A deep insight to heterogeneous routing protocols for harsh environment in Wireless Sensor Network

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Abstract: Wireless Sensor Networks (WSN) are gradually transforming into an essential part of human lives. The low-power, low-cost and multifunctional sensor nodes in WSNs lead to their extensive real time sensing and monitoring applications. WSNs can be used efficiently and reliably in various hostile environments like forest fire, volcanic eruptions, flood and other hazard prone areas. Various communication protocols and routing protocols are developed to enhance the capabilities of WSNs by making them energy efficient and reducing the network lifetime and stability period. In this literature, review of the various state of the art heterogeneous routing protocols meant for harsh environments monitoring of WSNs is considered. We have reviewed Stable Election Protocol (SEP), Distributed Energy Efficient Clustering Scheme (DEEC), Developed Distributed Energy-Efficient Clustering (DDEEC), and other state of the art heterogeneous routing protocols for harsh environment monitoring and analyzed them on basis of crucial parameters namely network lifetime, stability period and energy efficiency. This paper unveils a novel heterogeneous routing protocol "Multiple Gateway Nodes (MGN) based routing architecture (MRA)" that is most suitable for harsh environment monitoring based applications. MRA alleviate the stability period and network lifetime by employing MGNs outside of the network and maintaining lesser communicative distance between the gateway node and each of the cluster-head node. MRA also ameliorate hotspot problem in the network further enhancing the network's efficiency by improving the packet delivery ratio (PDR).

***Index Terms* -** Heterogeneous Networks; Routing Protocols, Wireless sensor networks, Forest Fire Detection

1. Introduction

The Wireless sensors nodes operate wisely under extreme energy constraints and are application specific. Various parameters like antenna type, the target application, target technology, storage, components, memory, lifetime, power, communication technology, security, computational capability, size, application and programming interface are considered in the designing of a WSN [1,4]. WSNs are widely used in low bandwidth and delay tolerant applications. WSNs consist of one or more sinks that may be static or mobile and thousands of sensor nodes [2] that sense the data according to its sensing range, and process the data and provide it to the base station or sink that further provides the information to the user that demands that information. The nodes may be homogeneous with all nodes having the same initial energy or heterogeneous i.e. different nodes with different initial energies [3]. WSN consist of sensing unit, power unit and computational unit. Various security protocols are also available to ensure the security of the data and ensure that the information is provided to the authorized user.

Energy consumption is a major issue in wireless sensor networks due to the low battery life of these devices [5]. The energy consumption is much higher in communication of data than that of data processing. It has been found that the energy consumed in transmitting one bit of data is same as that consumed in executing a few thousand instructions. So it is vital to reduce energy consumption during communication by planking down the network to sleep mode whenever communication is not ensuing.

This paper analyses various routing protocols that can employed in harsh monitoring environment like forest fire prone areas and volcanic eruption prone areas etc. and these protocols include Stable Election Protocol (SEP) , Distributed Energy Efficient Clustering Scheme (DEEC) , Developed Distributed Energy-Efficient Clustering (DDEEC), and other state of the art heterogeneous routing protocols for harsh environment monitoring[6-10]. Moreover, this paper unveils a novel routing protocol namely "Multiple Gateway Nodes (MGN) based routing architecture (MRA)" that improves the stability period and network lifetime and is found to overrule the aforementioned routing protocols. The multiple gateways used in this novel routing protocol improves the network performance by enhancing stability period and network lifetime and this happens with owe to the fact that these gateways have unlimited resources and these remain out of the danger prone region and provides accurate information to the user.

1.1 Architecture and applications of WSN

The architecture of a typical wireless sensor node, usually consists of four main components: (i) a number of sensors that makes a sensing subsystem (includes analog-to-digital converters) for data acquisition; (ii) a microcontroller that forms processing subsystem and a memory for storage of data (iii) communication is performed using a radio subsystem and (iv) a power supply unit. There may be additional components like location finding system and mobilizer etc. Mobilizer can be used to change the location or configuration. It can be used to change antenna orientation. The location finding system is used to locate the sensors in the sensing field.

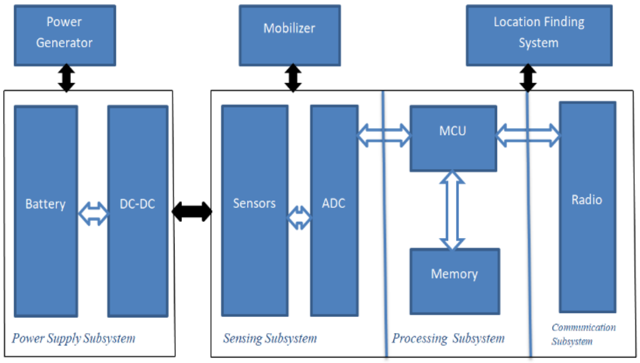

Fig1. Architecture of Wireless Sensor Node

The extensive research in WSN led to exploration of various applications in real time. Various applications include disaster relief operations like use of sensors in fire prone areas and volcanic regions for early detection and management by sensing various parameters like temperature etc and comparing the parameter with a threshold value which if crossed ,a danger is encountered, using sensor nodes in intelligent buildings, monitoring mechanical stress caused by earthquakes, etc[11]. WSN has a major impact on the agricultural field. Various sensors are used to sense temperature, humidity, and light, which is used to detect the risk of frost, and detect various plant diseases, finding watering requirements, monitor the exact condition in which plants are growing in fields/nurseries, monitoring delicate crops like tropical fruit where even slightest climatic changes can harm the plant growth, enabling the best harvest by using the sensor data to evaluate the optimum conditions for plant growth and many more. Wide range of applications of WSN, thus extend from civil and military applications to various healthcare monitoring and environmental issues monitoring.

1.1.1 Applications of WSN in Volcano prone areas

A WSN was deployed on Volcan Reventador in August 2005 that consisted of 16 member nodes that provided a coverage of 3 km. These nodes were equipped with seismic-acoustic sensors [12]. This active volcano is studied to analyze the strength of WSNs in providing accurate data and significant bandwidth during disaster and help provide disaster management. It comes under event detection so appropriate measures should be taken to save bandwidth keeping in mind the energy constraints provided by WSNs. To analyze the active volcanoes high data fidelity and high data rates are required. Moreover, spatial separation between nodes should be accurate so that data is not corrupted due to interference. To meet the above demand, the complexity of the network increases as complex computer science problems arise. Highly accurate data processing tools and techniques are required to process the collected data and interpret it.

1.1.2 Investigating rare and endangered species using WSN

WSN can be designed to study rare and endangered species of plants [12-13]. We require high-resolution cameras and temperature, rainfall, humidity, wind, and solar radiation sensors. The nodes are invisible and perform local computations. To save the bandwidth redundancy of data is performed. Nodes decline in energy after a certain duration so data must be routed continuously through active nodes. Large network can be employed however prototype used had 60 nodes. Two routing protocols are discussed in this paper: Multipath On-demand Routing (MOR) and Geometric Routing. MOR continuously monitors the network and analyzes the various routing paths. It then selects one of the routes and forwards the packet through it sending a passive acknowledgement to the sender.

In geometric routing, node first determine whether it's surrounded by neighboring nodes or lies on the edge of sensor network polygon. If node lies on edge geographic routing can't be used and the nodes communicate data through the shortest edge till it reaches destination.

1.1.3 Monitoring earthquakes and locating the survivor

During an earthquake, WSN monitors disaster situation and can locate the survivor [14]. When the localization devices are damages, WSN can provide a 3D location of the survivor. It performs this task in two stages. Firstly, it provides a draft location of the survivor from the mobile base station set around the collapse region using Received Signal Strength Indicator (RSSI). Then the accurate 3D location is found by estimating the range from the survivor to the mobile beacon node set on the equilateral triangle device. Thus, WSN can compute the depth of the buried survivor and can help save its life.

1.1.4 Detection of forest fire using WSN

Wireless sensor network can be used in forest fire detection to save the environment. We can incorporate the feature of Intelligent Decision Making (IDM) using fuzzy logic system (FLS)[15]. Due to IDM, the system becomes autonomous due to which energy is saved which is a critical issue in WSN due to limited battery life. Moreover, in FLS, the various sensitivity levels are pre-defined which help prevent man-made disasters like forest fire due to human interference at an early stage and can save numerous lives during natural disasters like volcanic eruptions, earthquakes, forest fires etc. The membership functions (MF) used for forest fire detection are smoke, temperature, humidity, light and distance. The values for temperature, light, humidity and smoke are Low (L), Medium (M) and High (H) and values for distance are close, average and far. The inference system of FLS produces output which is probability of forest fire and it's values are Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH). Fuzzy Rule Base used is stated as: IF x1 is F1 and x2 is F2 …and xn is Fn THEN y is yk where n are the number of MFs and k is the kth output.

1.1.5 Using WSN to measure disaster by analyzing gradient

Any increase or decrease in the original value give rise to a gradient. Various sources of nature cause gradient example fire causes temperature gradient. WSN can be used to detect such gradient sources and track them in order to detect disasters. In this paper

[16], a robot inspired by bacterial chemotaxis is introduced that measures gradient and uses random walk model to locate the sources causing gradient. Bacterial chemotaxis is the technique by which bacteria locate the nutrient sources by analyzing chemical gradients in the environment using receptors. These bacteria move based on flagellar rotation. For anti- clockwise flagellar rotation, these bacteria move in a straight line in a particular direction termed as a run and for clockwise rotation, these walk randomly termed as tumble and follow a new direction for next run. Similar technique is followed by robot to detect the sources causing gradient example temperature gradient. This technique of biased random walk can also be used to detect the boundary of gradient source.

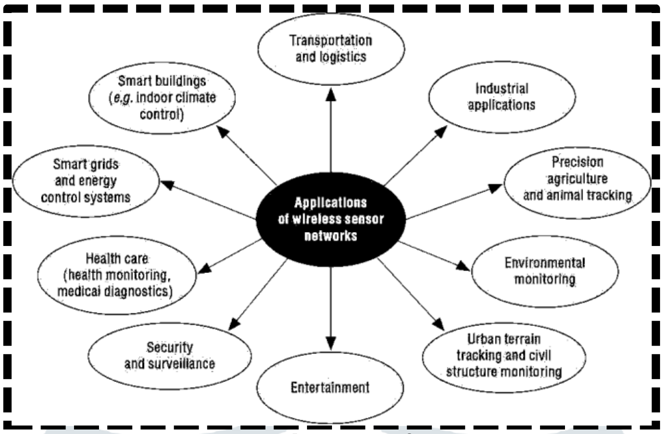

Fig2. Applications of WSN

The different adverse conditions for the environmental operations are discussed in [17].
The rest of the paper includes basic literature work, section 3 covers inferences and discussion and fourth section describes the conclusion and thereafter references are listed.

2. Related Literature Work

Table 1 discusses the various clustering protocols namely, Stable Election Protocol (SEP)[18], advanced protocols for forest fire detection [19-23], Distributed Energy Efficient Clustering Scheme (DEEC) and it's modified versions of protocols [24-27], Protocol to detect Sybil Attack in a Stratified Network[28] and so on. Some of these protocols are described below.
In paper[29] four levels of heterogeneity of Hybrid Energy Efficient Distributed Multilevel Clustering Protocol (HEEDML) are considered namely HEEDML-0, HEEDML-1, HEEDML-2, HEEDML-3 & HEEDML-4. HEEDML-0 is the original HEED protocol. Node density and residual energy of the network determines the cluster. Also, fuzzy implementation is performed in all the aforementioned HEEDML energy levels. Distance and Average energy are additional factors responsible for CH selection. The network lifetime is found to be increased by 223.77% in non-fuzzy HEEDML protocol as compared to 589.07% increase in HEEDML-FL for the same level of increase in network energy (24%).
Paper [30] discusses Prolong Stable Election Protocol (P-SEP) that outperforms SEP in a way that cluster head selection is not random in the proposed protocol. P-SEP considers the average of the energy for each node to increase efficiency and reasonably decreases the overhead on each FN. P-SEP takes into account for the number of nodes that are associated with each CH and optimizes the minimum distance (md) between the CHs and FN.
Paper [31] introduces SEECP (Stable Energy Efficient Clustering Protocol) that performs numerical calculations for selection of optimal radius around BS for dual-hop communication to minimize the energy consumption of distant CHs. In paper [32] BEENISH (Balanced Energy-Efficient Network Integrated Super Heterogeneous protocol), iBEENISH(Improved BEENISH), MBEENISH(Mobile BEENISH) and iMBEENISH(Improved Mobile BEENISH) are considered. BEENISH protocol uses four different levels of node. iBEENISH improves the probability of CH selection solving hotspot problem in BEENISH. The model of sink mobility is introduced in MBEENISH and iMBEENISH.
Paper [33] uses dual hop communication protocol that emphasizes on load balancing and a differential evolution based clustering protocol is also introduced. The data is transmitted to CH using threshold decision making. Paper [34] discusses photovoltaic wireless sensor networks for forest fire propagation detection (PV-WSN) that uses PV-Cells to harvest energy for WSNs. Paper [35] uses an encoding scheme and a novel fitness function to improve cluster head selection process for increased network lifetime and stability period. The protocol is termed as GATERP (Genetic Algorithm-Based Threshold Sensitive Energy Efficient Routing Protocol).
EECPEP-HWSN (Energy Efficient Clustering Protocol to Enhance Performance of Heterogeneous Wireless Sensor Network) is focused on in paper [36] to enhance stability period and lifetime by reducing energy consumption in the form of reducing internal overhead and cost of processing energy.
Paper [37] discusses a novel architecture Multiple Gateway Nodes (MGN)-based routing architecture (MRA) that uses four gateway nodes that can perform tremendous calculations and doesn't pose any limitations on available energy, and can provide long range coverage. The use of gateway nodes increases both network lifetime and stability period of the network. In MRA, the inclusion of node density has improved the selection of Cluster Head w.r.t other state-of-art protocols that use only energy and distance as CH selection parameters. However, further average energy of network can be used to further improve CH selection. Three types of nodes are used namely advanced, super and normal nodes that differ in their initial energy values. The network lifetime and stability period can further be enhanced by incorporating an additional type of nodes called ultra-nodes with maximum initial energy.
The following table1 discusses various routing protocols with their targeted attributes, work performed by these protocols and their limitations that led to further research in the field of Wireless sensor networks.

3. Inferences and Discussions

After doing the literature survey, the following inferences can be drawn that can help the researchers to select the appropriate routing technique for their objectives.

A. Finding:

a) The communication among the nodes consumes a lot of energy. The basic foundation to preserve the energy of nodes is to make routing as energy efficient as possible.
b) While working for routing, the clustering has been found to be the most efficient way of saving energy in the literature work reported so far.
c) The various heterogeneous protocols have worked towards the network stability period and enhancing network lifetime. The BEENISH protocol that worked for four level of energy has been very less stretched forward for any further research.
d) The some of the significant parameters for the CH selection include residual energy, distance and node density.
e) The MRA architecture reported in the literature has not only mitigated hot-spot problem but also worked remarkably well for disaster applications.

4. Conclusion

Heterogeneous WSN has variety of applications in real time scenarios. This paper reviews the most recent and the best routing protocols suitable for harsh environmental conditions. To the best of our knowledge, it is the first work to review the protocols beneficial for routing in extreme conditions. We have designed a table to analyze and compare the state-of-the-art heterogeneous routing protocols for harsh environment monitoring. Among the routing protocols discussed for the literature review, "Multiple Gateway Nodes (MGN) based Routing Architecture (MRA)" is found to be the most promising routing protocol. In MRA, the major focus is on CH Selection. The parameter of Node Density is incorporated to ameliorate CH selection. MGNs are placed equidistant from each other and delivers the optimal network performance. Incorporating MGNs also reduce the delay in data delivery by reducing the effective communicative distance between nodes and gateways (sink). MRA also mitigates the hotspot problem further leading to efficient data delivery. In future work, four levels of nodes can be used to further increase network lifetime and stability period.

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