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Enhancing Network Lifetime of a Wireless Sensor Network Using Swarm Intelligence

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Abstract

A Wireless Sensor Network is a resource constrained, cooperative, self-organized, distributed network consisting of large no. of small Sensor Nodes generally deployed in unattended and harsh environments. Each Sensor Node connected to the Network consists of sensing unit, communication unit, memory unit, and processing unit operating on limited power supply. Performance of a Sensor Node is highly dependent on the effective and efficient usage of these available limited resources that leads to maximum lifetime of WSN. Since WSNs are more prone to failures due to battery depletions, hardware failures, communication link failures, the faulty sensor nodes should be identified and discarded from data routing process to ensure the overall data quality. Therefore, protocols that consider the unique characteristics of WSNs are to be designed for improving the network lifetime. So, in this paper Ant Colony Optimization based routing method which considers the dynamic nature of WSNs along with the Fault Detection mechanism based on spatio-temporal correlation among sensor measurements is proposed. The proposed method can detect and detach the faulty Sensor Nodes and improves the network lifetime with the usage of optimal routing path based on meta heuristics

Keywords: Ant Colony Optimization, Fault identification, Network lifetime, Sensor Node, Wireless Sensor Network

Introduction

With the recent advancements in MEMS Based technology, communication and computing domains, the development of low cost, low power and highly miniaturized Sensor Nodes(SNs) is possible. A Wireless Sensor Network (WSN) is a wireless network consisting of these SNs to monitor a variety of environments. Due to their size and cost, hundreds or thousands of SNs are deployed to monitor the target area. The observed physical phenomenon is transmitted in a multi hop fashion to a remote sink or Base Station. WSNs have applications in various fields including security surveillance, combat operations, environment monitoring, disaster management etc [1]. Generally, WSNs are required to operate in unattended environments. Most often the power source of each SN can’t be recharged and replaced. Hence, Network lifetime is a major critical issue in the design of a WSN. The lifetime of a WSN can be defined as the time span from the deployment of the network to the instant when the network is nonfunctional. However, network lifetime is application specific[2]. Even though the energy is consumed by SN for its sensing, processing and communicating, the energy consumption for radio transmission dominates the other [3]. Hence designing of routing protocols that consume minimum energy is required..

Since the SNs directly interact with the environment they may be subjected to failures due to physical, chemical and biological effects. Since the WSNs are generally deployed in inhospitable environments, it is necessary to provide fault tolerant capabilities to the WSNs. So, the main objective of our research is to propose a mechanism that increases the lifetime of a fault tolerant WSN.

The rest of the paper is organized is as follows: Section 2 gives the related work, Section 3 focuses on existing mechanisms for increasing the lifetime of a fault tolerant WSNs , and in Section 4 our mechanism for enhancing the network lifetime is proposed. In Section 5 the proposed Fault Tolerant Ant Colony Optimization based Routing Protocol (FT-ARP) mechanism is compared with the ACORP which is previously proposed by us. Conclusion is presented in the last section.

Related Work

Recently, a lot of interest is being observed in the use of swarm intelligence, a technique that involves collective behavior of autonomous agents in finding a global solution to the problem. Ant colonies, fish schooling, bird flocking and animal herding are some of the examples in nature that use swarm intelligence [4].

Ant Colony Optimization (ACO) is based on the foraging behavior of ants in search of a shortest path from source to destination. Ants lay pheromone on the path they travel. Using the deposited pheromone concentration, ants can interact with each other and choose the shortest path. Since WSNs environment is unstructured, dynamic and distributed like the ants environment, this property of real ants colonies is exploited in ACO algorithms to solve many optimization problems such as scheduling problems, graph coloring, assignment problems or vehicular routing problems[5]. In ACO, the ant agents are launched periodically from every source S to randomly chosen destination D.

The SNs in WSN are more prone to failure due to hardware failures, communication link failures, malicious attacks , energy depletion and so on. So, Fault tolerance, which enables a system to continue functioning properly in the event of failures is required. The taxonomy of fault tolerant techniques used in traditional distributed systems are fault prevention, fault detection, fault isolation, fault identification and fault recovery. Fault prevention techniques can be implemented mostly in network layer where as fault detection and recovery techniques operate at the transport layer and a few fault recovery techniques can also be operated at application layer.

Fault detection is the first phase of Fault Tolerant management which identifies the unexpected failure in the network system. The Fault Detection approaches in WSNs are classified into centralized and distributed approaches [6] based on how the fault is being identified by SNs. In centralized approach, a geographically or logically centralized node finds the misbehaving node, but due to resource limitations this approach is not suitable for WSNs. In distributed approach, the fault detection is evenly distributed to all the SNs. Various fault detection mechanisms in distributed approach are : Node self detection, neighbor coordination and clustering or hierarchical approach. In node self detection model, a node observes its output values and compares with the predefined values. In neighbor coordination method, the faulty node is identified in coordination with its neighbors. In clustering approach the fault detection is distributed to clusters within the network. Since we are considering a flat based small scale WSN we are finding the faulty nodes with the help of node self detection and neighbor coordination mechanisms.

Literature Survey

The Routing Algorithms for WSNs can be classified as static or dynamic [7]. Static routing algorithms give best paths according to some criterion without considering the current state of the network whereas dynamic routing algorithms are more attractive as they attempt to adapt the routing policy to the varying network traffic conditions. Another classification of Routing techniques in WSNs is flat, hierarchical and adaptive [8]. In flat based routing protocols all the nodes will have equal role or functionality. The nodes will have different roles or functionality in hierarchical based routing. Certain system parameters are controlled in order to adapt to the network's current conditions and available energy levels in adaptive routing technique. These routing strategies can be further classified into query based, multipath based, negotiation based, Location based and QoS based depending on principle of routing operation [9].

Many routing algorithms inspired by ant collective intelligence are defined that deal with dynamic topologies due to the ability of ants to perceive changes in networks through pheromone. Zhang et al. [10] have proposed a routing algorithm directly derived from Ant Net, and three variants of it : Sensor-driven Cost-aware Ant Routing (SC), Flooded Forward Ant Routing(FF), and Flooded Piggybacked Ant Routing(FPAnt).The AntNet algorithm makes use of unicast forward ants generated by nodes. The cost of a sampled path is calculated in terms of the number of hops. Some other protocols [11] under this category include Energy Efficient Ant-Based Routing (EEABR), ACO-based quality-of-service routing (ACO-QoSR), Ant-based service-aware routing algorithm (ASAR), AntChain, Energy-Delay ant-based (E-D ANTS).

In [12], a distributed fault detection algorithm is proposed for detecting and isolating the faulty SNs. Time redundancy is used to tolerate faults in sensing and communication. Local comparisons of sensed data between neighbors and dissemination of the test results is made to enhance the accuracy of diagnosis. In [13], faulty sensor node is detected by discrete path selection technique by comparing the actual Round Trip Time (RTT) with present RTT. If they are differing then it represents an error. When the number of nodes which is initially diagnosed as possibly normal (LG) in its neighbor nodes is less than half of the total neighbor nodes, then the Distributed Fault Detection (DFD) scheme will misdiagnose the normal node as faulty. So in [14] an improved DFD scheme is proposed to address this shortcoming.

Proposed Mechanism

To find an optimal path from source to destination two kinds of ants, Forward ANT and Backward ANTs (FANT,BANT) are generated in ACO mechanism. FANT is launched by source and is moved towards the destination. While moving FANT collects local information such as remained energy in the node, number of hops required to reach the node from source etc. FANT selects the next hop based on the probability of pheromone. Once the FANT reaches the destination the FANT is converted into BANT and travels in the reverse path towards the source. Source receives all the BANTs , analyses the information supplied by BANTs to find the path with minimum no.of hops and having higher residual energy. The format of the FANT is:

Table 1: Foramat of FANT

Dest. ID	Next Hop	Residual Energy	Hop count

Next Hop Selection: FANTs select the next hop based on the probability of pheromone. Initially all the nodes probability of pheromone is assumed as 0.5 From the neighbor nodes the FANT will calculate the probability of pheromone based on equation 1, compares all the node probability values and chooses the node having more probability of pheromone as its next hop.

$$\text{Prob of pher}= \frac{old\_pher(Ni)+\Delta ph}{1+\ \Delta ph} \qquad 1$$

In equation 1, Ni indicates any intermediate node between source and destination, old_pher(Ni) indicates the node's old pheromone value, Δph is the difference of old and new pheromone values [15].

Once the next hop is selected by FANT, the pheromone to be added is given by the following equation

$$Pnew = Pold + r * (1- Pold). \qquad - 2$$

where r denotes reinforcement factor.

Residual Energy (RE): The Residual energy [16] of a node is the difference between it's initial energy and the energy consumed for its data transmission and processing . Since the energy required for receiving or processing of a packet much smaller than the energy required for packet sending, RE can be computed as the difference between initial energy and the energy required for transmitting a packet of unit length at a distance r.

BANT: When the FANT reaches the destination, all the information is extracted from the FANT and is killed by the destination. BANT is created with the same format and is sent towards the source using the recorded path information

Route discovery: Source maintains a routing table using the information supplied by the BANT. The format of the routing table at source is shown in Table 2.

Table 2: Routing table at source

Neighbor node id	Destination Id	Hop count	Residual Energy

Robust path selection mechanism: The source selects the path containing minimum hop count and maximum residual energy from the route table. Source uses the selected path as the primary path for data transmission

Fault detection mechanism: Here, node self detection mechanism is used to observe the malfunctioning of physical components of a SN in which a node observes its output values and compares with the predefined values. Neighbor coordination technique is also implemented to not allow faulty nodes to participate in the route discovery process. We use correlation of mean values of sensor signals for detecting failures. The inconsistencies in sensor inputs are detected and low false positives are provided using the equation 3.

$$C_{(P,Q)} = \frac{M(P,Q) - M(P)M(Q)}{\sqrt{M(P^2) - M^2(P)}\sqrt{M(Q^2) - M^2(Q)}} \quad - (3)$$

Where M(P) is the mean value of the random variable P or sensor signal P. M(Q) is the mean value of the random variable Q or sensor signal Q. M(P,Q) is the mean value of the random variable PQ or sensor signal PQ. And the correlation is varied between -1 to 1.The high value of correlation between P and Q denotes no failure and low value indicates, misbehavior of a node. The proposed mechanism is shown in fig 1.

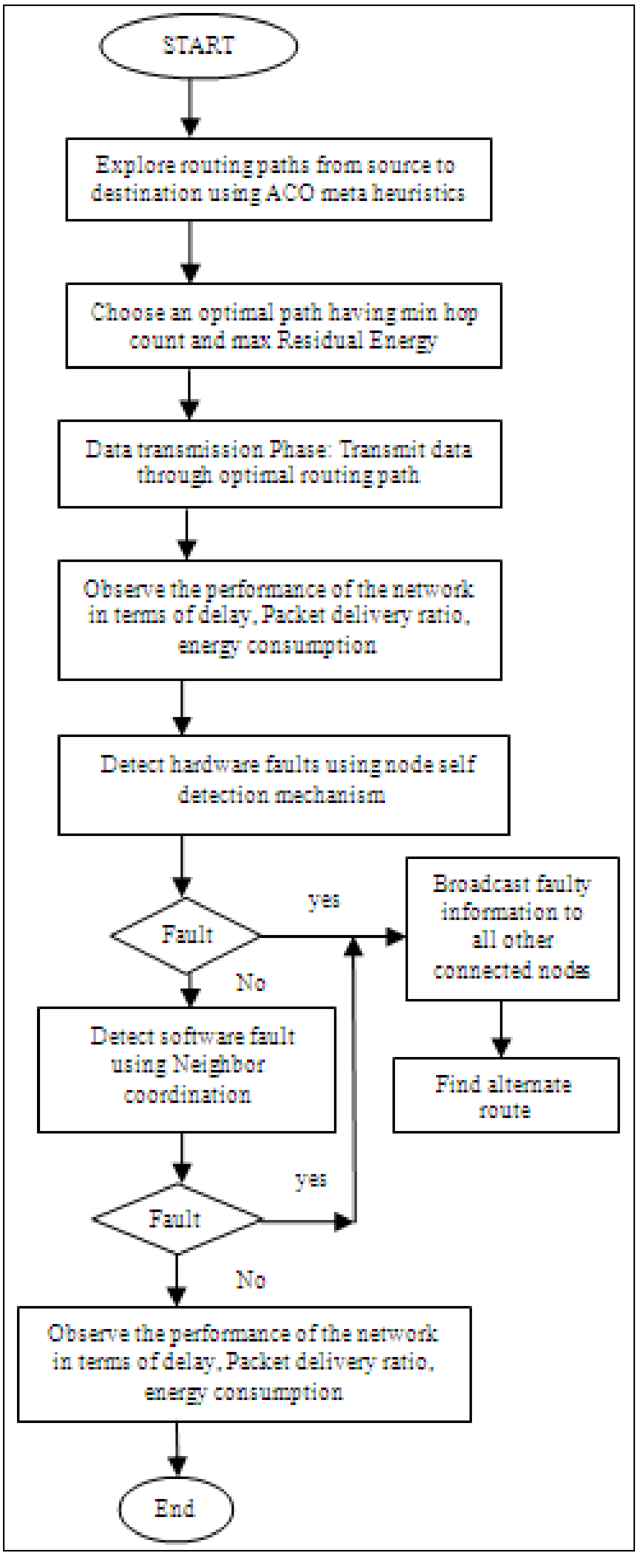

Figure 1: Flowchart for proposed mechanism

Simulation

Simulation platform and Configuration parameters: The simulation is conducted on NS-2 simulator. In this simulation we placed nodes in a bounded region of 500 × 500 sqm, and the no. of nodes is varied as 50,100,150 and 200. The transmission range of the nodes varies from 250m to 400 m. Distributed Coordination Function (DCF) is used as the MAC layer protocol. The following table 3 summarizes the configuration parameters used:

Table 3: Simulation parameters

No.of Nodes	50
Area Size	500 × 500
MAC	802.11
Transmit power	0.6450 W
Receiving power	0.467 w
Idle power	0.025 W
Simulation time	50 sec
Traffic source	CBR
Packet size	500B
Transmission range	250m-400m
Initial Energy	15.0 J
Routing protocol	ACORP
Rate	50,100,150,200 and 250Kb

We compared the performance of our proposed mechanism with ACORP which is previously proposed by us in terms of packet delivery ratio, packet drop, average end to end delay, and energy consumption at different data rates 50Kb, 100Kb, 150Kb, 200Kb and 250Kb.

The end-to-end delay is averaged over all surviving data packets from source to destination. The delay of our proposed mechanism is having less delay and is shown in fig 2.

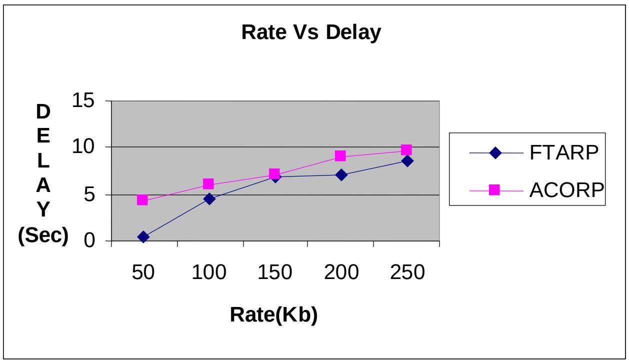

Figure 2: Performance on Delay

Packet Delivery Ratio is the total number of packets received by the receiver during the transmission and is shown in fig 3.

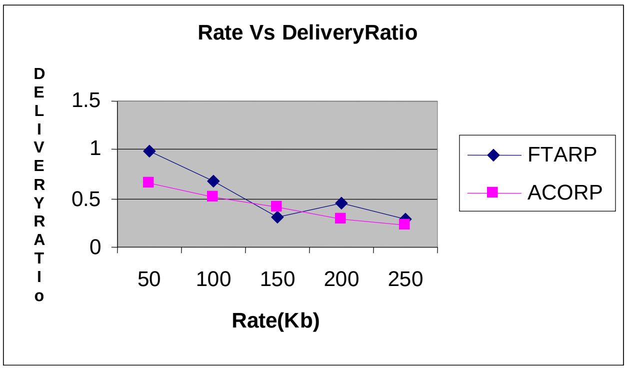

Figure 3: Performance on Delivery Ratio

Packet drop denotes the number of packets dropped during the data transmission. As the data rate increases the number of packets dropped are more with ACORP and is shown in fig 4.

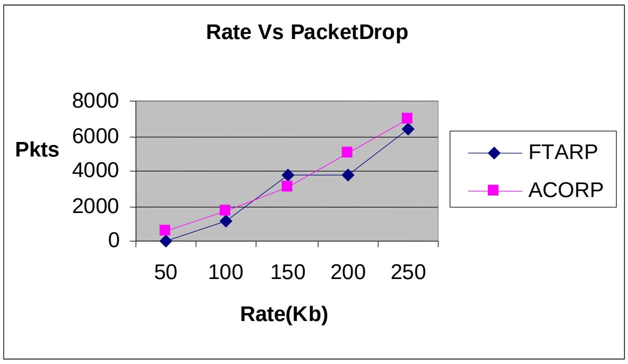

Figure 4: Performance on Packet Drop

The average energy consumed by the nodes in receiving and sending the packets is shown in fig 5.

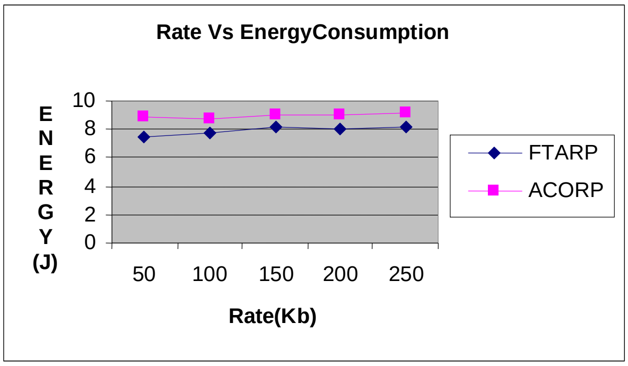

Figure 5: Performance on Energy consumption

Conclusion

In this paper, a mechanism for finding the faulty node in addition to finding the optimal path between source and destination is proposed for wireless sensor networks. The path having minimum number of hops and high remained energy is chosen as the primary path for data transmission. The fault probability of each SN is generally high for a WSN deployed in harsh and unattended environments. So, failure of a node due to software or hardware is detected. The performance of the Network is compared in terms of packet drop, Packet Delivery ratio, Delay and energy consumption with and without having the fault detection capability. It is observed that the mechanism that includes fault detection capability is producing better results. In the proposed mechanism the fault information is propagating to the source and alternate path is found to continue the data transmission. In future, the performance of FTARP is to be compared with any of the existing WSN fault tolerant mechanisms.

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