A Noble Wireless Sensor Routing Application for Disaster Mitigation

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***Abstract*— Wireless sensor networks can provide low cost solution to verity of real world problems. Sensors are low cost tiny devices with limited storage, computational capability and power. They can be deployed in large scale for performing military, civilian and environmental surveillance tasks. The focus of this paper is a specialized architecture of wireless sensor networks targeted to disaster mitigation and have developed a new fault tolerant routing application for disaster monitoring and mitigation. This scheme can be used in cases where we need to continue our surveillance even after disaster, this happens specially in case of earthquake where minor and major seismic generally follow one after another and also in some post disaster relief services like checking of road availability and rescue of casualties. The resulting protocol is shown to continue operation in spite of breakdown of several components in the system i.e. fault tolerance.**

Keywords*— Disaster; protection; alarm; relay; mitigation; control station; earthquake; wsn;

I. INTRODUCTION

Disaster is the name of any natural calamity which can cause severe damage to lives and infrastructures like earthquakes, floods, volcanic eruptions or tsunamis. Here we intend to provide an alternative communication in situations of large scale destruction when most of the other public communication facilities gets disrupted, which will provide information to the disaster control stations to aid in relief and scientific observations for research. It has often been encountered that the disasters like earthquake occur repeatedly over short intervals of time as such if the wireless sensor remains somehow active after disasters the surveillance facility will continue to benefit us. But design of a wireless system which remains alive even after disaster involves some additional constraints like the base station or the sink may be collapsed during the first reverberation of the quake as shown in the system overview in Fig 1. For this reason most of the public telephone lines and internet go dead in disaster situations. Then only satellite communications remain active but since the grounded nodes use short range transmission range they cannot directly connect to the satellite. In such we have to include some additional assumptions in our network architecture viz.

1. Among the deployed node α= 20% of the nodes are Relay nodes (RN) which are more powerful than ordinary nodes and act as Cluster Heads. Α is the relay factor.

2. During a disaster the sink collapses, in such cases, along with normal application the Relay Nodes (RN) are vested with the original capabilities of remote individual data transfer directly to the control station, without the help of sink.

3. If one or more relay nodes (RN) fail, then other RNs take over the additional charge.

4. The control station can issue a query to the relay nodes directly or using a mobile sink called Mobile Data Collectors (MDCs).

The sensor nodes under a collapsed RN co-operate among themselves to find an active RN to connect.

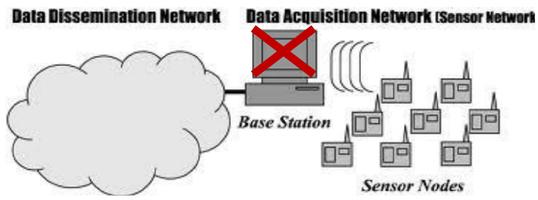

Fig.1: System Overview: Disaster Scenario

The rest of the paper contains related work in section II, a proposed fault tolerant WSN model in section III followed by a conclusion in section VI.

II. RELATED WORK

We illustrate some of the following traditional routing protocols and evaluate their suitableness to the disaster mitigation applications. Furthermore we study wireless sensor networks dedicated towards disaster mitigation.

A. LEACH

In our literature survey in [1] we have studied various sensor routing protocols and LEACH was the most preferable of all. But LEACH wastes energy in terms of long run. When clusters are created each node autonomously decide whether it can be a cluster head for the next round using a stochastic formula:

$$T(n) = P \div (1 - P \times (r \bmod 1/p))$$

Where P is determined a priori and r is the current round number. The purpose of using this formulae is to ensure that each node becomes the cluster head only once in 1/P rounds. The outcome of this round calculation in LEACH is nothing but amount of energy, T(n), left in each node and if the energy value is higher to a predefined value called threshold, the node is selected as the cluster head. If more than one node in a cluster has the predefined threshold value the selection is probabilistic as in [9]. Another point that goes against LEACH is that it considers the number of times a node has been a cluster head as a parameter for the next round and not the remaining energy.

B. PEGASIS

In another traditional wireless sensor protocol PEGASIS the local collaboration between each nodes is improved and thus using Greedy approach each time to find a random chain so that the aggregated data gets transferred to the base station or sink by each node communicating with only one of its neighbors.

Some researchers in [2], [3], [4] have worked in a hybrid technology regarding the integration of cellular network with wireless sensors to attain higher degree in coverage of speed, capacity, area through radio, multi hopping etc but unfortunately ended up in a highly load imbalanced and congested integration. Finally [5] proposed to introduce Ad-hoc Relay Station (ARS) which solved the problem of congestion. ARSs were strategically placed in the cells which extended the services from a Base Transceiver Station (BTS) of an uncongested cell in advent of congestion in a particular cell. We elaborate on the placement strategies of ARSs in the following sub sections.

C. A Sensor Network for Surveillance of Disaster-hit Region

Miyazaki et. al. in [7] advocates a WSN system where nodes within a cluster are allotted slots in such a way that they are active in different time. For example if we need to rest each node for 5 time units and we have three nodes than the nodes should wake up after 1.66 units (5/3).

So, the first node operates at 1.66, 6.66, 11.66…..., the second node operates at 3.32, 8.32, 13.32….. and the third node operates at 4.98, 9.98, 14.98…… so on. In this way we receive data after every (Ts/N) time units, where Ts is the sleep time and N is the total number of nodes and this that no two nodes remain active at the same time. This is done by difference in wakeups for each node. In addition the authors also propose a n-graph coloring approach for assigning a time slot for data transfer by each node to the sink using TDMA, but the problem of finding the lowest number of colors needed so that no two adjacent nodes have the same color is computationally hard NP complete i.e. non findable in polynomial time . They provide N slots to M nodes (M<=N) and they try a optimization task to find out minimum N, but using the greedy it is only possible to find at most N colors required to color the graph.

D. SQPWSN

Spatial Query Processing in Wireless Sensor Network (SQPWSN), proposed in [6], enabled spatial query processing mechanisms that would allow the users to collect data from a specified region. This protocol uses the concept of Minimum Bounding Rectangle (MBR) from [10], which means the smallest rectangle involving all the descendants of a node in a routing tree. Whenever a node receives a query it checks if its MBR has any part of the region of interest, if so then the node retransmits the query to the nodes of its MBR. The five stages of SPQWSN are pictured in Figure 2.

Injection: Injection of query in the network by the user.

Dissemination: Dissemination starts when the first node inside the region of interest get the query, the query is then flooded to all nodes in the region of interest.

Aggregation: Here all the nodes in the upper level of routing tree aggregate the result.

Reading: The final aggregated result is consecutively read by the last (uppermost) node in the region of interest.

Return: The final result is returned to the user through the same path with which the query was injected.

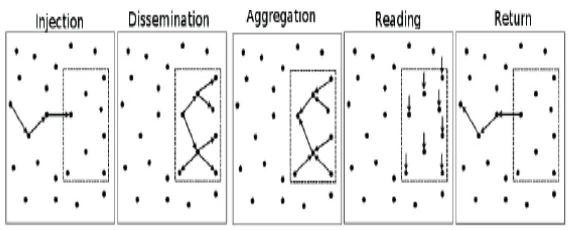

Fig. 2: SQPWSN stages[3]

This mechanism reduces the number of packets transmitted though the nodes by simplifying the region of interest and thus saving node energy.

E. WSNDM

In this section we discuss a protocol called Wireless Sensor Network for Disaster Management (WSNDM), which was proposed in [5]. WSNDM is an integration of Wireless Sensor Network (WSN) and cellular networks using ARS. WSNDM is used for both disaster monitoring and rescue operations. For a detailed understanding of disaster mitigation architecture we present Figure 3 (b), where in the integration of cellular and WSN some of the base stations are collapsed by a disaster. Figure 3 (b) depicts a cellular system with 19 cells, where major classification of cell is two: boundary cell and non boundary cell.

According to [5], an ARS is placed in every shared edge between two cells. For performance study, in section 4, we divide boundary cell class into two subclasses: boundary cell with two non shared edges and boundary cell with three non-shared edges.

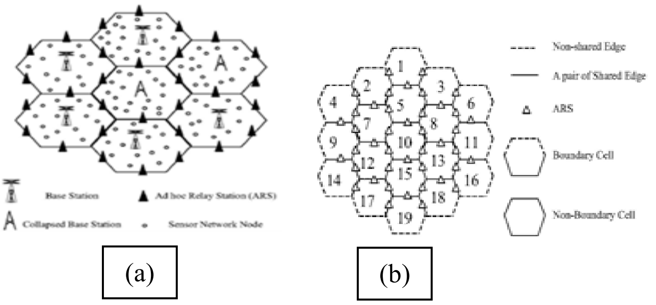

Fig. 3: WSNDM working Principle [5]

The operation of Wireless Sensor Network for Disaster Management (WSNDM) is divided into rounds, where each round consisting of a setup and data communication phase. In setup phase, according to LEACH method, clusters are formed using a distributed algorithm, where nodes make autonomous decisions without any centralized control.

F. Data Collection in WSN using a Mobile Sink for Supervision Activities

Yasmine and Kechar et. al. [11] considered a mobile sink in form of a drone hovering around the deployed area which is an international border for intrusion detection. The nodes deployed are used for video surveillance and whenever the nodes detect an intruder they send alert to the drone and the mobile sink drone reaches the node and collects the data. In this way they save energy in minimizing the transmission distance and the movement velocity as well as direction of the intruder can be identified.

G. Sensors on Sea (SoS)

Here they deployed some sensor nodes into the sea and the sensors detected certain parameters to guard against all types of sea disasters like storm, tsunami etc. the network then used Active Update algorithm. But the disadvantage is that the system cannot be used for monitoring for longer time as the deployed nodes get lost in the unending ocean.

III. PROPOSED MODEL FOR DISASTER MITIGATION

For a disaster mitigation application we consider a heterogeneous system consisting of ordinary and relay nodes.

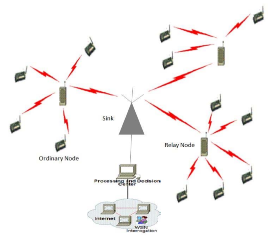

Fig. 4(a): Proposed System Architecture for disaster

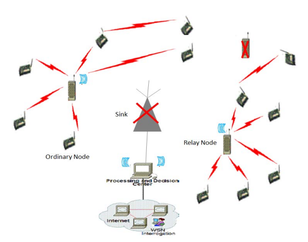

Fig. 4(b): Disaster Scenario: fault tolerance Sink and relays collapsed

Fig.4 (a) shows the proposed system model for the disaster mitigation application. In normal operation i.e. before the advent of disaster the Relay nodes which are more powerful than ordinary nodes act as the cluster heads.

Each node associates itself with the nearest cluster head and send their data to the relay node. The relay nodes then transfer the aggregated data to the sink. These phases work according to the protocols designed for power minimization in section 3. But during disaster if the sink collapses the relay nodes store the data and later the data is either directly communication on query to the control station via a long haul transmission or using mobile data collectors (MDC). MDCs are carried by a helicopter or by relief forces which is a mobile sink that issues queries to the relay nodes after a disaster for analysis of surveyed data and early alarm of further disasters.

In some cases of disaster some nodes and even some relay nodes get collapsed in such a scenario the other relay nodes has to take over the control of the collapsed relay. The nodes of the collapsed relay region lose their cluster head and they either find another relay node if accessible in their radio range or collaborate with other connected nodes to find a path to send data to a relay node. The detailed algorithm is described next. Under normal operation follow any of the conventional algorithms as described in chapter 3 with RNs acting as cluster head.

If the base station or sink collapses

- All RNs do not receive ACK message and they stop their transmission to the BS.

If some RN Collapses

- The individual nodes (Status =ACTIVE) do not receive 'ACK' message from the RNs, so they broadcast 'Discover' message all along and sets its status as LOST.
- If a Relay Node RN receives 'Discover' message they broadcast HOLD message all along their range and the lost node on receiving HOLD signal transfer its data directly to the RN.
- When a LOST node receives another Discover message it stores the id of the sender.

- When a node which has an ACTIVE status receives this Discover message, it sends Hold message to the sender LOST node.
- The LOST node on receiving the HOLD message forwards its data to the issuer node, which further communicates the data to the relay nodes RN.
- The LOST node changes its status to ACTIVE and sends HOLD message to the previously stored id nodes if any.

The process gets repeated until there is no stored LOST id with ACTIVE nodes.

In case of disaster, as shown in fig. 4 the sink and one of the relay node is collapsed, then following the disaster mitigation algorithm as described above one of the node in the collapsed relay region directly connected to another relay which was accessible to it and for other nodes which had no relay node directly in range, connected themselves with another working node and transferred their data to the relay nodes through them.

IV. SIMULATION RESULTS

The list of assumptions for the wireless sensor routing protocol for disaster mitigation is given next. We make a simulation of the application using Matlab R2011a.

In the simulation we have considered that the sink is collapsed due to a disaster and the system can work even without it. The relay nodes have the facility to transfer data to the control station without the help of sink. The transfer takes place either through a long haul transmission from the relay nodes or Mobiles sinks are used for a query based approach. The 20 percentage of the total nodes deployed are relay nodes which are 3 times more powerful i.e. resourced with more energy than ordinary nodes. If there are nxα relays and n(1-α) ordinary nodes then in average n(1- α)/nα which is (1-α)/α are lost if any one relay collapses. Here n is the total number of nodes deployed and α is the percentage of relays among the nodes, in our case α=20% i.e. 0.2.

In the simulation we employ the disaster mitigation algorithm to find the number of connected nodes to the relay nodes under decreasing number of relay nodes in a disaster scenario. We plot a graph for number of active relay nodes versus number of connected ordinary nodes to show the result.

In any disaster scenario any of the relay nodes may crash and as such the nodes try to find an alternative relay node or they connect to the relay nodes through other ordinary nodes. The transmission range of the relay node is 30 meter and that for ordinary node is 10 meter and so in order to get connected in case when a base station is collapsed, the member nodes of the collapsed relay should either find a relay within 30 meters or a connected ordinary node within 10 meters. In theoretical point of view any active relay node within 30 meter or ordinary node within 10 meters will listen to its 'Discover' message and send Hold signal to it.

Table 1. Assumed value of Network Parameters

Parameter	Value
Deployment area	$100x100m^2$
Total No. of Nodes	60
Percentage of Relay Nodes	20%
Percentage of Ordinary Nodes	80%
Initial Energy for ordinary nodes (E)	0.5J
Initial Energy for relay	3xE
Relay node Range	30m
Ordinary node Range	10m
Sink	Assumed Collapsed in
Relay Node to Control Station	Yes
Ordinary Node to Control Station accessibility tion Accessibility	No

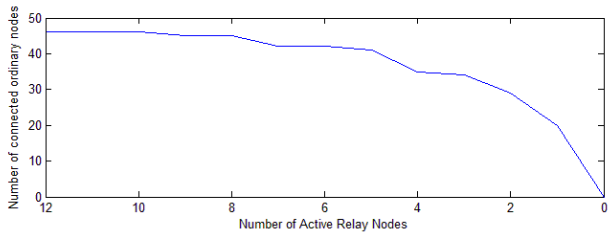

Fig.5. Graph showing Number of Connected Nodes Vs No of available Relay node

From the graph in fig. 5 we can see the fault tolerance of the proposed algorithm necessary in cases of disaster. The algorithm works in situations when the sink gets collapsed and relay nodes take over the extra charge of the sink. Here we have shown that even if the relay nodes gets collapsed the proposed fault tolerance routing protocol can still manage to connect the ordinary sensory nodes to the alive relays., so that monitoring activities continue even if there are at least some relays working.

Table 2. Experimental Results

No of relays	Percentage of
12	100%
10	100%
8	90%
6	83%
4	66%
2	58%
0	-

If N be the number of nodes, A be the deployed area magnitude (m2), α be the percentage of relay from N and ρ be the relay range then the probability (P) that a lost ordinary node will find a redundant or alternative relay to connect is given by

$$P = (N\rho - \text{ceiling}(A/\rho)) \div A$$

V. COMPARISON

TABLE III. Assumed value of Network Parameters

Algorithm	Fault Tolerance	Low Cost	Sink Mobilit	Sink Indepen
Peng and Li [8]	X Even one node in the sequence fails the entire system	✓	X	X
Mascaranous et.l. [9]	✓	✓	✓	X
Yasmine et. al. [11]	X If one Relay node collapses the entire system is dead	✓	✓	✓
Raghavan et. al.[12]	✓	✓	✓	X
Nakajima et al. [6]	✓	✓	X	X
WSNDM [5]	✓	X	✓	✓
Proposed Fault tolerant WSN disaster mitigation application	✓	✓	✓	✓

VI. CONCLUSION AND FUTURE SCOPE

A specialized application on disaster mitigation was developed using wireless sensor network and it was shown to be fault tolerant. The architecture used here was a little different from the earlier ones by the introduction of heterogeneous node system where there were two types of nodes called the ordinary nodes and the relay nodes. The nodes have the power to transmit information to the remote control site and the ordinary nodes also collaborate to connect the isolated nodes in disaster. We also find an empirical formula for probability of an isolated node to find an alternative relay node.

The future research can be considered in the following developments:

- Efficiency in WSNs can be improved by using mobile sinks i.e. the sink can be a robot or a helicopter.
- Results can be verified and improved using practical data instead of simulation.
- The power efficiency can be combined with fault tolerance to obtain a better system for disaster mitigation.

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