Fault-Tolerance Algorithm in Wireless Sensor Networks.

Nasser Al-Qadami and Andrey Koucheryavy

***Abstract*— In wireless sensor networks that rely on clustering hierarchical structure for routing and information exchange, some nodes are essential and have a pivotal role in the clustering process and data routing. Consequently, any failures of these important nodes may cause paralysis of the network and effect on the quality of services and the reliability of the network. In this paper, we proposed a fault tolerant routing TEEN (FT-TEEN) algorithm which is a modified version of the well-known TEEN protocol; FT-TEEN proposes vital solutions to some shortcomings of the pure TEEN. It provides fault detection, recovery process, reliability and quality of service. The simulation results showed a significant reliability in the amount of receiving data by the cluster heads and the base station compared to the amount of data in the reference TEEN protocol. The developed algorithm can be used in the ground fragments flying ubiquitous sensor networks.**

***Keywords* — Wireless Sensor Networks (WSNs), Fault-Tolerance (FT), Fault Detection, Fault Recovery, Reliability, Clustering, TEEN protocol.**

I. INTRODUCTION

A WIRLESS sensor network is made up of ultra-low-power consuming, low cost, distributed devices called sensor nodes that combine sensing, computation and communication [1]. Features such as low cost, low power, compact size and robustness of these sensor nodes aid them from being used for various applications [2]. One of the important sensor network applications is to detect, classify, and locate specific events, and track targets over a specific region. An example is to deploy a sensor network in battlefield to detect tanks [3]. A new application of sensor networks is flying ubiquitous sensor networks, which required high reliability and quality of service [11]. Data aggregation is a typical operation in many WSNs applications, especially, in hierarchical routing protocol for self-organizing WSNs manner is widely used for prolonging network lifetime, eliminate data redundancy and reduce the communication load. One of the most important design issues and challenges for designing an effective and efficient wireless sensor network is adapting to changes in connectivity, scalability and fault tolerance.

A failure of some nodes in WSNs is almost unavoidable, due to a variety of reasons: energy depletion, hardware failure, software failure, communication link errors, malicious attack, etc. [4]. So the fault detection and recovery should be addressed in different applications of WSNs. Fault tolerance is the ability of a system to deliver a desired level of functionality in the presence of faults [5].

Actually, several works have been done that address one way or another fault tolerance in WSNs. In [6] the authors classified fault tolerance in WSNs into five levels, physical layer, hardware layer, system software layer, middleware layer, and application layer. Another research work on fault tolerance is fault management using cluster-based protocol in WSNs [7]. A priori methods for fault tolerance in wireless sensor networks were discussed in [8]. In hierarchical routing algorithm nodes organize themselves into clusters and cluster head is selected for each cluster. Cluster head nodes collect data from cluster members, produce processing and transmission of information on gateway or base station. This aggregation of data nodes in the head considerably reduces the energy consumption in the network and increases the life cycle duration. A typical example of the implied hierarchical clustering in WSNs is further illustrated in fig. 1.

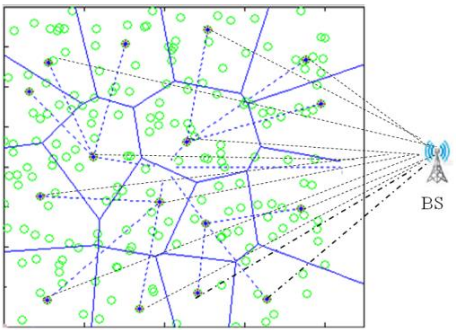

Fig. 1. Clustering Architecture

II. REVIEW OF TEEN PROTOCOL

TEEN [9] (Threshold sensitive Energy Efficient sensor Network protocol): is a reactive, event-driven protocol for time-critical applications, which uses randomization to

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distribute the energy load evenly among the wireless sensor network [9]. A non-cluster head node senses the environment continuously, but turns the radio on and transmission only if the sensor value changes drastically and doesn't wait until the next period to transmit critical data.

Functioning of TEEN protocol:

At the beginning of each round each node in a cluster takes turns to become the cluster-head (CH) for a time interval called cluster period (cluster change time). The CH broadcasts in the following threshold values to its cluster members at every cluster setup phase (cluster change time):

- Hard Threshold (HT)
  - An absolute value for the sensed attribute.
  - A cluster member only reports/sends data to CH by switching on its transmitter, only if the node senses this value.
- Soft Threshold (ST)
  - It is a small change in the value of the sensed attribute which causes the node to turn on its transmitter.
  - A cluster member only reports/sends data to CH by switching on its transmitter, if its value changes by at least the soft threshold.

The operation is divided into rounds, each round contains two states:

A. *Setup phase:*

In TEEN protocol, cluster head formation process is based on LEACH [10] (Low Energy Adaptive clustering Hierarchy). Each sensor node generates a random number between 0 and 1. The node becomes a cluster head for the current round if the number is less than the following threshold:

$$T(n) = \begin{cases} \dfrac{P}{1 - P[r * \mathrm{mod}(1/P)]} & \text{if } n \in G \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

Where: P = Desired cluster head, percentage (e.g., P= 0.05), r = Current Round, G = Set of nodes which have not been cluster heads in 1/P rounds, 1/P is the expected number of nodes in one cluster. After a cluster head selection, each sensor node joins a cluster-head that requires the minimum communication energy.

B. *Steady-state phase:*

Once the cluster heads (CHs) are selected, the CH node creates a TDMA schedule and assigns each node a time slot when it can transmit. The members of the cluster sense their surroundings continuously. The first time a sensed data reaches its hard threshold value, the node transmits the sensed data. The sensed value is stored to a variable called the sensitive value (SV).

- Sensor nodes transmit data in the current cluster period only when the following conditions are true:
  - The current value of the sensed attribute is greater than the hard threshold.
  - The current value of the sensed attribute differs from the sensed value by an amount equal to or greater than the soft threshold.

In TEEN protocol, the hard threshold (HT) reduces the number of transmissions by sending only when the sensed data is in the range of interest. Also, the soft threshold reduces the number of transmissions by excluding from the transmissions which have little or no change in the sensed data.

III. ALGORITHM DESCRIPTION

Unexpected failure of CH may cause paralyzing the network or degrades application performance; therefore, CH node fault detection and recovery are very important.

For our proposed model, we adopt a few reasonable assumptions of the network model as follows:

- Sensor nodes are deployed densely and randomly in sensor field.
- The radio channel is symmetric.
- All the sensor nodes had an equal amount of energy.
- The proposed mechanism can be applied to many hierarchical routing protocols such as LEACH protocol.

The proposed algorithm is a modified version of the TEEN protocol, introduces a backup mechanism for cluster heads, providing fault recovery process and consists of two phases:

A. *Advertising Phase (cluster formation)*

In advertising phase, the clusters are organized and CHs are selected based on LEACH protocol mechanism. After selection the CHs advertise their selection to all other nodes. All nodes choose their nearest CH after receiving advertisements based on the received signal strength (RSS) and send to them join request including their current energies.

The CHs then find the node that has the max energy from cluster members, determine it as a sub-CH and send it to cluster members.

Fig. 2 shows the cluster formation in the proposed algorithm.

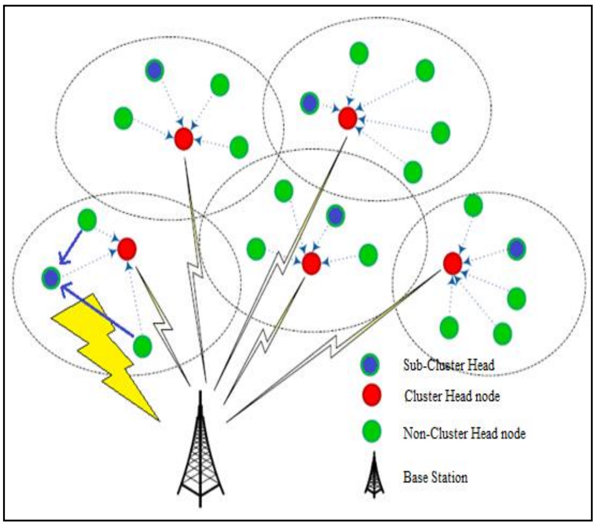

Fig. 2. Clustering in the proposed algorithm

The steps of advertising phase (cluster formation) procedure are described in Algorithm1.

Algorithm 1 – *Advertising Phase*

```
do { //repeat for R rounds
if $(Einit(s) > 0 \; \& \; s \; in \; G)$ Then
    $r \leftarrow random\ (0, 1)$;
    Compute $T(s)$; //given by (1)
    if ($r < T(s)$) Then
        $CH\{s\}=TRUE$; //node s be a CH;
else
    $CH\{s\}=FALSE$; //node s not be a CH;
    end if
end if
if ($CH\{s\} = TRUE$) Then
    $BC\ (ADV)\ includes$ ← broadcast an advertisement message;
    $Join\ (IDi, Residual\ energy)$; // non-cluster head node $i$ join;
    Select the node with max energy as sub CH;
    Cluster(c); //form a cluster c;
end if
```

R:	round
$Einit(s)$:	Initial energy
T(s):	Threshold value
Msg:	Check message
ADV:	Advertisement message
BC:	Broadcast
PCK:	Packets
IDi :	Node Identification id

B. Data Transmission Phase

In data transmission phase the CH and sub CH exchange status message periodically and all normal nodes begin sensing and transmitting data to the cluster-head and sub cluster-head in their cluster. After receiving all the data, the cluster-head nodes aggregate it before sending it to the Base-Station (BS). Just like TEEN protocol the hard threshold (HT) reduces the number of transmissions by sending only when the sensed data is in the range of interest. Also, the soft threshold reduces the number of transmissions by excluding from the transmissions which have little or no change in the sensed data.

The steps of data transmission procedure are described in Algorithm 2.

Algorithm 2 – *Data transmission*

```
If (node is CH or sub) then
    $Receive(IDi, DataPCK)$ //receive data from members;
    $Aggregate(IDi, DataPCK)$ //aggregate received data;
    $Trans\ To\ BS\ (IDi, DataPCK)$; //transmit received data;
else
    If (node has data values are in the range of interest) then
        $Trans\ To\ CH\ and\ sub\ CH\ (IDi, DataPCK)$; //transmit sensed data to CH and sub CH;
    else
        $SleepMode(i) = TRUE$; //node $i$ at a sleep state;
    end if
end if
// one Round is completed.
```

IV. FAULT DETECTION & FAULT RECOVERY PROCESS

The proposed algorithm (FT-TEEN) detects and recovers the fault according to the following mechanism:

Step 1: Initialize CH & sub-CH in every cluster.

Step 2: IF no response comes from CH to sub CH within a time interval.

THEN

Step 3: Set CH as Faulty and sub-CH becomes CH in the cluster.

Step 4: IF no response comes from sub-CH to CH within a time interval.

THEN

Step 5: Set sub CH as Faulty and CH finds a new sub-CH from its cluster member.

Algorithm 3 – *Fault Detection & Fault Response*

```
Do{ // For every cluster (c)
    $Exchange\ check\ Msg\ between\ CH\ and\ sub\ CH$;
    if no response comes from CH;
        Set CH as Faulty, CH ← sub CH;
    if no response comes from sub CH;
        Set sub CH as Faulty, CH find new sub CH
}
```

The flow chart of the distributed cluster formation process is shown in fig. 5. While the flow chart of the steady state phase for the proposed algorithm shown in fig. 6.

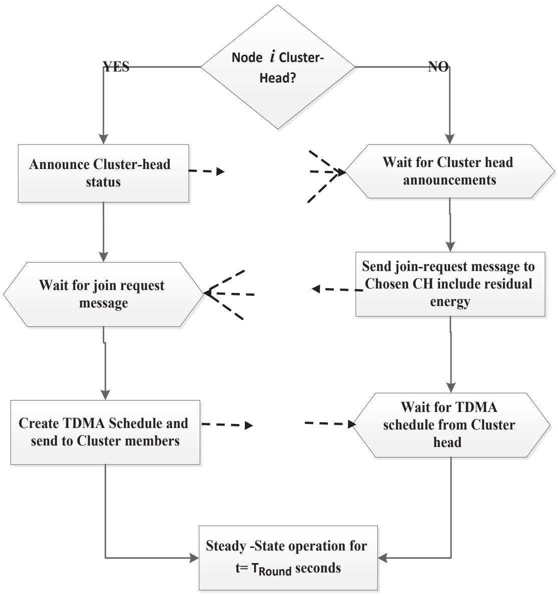

Fig. 5. Flow chart of the distributed cluster formation for the proposed algorithm

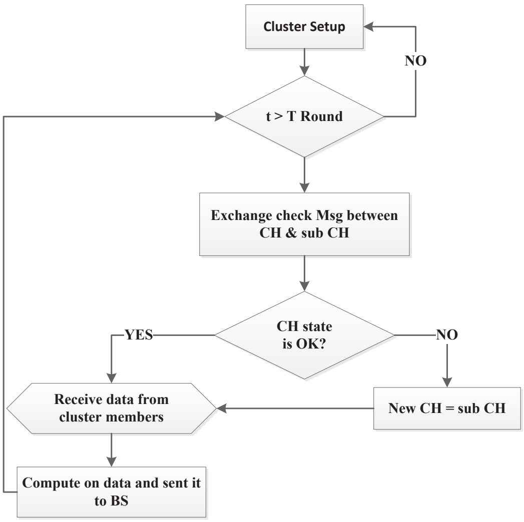

Fig. 6. Flow chart of the steady state phase for the proposed algorithm

V. SIMULATION/PERFORMANCE EVALUATION

In this section, for evaluating the performance of our proposed fault-tolerant algorithm through simulation results using MATLAB, we (compared) simulated FT-TEEN with TEEN protocol in terms of the number of data packets that are successful in reaching the base station from cluster heads and cluster heads from their members every round and the cumulative average for the amount of data transferred over the network lifetime to the CHs and BS respectively. We have carried out these simulations with the same scenario presented in TEEN in order to illustrate the performance of our contribution. Hence, we considered a network topology with 100 sensor nodes placed randomly in a 100m*100m network region and a remote base station, which is located outside the area at (X=130, Y=50), with the radio model communication parameters shown in Table I.

The other values in the Table I selected based on [12]; the simulations were performed until all the sensors in the network consumed their energy. The data packet size was 512 and the number of frames in every round is 10.

TABLE I. SIMULATION PARAMETER

Parameter	***Value***
E_{elec}	50 nJ/bit
ε_{amp} friss-amp	10 pJ/bit
ε_{amp} two-ray-amp	0.0013 pJ/bit
DCrossover	87 m
P	5%
Initial energy	0.5 Joule
Packet size	512 bits
Soft Threshold(ST)	2
Hard Threshold(HT)	100

Fig. 7, 8 show the average of packets received at the CHs and the BS in TEEN and FT-TEEN per round when the fault probability in the CHs at 10 % and desired cluster head percentage is p=5%.

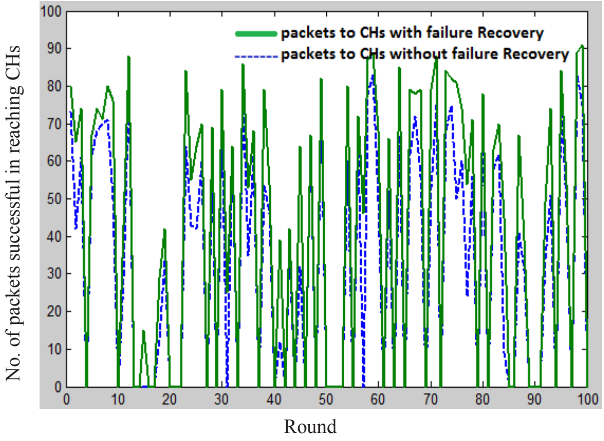

Fig.7. No. of data packets those are successful in reaching the CHs in TEEN & proposed protocol every round (Pf=10%)

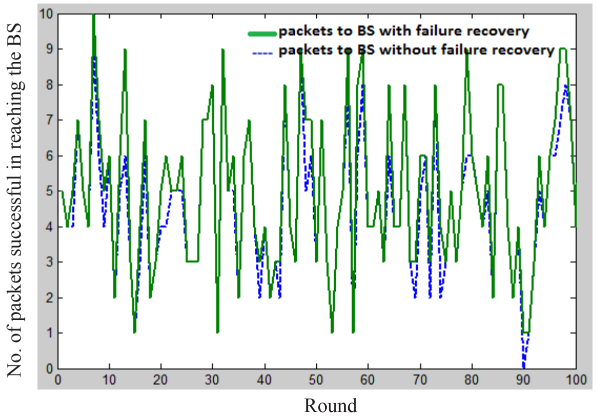

Fig. 8. No. of data packets those are successful in reaching the base station in TEEN & proposed protocol every round (Pf=10%)

In this scenario, to test the performance of the proposed protocol when the fault Probability is bigger, we set the fault probability in the CHs at 20 %, p=5%.

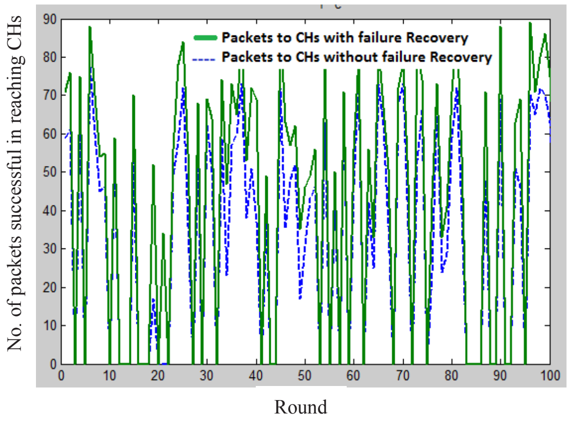

Fig. 9. No. of data packets those are successful in reaching CHs in TEEN & proposed protocol every round (Pf=20%)

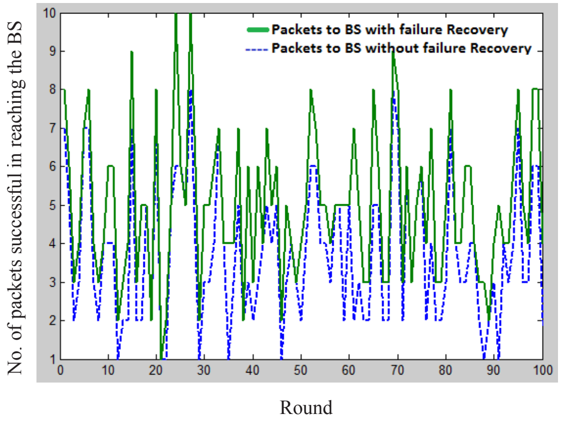

Fig. 10. No. of data packets those are successful in reaching the base station in TEEN & proposed protocol every round (Pf=20%)

It is clear from the simulation results shown in Fig. 7, 8, 9, 10 that, the average packets received at the CHs and the sink in TEEN protocol is less compared to the new mechanism (with failure recovery). The result show also, whenever the fault probability is bigger, the feasibility and efficiency of the proposed protocol is better. Here it should be noted that the fluctuations in the number of receiving packets caused by the fluctuation in the number of elected CHs in TEEN protocol every round.

The cumulative average of the amount of data transferred over the network lifetime to the CHs and BS with failure detection (FT-TEEN) and without failure detection (normal TEEN) at different fault probability is shown in the cumulative graphs 11, 12. Where the loss of transferring data, increasing when the fault probability increasing for TEEN, while the amount of data transferred by the proposed algorithm is constant and much more than TEEN, because the proposed algorithm detecting and recovering any fault in the CHs.

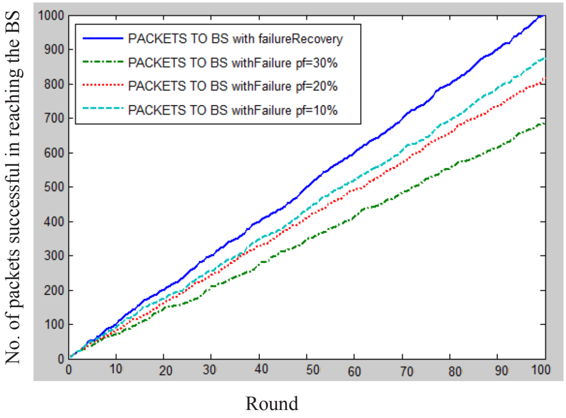

Fig. 11. Transferred data over the network lifetime to BS

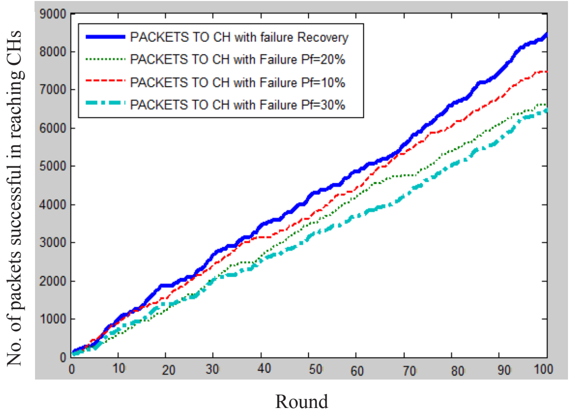

Fig. 12. Transferred data over the network lifetime to CHs

These results are shown in numbers in Table II besides, the improvement ratio of the amount of data transferred over the network lifetime to the CHs and BS with failure detection (FT-TEEN) and without failure detection (normal TEEN).

TABLE II. SIMULATION RESULTS

Head Failure Rate	Head Failure Rate					
	TEEN		***Proposed Algorithm***		***Improvement Ratio***	
	Without Failure detection and Recovery		***With Failure detection and Recovery***			
	No. Packets in CHs	No. Packets in BS	No. Packets in CHs	No. Packets in BS	In CHs	In BS
Pf=10%	7500	876	8409	1005	12%	15%
Pf=20%	6655	822	8409	1005	26%	22%
Pf=30%	6405	692	8409	1005	30%	45%

VI. CONCLUSION

In this paper, we proposed an innovative, scalable way to avoid the fault-tolerance in WSNs (FT-TEEN) which is a modified version of the well-known TEEN protocol, simulation results showed that:

1) The proposed mechanism out performs TEEN protocol and has improved the performance of TEEN in terms of number of packets successfully received at the base station with 12% and the number of packets successfully received at cluster heads with 15% if cluster heads failure percent is 10% and with 26% & 22% if the failure probability is 20%.

2) TEEN is not an efficient in data transferred to CHs as in data transferred to BS, because CHs may be failed for all rounds. The proposed algorithm delivers more data to CHs and to BS because it uses many steps to detect CHs failure and use alternative CHs.

3) The proposed algorithm detecting and recovering any fault in the CHs so, the amount of data transferred by the proposed algorithm is constant and much more than TEEN while, the loss of data transferring data increasing when the fault probability increasing in teen protocol.

4) The proposed algorithm enables the network to maintain maximum network connectivity and quality of service under failure conditions.

5) The drawback of this algorithm is the overhead communication that caused by exchanging status messages between the CH and sub CH at the beginning of each frame and also caused by advertising a new cluster head to the members of the cluster in the event of failure.

FUTURE WORK

In the future work we are going to quantify the communication overhead between CH and sub-CH and applied this mechanism to others hierarchical routing protocols.

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