Clustering and Fault Tolerance for Target Tracking using Wireless Sensor Networks

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ABSTRACT

Over the last few years, the deployment of WSNs (Wireless Sensor Networks) has been fostered in diverse applications. WSN has great potential for a variety of domains ranging from scientific experiments to commercial applications. Due to the deployment of WSNs in dynamic and unpredictable environments. They have potential to cope with variety of faults. This paper proposes an energy-aware fault-tolerant clustering protocol for target tracking applications termed as the FTTT (Fault Tolerant Target Tracking) protocol. The identification of RNs (Redundant Nodes) makes SN (Sensor Node) fault tolerance plausible and the clustering endorsed recovery of sensors supervised by a faulty CH (Cluster Head). The FTTT protocol intends two steps of reducing energy consumption: first, by identifying RNs in the network; secondly, by restricting the numbers of SNs sending data to the CH. Simulations validate the scalability and low power consumption of the FTTT protocol in comparison with LEACH protocol.

Key Words: **Target Tracking, Cluster, Energy, Fault Tolerance, Sensor Network.**

1. INTRODUCTION

WSNs are gaining diverse attentions due to their appropriateness to observe environments where the deployment of wired networks is either complicated or impractical [1]. Target tracking is an active research area in the field of surveillance, military and habitat monitoring. In an object tracking application, a group of SNs process their observation regarding positions of a moving object cooperatively and periodically. If one or more SNs fail due to any reason during the estimation, the resulting estimation value can be incorrect. The most frequently used fault-tolerant technique for the WSNs is the deployment of redundant/surplus SNs. Generally, a WSN consists of a number of SNs which work collectively to obtain data about the environment and then send the gathered data to the BS (Base Station). When RNs are provided, then the BS is able to get data; even some SNs fail due to any reason [2]. In addition, energy is precious resource for such applications as SNs are expected to work until energy depletion. One way to preserve energy is to increase sleeping time of SNs in absence of an event. Another approach is cluster-based network arrangement, which maintains scalability, energy efficiency and better resource allocation [3-4]. The two-tier architecture is

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actually a cluster-based network, in which the SNs are able to gather required information and send data packets directly to their CHs [2].

There are two main objectives of this paper. First is to propose a simple cluster formation procedure; second is to ensure CH and SN failure recovery procedure. The rest of the paper is organized as follows. Section 2 provides a summary of related work. In Section 3, details of proposed FTTT protocol are illustrated. The energy consumption model of the FTTT protocol is demonstrated in Section 4. Section 5 explains the experimental setup in J-sim. In Section 6, experimental results are analyzed and finally Section 7 states concluding remarks.

2. RELATED WORK

This section briefly focuses on some of the solutions from existing WSN literature for tracking a moving target, cluster formation and fault tolerance techniques.

A distributed algorithm which takes (x,y) coordinates and the ID number of each SN as input and provides the location of the SN as output is proposed by [5]. To continuously keep a watch on the roaming path of the target; an agent node is selected, which may be transferred to the node closer to the target. However, the proposed strategy lacks experimental validation in order to prove its efficiency. The HVE mobicast is a Hierarchical Variant Egg mobicast routing protocol presented in [6]. The HVE mobicast protocol improves power efficiency of message delivery by providing cluster-to-cluster instead of node-to-node delivery of mobicast message while taking into account the changing speed of delivery zone as well. Mobicast message deliveries in forwarding zone occur in two steps, cluster-to-cluster and cluster to node. A static clustering algorithm based on an optimal one-hop distance is presented by [3]. The clustering algorithm in optimal one-hop communication is combined with the LEACH [7] algorithm; in which clustering is broken into rounds. At first, the CH in each cluster is selected at the border line, which would decide the candidate CH based on the received signal strength. An EECT (Energy Efficient Clustering Technique) based on a virtual hexagon cluster formation is proposed in [4]. The BS manages the virtual hexagon's centre location information, optimal cluster radius and broadcasts this information to all SNs. The SNs join the nearest virtual hexagon cluster after determining their distance with all virtual hexagons. A hierarchical clustering protocol for WSN is presented in [8], named as PEAP (Power aware Energy Adaptive Protocol). This protocol depends on confidence value related to broadcast from CHs. Confidence value of a CH is a function of parameter such as distance between the CH and the node, the CH current battery power and the number of nodes already were a member of this CH. The energy consumption and network lifetime comparisons with LEACH proves it efficient than LEACH.

In the algorithm developed in [9], fault tolerance is controlled by a BS, which changes the network configuration from shortest path to multiple paths. However, the algorithm is not energy efficient, since fault tolerance is handled centrally. The authors of [10] pointed out that the sensor reading is compared with its neighbor's median reading. If the difference is large or large but negative, the SN is assumed to be faulty. The computational overhead of the algorithm is low due to simple numerical operations. Each SN identifies its own status to be faulty or non-faulty with the help of neighboring SNs in [11]. The probabilistic analysis shows a correct diagnosis but in reality there may not be enough neighbor SNs due to ad hoc network deployment.

From the discussion above, it is clear that most of the target tracking protocols using existing clustering algorithms lack fault tolerance, although these issues might have to or better be tackled all together. Our proposed FTTT protocol addresses clustering, CH fault tolerance and SN fault tolerance using a unique approach in the target tracking scenario.

3. FTTT PROTOCOL

CHs are not energy constrained like SNs with times more energy than SNs and their responsibility is to report back to the BS. It is assumed that in FTTT each node knows its position using GPS or any localization algorithm. Three states are defined for CHs and SNs, i.e. active, sleep and idle state. The SNs remain in the idle state most of the time and switch to the active state at specified time slots scheduled by CHs. CHs can communicate with their NCHs (Neighbor CHs). Following are the steps defined in tracking a moving object model:

(1) Cluster formation

(2) Redundancy reduction

(3) Target tracking strategy

(4) CH fault identification and recovery

(5) SN fault identification and recovery

The clustering mechanism proposed by [1] is extended to apply it in target tracking scenario. Let M sensor nodes and N cluster heads are randomly distributed in 2D space. Let $LS_i(x_i,y_i)$ where $1< i < M$ be the location of i^{th} SN and $LH_j(x_j,y_j)$ where $1< j < N$ be the location of j^{th} CH. The cluster is formed based on the communication range of an SN and a CH. The CH_j will broadcast MM (Membership Message) to the SNs. The receiving SNs calculate their distance from the CH_j and will reply with a MAM (Membership Accept Message) to CH_j if their distance value is less than φ_1; which depends on the transmission range of SNs. Two tables are maintained by each CH, one keeps information about its MNs (Member Nodes) called MNT (Member SN Table). Each CH share it's MNT with its NCHs, which is maintained along with the ID of the sending CH. This table is named as NNT (Neighbor MN Table). Fig. 1 and Table 1 illustrate the cluster formation and redundancy reduction steps of FTTT.

It is assumed that each point within the area of interest is covered by atleast n SNs so that n degree of redundancy is achieved in the area. Each node determines its overlap with every other node in the MNT by closeness relationship and then compares this value with φ_2 to find out overlapping with that particular node; where φ_2 depends on the transmission range of SNs. If the closeness relationship value is less than φ_2, it is found that the two SNs are overlapping. The CH then identifies the SNs with maximum overlaps and sends them a SM (Sleep Message).

The MNs in each cluster accommodate the SCH (Schedule) set up by the corresponding CH. The active SNs in a cluster can sense the target when it comes in their transmission range. Assume a sufficient number of SNs within the vicinity of the target with correlated data. One

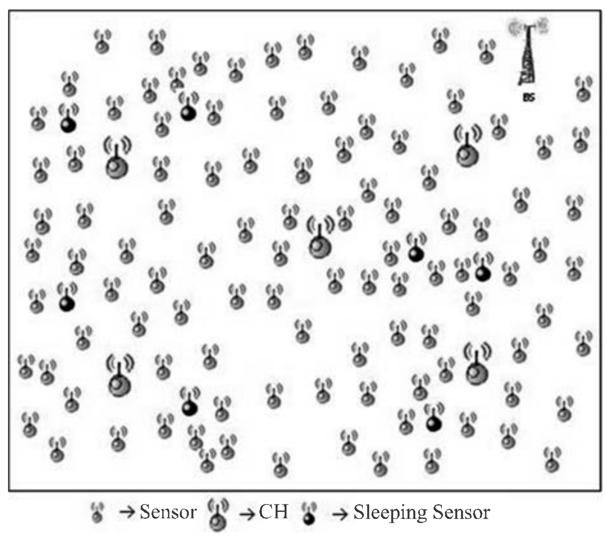

FIG. 1. CLUSTERING AND REDUNDANCY REDUCTION

TABLE 1. PSEUDO CODE FOR CLUSTER FORMATION AND REDUNDANCY REDUCTION

1	$CH_j(MM) \rightarrow SN_i$
2	Calculate Ed_{ij} from $_iLS_i(s,y_i)$ and $LH_j(x_j,y_j)$
3	If $(Ed_{ij} < \varphi_1)$
4	$SN_i(MAM) \rightarrow CH_j$
5	Set $MNT_j = MAM_{ij}$
6	$CH_j(SM) \rightarrow SN_i$
7	End If
8	Set $NNT_j = MNT_{j+1}$ and $NNT_{j+1} = MNT_j$

of the ways to maximize lifetime of a motion tracking WSN is, selecting and allowing a fewer number of SNs to estimate the location of a moving object. Each SN after getting location information of the target is measuring its Ed_u from the target and comparing it with φ_3. Only K SNs with a distance value less than the φ_3 (threshold distance) are allowed to send DM (Data Message) to the CH, reducing transmission cost. This process will continue until the target is in the sensing region. Pseudo code for target tracking is given in Table 2.

There can be three possible fault scenarios for a CH or an SN; first is the link failure due to any type of interference. Second is the energy depletion and third is the complete damage. Every CH is sending an AM (Activate Message) to NCH in order to check their status periodically. If a NCH does not send a RM (Reply Message) to the sending CH then it is assumed to be a faulty CH, CH_f. The first step is to identify which fault has occurred. The CH will ask its NCHs to send an AM to CH_f. If they get a RM from CHf, then it is identified that communication link between the CH and CH_f is failed. Thus, no recovery procedure is required as other CHs can communicate with CHf and it can take part in the tracking process. If NCHs also do not get RM, then it is identified that CH_f has failed either due to energy drainage or due to damage. In such a situation, NCHs come to know that CHf is not responding and will use NNT to find MNs of CH_f and the clustering process is executed. When the CH knows that any SN has died, it activates the overlapped SNs whose neighbor node has died. From the ID of dead SN, CH finds out the location of the dead SN from the MNT table and then determines any

TABLE 2. PSEUDO CODE FOR TARGET TRACKING

1	$CH_j(SCH) \rightarrow SN_i$
2	Calculate Ed^{it} from $LS_i(x_i,y_i)$ and $TL_t(x_t,y_t)$
3	If $(Ed_{it} < \varphi_3$ *and count* $< k)$
4	$SN_i(DM) \rightarrow CH_j$
5	End If
6	$CH_j(DM) \rightarrow BS$

overlapped SN, which is in sleep state near the dead SN and sends an AM to it. Table 3 presents the pseudo code for target tracking step.

4. COMMUNICATION ENERGY CONSUMPTION MODEL

The energy consumption of a node is divided into two main domains: communication and data processing. The energy consumption model for an SN and a CH is adapted from [7,12]. The data processing cost is considered to be negligible as compared to communication cost in this model. The energy dissipation of an SN for transmitting and receiving b bit data packets over distance Ed_u is E_c. For modulating or demodulating 1 bit, the energy consumption is 50 nJ/bit and for spreading 1 bit to an area of 1 meter, the energy loss is 100 pJ/bit/m^2. The energy loss of an SN for transmission and reception is given as:

$$E_C = (50 + 0.1 * Ed_{ij}^2)k + 50 * b$$

$$E_C = (100 + 0.1 * Ed_{ij}^2)b$$

The energy consumed during communication between CHs and SNs is given as:

$$E_{MN} = \sum_{j=1}^{N} \sum_{i=1}^{M} (100 + 0.1 * Ed_{ij}^2)b \quad (1)$$

Let CH_j has D_j distance to the BS, while d_j is the distance between CH_j and $CH_{(j+1)}$. The energy consumed by all CHs for communication with NCHs is:

$$E_{NCH} = \sum_{j=1}^{N} (100 + 0.1 * d_j^2)b \quad (2)$$

TABLE 3 PSEUDO CODE FOR FAULT TOLERANCE

1	$CH_j(AM) \rightarrow CH_{j+1}$
2	If $(CH_{j+}1(RM) \neq CH_j)$
3	CH_{j+1} = faulty
4	End If
5	$LS_i(x_i,y_i) = MNT_i$
6	$CH_i(AM) \rightarrow SN_i$

The energy consumed by all CHs and mi SNs unable to join any CH; for communication with the BS is:

$$E_B = \sum_{j=1}^{N} \sum_{i=1}^{m_i} (100 + 0.1 * D_j^2) b \quad (3)$$

The total energy dissipated by the network is given as:

$$E_{Total} = E_{MN} + E_{NCH} + E_B \quad (4)$$

5. EXPERIMENTAL SETUP

The performance of FTTT protocol is evaluated by comparing it with a clustering based method LEACH [7], which is one of the paramount clustering protocols in literature. The simulations of FTTT protocol are performed via J-sim [13], by varying the number of SNs i.e. 100, 150, 200 SNs, which are randomly distributed over a 400x400 m^2 region. Initially, 3 CHs are placed at specified places so as to cover the whole region and the CH number is varied to 4 and 5 with slight change in communication radius as well. The target moves according to random waypoint model with a maximum speed of 10 m/s and generates stimulus every three seconds. The initial energy of each SN is set 1J and each CH is set 2J. The communication range of SNs is set 50m and sensing range is set 40m. The parameters of LEACH are same as FTTT, among them CHs are identified dynamically with initial energy of 2J. The results are taken after calculating the mean of five simulation runs of 800s.

6. PERFORMANCE RESULTS

In the results, FTTT3, FTTT4 and FTTT5 indicate the simulation with 3, 4 and 5 CHs respectively.

6.1 Total Energy Consumption

The total energy dissipation by FTTT is calculated by Equation (4). The energy consumption comparison of FTTT and LEACH as the function of time is demonstrated in Fig. 2(a-b). The efficiency and scalability of FTTT is shown by energy consumption difference between LEACH and FTTT; noticeable in all cases. With the increase of the number of SNs, energy consumed by LEACH increases, involving 53, 45 and 39% more energy when compared with FTTT3, FTTT4 and FTTT5 respectively with 200 SNs. With 100, 150 and 200 SNs, FTTT3 is showing the lowest energy consumption than all other cases.

6.2 Tracking Packet Delivery Probability

It is defined as the probability of total packets received by the BS in response of total number of packets delivered by CHs and SNs unable to join any CH.

Thus, the BS is receiving two types of data, one from SNs directly and another from CHs. With the increase in the number of SNs, the tracking packet probability consistently increases in FTTT, while decreases in LEACH

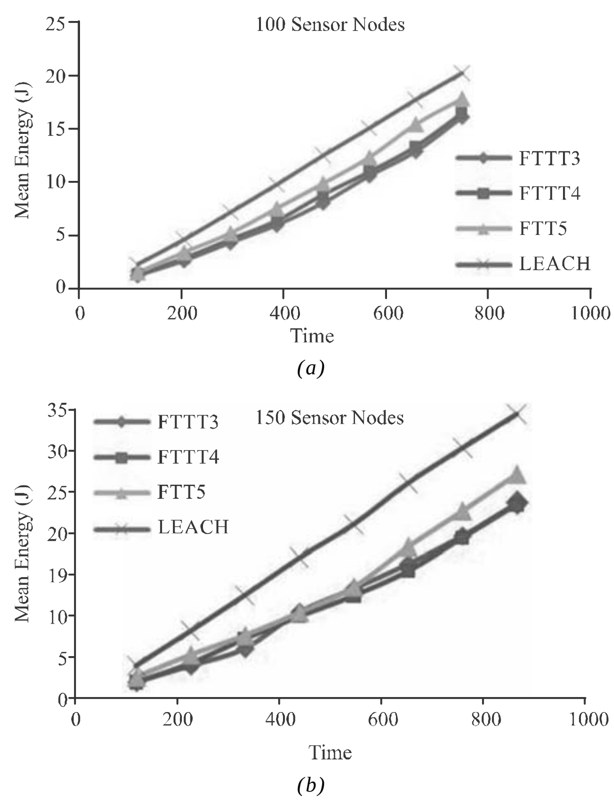

FIG. 2. ENERGY CONSUMPTION WITH VARYING NUMBER OF SNS AND CHS

as examined in Fig. 3(a-b). With 100 SNs, FTTT4 is showing highest tracking packet delivery probability. With 150 and 200 SNs, packets received by the BS are more in FTTT3 than all others. The total packets received by the BS in LEACH are less because of dynamic clustering [7].

6.3 Energy Reduction with Redundant Nodes in Sleep State

The energy dissipation comparison completed with all steps of FTTT protocol is specified by RN: Sleep state and without applying step 2 of FTTT protocol and allowing RNs to transmit information to CHs is represented as RN: Active state in Fig. 4. It is obvious that a significant amount of energy saving is achieved in case of the RN: sleep state. In the RN: active state more SNs are sending data to CHs at the cost of additional energy, while in the RN: sleep state; RNs are in sleep state.

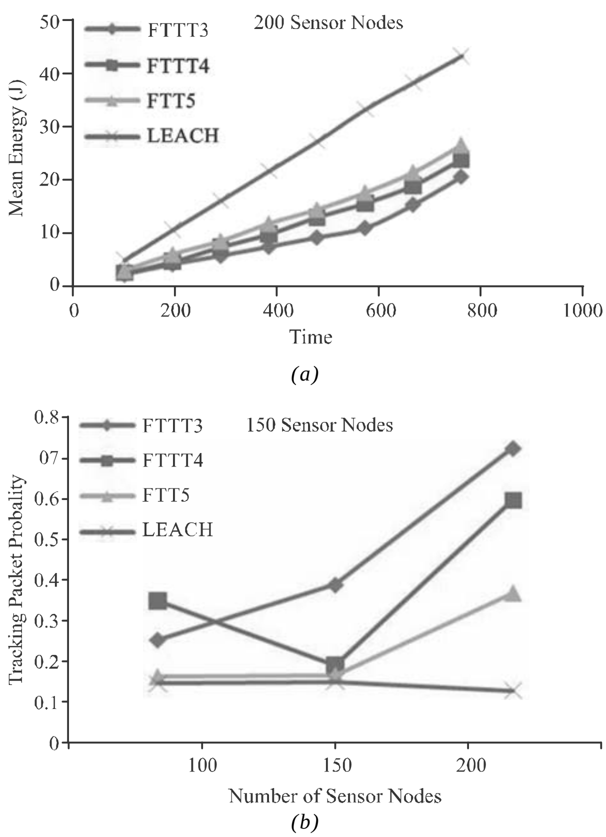

FIG. 3. TRACKING PACKET DELIVERY PROBABILITY WITH VARYING NUMBER OF SNS AND CHS

6.4 Network Throughput

It is defined as the total number of packets received at the BS divided by simulation time and the results are highlighted in Fig. 5. In RN: active state, there is continuous raise in network throughput due to greater number of packet reception by the BS, thus consuming more energy as compared to FTTT3, FTTT4 and FTTT5. It rises with the increase of number of SNs in FTTT3, FTTT4, FTTT5 and LEACH with highest rate in RN: active state having approximately 52%, 50% and 53% more rate in case of FTTT3, FTTT4 and FTTT5 respectively.

6.5 Average Latency

It is the time interval when a target information packet is received by a CH or an SN until the time instant when the

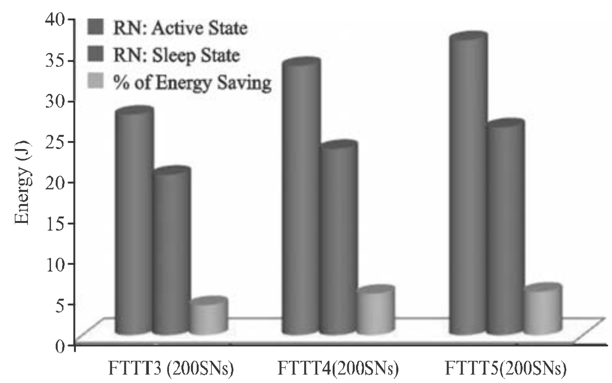

FIG. 4. ENERGY REDUCTION WITH VARYING NUMBER OF SNS AND CHS

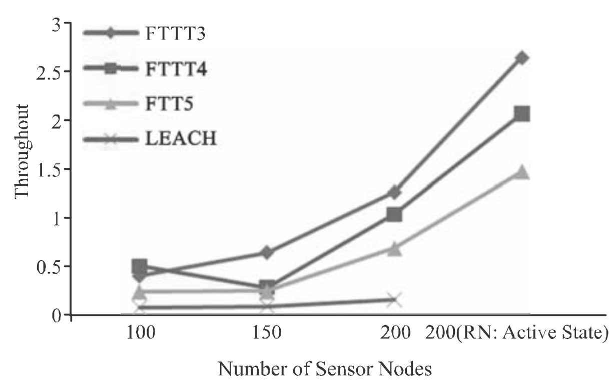

FIG. 5. NETWORK THROUGHPUT WITH VARYING NUMBER OF SNS AND CHS

packet is delivered to the BS. It is the sum of all times taken by a packet send from CHs or SNs to reach the BS. The average latency is highest in RN: Active state due to redundant data transmission. In case of 200 SNs, the average latency of FTTT is approximately equal to LEACH, while the other latencies does not show consistent increase or decrease as high lighted in Fig. 6.

6.6 Fault Tolerance

Percentage of fault tolerance is measured by the number of overlapping SNs and the total number of SNs in the network. Fig. 7 depicts fluctuation in the % of fault tolerance with the increase of network size. FTTT5 offers best fault tolerance due to the identification of more RNs by CHs.

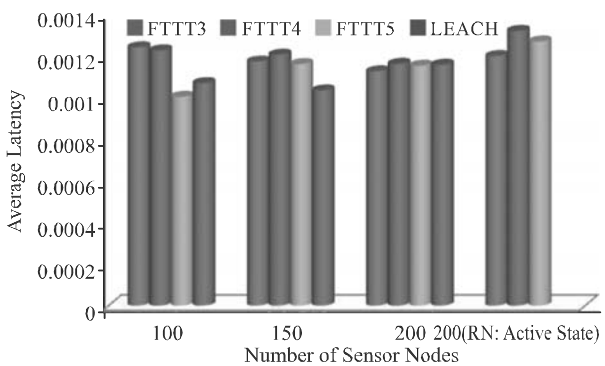

FIG. 6. AVERAGE LATENCY WITH VARYING NUMBER OF SNS AND CHS

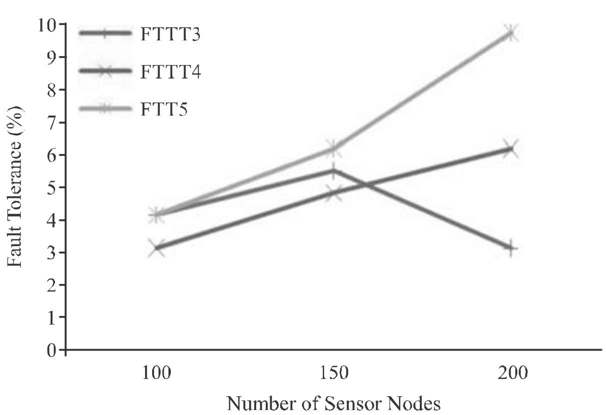

FIG. 7. FAULT TOLERANCE OF SNS

Overall, simulations demonstrated that the FTTT protocol can achieve high tracking packet probability, low latency, high throughput by implementing node duty cycle for each MN in favor of power saving.

7. CONCLUSIONS

A well written overview of node clustering schemes of WSNs is presented in previous work. In this paper, we have proposed an energy-aware cluster-based fault-tolerant target tracking strategy. The CHs are the network managers supporting schedule management, moving target tracking, as well as recovering SNs and CHs from failures. The cluster-based approach and identification of overlapping SNs made fault tolerance plausible.

During the target tracking, only the SNs with stronger signal are allowed to send information to CHs, minimizing transmission energy utilization. The simulation results prove the advantages and scalability of FTTT in terms of trade off between number of SNs, energy utilization, network throughput and average latency as compared to LEACH. Our future plan includes extending the energy model by taking into account sensing and processing energy utilization. Dealing with multiple target identification, tracking and recovery of track losses is another avenue for research.

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