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Unmanned Aerial Vehicle based Reliable and Energy Efficient Data Collection from Red Alerted Area using Wireless Sensor Networks with IoT

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Most important characteristics of the Wireless Sensor Networks (WSNs) is self-configuration, in which each deployed sensor node configures itself with neighbor node and establishes the network topology. In the proposed work, an Unmanned Aerial Vehicle (UAV) based Reliable and Energy Efficient Data Collection Mechanism (REEDCM) is introduced using Wireless Sensor Networks with the Internet of Things (IoT). It mainly focuses on the effective data collection from the man un-attended area (*i.e.*, red alerted area) including nuclear disaster zone, volcanic eruption, forest fire, and battlefield, *etc.* Battery energy is a major constraint of the WSNs, thus an efficient data collection mechanism is needed to enhance the energy efficiency and scalability. In REEDCM, a novel clustering mechanism is presented which selects the Cluster Head (CH) based on the residual energy, speed and number of neighbors. Besides, the UAV Data Collector (UAV_DC) is used to gather the data directly from the CHs which in turn transmits the collected data to the Base Station (BS), then the BS shares the sensor information to the users through the Internet. From the simulation results, it is revealed that the proposed REEDCM provides better network performances in terms of average residual energy, average end-to-end delay, Packet Delivery Ratio (PDR) and throughput.

Keywords: cluster head, energy efficiency, unmanned aerial vehicle, wireless sensor networks, Internet of Things

1. INTRODUCTION

Advances in the recent technology including the embedded system, Micro-Electro-Mechanical Systems (MEMS), and wireless communication have made easy in visualizing a multi-functional, tiny, and low power sensor at an affordable cost. The Wireless Sensor Networks (WSNs) are mainly deployed over a man-unattended or hazardous area in order to collect the data such as temperature, humidity, and pressure, *etc.*, [1-4]. And also, the advancements in the sensor technology detect the chemical, biological, radiological, and nuclear events. This feature makes it suitable for a number of real time applications such as forest fire detection, poisonous gas and radiation detection, and landmines bomb detection with the help of robots. Due to the constraints on the sensor node's resources such as bandwidth, processing capability, memory and battery energy [5], the compression and processing of the multimedia data such as video, audio, image, *etc.*, is very difficult in small battery powered WSNs. This is because of the multimedia data consume more battery power. Additionally, the replacement and recharge of the sensor battery is not possible in man inaccessible area. Thus, the conservation of the bat-

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tery energy and prolonging the network lifetime is becoming a crucial task in WSNs. Internet of Things (IoT) is a framework which can establish a network of several devices communicating with each other throughout the world by using the Internet. It is used to achieve a feasible solution in many real-time applications [6].

The clustering is a powerful data collection technique in spatially distributed WSNs [7] which aims at improving the energy efficiency and scalability of the networks. In this mechanism, the sensing area is divided into clusters. Each cluster consists of one head node, called as Cluster Head (CH) and Cluster Member (CM). The CH performs the operation such as assigning the Time Division Multiple Access (TDMA) schedule to the CM, collecting the data from the CM, performing the data aggregation and transmitting the aggregated data to the BS. The main role of CM is to sense the event from the targeted network area and forwards to the CH with respect to the TDMA schedule. The Low Energy Adaptive Clustering Hierarchy (LEACH) is presented in [8], in which the CHs were elected probabilistically and also CH sent the aggregated data to the BS over a long distance. Thus, the CH depletes the battery energy very quickly than other nodes and gets a premature death. And also, it fails to ensure a uniform distribution of the CHs, thereby formulating an orphan node, that is, a sensor node which is left out by the CH and lives alone, and it communicates with the BS directly for transmitting its sensed data. Scalable Energy Efficient Clustering Hierarchy (SEECH) was proposed in [9], in which the CHs were elected based on the priority value and it was calculated using residual energy and node density. Deng *et al.* [10] proposed Mobility Based Clustering (MBC) protocol, in which the selection of CH was based on the node's residual energy and velocity. The main drawback here was that the MBC frequently meets a link failure problem. Velmani *et al.* [11] presented Velocity Energy-efficient and Link-aware Cluster-Tree (VELCT) scheme which uses the node's residual energy, speed, coverage, and node density for selecting the CHs. The topology instability is the main drawback of the VELCT which is due to the inclusion of Received Signal Strength (RSS) alone for finding the coverage and connection time of the networks. Sasirekha *et al.* [12] proposed Cluster-Chain Mobile Agent Routing (CCMAR) algorithm, in which the chain was organized by the CM within the cluster for sending their data to the CH. Further, the CCMAR utilized a mobile data collector to collect the data from CHs. In Novel Energy Efficient Clustering (NEEC) [13], the network area was partitioned by the BS into layers based on the node's location information. The delay time of CH awareness message broadcasting was calculated in each and every sensors based on the battery energy and the neighbor node. Then, the CHs sent the aggregated data either in a multi-hop manner or directly communicated to the BS.

But, numerous clustering protocols have been proposed for WSNs with static BS, in which the CH usually sends the collected data to the BS through direct hop or multi-hop manner. However, such strategies do not scale with the number of nodes and also increases the energy consumption. In multi-hop routing, a node nearer to the BS frequently uses a network traffic, resulting in network congestion and high battery power consumption than others. Many research studies have demonstrated the advantages of the Mobile Sink (MS) in many real-time applications to enhance the network connectivity and to collect the data from the isolated area [14]. A swarm intelligence based energy efficient data acquisition protocols with mobile sink is discussed in [15]. A distributed local algorithm based network lifetime maximization technique with mobile sink is presented in

[16]. Jin Wang *et al.* [17] proposed a Mobile sink based Energy-efficient Clustering Algorithm (MECA), in which the CHs are selected based on the residual energy.

To address these problems, the REEDCM is proposed to provide a framework which enhances a lifespan of WSNs by taking the advantages of a clustering mechanism and Unmanned Aerial Vehicle Data Collector (UAV_DC). In cluster formation, the CHs are selected in distributed manner, in which each node waits a time before broadcasting the final CH awareness message. The CH is used to collect the data from the CM with respect to the TDMA schedule. Then, the UAV_DC gathers the data from CHs which in turn sends to the BS. Finally, it connects the end users using the Internet. In the proposed work, we examine the performance of the networks based on the applications including static scenario and mobile scenario. In static scenario, the sensor nodes are continuously monitoring the physical events and also report the events automatically to the BS till the end of the battery life time. This information is mainly used to detect and aware the people before the occurrence of the hazards. For example, in forest fire detection and monitoring, the sensor nodes are deployed to sense the events such as temperature and humidity for finding the environmental condition of the forest area. However, we cannot guarantee the operability of the sensor nodes in high temperature. But in mobile scenario, the sensor nodes are equipped with mobile robot for sensing the events (poisonous gas or radiation) from the targeted area which is highly suffered by the disaster, for example in radiation monitoring and detection after the occurrence of nuclear disaster due to the earthquake and tsunami, the mobile robot carries a sensor node for recording the Gamma rays level which is used to further process and assist the system in all the ways till the end of battery energy. Both the applications use the UAV_DC which is flying over the targeted sensing area in a fixed traveling path regularly to collect the sensed data. The proposed REEDCM continuously monitors and provides necessary field information about the targeted area to the corresponding clients to make a decision in order to alert and help the people in disaster condition. The important feature of this protocol is that it does not allow all the deployed nodes attempt to send the data to the UAV_DC, resulting in a reduced contention of accessing the channel and also avoids the packet collision and drop. Besides, it increases the energy efficiency and scalability of the networks.

The remainder of this paper is organized as follows. Section 2 presents the operation of the proposed REEDCM scheme. The mathematical analysis of the REEDCM is depicted in section 3. Section 4 illustrates the results and discussion. Finally, conclusion is presented in section 5.

2. PROPOSED METHODOLOGY

The operation of REEDCM is detailed in this section, in which it achieves an effective data collection from the sensor node in two phases: (1) Cluster formation and (2) Data communication. In cluster formation phase, the CHs are elected with respect to the waiting time based CH awareness message broadcasting, and then follow the CM-CH and CH-UAV data communication. The UAV is used as a mobile data collector that flies over the targeted sensing area to collect the data from the CHs and forwards to the BS. Here, BS is a rich resource device which is used to collect the data from the UAV and forwards to the Internet cloud, that is, it acts as a gateway between the user and targeted sensing area through the Internet, WSNs and UAV.

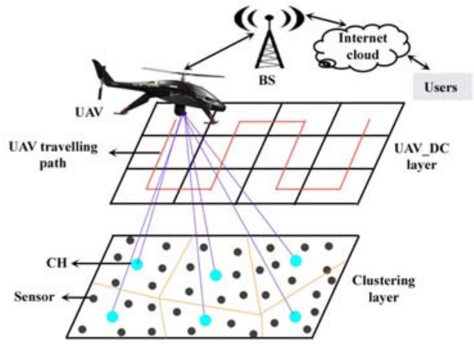


Fig. 1. General architecture of REEDCM.

2.1 Network Model Assumption

The following assumptions are made in the proposed design:

(1) All the sensor nodes are static in scenario 1 and mobile in scenario 2.
(2) All the sensor nodes know their location.
(3) The sensor nodes are synchronized with time [18, 19]. The time synchronization is a crucial procedure for achieving a common time to all the nodes which is operated in distributed manner. For example, all the deployed sensor nodes should be synchronized with respect to the time, in order to distribute the common time scale for achieving an effective data fusion by integrating the gathered data in a meaningful manner. A well known TDMA scheduling in distributed WSNs strictly requires the synchronized networks for minimizing the data collision, and also conserves battery energy of the sensor nodes by utilizing the duty cycle effectively for sleep and wake-up controls.
(4) Links between the sensor nodes are symmetric, *i.e.*, the same power is used to transmit the packets between the any two sensor nodes.
(5) Nodes can adjust their transmission power according to the distance between them.
(6) All the deployed sensor nodes can directly communicate with UAV when it comes nearer to them.
(7) BS is located outside of the sensing area. It has sufficient transmission power to reach all the deployed sensor nodes.

Let us consider that there is N_{DS} number of sensor nodes deployed over the sensing region of $N \times N$ *meter*^{2}. The total sensing area (δ_{TSA}) and the coverage area of each sensor node (*i.e.*, the area of hexagon) δ_{SCA} are calculated by using Eqs. (1) and (2).

$$\delta_{TSA} = N \times N \,(meter^2) \tag{1}$$

$$\delta_{SCA} = \frac{3\sqrt{3}}{2} R_{\max}^2 \,(meter^2) \tag{2}$$

where $R_{\max}$ is the maximum transmission range of the sensor node.

The minimum number of sensor nodes required to cover entire sensing area ($N_{\min}$) is calculated by the ratio of total sensing area to the coverage area of a sensor node and it is given in Eq. (3)

$$N_{\min} = \frac{\delta_{TSA}}{\delta_{SCA}}. \tag{3}$$

The optimum number of CM in each cluster (N_{Nm}) is given in Eq. (4)

$$N_{Nm} = \frac{N_{DS}}{N_{\min}}. \tag{4}$$

2.2 Cluster Formation

2.2.1 Static scenario (Scenario 1)

The proposed clustering mechanism is similar to that of LEACH, in which it gives a chance to the certain amount of sensor node to become a final CH in each round, *i.e.*, twice that of a minimum number of sensor which is required to cover the entire sensing area. Each node calculates the threshold value of static scenario ($\xi_s(n)$) by using Eq. (5). Additionally, the residual energy and number of neighbor nodes are considered in Eq. (5) in order to ensure a well distributed energy consumption of the sensor node and extends the network lifetime. The normalized value of the residual energy with respect to the maximum residual energy of the neighbor avoids the selection of the low energy node as a CH and the normalized value of the optimum number neighbor balances the work load of the CH, resulting in prevention of the premature death of the sensor nodes.

$$\xi_s(n) = \frac{\frac{2\times N_{\min}}{N_{DS}}}{1-\frac{2\times N_{\min}}{N_{DS}}[r \bmod \frac{N_{DS}}{2\times N_{\min}}]} \times \frac{E_c}{E_{Nm}} \times \frac{N_{Nc} \bmod (N_{Nm}+1)}{N_{Nm}} \tag{5}$$

where r is the index number of each round, E_c and E_{Nm} denotes the current energy of sensor node and maximum residual energy of the neighbor node, N_{Nc} is the number of current neighbor nodes.

2.2.2 Mobile scenario (Scenario 2)

The consideration of the speed of the sensor nodes plays a vital role in ensuring reliability of the WSNs which is directly attributed to the stability of a routing topology. The mobile sensor nodes frequently change their position which leads to an uncertainty in the network topology, that is, it often makes the connectivity failures, thereby increasing the packet drop with high expenditure of the battery energy. In order to select the low speed node as a final CH and to avoid the frequent network topology changes, $\frac{V_m - V_c}{V_m}$ is considered instead of $\frac{V_c}{V_m}$ in Eq. (6). The threshold value of mobile scenario $\xi_m(n)$ is calculated as

$$\xi_m(n) = \frac{\frac{2\times N_{\min}}{N_{DS}}}{1-\frac{2\times N_{\min}}{N_{DS}}[r \bmod \frac{N_{DS}}{2\times N_{\min}}]} \times \frac{E_c}{E_{Nm}} \times \frac{V_m - V_c}{V_m} \times \frac{N_{Nc} \bmod (N_{Nm}+1)}{N_{Nm}} \tag{6}$$

where V_m and V_c denotes the maximum, and current speed of the sensor node respectively.

2.2.3 Waiting time based final CH broadcasting

In final CH selection, each sensor node produces a random number $R(n)$ between [0,1]. If the threshold value ($\xi_s(n)$ for static scenario, and $\xi_m(n)$ for mobile scenario) is greater than a random number, then it has a chance to become a CH Candidate (CHC). Each CH candidate calculates the waiting time based on Eq. (7) and broadcasts CH awareness message with respect to $\psi_b(t)$.

$$\psi_b(t) = (1-\xi_s(n)) \times t_{CF} + \eta_t \quad (\textit{static scenario})$$
$$\psi_b(t) = (1-\xi_m(n)) \times t_{CF} + \eta_t \quad (\textit{mobile scenario}) \tag{7}$$

where t_{CF} is the total duration of cluster formation, η_t is very small time *i.e.*, $\eta_t \ll t_{CF}$, it is used to avoid the collision in accessing the channel.

Algorithm 1: Cluster Formation

```
initialization:
sensor node[.].broadcast "HELLO message"
sensor node[.].Calculate "threshold value ξs(n) or ξm(n)"
sensor node[.].Generate "Random number R(n) between (0,1)"
while Each node check the status do
    if (ξ(n) > R(n)) then
        sensor node[i].Status "CH Candidate"
        CHC[i].Calculate ψb(t)
    else
        sensor node[i].Status "Cluster Member"
    end
    if CHC[i].ψb(t) == "expired" then
        CHC[i].Status "final CH"
        final CH[i].Broadcast "CH awareness message"
    else
        CHC[i].WaitToReceive=="awareness CH message (OR) CHC[i].WaitTo expire==ψb(t)"
    end
    if sensor node[.]&CHC[i].Receive=="CH awareness message from other CHC" then
        sensor node[.]&CHC[i].Status "Cluster Member"
        sensor node[.]&CHC[i].Send "join request message"
    else
        sensor node[.]&CHC[i].WaitToReceive "CH awareness message"
    end
    if CH[i].Receive=="join request message" then
        CH[i].calculate "TDMA schedule"
        CH[i].SendToCM "TDMA schedule"
        CM[i].SendToCH "Data"
    else
        "Orphan node"
    end
end
```

Each CH candidate node waits a time till the expiry of its $\psi_b(t)$. If it reaches the waiting time, then it broadcasts a CH awareness message to the neighbors. The CH candidate which has a low waiting time than other nodes and it has the highest priority to broadcast the CH awareness message, *i.e.*, the CH candidate has high residual energy, optimum number of neighbors, and low speed than others. The candidate CH node gives up its CH competition and joins as a CM when it hears a CH awareness message from other before the expiry of its $\psi_b(t)$ (based on Algorithm 1). Upon receiving the join request message from the CM, the final CH assigns a TDMA schedule to the CM based on the distance between them in descending order. Considering (x_i, y_i), (x_j, y_j) as the coordinates of two sensor nodes and its distance $d_{i,j}$ between them is calculated based on Eq. (8)

$$d_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j^2)}. \tag{8}$$

The example of the waiting time based CH selection is provided in Table 1. In this method, all the sensor nodes have a chance to broadcast the final CH message based on a waiting time.

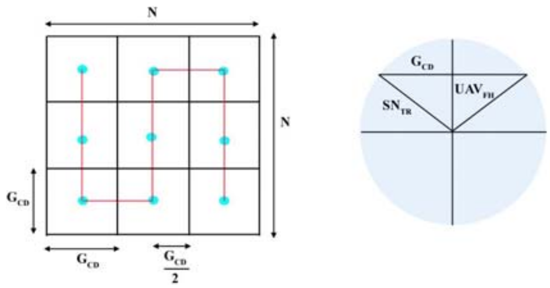
Table 1. Example of the waiting time based CH selection.

Sensor nodes	Threshold value $\xi_s(n)$ or $\xi_m(n)$	Random value	Role in the current round	Final status of sensor node
SN1	0.80	0.78	Chance to act as a CH	CM
SN2	0.86	0.79	Chance to act as a CH	CH
SN3	0.56	0.71	CM	CM
SN4	0.86	0.65	Chance to act as a CH	CH
SN5	0.78	0.77	Chance to act as a CH	CM
SN6	0.87	0.76	Chance to act as a CH	CH
SN7	0.97	0.80	Chance to act as a CH	CH
SN8	0.67	0.74	CM	CM
SN9	0.92	0.78	Chance to act as a CH	CH
SN10	0.76	0.79	CM	CM

From this example, we consider only ten sensor nodes, in which each sensor node calculates the threshold value $\xi_s(n)$ based on Eq. (5) for static scenario and Eq. (6) for mobile scenario. And also, each sensor node generates the random number between (0, 1). The sensor nodes SN1, SN2, SN4, SN5, SN6, SN7, and SN9 have a chance to act as a CH because their threshold values are greater than generated random value. If the threshold value is less than that of the random number, then node gives up its CH completion and joins as a CM like SN3, SN8, and SN10. After that, the sensor nodes SN1, SN2, SN4, SN5, SN6, SN7, and SN9 find the waiting time for broadcasting the final CH awareness message based on Eq. (7). From this example, the SN7 has a low waiting time than other nodes, (it means that the high chance value has a low waiting time, *i.e.*, the node SN7 has high residual energy, optimum number of neighbors, and low speed) therefore it has the highest priority to broadcast the CH awareness message. Once a waiting time of the SN7 is expired, then it broadcasts the CH awareness message to neighbors and also establishes the cluster. If any SN receives CH awareness message from another SN (SN7), which means that it lies in its transmission range, then the received SN gives up the CH competition and joins as a CM like SN1 and SN5. As a result, it avoids more than one CHs come to serve in the same cluster region and ensures the uniform distribution of CHs. Furthermore, it avoids the isolated nodes and interference, thereby reducing the consumption of battery energy and prolongs the network lifetime.

2.3 UAV Based Mobile Sink

The UAV_DC is employed to collect the data from CHs, in which UAV_DC travels along a fixed path, is shown Fig. 2. The dividing factor of the network area (G_{CD}) is formulated based on Eq. (9) by considering a transmission range of sensor node (SN_{TR}) and the flying height of a UAV_DC (UAV_{FH}).



(a) (b)

Fig. 2. (a) UAV_DC zigzag path; (b) G_{CD} measurement.

$$G_{CD} = \sqrt{SN_{TR}^2 - UAV_{FH}^2} \tag{9}$$

By using G_{CD}, the targeted sensing area is partitioned as a grid. The center of each grid act as a data collection point and then the UAV_DC constructs a traveling path in a zigzag manner through the data collection point. This traveling path ensures the UAV_ DC to cover the entire sensing area. The UAV_DC pauses some time at each data collection points and then it broadcasts the (Ready to Receive) RTR BEACON to the sensing area. Upon receiving this BEACON, the one-hop distance CHs and orphan nodes send the Ready to Send RTS BEACON to the UAV_DC. A node which misses its scheduled time to send the sensed data to the concerned CH due to its mobility (*i.e.*, the sensor node moved out of its CH coverage region before sending its sensed data to the CH), also called as orphan node. These nodes also directly communicate with the UAV to send their sensed data when it receives the RTR BEACON. Based on the RTS BEACON message, the UAV_DC assigns the TDMA schedule and broadcasts the schedule message to the registered CH and orphan node in order to prevent the interference and collision. Then, the CHs and orphan nodes directly send the aggregated data to the UAV_DC accordingly.

3. MATHEMATICAL ANALYSIS OF REEDCM

3.1 Average Energy Consumption

The communication energy consumption model is employed in the proposed work which is similar to that of [20]. In Eqs. (10) and (11), $E_t(L, d)$ and $E_r(L)$ denotes the energy required for transmitting and receiving the message packet over a distance d.

$$E_t(L, d) = L\times(E_{elec} + \varepsilon_{amp}d^{\alpha}) \tag{10}$$

$$E_r(L) = L \times E_{elec} \tag{11}$$

where d is the distance between the sensor nodes, E_{elec} is the energy dissipation due to the electronic circuits, L is the length of the message packets, ε_{amp} is the transmitter amplifier energy consumption, α is amplifying factor, for free space model $\alpha = 2$, when $d \leq d_0$ and multi-path fading model $\alpha = 4$ when $d > d_0$, where $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$. The total energy consumption of the CM (E_{CMt}) depends on the event sensing, transmitting the sensed event and join request message to the CH, receiving the CH awareness and TDMA schedule message. It is calculated based on Eq. (12)

$$E_{CMt} = E_t(L_d, d) + E_s + E_t(L_c, d) + 2E_r(L_c) + E_{idle} \tag{12}$$

where L_d and L_c denotes the length of the data and control packets, E_{idle} is the energy consumption due to the idle listening, E_s is the energy consumption for sensing the events. The total energy consumed by the data aggregation process (E_{DA}) is calculated by using Eq. (13)

$$E_{DA} = E_{aggr} \times L_d \times N_{CM} \tag{13}$$

where N_{CM} is the number of CMs, E_{aggr} is the energy required for aggregating the data per bits. The total energy consumed by the CH (E_{CHt}) is calculated based on Eq. (14), which spends the energy for sensing the event, receiving the join request and data message from its CMs, performing the data aggregation, transmitting the data and RTR message to the UAV_DC, CH awareness message and TDMA schedule to the neighbors.

$$E_{CHt} = N_{CM} \times E_r(L_d) + E_s + E_{DA} + E_t(L_d, d) + 3E_t(L_c, d) + E_{idle} + E_r(L_c) \tag{14}$$

The additional energy consumed by sensor node for broadcasting of the HELLO packets is given as in Eq. (15).

$$E_{HELLO} = N_{DS} \times E_t(L_c, d) + \sum_{n=1}^{N_{DS}} (N_{NN} \times E_r(L_c))_n \tag{15}$$

where N_{NN} is the neighbors of each sensor node. The average energy consumption of the sensor node is expressed in Eq. (16)

$$E_{SNavg} = \frac{N_{CH} \times E_{CHt} + (N_{DS} - N_{CH}) \times E_{CMt} + E_{HELLO}}{N_{DS}} \tag{16}$$

where N_{CH} is the number of CHs in each round.

3.2 Control Overhead

The control overhead of REEDCM is similar to the LEACH protocol, *i.e.*, $O(N_{DS})$. At the beginning of each round, the sensor nodes broadcast N_{DS} of HELLO packets. There are N_{CH} of final CH awareness message, N_{CH} of TDMA schedule message, and $N_{DS} - N_{CH}$ of Join Request Message utilized during the cluster formation. N_{CH} of RTS message is used to communicate with UAV. The total control overhead of cluster formation (O_{CF}) and network ($O_{network}$) are calculated based on Eqs. (17) and (18).

$$O_{CF} = N_{CH} + N_{CH} + N_{DS} - N_{CH} = N_{DS} + N_{CH} \approx O(N_{DS}) \tag{17}$$

$$O_{network} = 2(N_{DS} + N_{CH}) \tag{18}$$

4. RESULTS AND DISCUSSION

The Network Simulator version-2 (NS-2) is used to carry out the simulation of REEDCM and the performance of the proposed REEDCM is analyzed by comparing with MBC, SEECH, and NEEC. Table 2 describes the simulation parameters of the proposed REEDCM.

Table 2. Simulation setup.

Simulation parameters	Values
Targeted sensing network area	800 × 800 *meter*^{2}
Number of sensor nodes	100 – 500
Min. speed of the sensor node	0 *m/s*
Max. speed of the sensor node	10-50 *m/s*
Transmission range of antenna	100 *m*
The flying height of UAV	75 *m*
Data packet size [8]	512 *bytes*
Control packet size [8]	25 *bytes*
Initial energy of sensor nodes	100 *joules*
E_{elec} [8]	50 *nJ/bits*
E_{amp} [8]	1.3 *fJ/bits/m*^{4}
E_{aggr} [8]	5*nJ/bits/signal*

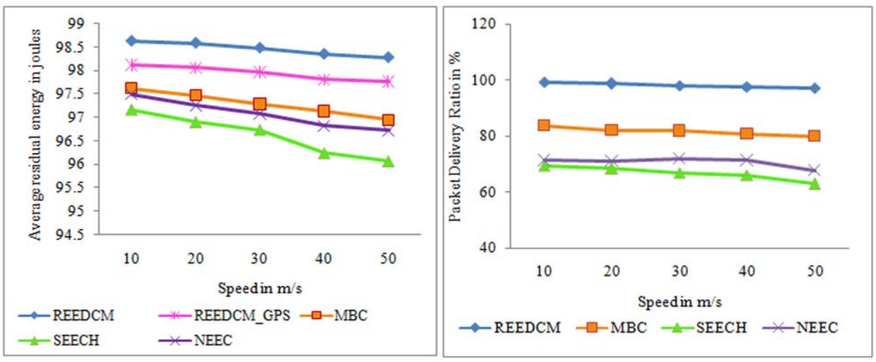
In simulation setup, the sensor nodes are randomly deployed over the sensing area of 800×800m^2 for collecting the information about the targeted environment. The transmission range of the sensor node is set as 100 meters. Table 3 provides the real time scenario which is more suitable for analyzing and evaluating the performance of the proposed protocols. For example, in forest fire detection, HIH6100 Series sensor, DHT11, and BME280, *etc.*, are widely used in finding the environmental humidity and temperature. The number of sensor nodes is varied from 100 to 500 in order to evaluate the scalability of the networks and also evaluates the stability of the network topology under the mobile network environment by varying the speed of the sensor equipped robots from 0 to 50 m/s. The UAV flies at a constant speed of 5 m/s at an altitude of 75 meters over the targeted sensing area. The UAV consists of the RF-antenna for transmitting and receiving the message packets and Global Positioning System (GPS) for navigation purpose.

Table 3. Disaster scenarios in real time – Some examples.

Applications	Static (or) Mobile	Purpose	Parameter measurement	Real time incidents
Forest fire	Static	Early detection & warning	Temperature, humidity	Hayman Fire 138,114 acres (2002), North American. Summer of Fire, Yellowstone National Park (1988)
Atomic radiation monitoring	Static or mobile robot	Finding & warning the leakage	Gamma rays	Chernobyl Nuclear Power Plant, Ukraine (1986), Fukushima Daiichi nuclear disaster following the earthquake and tsunami in Japan (2011)
Volcanic Eruption	Static or Mobile robot	Monitoring	Temperature, CO_2	Mt Tambora, Indonesia (1815), Nevado del Ruiz, Columbia (1985)
Land-mine bomb detection	Mobile robot	Detection and deactivation	Explosive material	Syrian Civil War, Iraqi Civil War (2014-present), Yemeni Civil War (2015-present)
Poisonous gas leakage in industry	Static or mobile robot	Early detection or removing the leakage	Gas sensor	Bhopal, India, Poison gas leak disaster, 1984

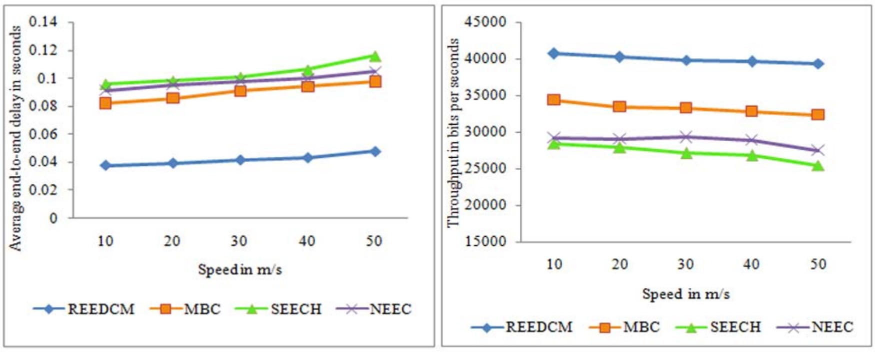
4.1 Impact of Speed of Sensor Nodes

In Fig. 3, the set of simulations is carried out by varying the speed of sensor nodes from 0 m/s to 10 m/s-50 m/s for the network of 300 nodes with the runtime lasted to 300 seconds. Figs. 3 (a)-(d) show that the proposed REEDCM gives a better performance than MBC, SEECH, and NEEC. The node speed is normalized by the maximum speed of sensor node, thus it ensures the stable network topology, and also enhances the network connectivity. The use of UAV_DC effectively collects the data from CHs as well as from the void area. Further, the proposed scheme enables to collect the data from the orphan nodes, thereby achieving high PDR, and also avoids the high energy depletion of the CH and orphan nodes. Fig. 3 (a) shows that for REEDCM, the average energy consumption is 43.59%, 56.32%, and 47.53% lower than MBC, SEECH, and NEEC respectively and Fig. 3 (b) shows that for REEDCM, the PDR is 17.87%, 35.30%, and 30.19% higher than MBC, SEECH, and NEEC respectively, when the speed of sensor node is set as 50 m/s. In addition, the energy consumption of the GPS is considered in the proposed



(a) Average residual energy. (b) Packet delivery ratio.

Fig. 3. Impact of the node speed.



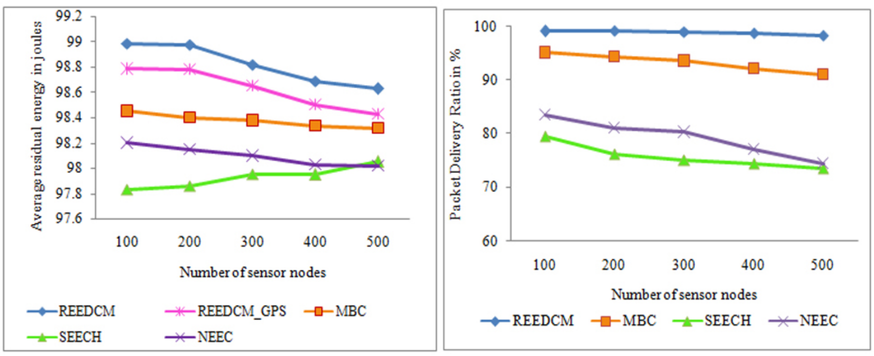
(c) Average end-to-end delay. (d) Throughput.

Fig. 3. (Cont'd) Impact of the node speed.

REEDCM which also provides better performance than the MBC, SEECH, and NEEC, although, the link connectivity and stability between the CH and CM is directly related to the speed of the sensor nodes. If the speed of the sensor node increases, it makes an uncertainty in the connection between them causing packet loss, increasing the end-to-end delay and battery energy consumption.

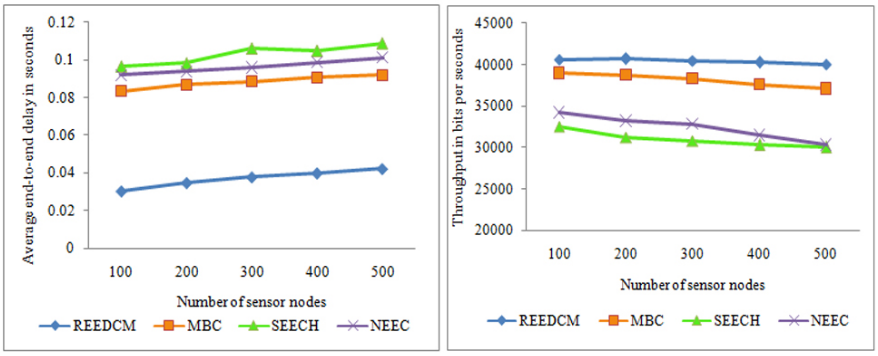
4.2 Impact of Number of Sensor Nodes (Mobile Scenario)

In Fig. 4, the set of simulations are carried out by varying the number of deployed sensor nodes from 100 to 500 over a simulation run time of 180 seconds and the speed of sensor node is set as 0-30 m/s. Figs. 4 (a)-(d) depicts that the proposed REEDCM provides a better performance than MBC, SEECH, and NEEC. The REEDCM uses the UAV_DC which avoids a direct communication of sensor nodes with the BS and thus conserving the significant amount of the battery energy than MBC, SEECH, and NEEC. Moreover, the UAV_DC collects the data from the CHs and orphan nodes based on the TDMA, thereby reducing the collisions and contention delay in the channel access. Fig. 4 (a) shows that for REEDCM, the average energy consumption is lower *i.e.*, 18.55%, 29.47%, and 30.73% than MBC, SEECH, and NEEC respectively, and in Fig. 4 (b), the REEDCM provides a high PDR of 7.43% than MBC, 25.13% than SEECH, and 24.31% than NEEC, when the number of sensor node is set as 500.



(a) Average residual energy. (b) Packet delivery ratio.

Fig. 4. Impact of number of nodes.



(c) Average end-to-end delay. (d) Throughput.

Fig. 4. (Cont'd) Impact of number of nodes.

4.3 Impact of Number of Sensor Node (Static Scenario)

In Table 4, the set of simulations is carried out by varying the number of deployed sensor nodes from 100 to 500 and the simulation runtime is taken for 180 seconds. The proposed clustering mechanism ensures the uniform distribution of CHs, thereby lessening the interferences and redundant data packets. The battery energy and the number of neighbor nodes are primary parameters for the CH selection process providing a balanced workload and reduce the early depletion of the battery energy. In addition to that, the residual energy is normalized by the maximum residual energy of its neighbor which avoids the low energy node to select as a CH. The CH collects a data from its member nodes according to the TDMA schedule reducing the data collision, packet loss, and data retransmission, and also conserves the significant amount of the battery energy. Besides, the UAV_DC directly collects the data from the CH location, thereby avoiding the data transmission over a long distance and reducing the end-to-end delay. Table 4 depicts that the PDR of REEDCM consistently remains over 98%, and average energy consumption is about less than 1.5 joules, when varying the number of sensor nodes from 100 to 500.

Table 4. Impact of number of nodes.

REEDCM	100	200	300	400	500
Avg. residual energy in joules	98.9234	98.7824	98.6347	98.5091	98.3704
PDR in %	99.3497	98.9425	98.7651	98.278	97.9807
Avg. End-to-End delay in seconds	0.03454	0.03582	0.03621	0.03707	0.03876
Throughput in bits per seconds	41023.7	40943.3	40459.1	40246.6	39989.8

Case study: The people in the affected area meet high risk of developing certain cancer such as solid cancer, breast cancer, thyroid cancer, and leukemia due to the Fukushima Daiichi nuclear disaster following the earthquake and tsunami in Japan (2011). The Nuclear Safety Technology Center (NSTC), Japan's Ministry of Education developed a Monirobo of about 0.8 meters long, 1.5 meters high, 1.5 meters in diameters, weighs about 600 kg and it can travel 0.67 meters per seconds. It is a remote controlled disaster monitoring robot (wireless controller holds their operating distance up to 1.1km) which is deployed for measuring the radiation levels by using alpha, beta and gamma detector, heat and humidity sensors, and flammable gas sensors.

Challenges in the existing monitoring system are as follows:

(1) The scalability of the network is limited because it is operated within 1.1km. If we want to increase the communication range of the device, consequently it requires more transmission power.
(2) It is also unsafe for humans to control the operation of the robot within the site (*i.e.*, $1.21km^2$) and also it is difficult in establishing BS in the disaster area and it needs a high installation cost.

If we incorporate the proposed REEDCM with current nuclear monitoring system (Monirobo, NSTC, Japan) which will enhance the performance by reducing the human risk. This is because the randomly deployed sensors in REEDCM will self-configure themselves with neighbors to establish the network by reducing the human sources. It prevents the direct communication by sensor nodes to the BS, thus it conserves significant amount of the battery power. And also, we utilized a UAV_DC for collecting the data from the CHs which helps in extending the search space without establishing the BS in the disaster area and human interventions and also reduces the cost of installation. Based on the UAV specifications, we can fix the safer zone which is far away from the disaster area. From the simulation results, the REEDCM provides good scalability when the number of sensor nodes is increased from 100 to 500 and evinces high network stability when increasing the speed of sensor nodes from 0-50 m/s.

5. CONCLUSION

In this work, we have proposed a comprehensive framework to WSNs with IoT for collecting the information from the red alerted area, which can be used for surveillance and detection. The proposed contention time based CH selection provides a well-distributed cluster formation and ensures the uniform energy distribution over the entire network. Besides, the UAV_DC is utilized to collect the data directly from the CHs, which in turn transmits the collected data to the BS and shares the sensor information to the IoT. Thus, the end user easily gets the valuable information from the man inaccessible area using the Internet. From the simulation results, it is revealed that the performance of the proposed REEDCM is superior in terms of the PDR, average end-to-end delay, throughput, and average residual energy than the MBC, SEECH, and NEEC. This data collection mechanism provides a better utilization of limited battery energy which extends the lifetime and scalability of the WSNs. And also it has a great opportunity for WSNs based real-time application with IoT. In future, the performance of the REEDCM has to be analyzed using the multimedia packets such as image, audio, video through the solar power operated WSNs.

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