genetic Algorithm for Target Tracking in Wireless Sensor Networks

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Abstract- In this paper, we explored the possibility of using Genetic Algorithm (GA) being used in Wireless Sensor Networks in general with specific emphasize on Fault tolerance. In Wireless sensor networks, usually sensor and sink nodes are separated by long communication distance and hence to optimize the energy, we are using clustering approach. Here we are employing improved K-means clustering algorithm to form the cluster and GA to find optimal use of sensor nodes and recover from fault as quickly as possible so that target detection won't be disrupted. This technique is simulated using Matlab software to check energy consumption and lifetime of the network. Based on the simulation results, we concluded that this model shows significant improvement in energy consumption rate and network lifetime than other method such as Traditional clustering or Simulated Annealing.

Keywords: Genetic Algorithm, Wireless sensor network, Fault tolerant, energy efficiency, Network lifetime, K-means clustering, Reliability

1. INTRODUCTION

Nowadays, there are numerous applications in which Wireless Sensor networks being used like Military and civilian as well. This includes target tracking, surveillance, and security management etc. Since a Wireless sensor is a small, lightweight, untethered, battery-powered device, it has limited energy, processing power, memory [15]. Hence, energy consumption is a critical issue in sensor networks. Since these devices are less expensive, It is possible to design and construct the deployment of large scale wireless sensor networks (WSN) with potentially thousands of nodes [1]. WSN and their applications have tremendous potential in both commercial and military environments due to their low cost and pervasive surveillance [2]. For critical environment with high degree of dependability is required, WSN should offer characteristics such as: reliability, availability and maintainability. Availability to a large extend depends on fault tolerance to keep the system working as expected. Availability on the service level means that the service delivered by a WSN (or part of it) is not affected by failures and faults in underlying components such as single nodes or node subsystems. In WSNs, the failure of such components is almost unavoidable. Most of the detection and recovery techniques therefore aim at reducing MTTR (the amount of time required for detecting and recovering from a failure) as much as possible. In these WSN deployments, it is common to have a node providing functionality to its neighbors. In a typical WSN, all data obtained by member sensors must be transmitted to a sink or data collector. More energy will be consumed during transmission, if the communication distance is longer. It is estimated that to transmit a *k*-bit message across a distance of *d*, the energy consumed can be represented as follows:

$$E(k,d)=E_{elec}*k + E_{amp}*k*d^2 \qquad (1)$$

where E_{elec} is the radio energy dissipation and E_{amp} is transmit amplifier energy dissipation. In this scenario, it would be ideal if there is a cluster head and it could aggregate sensor data before it is forwarded to a base station, thereby saving energy. [4] In the cellular networks and ad hoc networks energy requirements is not a constraint as base stations or batteries can be replaced as needed, but nodes in sensor networks have very limited energy and their batteries cannot usually be recharged or replaced due to hostile or hazardous environments. Hence energy saving is one of the important factor in WSN and hence important characteristic of sensor networks is the stringent power budget of wireless sensor nodes. There are two components of a sensor node viz sensing unit and wireless transceiver, usually directly interact with the environment, which is subject to variety of physical, chemical, and biological factors. On such cases, Nodes with stronger hardware capabilities can perform operations for other nodes that would either have to spend a significant amount of energy or would not be capable of performing these operations. These services, however, may fail due to various reasons, including radio interference, de-synchronization, battery exhaustion, or dislocation due to inhospitable conditions. Such failures are caused by software and hardware faults, environmental conditions, malicious behavior, or bad timing of a legitimate action. In general, the consequence of such an event is that a node becomes unreachable or violates certain conditions that are essential for providing a service. Besides, a failure caused by a trivial software bug can be propagated to become a massive failure of the sensor network. In other cases, some sensor nodes became faulty due to transient conditions like high heat due to hostile environment as well. For example, in multiple moving objects tracking which is an active research area in WSNs due to its practical use in a wide variety of applications [3], including military or environmental monitoring applications, may missed out the target being tracked if any one of the sensor nodes that monitoring it becomes faulty. In such scenarios, prediction or node failure in these methods must be handled quickly before target slips far away. For reporting on the other hand, optimization techniques are applicable on different clustering and data fusion methods. Since the number of nodes participate in the tracking process, clustering phase can be the critical phase of the tracking from the energy consumption point of view. After clustering phase is done, it is equally important to use the member nodes in the cluster optimally so that cluster lifetime should be extended which in turn extends the network life time.

The rest of the paper is organized as follows: section II discusses about the assumption and background , section III discusses related work that has been done in WSNs with Fault tolerant and GA perspective, section IV presents the challenges involved in monitoring multiple objects with transient fault in particular and the proposed method and Section V gives the conclusion and the future work.

2. BACKGROUND

A. Assumptions

Following assumptions are made about the sensors and the sensor network in the development of the proposed target tracking algorithm:

- A set of sensors are deployed in a square terrain. The nodes possesses the following properties
- The sensor network is static
- All nodes are assumed to have the capabilities of a cluster-head and the ability to adjust their transmission power based on transmission distance.
- Two nodes communicate with each other directly if they are within the transmission range
- The sensor nodes are assumed to be homogeneous i.e. they have the same processing power and initial energy.
- The sensor nodes are assumed to use different power levels to communicate within and across clusters.
- The sensor nodes are assumed to know their location and the limits S (Number of nodes in each cluster).
- For multiple object tracking, no 2 objects are in same cluster at same time.

3. RELATED WORK

In the paper by Heinzelman et al's paper[5] "Energy-Efficient Communication Protocol for Wireless Micro -sensor Networks" which describes a clustering-based protocol called LEACH. Here the performance of LEACH with direct communication and MTE is being compared. They use a pre-determined optimal number of clusters (5% of the total number of nodes) in their simulations. In the paper [6] Heinzelman et al determine that the optimal number of clusters for a 100-node network to be 3-5 by using a computation and communication energy model; however, determining the optimal number of cluster-heads depends on several factors such as sensor densities, the position of a sink, etc.

In the paper [7] by Tillett et al, the PSO (Particle Swarm Optimization) approach is proposed which would divide the sensor node field into groups of equal sized groups of nodes. PSO is an evolutionary programming technique that mimics the interaction of ants or termites to find a good solution. Although partitioning into equal sized clusters balances the energy consumption of cluster heads, this method is not applicable to some networks where nodes are not evenly distributed.

In the paper [8] by Ostrosky et al, address a somewhat different partitioning problem: Given n points in a large data set, partition this data set into *k* (*k* is known) disjoint clusters so as to minimize the total distance between all points and the cluster-heads to which they belong. The authors use a polynomial-time approximation scheme to solve the problem.

A small number of nodes are selected to become clusterheads. They are responsible for coordinating the nodes in their clusters, for instance by collecting data from them and forwarding it to the base station. In case that a cluster head fails, no messages of its cluster will be forwarded to the base station any longer. The cluster head can also intentionally or due to software bugs forward incorrect information. Depending on the application case, the impact of such a failure can vary from quality degradation of measurements to alarm messages not being delivered to a back-end system. While forwarding messages, nodes can aggregate data from multiple other nodes in order to reduce the amount of data sent to the base station. One common simple approach is to calculate the average of correlated measured values such as temperature, humidity and pressure, sending only one message to the back-end. If a node generates incorrect data, the data aggregation results can suffer deviations from the real value. Also, if a node responsible for generating the aggregated data is subject to a value failure, the base station will receive incorrect information of an entire region of the network.

This paper [9] investigates prediction-based approaches for performing energy efficient reporting in object tracking sensor networks. A dual prediction-based reporting mechanism (called DPR) has been proposed, in which both sensor nodes and the base station predict the future movements of the mobile objects. Transmissions of sensor readings are avoided as long as the predictions are consistent with the real object movements. DPR achieves energy efficiency by intelligently trading off multi-hop/long-range transmissions of sensor readings between sensor nodes and the base station with one-hop/short-range communications of object movement history among neighbor sensor nodes. The impact of several system parameters and moving behavior of tracked objects on DPR performance has been explored, and also two major components of DPR are studied: prediction models and location models through simulations. In this paper, Profile-Based Algorithm (PBA) [10] has been proposed that aims to use the information contained in the network and in the object itself to optimize energy consumption, thus extending lifetime. Here it utilizes the regularity in the object's behavior to reduce energy consumption. In this paper [11], In Target Tracking application, the sensor nodes collectively monitor and track the movement of an event or target object. The network operations have two states: the surveillance state during the absence of any event of interest, and the tracking state which is in response to any moving targets. Thus, the power saving operations, which is of critical importance for extending network lifetime, should be operative in two different modes as well. In this paper, we study the power saving operations in both states of network operations. During surveillance state, a set of novel metrics for quality of surveillance, which suggests that atleast p-sesnor nodes required to cover any location, is proposed specifically for detecting moving objects. In the tracking state, we propose a collaborative messaging scheme that wakes up and shuts down the sensor nodes with spatial and temporal preciseness. In this paper [12], a novel approach toward Base Station (BS) oriented clustering and tracking in WSNs is introduced. Proposed method overlooks ad-hoc ability of WSNs to earn energy efficiency and fault tolerance. BS is a powerful energy and computational resource, therefore, BS is burdened with major part of clustering and tracking operations. 3-D cubic antenna is used to enable our sensors to receive BS packets from long distance. Also, BS has a good knowledge of nodes energy level, as a result, BS rotates activated nodes and CH to avoid load balancing problem.

4. PROPOSED SOLUTION

Genetic Algorithm:

Chromosome:

All living organisms consist of cells. In each cell there is the same set of chromosomes. Chromosomes are strings of DNA and serves as a model for the whole organism. Usually a chromosome consist of genes which is basically blocks of DNA. Each gene encodes a particular protein. Basically it can be said, that each gene encodes a trait, for example color of eyes. Possible settings for a trait (e.g. blue, brown etc) are called alleles. Each gene has its own position in the chromosome. This position is called locus.

Complete set of genetic material (all chromosomes) is called genome. Particular set of genes in genome is called genotype. The genotype is with later development after birth base for the organism's phenotype, its physical and mental characteristics, such as eye color, intelligence etc.

Reproduction:

During reproduction, first occurs recombination (or crossover). Genes from parents form in some way the whole new chromosome. The new created offspring can then be mutated. Mutation means, that the elements of DNA are a bit changed. This changes are mainly caused by errors in copying genes from parents. The fitness of an organism is measured by success of the organism in its life.

Search Space:

If we are solving some problem, we are usually looking for some solution, which will be the best among others. The space of all feasible solutions (it means objects among those the desired solution is) is called search space (also state space). Each point in the search space represent one feasible solution. Each feasible solution can be "marked" by its value or fitness for the problem. We are looking for our solution, which is one point (or more) among feasible solutions - that is one point in the search space. The looking for a solution is then equal to a looking for some extreme (minimum or maximum) in the search space. The search space can be whole known by the time of solving a problem, but usually we know only a few points from it and we are generating other points as the process of finding solution continues.

The problem is that the search can be very complicated. One does not know where to look for the solution and where to start. There are many methods, how to find some suitable solution (ie. not necessarily the best solution), for example hill climbing, tabu search, simulated annealing and genetic algorithm. The solution found by this methods is often considered as a good solution, because it is not often possible to prove what is the real optimum.

Problem definition:

The clustering strategy limits the number of nodes in each cluster,S. The clustering aims to associate every node with one cluster. Here clustering has been done using improved K-means algorithm which takes into account the node distance from given cluster center, energy requirement and Fault prone.

The objective is to propose a fault tolerant approach in wireless sensor networks for target tracking application with Genetic algorithm for optimal resource utilization. The idea of target tracking is that, the sensor nodes are deployed randomly in a boundary and based on given cluster center, the improved K-means clustering algorithm select the cluster head. Now a node is faulty (transient fault) and the other nodes should take care of the functionality of this node and target should not slip away from the monitored region.

In the first step, for the given nodes and cluster center, the improved k-means clustering algorithm being used[13].

K means is an exclusive clustering algorithm and it is the one of the simplest unsupervised learning algorithms that solve the clustering problem [14]. Wireless Sensor Network has number of nodes, which are randomly scattered over the sensor network. The sensor nodes which are deployed in the sensor network, knows their location information. The coordinates (xi, yi) of each sensor node are used to estimate the distance between two sensor nodes. Based on minimum distance and highest energy, the sensor nodes are clustered by using improved K means clustering algorithm.

GA Operators:

Crossover and mutation provide exploration, compared with the exploitation provided by selection. The effectiveness of GA depends on the trade-off between exploitation and exploration.

Crossover: We use one-point crossover in this paper. The crossover operation takes place between two consecutive individuals with probability specified by *crossover rate*. These two individuals exchange portions that are separated by the crossover point The following is an example of crossover:

Indv1: 1 0 1 0 0 1 0 1

Indv2: 1 0 1 1 ↑ 1 1 1 0

Crossover point

After crossover, two offspring are created as below:

Child1: 1 0 1 0 1 1 1 0

Child2: 1 0 1 1 0 1 0 1

Mutation: As discussed earlier, the mutation operator is applied to each bit of an individual with a probability of *mutation rate*. When applied, a bit whose value is 0 is mutated into 1 and vice versa. An example of mutation is as follows.

Indv: 1 1 0 1 1 1 1

↓ ↓

Indv: 1 1 1 0 1 1 0

Selection: The selection process chooses the candidate individuals based on their fitnesses from the population in the current generation. Otherwords, if the chromosome is better, then the chances of getting selected is higher. Some of the selection methods being used are roulette wheel selection, Rank selection, steady-state selection etc. Proportional selection (or roulette wheel selection) is used in this algorithm. It is implemented by using a biased roulette wheel, where each individual is assigned a slot, the size of which is proportional to the fitness value. Those individuals with higher fitness values are more likely to be selected as the individuals of population in the next generation.

Fitness Evaluation:

The main criteria we need to consider is to find out nodes with most residual energy (E_n) and least fault prone (F_n) in a given cluster.

$F(x)= max(E_n) + min(F_n);$

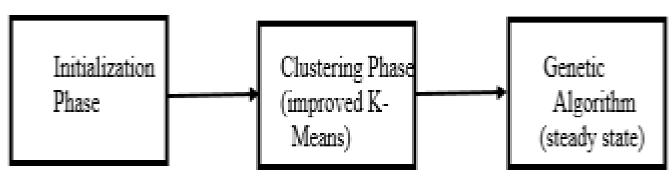

Fig.1. Process Flow

In the first step, select a cluster center with their xi, yi coordinates. Then calculate the distance between each sensor node and the selected cluster center and also get the energy of each node. The node which is nearer to the cluster center with maximum energy becomes the cluster head and other associated nodes which are nearer to this cluster head than other cluster center becomes part of this cluster. This step is repeated for setting up of all initial clusters.

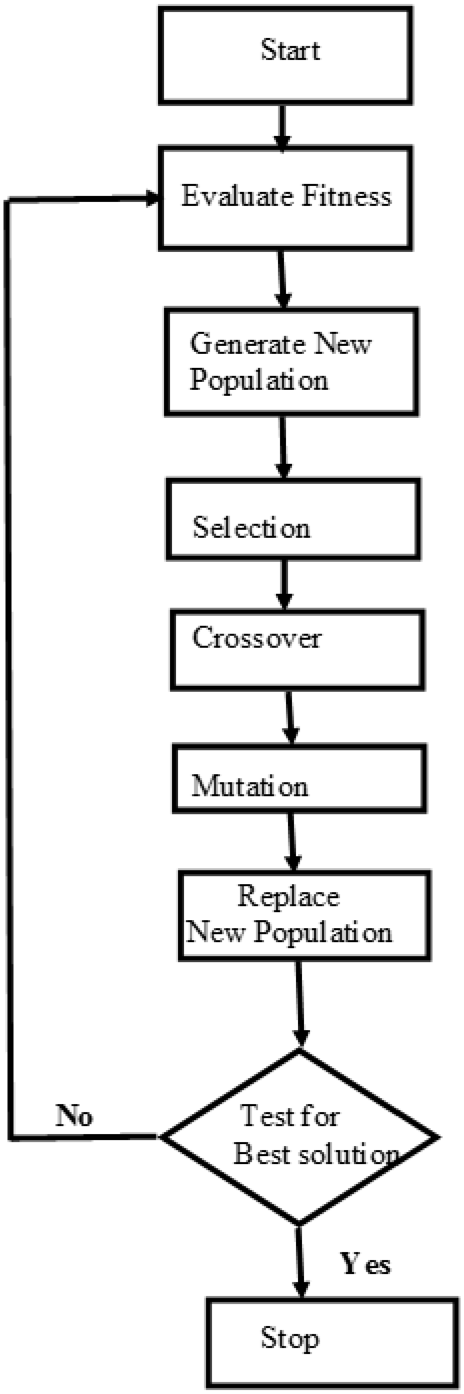

Fig.2. Flow Diagram

The distance between reference nodes is computed by using this formula,

Distance=√(x2-x1)^2+(y2-y1)^2 (2)

Where, (x1, y1) and (x2, y2) are the coordinates of the reference node.

Cluster head selection:

After the formation of cluster, re-compute the calculated distance of each cluster member with cluster head and based on maximum residual energy and least distance with less fault prone, the cluster member get ranking. This will be used when the cluster head gets down when their energy level threshold value becomes less than the fixed threshold value.

Object tracking with Fault Tolerance:

Once Object tracking started, If a cluster head gets down due to energy depletion, the next cluster head within that cluster being selected which satisfied energy requirement and less fault prone using GA. This cluster head change process has been continued till all nodes are exhausted within that cluster. By this process, we can do load balancing which improves network lifetime, avoid energy wastage for new cluster head election and reduce the probability of fault happened due to energy depletion. If an object is missed due to fault, target tracking can be recovered by alerting the neighboring clusters based on the velocity of the moving object. GA algorithm optimally uses the sensor nodes inside the cluster and also include the faulty nodes if repaired. Here the repair is possible since the fault is assumed to be transient in nature as discussed earlier.

Simulation:

To study the effectiveness of the proposed method, this is simulated and compared against the existing method using MATLAB software. For that, we assume the algorithm which would consider fixed cluster head, means the cluster head won't be changed dynamically as traditional algorithm and the one which would change the cluster head in the improved k-means approach with simulated annealing algorithm. For simplicity for this case, we assume the same track needs to be sensed and the same set of nodes is used for tracking purpose, if available. After iterating for different number of time periods, the energy consumption of nodes differ significantly for these 3 methods as shown in the graph below.

TABLE I: PARAMETERS SETTING

Simulation Parameters	**Value**
Population Size	90
Selection type	Proportional Selection
Cross Over rate	0.60
Cross Over type	One point
Mutation rate	0.0065
Generation Size	500

Performance Evaluation:

Here the performance is being evaluated with traditional clustering scheme with varying sensor nodes and can be deduced that improved k-means approach with simulated annealing algorithm gives better performance.

A. **Energy Consumption:** The energy consumption rate is reduced in Genetic algorithm based approach when compared to similar approach like traditional clustering, simulated annealing etc.

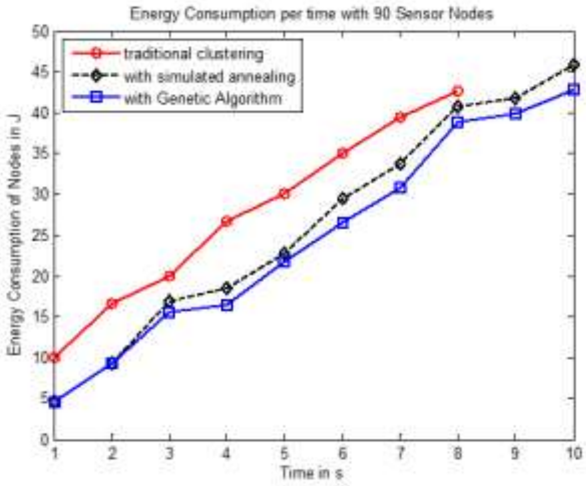

Fig.3. Energy consumption per time with 90 Sensor Nodes

B. Number of Alive Nodes:

The number of alive nodes decreases as the time increases and Genetic algorithm approach perform better when compared to other approaches.

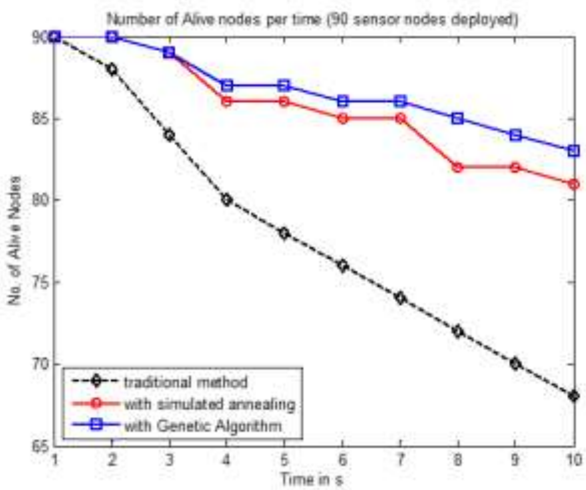

Fig.4. Number of Alive Nodes per time with 90 Sensor Nodes deployed

5. CONCLUSION

In this paper, the option of using Genetic Algorithm with improved k-means clustering algorithm is explored. Besides an idea to use Genetic algorithm to include faulty node that have repaired after transient fault is considered that could improve resource optimization. This would be evaluated on the basis of network lifetime and number of alive nodes. In the future, the method should be explored for other motion models with multiple targets tracking in wireless sensor networks should be studied.

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