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EDHRP: Energy efficient event driven hybrid routing protocol for densely deployed wireless sensor networks

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ABSTRACT

Efficient management of energy resources is a challenging research area in Wireless Sensor Networks (WSNs). Recent studies have revealed that clustering is an efficient topology control approach for organizing a network into a connected hierarchy which balances the traffic load of the sensor nodes and improves the overall scalability and the lifetime of WSNs. Inspired by the advantages of clustering techniques, we have three main contributions in this paper. First, we propose an energy efficient cluster formation algorithm called Active Node Cluster Formation (ANCF). The core aim to propose ANCF algorithm is to distribute heavy data traffic and high energy consumption load evenly in the network by offering unequal size of clusters in the network. The developed scheme appoints each cluster head (CH) near to the sink and sensing event while the remaining set of the cluster heads (CHs) are appointed in the middle of each cluster to achieve the highest level of energy efficiency in dense deployment. Second, we propose a lightweight sensing mechanism called Active Node Sensing Algorithm (ANSA). The key aim to propose the ANSA algorithm is to avoid high sensing overlapping data redundancy by appointing a set of active nodes in each cluster with satisfy coverage near to the event. Third, we propose an Active Node Routing Algorithm (ANRA) to address complex inter and intra cluster routing issues in highly dense deployment based on the node dominating values. Extensive experimental studies conducted through network simulator NCTUNs 6.0 reveal that our proposed scheme outperforms existing routing techniques in terms of energy efficiency, end-to-end delay and data redundancy, congestion management and setup robustness.

1. Introduction

The main objective of the WSN is to witness and report the events of the physical world. Over the last couple of years WSNs have witnessed increased popularity in several scientific and industrial application domains to explore events. In many cases, sensor nodes rely on their limited powered battery and computational resources, and after deployment are usually left unattended in sensing regions to make individual decisions to perform sensing and routing tasks which extremely makes it very challenging or impossible to recharge or replace their batteries (Garcia et al., 2010). Such limitations demand the data traffic to be evenly distributed among the sensor nodes. Otherwise, heavily loaded sensor nodes may bring many challenges including large end-to-end delay, congestion, memory overflow, and data reliability issues. Due to harsh working environments, reliable data forwarding with the least amount of energy expenses is assumed to be one of the most critical challenges in WSN applications (Karim et al., 2013).

In recent years, many researchers have reported that clustering is an efficient method for organizing a network into a connected hierarchy, load balancing, and prolonging the lifetime of WSN (Sendra Compte et al., 2011; Hu et al., 2015; Singh and Lobiyal, 2012). Clustering is a method in which sensor nodes are organized into groups around central sensor nodes usually called CHs with the responsibilities of up-keeping state and inter cluster connectivity for data processing. After processing the received information from its member's nodes, each CH is responsible for sending data to BS via single or multiple deployed sinks (Gungor, 2007). Clustering dramatically reduces the energy consumption of each sensor node in a WSN with the expense of increasing communication and data traffic load on CHs. However, in energy-constrained wireless sensor networks, a cluster head consumes more energy due to additional workload of receiving the sensed

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data, data aggregation and transmission of aggregated data to the base station (BS) (Agarwal and Kishor, 2014). Moreover, an inappropriate formation of clusters may lead some cluster heads overloaded with higher number of sensor nodes. This overload can make quicker death of the CHs and partitions the network, and thus, degrade the overall performance of the Wireless Sensor Network. The hot spots and bottleneck problems arise because of this unbalanced load among CHs when using the multihop forwarding model for the inter cluster communication (Faheem et al., 2013).

To overcome this situation, the idea of unequal size clustering plays a critical role to balance the energy consumption and workload of CHs. Furthermore, in WSNs, sensor node scheduling and network clustering are two efficient techniques for maximizing network coverage lifetime by reducing node energy consumption. When incorporating these two techniques, the challenges include how to choose the utmost energy efficient cluster size and how to appoint CHs and active sensor nodes (Shah et al., 2011). Furthermore, conservation of energy and fault tolerance are two major issues in the deployment of WSNs. Design of clustering and routing algorithms for a large scale WSN should incorporate both these issues for the long run operation of the network. Therefore, it is necessary to explore clustering characteristics in dense and large network deployments taking into consideration major performance issues, such as efficient data gathering, effective data traffic load handling, quick and low-overhad setup and maintenance, shortest reliable communication paths, minimum end-to-end delay and robust adaptation to node failure etc. (Mo et al., 2011; Wang et al., 2011).

In summary, prolonging network lifetime with reliable data communication must be considered as a critical issue in WSNs. In WSNs, the routing protocol and algorithms are crucial to manage these limited sensor nodes resource efficiently and provide reliable communication to explore real world events (Gungor et al., 2008). Therefore, designing an energy capable routing protocol has become one of the important challenging issues to extend the lifetime of sensor nodes, maximizing network coverage, and improving robustness against node failures (Afsar et al., 2015). Inspired by the above advantages of clustering approach, the main goal of this paper is to develop an energy efficient routing scheme, which provides reliable communication by taking into account above mentioned routing challenges, and extend the lifetime of WSNs.

The rest of the paper is organized as follows. Section 2 presents an overview of the existing routing approaches implemented in WSNs. In Section 3, the details of the proposed routing scheme are explained. Section 4 presents network and simulation settings. Section 5 presents performance analysis. Finally, the paper is concluded in Section 6.

2. Literature survey

To balance the data traffic and energy consumption workload of each sensor nodes evenly with improved overall scalability and network lifetime has become one of the most critical issues in WSNs. In recent years, in order to prolong the network lifetime of sensor network many researchers proposed a number of energy efficient routing protocols for WSNs. The authors in Liu et al. (2012b) propose an innovative distributed energy efficient clustering with improved coverage algorithm to solve high communication energy consumption and the impact of node failures on coverage with different densities clustering environment. The proposed scheme does not require any time synchronization and knowledge of a node's geographic location information and performs superior to prolong the network lifetime and improve network coverage effectively with the lack of quality of fault-tolerant management and grouping resilience.

The work in Bhattacharjee and Bandyopadhyay (2013) proposes an energy efficient routing scheme that considers the remaining energy of the node as well as energy efficiency to relay data packets toward the sink. The proposed scheme performs superior to prolong the network lifetime by balancing the data traffic between the nodes with the expense of latency and scalability issues in dense deployment. Furthermore, it faces high data redundancy issues when deployed in dense network and performs poorly in setup robustness.

In Lin et al. (2012) the authors propose an energy efficient ant colony algorithm for data aggregation and delivery. In the proposed scheme to compute the probabilities for dynamically selecting the next hop each node estimates the remaining energy and the amount of pheromones of neighbor nodes. The proposed scheme performs well to prolong the network lifetime, computation complexity and success ratio of one hop transmission. However, in the aspects of robustness, fault tolerance and scalability its performance is debatable.

The research in Azharuddin et al. (2014) proposes a distributed clustering and routing algorithms jointly called as DFCR. The proposed scheme equipped with energy efficient and fault tolerant capabilities uses a distributed run time recovery of the sensor nodes due to sudden failure of the cluster heads with satisfy coverage. The performance of the scheme is observed better to prolong the network lifetime. However, in the dense deployment scheme faces partial and transient failure of the sensor nodes.

In Liu et al. (2012a) to minimum high energy consumption cost entire network is divided into several clusters of unequal size where each sensor node maintains a gradient value which helps to find the next hop to convey data packets toward the sink. The proposed scheme called gradient based energy balancing unequal clustering routing approach performs well to prolong the network lifetime. However, in dense deployment it ignores fading and multi-path effects which cause a high data packet collision in the work.

The study in Kuila and Jana (2014a) provides a novel clustering algorithm equipped with a vector encoding and local improvement mechanisms to prolong the lifetime of the network by preventing faster death of the highly loaded cluster heads. The proposed scheme performs better to prolong the network lifetime in sparse areas. However, in dense deployment it shows poor in efficient cluster management and faces setup robustness issues.

Gong et al. (2013) propose one-hop and k-hop distributed clustering algorithms that account both residual energy of a node and the link qualities in its neighborhood to convey robust information. The proposed scheme shows its behavior superior to improve the data reception ratio and reduce the total energy consumption by providing better network scalability. However, excessive end-to-end (E2E) delay and congestion management are the challenging issues of the offered scheme.

Kuila and Jana (2014b) study the Linear and a Non-linear Programming for energy efficient routing and clustering issues in WSNs. The developed routing algorithm follows an efficient particle encoding scheme equipped with multi-objective fitness functions while the clustering algorithm considers energy conservation of the nodes through load balancing. The performance of the proposed algorithms is observed remarkable to prolong network life, number of inactive sensor nodes and the total data packets transmission with the expense of excessive network implementation complexity and synchronization issues in dense deployment.

Liu et al. (2013) propose an innovative balance energy efficient and real time reliable communication routing protocol to achieve joint performances of real-time, energy efficiency and reliability in

WSNs. The proposed scheme selects the next hop node with smaller distance and adopts the retransmission mechanism to overcome reliability and energy consumption issues. The performance of the offered scheme is witnessed remarkable in term of energy consumption, network lifetime, reliability and small transmitting delay. However, control message overhead and efficiency to find next hop node with the minimum distance is highly limited.

In Han et al. (2013) to reduce high energy consumption cost a branch and bound algorithms for small-scale and for large-scale wireless sensor networks has been proposed. The offered scheme performs superior in terms of energy efficiency and packet delay in small deployment. However, its performance in terms of control message overheads and memory overflow is highly debatable in both parse and dense network deployment.

A new coverage aware clustering protocol is proposed in Wang et al. (2012). The offered scheme uses a coverage aware cost metric for the best cluster size and cluster head selection to reduce the average energy consumption rate per unit area based on the cost metric. In the proposed scheme a layered self-activation mechanism helps to select most efficient active nodes in the network. The performance of the proposed method is found remarkable in term of lifetime, however in dense deployment it fails to achieve its goals due to heavy data traffic load and cluster head bottleneck issues.

The work in Taheri et al. (2012) proposes an on demand fuzzy logic based energy-aware distributed dynamic clustering protocol to distribute high energy consumption load evenly in the network. Here it is revealed that the proposed scheme extends the network lifetime by saving energy. However, it faces the problem of cluster overlapping interference issues which reduce the probability of efficient data packet reception.

Ghaffari proposes a new energy-efficient routing protocol in (Ghaffari, 2014). The proposed scheme takes into account high link quality; buffer occupancy and minimum hop counts while forwarding data packets over optimal shortest paths toward the sink. The offered scheme performs well to improve the lifetime of WSNs. However, in sparse it fails to appoint next hop node with minimum cost and consume more network energy.

Shi et al. (2013) proposed an efficient data-driven routing protocol to reduce the protocol overhead for data gathering in WSNs. The offered scheme is equipped with broadcast feature of wireless medium for route learning. The offered scheme achieves lower overhead and longer network lifetime while preserving high packet delivery ratio. However, this lower overhead is a tradeoff with network delay.

Jin et al. (2010) proposed an energy efficient tree based data collection protocol (EEDCP-TB) to extend the network life of WSNs. The offered scheme uses the flooding avoidance and cascading timing schemes to allocate aggregation time in order to save nodes energy. The performance of the proposed scheme is found better to prolong network lifetime with the expense of delay and robustness issues.

The work in Kim and Han (2005) proposes a balanced aggregation tree routing protocol (BATR) which takes into account optimal or near optimal minimal spanning tree for balancing the energy consumptions over all nodes. The offered scheme prolong network lifetime and provides efficient data gathering. However, data redundancy and long distance communication along with control message overheads degrades its performance.

A greedy chain based power efficient gathering in sensor information systems (PEGASIS) is proposed in Lindsey and Raghavendra (2002). The core aim to propose offered scheme was to remove some of the major drawbacks of low energy adaptive clustering hierarchy routing protocol (LEACH) (Heinzelman et al., 2000).

A chain routing with even energy consumption (CREEC) is proposed in Shin and Sun (2011). The core aim of the proposed scheme is to maximizing the fairness of energy distribution at every sensor node in the network. The performance of the scheme is noticed well in terms of network lifetime and delay. However, it has to face the problem of setup robustness, data redundancy and repairing overheads due to long chain size.

Different from the abovementioned studies, in this paper, a novel energy efficient hybrid routing scheme which relies on three collaborating algorithms is proposed to extend the lifetime of WSNs. The proposed scheme differs from the others since it focuses on the important performance parameters together, including network lifetime, packet delivery ratio, end-to-end delay, and data redundancy of densely deployed large scale WSNs.

3. Energy efficient event driven hybrid routing protocol (EDHRP)

The entire working principal of EDHRP is divided into three basic collaborating phases where each individual segment plays an important role to build energy efficient event driven routing protocol for WSNs.

3.1. Active node cluster formation (ANCF) algorithm

In EDHRP, after sensor nodes deployment ANCF algorithm plays an important role to generate unequal size clusters. The key idea to generate unequal size clusters is to distribute entire data traffic and energy consumption load evenly in the network. In each individual cluster, ANCF algorithm is responsible for appointing CHs near to the sink and sensing event while the rest of the CHs are appointed in the middle of each cluster. After sensor node deployment BS is responsible for initiating the cluster formation process via sending initiation messages (initiate_msg) though multiple deployed sinks. Let assume that there are N_{TS} number of sensor nodes deployed in the network and due to some failure (e.g., software failure, hardware failure, etc.), it may happen that a certain amount of sensor nodes is not able to communicate. Therefore, $N_{\mathrm{TS-S}}$ number of sensor nodes in the region R_i after receiving initiate_msg from the sink start to communicate with each others by broadcasting hello messages (Hello_msg) in their communication range CR_i by taking into account CSMA mechanism as shown in Fig. 1.

This Hello_msg contains information about the node id and its residual energy (RE_i). The $N_{\mathrm{TS-S}}$ number of sensor nodes in the deployed region R_i after receiving Hello_msg calculate their Euclidean distance (Ed) to their neighbors based on the Eq. (1) and update their routing tables.

$$d=\sqrt{(x_j-x_i)^2+(y_j-y_i)^2} \tag{1}$$

Then, after a specific time interval t_i the $N_{\mathrm{TS-S}}$ sensor nodes in the region R_i after calculating their active node values defined by Eq. (2) broadcasts declaration message (Dec_msg) with their node id to their neighbors as CHs.

$$ANCF_{S_{ni}}=\frac{RE_i}{\left(\sum_{i=1}^{n} DN_{}^{\frac{2}{4}}/D_{\max\, i}\right)^2+\left(\rho-\left(\frac{DN_i}{100}\right)\right)^2}\forall_{SN}:\theta_{S_{ni}\rightarrow S_{nj}} \tag{2}$$

Thus, a set of sensor nodes with higher active node values are appointed as CHs for the current round near to the sensing event and sink while the rest of the CHs are appointed in the middle of each cluster. The active node cluster formation value is based on the following parameters.

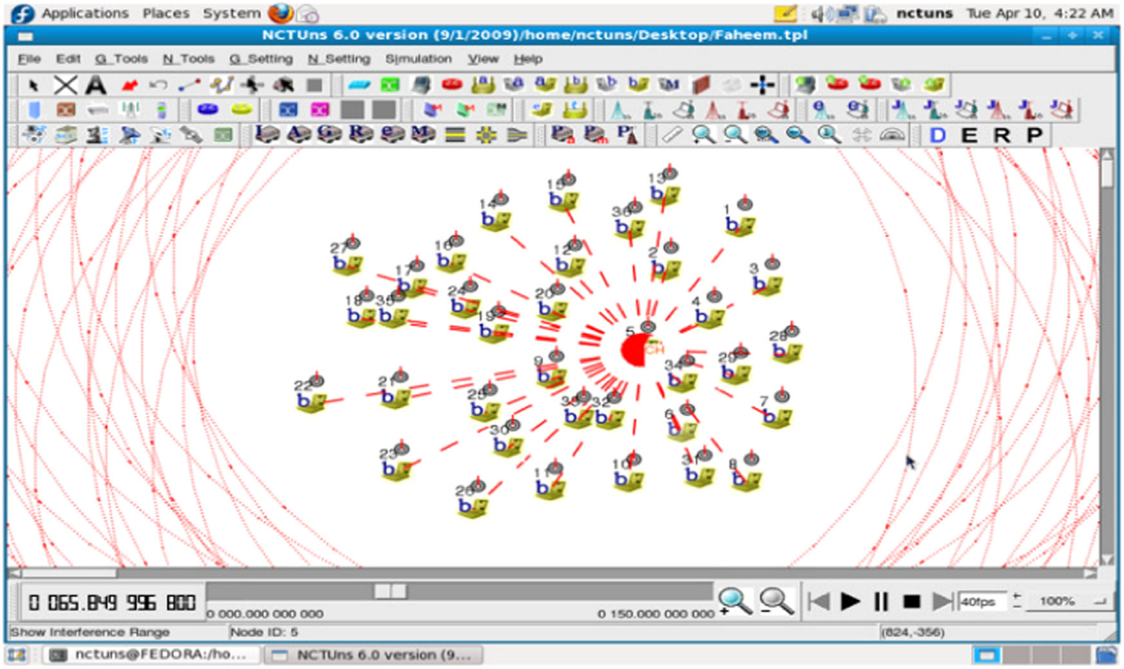

Fig. 1. Cluster formation process in ANCF algorithm.

1. *Up-keeping energy* (RE_i): a cluster head that has to witness, process and route event information continuously thus appointed cluster head should have enough energy to perform these tasks $\text{CH}_{i(\text{REi})} > \text{Th}_{\text{reshold}}$, where $\text{Th}_{\text{reshold}} \in$ distance threshold (d_o).
2. *Distance to the Neighbors* ($\text{DN}^{2/4}$): is the smallest transmission distance of a node to its neighbors node in the dense deployment region R_i, that covers the area efficiently in term of least amount of energy consumption $\text{SN}_{\text{active}} \propto 1/\text{DN}^n$.
3. *Density* (ρ): is the number of sensor nodes in a region R_i, and the values of node density varies from 1 to 2 for thick to thin regions, respectively.
4. *Maximum distance* ($D_{\max i}$): is a maximum defined distance between a sensor node S_{ni} to its neighboring sensor node S_{nj} in a cluster C_i.
5. *Angle* ($(\theta_{S_{ni}\rightarrow S_{nj}}$): is the angle of a sensor node S_{ni} to its neighboring node S_{nj}.

After CHs selection, each CH in its range R_i broadcasts joining message (Join_msg) to its neighboring sensor nodes. After receiving Join_msg each sensor nodes reply to their CH by joining accept request (join_acc). After receiving joining message request from neighboring nodes, each CH decides its member based on the minimum transmission distance (i.e., Ed) or based on received signal strength (RSS). After a specific time interval t_{i+1}, each CH limited broadcasts Join_ack message to its neighboring nodes. This Join_ack message includes both unique time slots by taking into account Time Division Multiple Access (TDMA) mechanism and joining acceptance message acknowledgement. To distribute work and energy consumption load evenly in the network the probability of CH selection rotates periodically and in each round a new CH is appointed by taking into account Eq. (3), formally can be defined as

$$R_{CH_i} = \begin{cases} \dfrac{K_{CH_i}}{S_n - K_{CH_i} * \left(r_i \bmod e \frac{N_{ci}}{K_{CH_i}} \right)} & \alpha_i(t) = 1 \\ 0 & \alpha_i(t) = 0 \end{cases} \tag{3}$$

where N_{ci} indicates the number of clusters, S_n shows the number of sensor nodes, α_i denotes the function to be determined, r_i is the current round number and K_{CH_i} represents the cluster head number, and 0 and 1 are the values associated to CH_i to be selected in the current round ($r_i \text{mode} N_{ci}/K_{CH_i}$).

The average Ed of all the sensor nodes to their associated cluster centers can be numerically defined as

$$D_{N_{TS}\rightarrow Center_{i\rightarrow j}} = \frac{\sum_{j=1}^{Nc} \left[\sum_{\forall S_n \in c_{ij}} d(S_n, Z_{ij}) \right] / |C_{ij}|}{N_c} \tag{4}$$

where

$$d(S_n, Z_{ij}) = \sqrt{\sum_{l=1}^{Nb} (S_{ni} - Z_{ij})^2} \tag{5}$$

where N_c shows the number of clusters, S_c indicates the N_b components of sensor nodes belongs to a cluster, Z_{ij} means the jth cluster center vector of the ith sensor node. C_{ij} represents the jth cluster of ith sensor node, $|C_{ij}|$ shows the number of sensor nodes in a group of the set C_{ij}, $d(S_n, Z_{ij})$ illustrate the Ed of a sensor node to their associated clusters and N_b means the number of sensor nodes split into clusters

The maximum intra-distance associated to sensor nodes and cluster centers can be mathematically defined as

$$d_{\max}(x_i, M) = \max i_{j=1,\ldots,Nc} \left\{ \sum_{\forall S_n \in C_{ij}} d(Z_{ij}, S_n) / |C_{ij}| \right\} \tag{6}$$

where M illustrates the individual sensor node clustering domain characteristic value of the matrix.

The minimum inter-distance between any pair of clusters can be numerically written as

$$d_{\min}(x_i) = \min_{\forall j_1, j_2, j_1 \neq j_2} \{ d(Z_{ij1}, Z_{ij2}) \} \tag{7}$$

To get better clustering qualities, the idea of partitioning the smallest cluster sets that are compact and well separated by maximum intra-distance could be calculated with the following formula

$$d_{\min}(C_{i,\dots,n}) = \min_{1 \le i \le N_c} \left\{ \min_{\substack{1 \le i \le N_c \\ i \ne j}} \left\{ \frac{\mathrm{d}(C_i, C_j)}{\max\limits_{1 \le k \le N_c} \{ d^*(C_k) \}} \right\} \right\} \tag{8}$$

where $\mathrm{d}(C_i,C_j)$ is the distance between clusters C_i and C_j and $\mathrm{d}^*(C_k)$ is the intra-cluster distance of cluster C_k. Thus, the number of nodes appointing as CHs in the whole network can be represented as

$$\mathrm{ANCF}_n = \sum_{i=1}^{n} \mathrm{ANCF}^1_{i+m} + \mathrm{ANCF}^2_{i+m} + \mathrm{ANCF}^3_{i+m} \cdots\cdots\cdots + \mathrm{ANCF}^n_{i+m} \tag{9}$$

where $m \in 0, 1, 2, 3 \dots n$.

$$\mathrm{ANCF}_n = \sum_{i=1}^{n} \mathrm{ANCF}^1_{i} + \mathrm{ANCF}^2_{i+1} + \mathrm{ANCF}^3_{i+2} \cdots\cdots + \mathrm{ANCF}^n_{i+m} \tag{10}$$

$$\mathrm{ANCF}_n = \sum_{i=1}^{n} \mathrm{ANCF}^1_{1} + \mathrm{ANCF}^2_{2} + \mathrm{ANCF}^3_{3} \cdots\cdots + \mathrm{ANCF}^n_{i+m} \tag{11}$$

Thus, the sum of CHs in thedeployed network can be numerically denoted as

$$\mathrm{ANCF}_n = \sum_{i=1}^{n} \mathrm{ANCF}^n_{i+m} \tag{12}$$

Pseudo-code for ANCF

```
begin ANCF ( )
After receiving initiation_msg from BS do
Broadcast Hello_msg ($\mathrm{N}_{\mathrm{N_{TS-S}}} \in$ Hello_msg)
if (Sensor nodes received Hello_msg) Then
Compute RE and Ed ($N_{\mathrm{TS-S}} \in \mathrm{RE}_{\mathrm{calculation}}$&&$\mathrm{E}_{\mathrm{calculation}}$) do
Compute ANCF values from Eq. (2)
If ($\mathrm{ANCF}_{\mathrm{Sni}} > \mathrm{ANCF}_{\mathrm{Snj}}$) Then
Broadcast declaration message in range
  ($S_{\mathrm{ni(CH_i)}}$Dec_msg $\in$ Range$_{\mathrm{i}}$)
Send joining message to its neighbors in range
  ($S_{\mathrm{ni(CH_i)}}$Join_msg $\in \mathrm{S}_{\mathrm{ni \to n}}$Range$_{\mathrm{i}}$)
If $\mathrm{S}_{\mathrm{ni}} \in \mathrm{Min}_{\mathrm{Ed}}$ to $\mathrm{S}_{\mathrm{ni(CH_i)}}$ Then
send joining acceptance request (Join_ack) to $\mathrm{S}_{\mathrm{ni(CH_i)}}$
Else
send joining acceptance request (Join_ack) to $\mathrm{S}_{\mathrm{nj(CH_j)}}$
assign TDMA ($S_{\mathrm{ni}} \in \mathrm{S}_{\mathrm{nj(CH_j)}} \in \mathrm{TDMA}_{\mathrm{(CH_I)}}$)
update routing table ($\mathrm{UR}_{\mathrm{table}}$)
memorize solution
End if all
End
```

3.2. Active node sensing algorithm (ANSA)

To prolong the network lifetime is one of the most challenging tasksin energy constrained WSNs. A significant amount of energy is consumed during forwarding huge amount of redundant data packets in the network. Furthermore, due to this huge amount of data redundancy CHs have to face the problem of memory overflow which leads to significant amount of data packet loss and excessive message retransmissions in the network. To overcome data packet loss network has to face extra control message overhead which further consumes a notable amount of node battery. To tackle above mentioned challenges, the main objectives of the active node selection algorithm, including minimize overlapping data redundancy with the least expense of control message overhead and save high transmission energy consumption cost by minimizing transmission distance. Furthermore, the developed scheme appoints a set of active nodes with satisfies network coverage near to the event and cluster head for close sensing by ensuring that the rest of the nodes are in sleeping mode. In ANSA, each CH in individual cluster is responsible for appointing a set of nodes as active nodes for close sensing with satisfy network coverage. Let assume that there are $C_iS_{1,\dots,n}$ number of sensor nodes in each cluster belong to event region $\mathrm{ER_i}$ where $C_iS_{n-\delta}$ are the number of sensor nodes that are in the range of an event at a time t_i. The sensor nodes in the event region after sensing an event will inform to their CHs by sending an information message (info_msg) as shown in Figs. 2 and 3, respectively. This information message contains information about the up-keeping node energy level, distance to the CH and the event information's. However, to find the exact distance of an event is an NP hard problem due to various harsh environmental challenges etc. After receiving info_msg from its all members nodes, in time t_{i+1}, each cluster head calculates active node sensing the value of each its member sensor node by taking into account Eq. (13), numerically can be expressed as

$$\mathrm{ANSV}_{S_{ni}} = \frac{\mathrm{RE}_i}{\left(\sum_{i=1}^{n}(\mathrm{DCH}^{2/4} + \mathrm{DE}_i^{2/4})/D_{\max\, i}\right)^2 + \left(E\rho - \left(\frac{\mathrm{DE}_i}{100}\right)\right)^2} \quad \forall_{SN}$$
$$: \theta_{S_{ni} \to CH_i \parallel S_{nj} \to CH_j} \tag{13}$$

The active node cluster formation value is based on the following parameters.

1. *Up-keeping energy* (RE_i): can be defined as a node has to continuously watch, process and route event information. Thus, appointed active node should have enough energy to perform these tasks $\mathrm{ESN}_{i(\mathrm{RE}i)} > d_o$ where ESN indicates sensor nodes in the event region.
2. *Distance to the Event* (DE_i): is the distance of a node to the event. Since the event area is located far away, this is a high-energy transmission. Thus, node energy is directly proportional to the up-keeping energy $\mathrm{ESN}_{\mathrm{active}\,(i)} \propto 1/\mathrm{de}^i$. where an event distance can be estimated based on the RSS.
3. *Distance to the Cluster Head* ($\mathrm{DCH}^{2/4}$): is the minimum transmission distance of a sensor node to its CH in the dense deployment region R_i, covers the area efficiently in term of energy $\mathrm{ESN}_{\mathrm{active}} \propto 1/\mathrm{DN}^n$.
4. *Density* (ρ): is the number of sensor nodes in a region R_i, and the values of node density varies from 1 to 2 for thick to thin regions, respectively.
5. *Maximum distance* ($D_{\mathrm{max}i}$): is a maximum defined distance between a sensor node S_{ni} to its neighboring sensor node S_{nj} in a cluster C_i.
6. *Angle* ($\theta_{S_{ni} \to S_{nj} \parallel CH_i}$): is the angle of a sensor node S_{ni} to its neighboring node S_{nj} or to its cluster head CH_i.

After calculating active node selection value of each individual sensor node, each CH in a cluster C_i is responsible for appointing a set of a set of sensor nodes with highest active node selection values for close sensing as shown in Fig. 4. To avoid data packet collision each CH is responsible for assigning its active member nodes participating in event sensing a unique time frame for communication by taking into account TDMA technique by assuring that no two nodes have the same time frame.

The active node selection mechanism guarantees to maximize the sum of sleeping sensor nodes according to the demand of network coverage by reducing the number of active nodes in a cluster under the restraint that the appointing sensor nodes guaranteed the coverage expectation. If two or more nodes have the same active node selection values, then priority is given to that node which has minimum distance to CH. To distribute work and energy consumption load evenly in the sensing network the probabilityof an active node rotates periodically and in each round a new active node is appointed by taking into account Eq. (14), formally can be stated as

$$R_{N_i} = \begin{cases} \dfrac{A_{c(n_i)}}{N_{N_i} - K_{N_i} * \left(r_i \text{ mode} \frac{C_{n_i}}{S_{ni}} \right)} & \alpha_i(t) = 1 \\ 0 & \alpha_i(t) = 0 \end{cases} \tag{14}$$

where S_{ni} denotes the number of sensor nodes in cluster C_{n_i}, $A_{c(n_i)}$ presents the active node number, where 0 and 1 are the value of a node $\boldsymbol{i}$ to be selected in the current round ($r_i\text{mode}C_{n_i}/S_{ni}$).

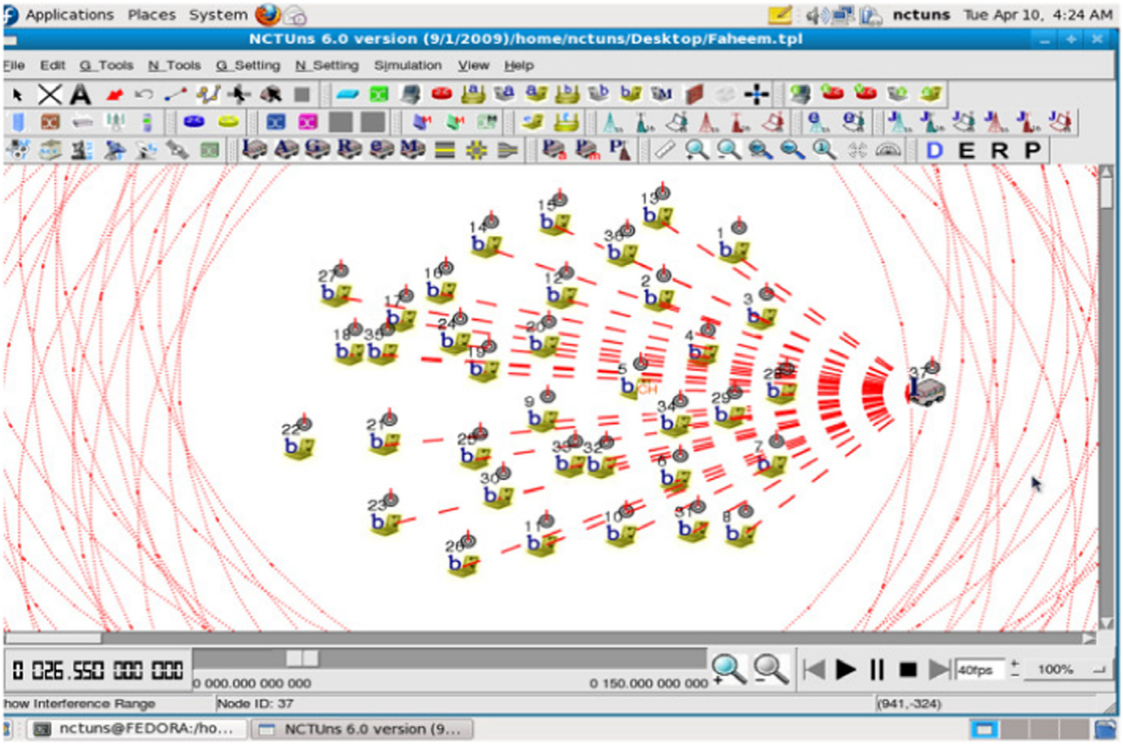

Fig. 2. Event sensing in ANSA.

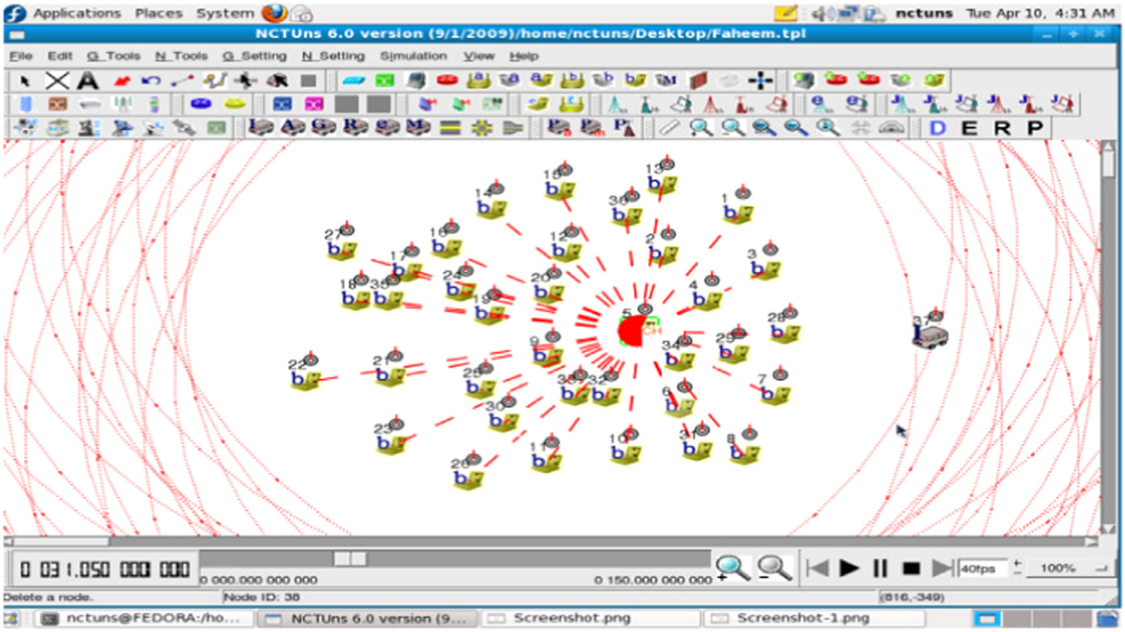

Fig. 3. After event sensing information sharing with CH in ANSA.

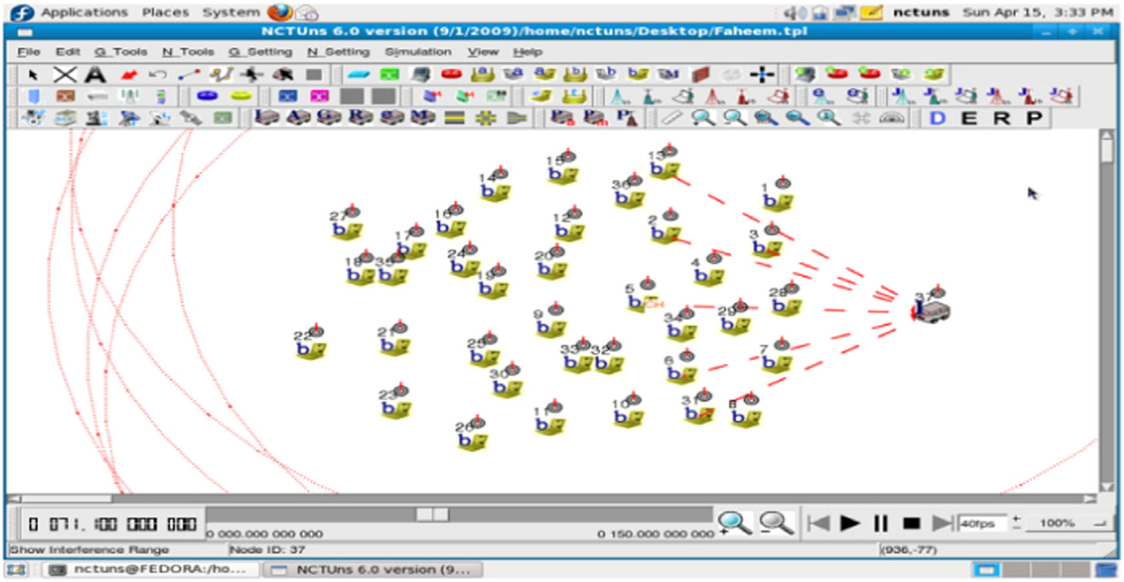

Fig. 4. Active sensor nodes for event monitoring are appointed by a CH.

The number of nodes appointing as active nodes in a cluster can be expressed as

$$\mathrm{ANSV}_c = \sum_{i=1}^{n} \mathrm{ANSV}_A^1 + \mathrm{ANSV}_B^2 + \mathrm{ANSV}_C^3 \ldots\ldots\ldots + \mathrm{ANSV}_N^n \tag{15}$$

The number of nodes appointing as an active node in the entire clustered network can be represented as

$$\mathrm{ANSV}_c = \sum_{i=1}^{n} \mathrm{ANSV}^1_{\mathrm{No's\ of\ SN}} + \mathrm{ANSV}^2_{\mathrm{No's\ of\ SN}} + \mathrm{ANSV}^3_{\mathrm{No's\ of\ SN}} \cdots + \mathrm{ANSV}^n_{\mathrm{No's\ of\ SN}} \tag{16}$$

where $J \in 0, 1, 2, 3 \ldots N$

$$\mathrm{ANSV}_c = \sum_{i=1}^{n} \mathrm{ANSV}^1_{30} + \mathrm{ANSV}^2_{20} + \mathrm{ANSV}^3_{37} \ldots\ldots + \mathrm{ANSV}^n_{\mathrm{No'\ of\ SN}} \tag{17}$$

$$\mathrm{ANSV}_c = \sum_{i=1}^{n} \mathrm{ANSV}^n_{\mathrm{TSN}_{\mathrm{network}}} \tag{18}$$

The energy consumed by a cluster head in a cluster can also be calculated. Suppose there are S_{n_i} number of sensor nodes in a cluster C_{n_i} and the average size of a cluster is S_{n_i}/C_{n_i}, then the members of cluster can be denoted as $(S_{n_i}/C_{n_i}) - 1$.

$$\text{If } \mathrm{Ed}_{\mathrm{CH}_i} \in \mathrm{Ed}(S_{n_i}) \&\& \mathrm{Ed}(S_{n_i}) > d_0 \text{ then } P_{\mathrm{loss}} = d^4 \text{ else } P_{\mathrm{loss}} = d^2 \text{ for } \mathrm{Ed}(S_{n_i}) < d_0 \tag{19}$$

Then for a cluster head E_{CH_i} energy consumption ($\mathrm{En}_{\mathrm{cons.}}$) can be numerically illustrated as

$$E_{\mathrm{CH}_i} = (E_{\mathrm{Tx-elec}}(l) + (S_{n_i}/C_{n_i}) - 1) + E_{DA}(S_{n_i}/C_{n_i}) + E_{\mathrm{Tx-amp}}\left(l, d^4_{BS}\right) + E_{\mathrm{Tx-amp}}\left(l, d^2_{\mathrm{CH}_i}\right) \tag{20}$$

Thus, above relation can also be described as

$$E_{N_i = E_{NCH} - \mathrm{CH}_i} = E_{\mathrm{Tx-elec}}(l) + E_{\mathrm{Tx-amp}}\left(l, d^2_{\mathrm{CH}_i}\right) \tag{21}$$

where E_{NCH} represents the non-CH sensor node

In a constant round $r_i \in t_{\mathrm{const.}}$ time slot assigned by a $C_{\mathrm{CH}_i} \in C_{n_i} = C_{NCH} - \mathrm{CH}_i$ to each member nodes in a cluster C_i is $t_{s(i)}$. Thus, the average time frame can be numerically indicated as

$$\mathrm{Avg}_{\mathrm{FT}} = (S_{n_i}/C_{n_i}) - 1) * t_{si} + t_{\mathrm{DA}} \tag{22}$$

Consequently, in a round r_i the average numbers of frames can be expressed as

$$\mathrm{NF}_{\mathrm{Avg.}} = t_{\mathrm{const.}}/\mathrm{Avg}_{\mathrm{Ft}} \tag{23}$$

where $C_{\mathrm{const.}}$ is some constant. Thus, the energy consumed $\mathrm{En}_{\mathrm{cons.}} \in C_{\mathrm{CH}_i}$ in a round r_i by a CH can be specified as

$$E_{r_{\mathrm{CHi}}} = \mathrm{NF}_{\mathrm{Avg.}} * E_{\mathrm{CH}_i} * C_{\mathrm{const.}} \tag{24}$$

If there are C^n numbers of cluster in the deployed network then energy consumption may be indicated as

$$E_{r_{\mathrm{CHi}}} = \mathrm{CF}_{\mathrm{Avg.}} * E_{\mathrm{CH}_i} * C_{\mathrm{const.}} \tag{25}$$

$$E_{= t_{\mathrm{NCH}}} = C * E_{r_{\mathrm{CHi}}} * C_{\mathrm{const.}} \tag{26}$$

where $C_{\mathrm{const.}}$ is a constant, we can also find the optimal number of clusters with respect to $C \rightarrow \mathrm{Zero}$ by setting derivation of $E_{t_{\mathrm{NCH}}}$ as

$$Cn_{\mathrm{optimal}} = \frac{\sqrt{N}}{2\pi}\sqrt{\frac{e_{fs} \quad M}{e_{\mathrm{fmp}} d^{2/4}_{n_i/\mathrm{CH}_i}}} \tag{27}$$

where M indicates the sensor nodes deployment area, and $\mathrm{DA}_{\mathrm{thick}}$ and $\mathrm{DA}_{\mathrm{thin}}$ are related to the sensor nodes deployment in dense and sparse areas, respectively. Here we assumed that energy consumption in both areas is same thus relation can be written as

$$\mathrm{DA}_{\mathrm{thick}} = ((n-1)\, E_{\mathrm{Thick}} + E_{\mathrm{CH}_i})/n \tag{28}$$

$$\mathrm{DA}_{\mathrm{thin}} = ((n-1)\, E_{\mathrm{Thin}} + E_{\mathrm{CH}_i})/n \tag{29}$$

Then according to equation $\mathrm{CH}_{i(\mathrm{active})} \propto 1/\mathrm{DN}^n$, we can conclude that

$$\dot{E}\left[d^2_{E_{\mathrm{Thin}} \text{ to } E_{\mathrm{CH}_i}}\right] = \frac{A}{2\pi} \tag{30}$$

$$\dot{E}\left[d^2_{E_{\mathrm{Thick}} \text{ to } E_{\mathrm{CH}_i}}\right] = \frac{A}{2\pi} * \frac{M^2}{2\pi k} \tag{31}$$

By following Eqs. (19, 27–29) we can conclude that

$$n \approx \frac{N(E_{\mathrm{elec}} + E_{\mathrm{DA}})}{e_{\mathrm{fs}} * M^2} + \frac{C}{e_{\mathrm{fs}} * M^2}\left(\frac{A}{\pi} - e_{\mathrm{mp}*} d^4_{\mathrm{Bs}} * d^2_{\mathrm{Bs}}\right) \tag{32}$$

It is more important to note that energy dissipation is proportional to the value of A. If the value of A is smaller then collected data in highly dense areas may have some amount of redundant information. So the network needs to satisfy the coverage and connectivity in thick area. To analyze the network coverage nodes have been deployed in a two dimensional region with a certain amount of density ρ (Soleimani et al., 2011). In the sensor field let p be a random selected point. If all sensor nodes are in active mode and this point p will be covered when there is at least one sensor node in the circle k with radius $R=\pi r^2$ is the area of the circle and the probability to find at least one sensor node is given below.

$$\mathrm{C}_\alpha = 1-e^{-\rho R} \tag{33}$$

Therefore, in the active node selection algorithm according to network demand, a set of sensor nodes remain in sleep modes while remaining of them are in active mode for close sensing. Thus, the involved active sensor nodes in a highly dense region can be numerically represented as

$$\mathrm{C}_\alpha = 1-e^{-\rho R\left(\frac{A_c SR_i}{r_t}\right)} \tag{34}$$

To achieve the network coverage equal to certain coverage constant describes as C_α, the low bound of the network density to fulfill the required network coverage requirements can be estimated as

$$\rho(\mathrm{C}_\alpha) = -\frac{\log(1-\mathrm{C}_\alpha)}{R\left(\frac{A_c r_i}{r_t}\right)} \text{ where } A=\frac{A_c r_i}{r_t} \tag{35}$$

$$\rho(\mathrm{C}_\alpha) = -\frac{\log(1-\mathrm{C}_\alpha)}{R(A)} \tag{36}$$

where A_c is the average active round of the node, r_t is the total number of rounds and SR_i is sensing radius.

Pseudo-code for ANSA

```
1. begin ANSA ( )
2. load memorized sample from Algorithm1 do
3. sensor nodes in a cluster sense event in range
   ($C_i S_{n-\delta} \in$ Sensing)
4. Compute RE and Ed ($C_i S_{n-\delta} \in RE_{\text{calculation}} \in E_{\text{calculation}}$)
5. Sensor nodes in event range send information message to CH
   ($C_i S_{n-\delta} \in$ info_msg) do
6. Compute ANSV values from Eq. (13)
7. If $S_{ni} \in \text{Min}_{Ed}$ to $S_{ni(\text{CH}_i)}$ Then
8. for ($\text{ANSV}_{Sni} > \text{ANSV}_{Snj}$) do
9. CH sends active message to active sensor nodes
   ($S_{ni(\text{CH}_i)} \in$ Act._msg)
10. assign TDMA ($S_{ni} \in S_{nj(\text{CH}_j)} \in \text{TDMA}_{(i)}$)
11. update routing table ($\text{UR}_{\text{table}}$)
12. memorize solution
13. End if all
14. End
```

3.3. Active node routing algorithm (ANRA)

The main purpose of the ANRA is to distribute entire data traffic load evenly in the entire network by distributing workload among sensor nodes and CHs. ANRA divides entire network traffic into two basic segments, first routing from sensing region to CH and then from CH to the sink. In the first phase, after sensing each active sensor nodes which are two or more hops away to the CH are responsible for forwarding their witnessed information to their neighboring nodes near to the CH, while the sensor nodes one hop away can directly communicate with CH. Thus, entire sensing data traffic in a cluster moves in the form of multi-hop minimum spanning tree toward CH. We take into account the key idea of prime algorithm to construct minimum spanning tree. In multihop spanning tree like routing, a next hop node with the least amount of minimum transmission distance is selected based on its highest active node routing value calculated by Eq. (37).

$$\text{ANRV}_{S_{ni}\to\text{CH}_i} = \frac{RE_i}{\left(\sum_{i=1}^{n}(DS_{ni}^{2/4}\to\text{CH}_\text{i}+DS_{ni}^{2/4}\to S_{nj})/D_{\max\, i}\right)^2+\left(E\rho-\left(\frac{DE_i}{100}\right)\right)^2} \quad \forall_{SN} : \Theta_{S_{ni}\to\text{CH}_i \,\|\, S_{ni}\to S_{nj}} \tag{37}$$

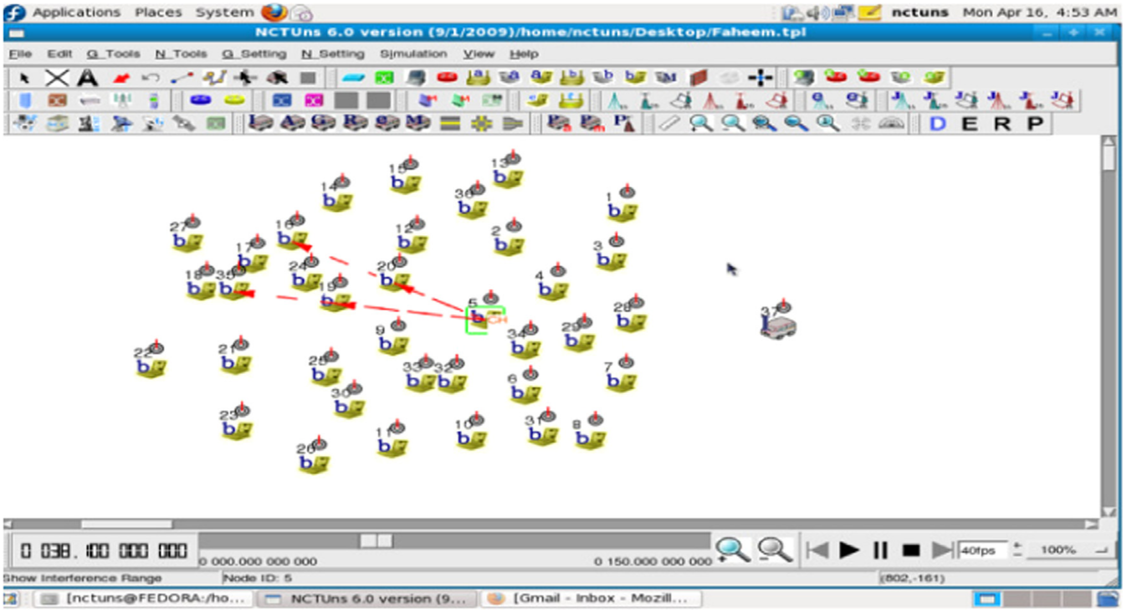

Fig. 5. Routing in ANRA.

Further to divide the entire network data traffic workload and to distribute energy consumption load evenly in the network over large network deployment a robust chain based fault tolerant routing is considered. In chain based routing, after receiving information each CH is responsible for immediately forwarding the up-keeping data to its nearer next hop nodes or CH based on its higher active node routing value calculated by Eq. (38) as shown in Fig. 5. To avoid a node or CH being appointed again and again after specific time interval node priority changes by taking into account Eqs. (3) and (14), and new nodes or CHs are selected to distribute the data traffic load with the least amount of energy consumption in the network.

$$\mathrm{ANRV}_{\mathrm{CH}_i \,\|\, S_{ni}} = \frac{RE_i}{\left(\sum_{i=1}^{n} (DS_{ni}^{2/4} \rightarrow S_{nj}) + (D\mathrm{CH}_i^{2/4} \rightarrow \mathrm{CH}_j)/D_{\max\, i}\right)^2} + \left(E\rho - \left(\frac{DE_i}{100}\right)\right)^2 \quad \forall_{SN} : \theta_{S_{ni} \rightarrow \mathrm{CH}_i \,\|\, S_{ni} \rightarrow S_{nj}} \tag{38}$$

where $DS_{ni}^{2/4} \rightarrow S_{nj}, DS_{ni}^{2/4} \rightarrow \mathrm{CH}_i$, and $DCH_i^{2/4} \rightarrow \mathrm{CH}_j$ indicates the minimum transmission distance between sensor node *i* and j, between sensor node i and cluster head *j*,and between cluster head i to cluster head *j*, respectively. While $\theta_{S_{ni} \rightarrow CH_i \,\|\, S_{ni} \rightarrow S_{nj}}$ is the angle between sensor node i to cluster head j or sensor node i to sensor node j.

To provide fault tolerant robust routing with minimum delay, we assume that each sensor node in ANRA is responsible for maintaining up to two hops routing information of its neighboring nodes and storing them with priority levels. The priority levels help to find the alternative sensor node to route information in case of a single route sensor nodes failure. Here, to identify the next hop sensor node failure is quite simple as each node after receiving information sends acknowledge message to its sender. If a sender does not receive this acknowledgement message in a specific time interval, then it considers it as a dead node and forwards its data packets to its neighboring node having second priority in the routing table. The proposed routing mechanism by taking into account priority level information provides robust routing with the least amount of control message overhead and end-to-end delay which has been verified by the obtained simulations result. To reduce communication energy cost in WSNs is extremely a challenging task. The energy consumption cost during conveying information toward sink is directly linked with transmission distance and number of hops count. Thus, the transmission energy cost can be reduced when the optimum communication distance and sum of hops can be correctly estimated. Suppose that $D\forall_{\mathrm{SN}}$ is the distance from the source nodes to CH_i and a single bit 1 size packet is sent by a source via *n* number of hops towards a CH_i then entire energy consumption numerically can be described as

$$\begin{aligned} E_T = E_{Tx}(l, d_i) &= \sum_{i=2}^{n} (E_{\mathrm{Tx-elec}}(l) + E_{\mathrm{Tx-amp}}(l, d) + E_{Rx}(l)) \\ &= (2n-1) l{*}E_{\mathrm{elec}}, + l{*}e_{\mathrm{mp}} \left(\sum_{i=1}^{n} d_i^2 \,\|\, \sum_{i=1}^{n} d_i^4 \right) \end{aligned} \tag{39}$$

The distance of the *j*th hop is d_j and *i*th hop is d_i thus total transmission energy consumption for sending a data packet from the source node to the cluster is given as

$$\text{For } d_1 + d_2 + d_3, \ldots, + d_n = D\forall_{SN} \quad \text{For } \sum_{i=1}^{n} d_i^4 \text{ else } \sum_{i=1}^{n} d_i^2 \tag{40}$$

Then above Eqs. (39) and (40) can also be written in the form of

$$E_n = (2n-1) l{*}E_{\mathrm{elec}}, + l{*}e_{\mathrm{mp}} \left(\sum_{i=1}^{n} d_i^2 \,\|\, \sum_{i=1}^{n} d_i^4 \right) / n^3 \tag{41}$$

when

$$E_n = 0 \,\|\, E_n^{]} = 2{*}l{*}E_{\mathrm{elec}}, - 3{*}l{*}e_{\mathrm{mp}} \left(\sum_{i=1}^{n} d_i^2 \,\|\, \sum_{i=1}^{n} d_i^4 \right) / n^4 \tag{42}$$

then

$$\sum_{i=1}^{n} = D\forall_{SN}$$

with the optimal number of hops can be numerically shown as

$$\partial_{\mathrm{opt}} = \sqrt[D\forall SN]{2{*}E_{\mathrm{elec}}/3{*}e_{\mathrm{mp}}} \tag{43}$$

The obtained optimal transmission distance numerically can be written as

$$D_{\mathrm{opt}} = D\forall_N / \partial_{\mathrm{opt}} = \sqrt[4\|2]{2{*}E_{\mathrm{elec}}/3{*}e_{\mathrm{mp}}} \tag{44}$$

The targeted information moves through the collaboration of sensor nodes in the form of minimum spanning tree. Let assume that S_{n_i} are the number of sensor nodes of the tree, S_m is the message size and in case of a large cluster size $\mathrm{ST}_{\mathrm{sub-tree}}$(cost) is the sub-tree data collection cost that can be determined as

$$\mathrm{ST}_{(\mathrm{sub-tree})\mathrm{cost}} = \int_{n_i \int ST_{\mathrm{sub-tree}}}^{\cdot} .(S_m(E_{CH_i}))dt + \int_{n_i \int ST_{\mathrm{sub-tree}}}^{\cdot} .(S_m(E_{N_i = E_{NCH} - CH_i}))dt \tag{45}$$

$$\begin{aligned} ST_{(\mathrm{sub-tree})\mathrm{cost}} = &\int_{n_i \int ST_{\mathrm{sub-tree}}}^{\cdot} .(S_m(E_{\mathrm{Tx-elec}}(l) + (S_{n_i}/C_{n_i}) - 1) \\ &+ E_{\mathrm{DA}}(S_{n_i}/C_{n_i}\ ) + E_{\mathrm{Tx-amp}}(l, d_{Bs}^4) + E_{\mathrm{Tx-amp}}(l, d_{\mathrm{CH}_i}^2))dt \\ &+ \int_{n_i \int ST_{\mathrm{sub-tree}}}^{\cdot} .(S_m(E_{\mathrm{Tx-elec}}(l) + E_{\mathrm{Tx-amp}}(l, d_{\mathrm{CH}_i}^2)))dt \end{aligned} \tag{46}$$

The data gathering cost of sub-tree is divided into two basic segments, first transmission energy loss due to sending data packets and second energy loss while receiving data packets. The energy loss of the sensor nodes in the minimum spanning tree is represented by $\mathrm{T}_{\mathrm{tree\ (cost)}}$. In case of multiple clusters minimum cost can be calculated as

$$T_{\mathrm{tree\ (cost)}} = \int_{e_i \int T_{\mathrm{tree}}}^{\cdot} .(\delta_m(E_{\mathrm{CH}_i}))dt + \int_{e_i \int T_{\mathrm{tree}}}^{\cdot} .(\delta_m(E_{N_i = E_{\mathrm{NCH}} - \mathrm{CH}_i}))dt \tag{47}$$

$$\begin{aligned} T_{\mathrm{tree\ (cost)}} = &\int_{e_i \int T_E}^{\cdot} .\delta_m(E_{\mathrm{Tx-elec}}(l) + (S_{n_i}/C_{n_i}) - 1) + E_{DA}(S_{n_i}/C_{n_i}) \\ &+ E_{\mathrm{Tx-amp}}\left(l, d_{Bs}^4\right) + E_{\mathrm{Tx-amp}}\left(l, d_{\mathrm{CH}_i}^2\right) dt \\ &+ \int_{e_i \int T_{\mathrm{tree}}}^{\cdot} .(\delta_m(E_{\mathrm{Tx-elec}}(l) + E_{\mathrm{Tx-amp}}\left(l, d_{\mathrm{CH}_i}^2\right) dt \end{aligned} \tag{48}$$

Thus, the total sensing routing cost of clustered network can be represented as

$$E_{\mathrm{Total\ (CHs)}} = ST_{(\mathrm{sub-tree})\mathrm{cost}} + T_{\mathrm{tree\ (cost)}} \tag{49}$$

If there are n numbers of clusters then each cluster sensing cost can be written as

$$E_{\text{Total (CLUSTERS)}} = \sum_{i=1}^{n} (E^{n}_{\text{Total (CH)}i} + E^{n}_{\text{Total (CH)}i+1} + \ldots + E^{n}_{\text{Total (CH)}n}) \quad (50)$$

The transmission distance of each sensor node i to j and then j to the cluster head in a chain can be represented as a sum of distance of all

$$\text{Chain}_i = \sum_{i=1}^{n} S^{i}_{ni} + \text{CH}^{i}_{ni} \quad (51)$$

Thus, the sum of the total number of chains involved in data routing in the entire large network deployment can be described as

$$T_{\text{chain}} = \sum_{i=1}^{n} \text{Chain}^{1}_{i} + \text{Chain}^{2}_{i+1} + \ldots + \text{Chain}^{n}_{n} \quad (52)$$

The total energy consumption in chain network during convening information can be denoted as

$$E_{\text{Total (CHAIN)}} = \sum_{i=1}^{n} E(\text{chain}^{1}_{i} + \text{Chain}^{2}_{i+1} + \ldots + \text{Chain}^{n}_{n}) \quad (53)$$

Thus, total routing energy consumption in the network can be numerically indicated as

$$E_{\text{Total}} = \sum_{i=1}^{n} (E^{n}_{T(\text{ClUSTER})i} + E^{n}_{\text{Total (CHAIN)}i}) \quad (54)$$

where n is round number.

Pseudo-code for ANRA

4. Network model

In this section, we present a network model as an undirected graph G (U,E,R), where G is weight, U is the set of all sensor nodes denoted by $U=\{n_1, n_2,\ldots, n_n\}$, E represents the set of all connected edges among the nodes and R indicates range in meters. The distance among sensor node k and l can be denoted as $k \in l$, $\delta(k,l) \le \delta_{\text{th}}$, where δ_{th} represents defined distance threshold. To obtain cooperative sampling of the two-dimensional scenario, a set of sensor nodes and a base station with multiple sinks are randomly deployed without isolation. The entire network is divided into several sectors where each sector represents an individual set of clusters (i.e., near to sink, middle and near to sensing region). To perform experiments in realistic scenario we take into account several assumptions. First, after deployment all sensor nodes and multiple sinks are unable to change their position and can only communicate with each other if they are in range. Second, all sensor nodes and sinks know their position, which can be obtained by taking into account localization scheme discussed in (Stoleru et al., 2012). Third, all randomly deployed sensor nodes have the same capability in terms of initial energy and transmission ranges and CHs one hop or two hops near to the sinks can directly communicate with each other's. Forth, to provide node to its neighbor's connectivity omnidirectional model is considered here, i.e., 360° or $R=\pi r^2$. Fifth, unlike existing simulation studies, asymmetric model is assumed, i.e., sensor node A is located within the transmission range of sensor B but B may be or may not be located within the transmission range of node A. Note that this assumption is highly depends on deployment environment and can be changed as per requirement. Finally, we assumed that at any given time at least one-route exits to the base station via a sink and deployed sinks are rich in resources. In addition, unlike most existing work to test routing protocols in a more realistic scenario, we adopt the medium access (MAC) layer scheme presented in (Hefeida et al., 2013) (Fig. 6).

4.1. Simulation model

Performance evaluations of this study were realized using NCTUNs6.0 (Wang and Huang 2012). The performance evaluations consist of 50 sets of simulations. All sensor nodes in a cluster have to carry out sensing tasks and immediately needed to forward sensed data to CH. In every 39 second, each sensor node measures its position broadcasts the measured information to its one-hop to two-hop neighbors. Furthermore, in every 33 second, each node reports the sensed data to the sink. Note that, for a given scenario data reporting time can be different and is based on the network complexity. The network model is based on IEEE802.11b standard where maximum data rate was set to 250 kpbs. The transmission range of each sensor node was set to 60 – 70 m. Throughout the simulations, a network size of 500 m in 2D(M × M) was considered. Total number of randomly deployed sensor nodes were 200 with their different lengths and the receiving power, ideal listening, and sleeping power were set to 0.035 W, 0.024 W and 3×10^{-6} W, respectively. Furthermore, we divided entire transmission power consumption into two basic parts, low and high energy consumption and parameter values are set 0.103 W and 0.063 W, respectively. In addition, the initial energy and packet length were set to 2.5 Joule and 32 bytes, respectively.

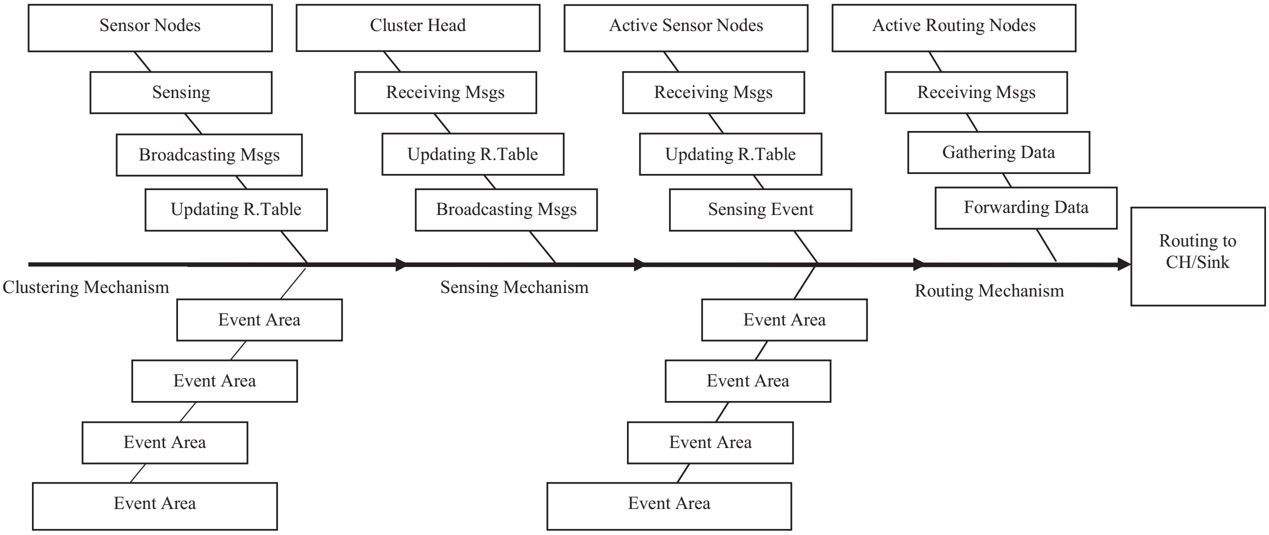

Fig. 6. ANCF, ANSA and ANRA in EDHRP.

5. Performance analysis

In this section, we first present the results and then analyze them in detail in terms of different network performance metrics in the following subsections.

5.1. Energy consumption and transmission distance

In the most of the scenarios, it is observed that network stability is directly proportional to the network energy consumption. A sensor network evolves sensor nodes with minimum energy consumption is considered as highly stable than the network with high energy consumption and can be numerically described as

$$N_{\text{Stability}}\,\alpha\,SN_{EC}\,||\,N_{EC} \tag{55}$$

Our experimental studies reveal that total network energy consumption in all the routing schemes is directly associated with the total number of rounds and sensor nodes involved in the network, respectively. Also, it is observed that the energy consumption increases with the increase in round numbers due to new sensor nodes involving in the network. However, after a specific time interval, the network consumes more energy when sensor nodes start to die in the network. It is shown in Fig. 7, in the beginning between round numbers 1 and 200 all routing schemes overlap each other's and try to achieve a minimum level of energy consumption during network setup by involving new number of sensor nodes in each round in the network. In the beginning, the performance of CREEC is witnessed significant than EEDCP-TB, BATR, PEGASIS and LEACH routing schemes to achieve a minimum level of energy consumption by taking into account new sensor nodes in the network which is found relatively slower in EEDCP-TB and LEACH till round numbers 200. However, with the passage of time when round numbers are increased between 300 and 500, BATR, PEGASIS and LEACH lose their stability and fail to maintain their minimum level of energy consumption which is found slower in CREEC and EEDCP-TB routing schemes. In the meanwhile between round numbers 1 and 200 and then from 300 to 500, the performance of EDHRP is observed remarkable in term of achieving a minimum level of energy consumption than all other routing schemes and sometimes overlaps with CREEC between round numbers 350 – 470. Here it is viewed that the superior performance of EDHRP is due to its aptitude of adoptability and well management of new sensor nodes in the large and dense network deployment. Furthermore, between round numbers 600 and 800 as shown in Fig. 8, the stability period of maintaining a minimum energy consumption level of LEACH and PEGASIS rapidly decreases compared to all other routing schemes. However, between round numbers 800 – 900, the stability period of PEGASIS for consuming least of energy is seen more remarkable than EEDCP-TB and LEACH routing schemes. In addition, with the passage of time when the round numbers are increased between 1000 and 1350 as shown in Fig. 9, the performance of CREEC to

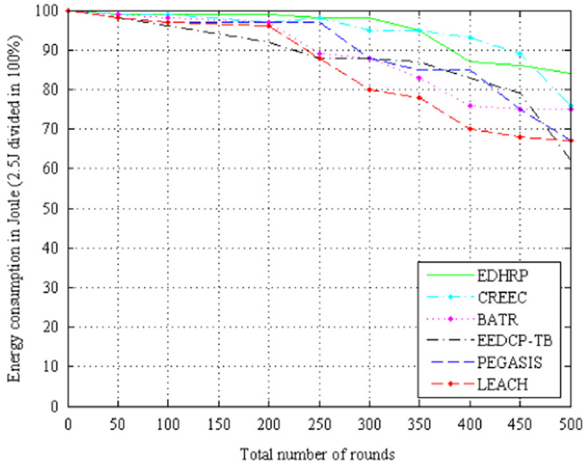

Fig. 7. Energy consumption vs total number of rounds between 1 and 500.

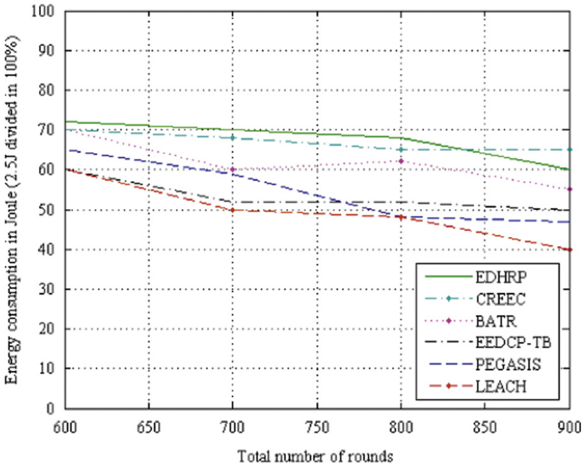

Fig. 8. Energy consumption vs total number of between 600 and 900.

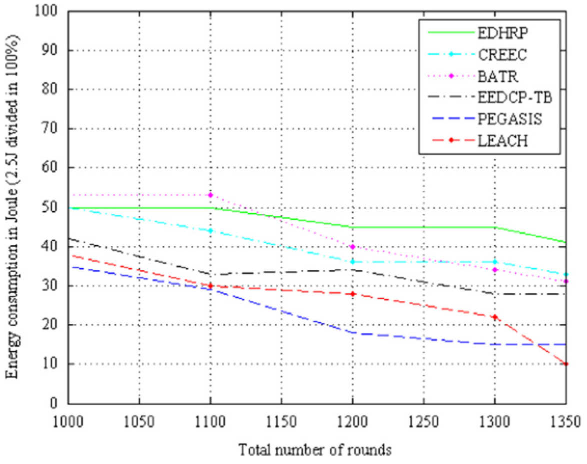

Fig. 9. Energy consumption vs total number of rounds between between 1000 and 1350.

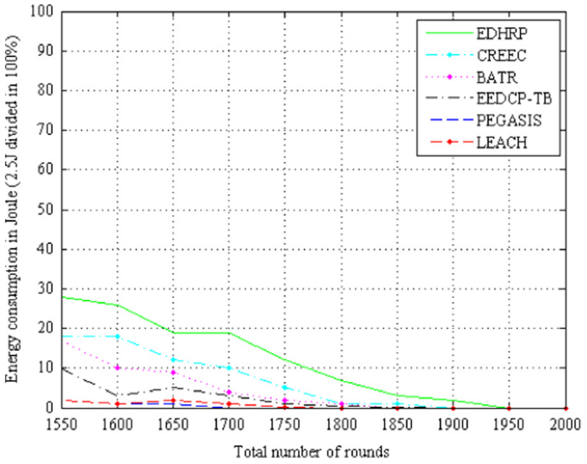

Fig.10. Energy consumption vs total number of rounds 1550 – 2000.

keep up the minimum level of energy consumption rapidly decreases due to increase in network stability issues which is found superior in EDHRP, BATR and EEDCP-TB than PEGASIS and LEACH routing schemes. Moreover, between round numbers 1550 and 2000, when nodes start to die in the network, the energy consumption profile of EDHRP is remarkable by keeping its graph level up than all other routing schemes in the densely deployed network as shown in Fig. 10. This high performance of EDHRP is due to its well management and adoptability to rapidly died sensor nodes in the work which is observed more poor in LEACH and PEGASIS than all other routing schemes. The overall performance of EDHRP in the beginning, middle and ending level of the simulations is more remarkable than all other routing schemes towards adopting and well management capabilities to new and died sensor nodes in the network. Here we noticed a number reason of high energy consumption in all routing schemes. A detail view of the energy consumption profile between all routing schemes is given in Tables 1, 2 and 3, respectively.

First, one of the main reasons which consume more node energy in all routing schemesis theexcessive long distance message

Table 1
Energy consumption profile of various routing schemes in terms of their first node died (FND), last node died (LND) and total number of rounds achieved.

Energy (2.5 J) consumption in 100%	Protocol name											
	EDHRP		CREEC		BATR		EEDCP-TB		PEGASIS		LEACH	
	FND	LND	FND	LND	FND	LND	FND	LND	FND	LND	FND	LND
10	148	240	140	205	140	240	130	234	140	200	118	190
20	340	435	335	480	310	460	340	484	290	370	260	350
30	528	640	600	760	540	595	570	669	480	580	400	480
40	718	850	812	880	688	790	778	928	650	730	550	690
50	901	1119	914	975	894	960	1043	1113	890	950	820	920
60	1222	1385	1080	1190	1090	1240	1212	1293	1170	1250	1030	1100
70	1494	1584	1330	1460	1340	1430	1390	1480	1370	1430	1240	1310
80	1601	1690	1585	1670	1490	1580	1590	1660	1490	1525	1370	1425
90	1790	1850	1740	1840	1688	1760	1710	1750	1640	1695	1540	1600
100	1920	1950	1860	1880	1835	1850	1800	1820	1720	1760	1625	1690
$Total_{\text{rounds.}}$	1950		1880		1850		1820		1760		1690	

Table 2
Energy consumption profile of vaious routing schemes between round numbers 1 to1000.

Round number	Protocol name					
	EDHRP Energy consumption	CREEC Energy consumption	BATR Energy consumption	EEDCP-TB Energy consumption	PEGASIS Energy consumption	LEACH Energy consumption
100	5.4812	5.7235	5.3571	4.4763	4.1733	4.1233
200	4.8722	5.0984	4.7320	4.7731	4.3761	5.1761
300	4.0457	5.4576	4.4841	5.3420	5.6470	5.8176
400	5.3343	4.9987	5.6329	5.4329	5.4359	5.4351
500	5.2758	4.8794	5.2799	5.2299	5.4499	5.1491
600	4.6341	5.5567	5.8337	5.8951	5.8951	6.1955
700	4.3893	5.3474	4.7434	6.9834	6.9834	6.1832
800	5.4330	5.3425	5.8831	5.8971	5.1973	6.1473
900	5.1310	5.3565	5.9432	5.9432	6.9331	6.4737
1000	5.4534	5.6763	6.8751	5.7916	6.7716	7.1111
$Energy_{avg.}$	50.0500	53.4370	54.7645	55.7646	56.8627	57.8120

Table 3
Energy consumption profile of vaious routing schemes between round numbers 1001 to 2000.

Round number	Protocol name					
	EDHRP Energy consumption	CREEC Energy consumption	BATR Energy consumption	EEDCP-TB Energy consumption	PEGASIS Energy consumption	LEACH Energy consumption
1100	4.4812	5.1481	5.0040	4.1240	5.1249	7.4241
1200	5.2722	5.0981	4.2101	5.2120	6.1129	6.1126
1300	4.0457	6.1328	5.4421	4.1111	5.3912	7.3311
1400	5.3343	6.0243	5.3325	5.4223	6.1529	7.1105
1500	6.2758	6.0292	6.0213	6.1221	6.2421	7.0103
1600	6.1341	5.0110	6.2111	6.0001	7.0051	7.0631
1700	5.3113	6.1023	7.0023	6.2023	7.1061	–
1800	6.5123	7.0172	6.1121	7.0415	–	–
1900	6.5831	–	–	–	–	–
2000	–	–	–	–	–	–
$Energy_{avg.}$	49.9500	46.5630	45.2355	44.2354	43.1373	42.1880
$Energy_{Total}$	2.5 J in 100%	2.5 J in 100%	2.5 J in 100%	2.5 J in 100%	2.5 J in 100%	2.5 J in 100%

transmission in the dense deployed network. Fig. 11 shows that the routing schemes ability to find the next hop node with minimum transmission distance is highly related to the number of sensor nodes deployed in the network. In the beginning when network size is small between 1 and 100 sensor nodes, the performance of all routing schemes to find next hop node is rapidly decreasing as shown in Fig. 12. In the beginning when the least amount of sensor nodes are involved in the network, ability to find the next hop node with minimum transmission distance is observed little better in CREEC and EEDCP-TB than BATR, PEGASIS and LEACH routing schemes. However, with the passage of time when new sensor nodes are added to the system between 120 and 200, the performance of CREEC, EEDCP-TB and BATR become better than BATR, PEGASIS and LEACH routing schemes as shown in Fig. 13. On the other hand, the performance of EDHRP is witnessed excellent to find the next hop node with minimum transmission distance in both small and large size densely deployed network by keeping its graph level up than all routing schemes. Here, it is noticed that this message transmission over long distance most of the time in CREEC, EEDCP-TB, BATR, PEGASIS and LEACH routing schemes is due to their lack of an appropriate mechanism to find the next hop node with minimum transmission distance appropriately. Since CREEC and BATR consider next hop node with the least amount of transmission distance cost, however their performance ability to dense deployed network is limited and most of the time fail to attain the goal of minimum transmission distance. In addition to the fact that after a specific time interval when sensor nodes start to die in the network, the algorithms employed by CREEC, EEDCP-TB and BATR routing schemes are unable to appoint next hop nodes with minimum transmission distance because of the high network instability issues. In a situation when all routing schemes are suffering from high network instability issues, the performance of our proposed scheme is remarkable in term of appointing next hop nodes with minimum transmission distance. In EDHRP, ANRA plays an important role towards scalability and provides robust optimal or near optimal solutions to appoint next hop node with the least amount of transmission distance to reduce high transmission energy consumption cost.

5.2. *Data redundancy and congestion management*

The other main source of energy consumption in all routing schemes is their high data redundancy generation in the network. As shown in Fig. 14, in all routing schemes data redundancy is directly proportional to the number of overlapping sensor nodes involved to witness an event which numerically can be defined as

$$D_R \propto SN_{OLR} \tag{56}$$

A network with the least amount of active sensor nodes with satisfy coverage has to face a small amount of data redundancy compared to the large number of active nodes because of their high overlapping regions. A huge amount of redundant information also affects the node over-assignment cost during forwarding information. Since a node is equipped with limited buffering memory capacity, if not utilizes effectively network has to face excessive data retransmission issues due to buffer overflow caused by redundant information, e.g. If a node wants to forward its watched information to its neighboring node, which is already busy in processing some of its local information received from another neighboring node. In this situation, if a sender node will not consider this receiving node over-assignment cost and send its watched information directly to receiver node, then receiving node has to face the problem of memory overflow due to the huge amount of redundant information, which results in excessive message retransmission due to data packets dropped/loss. This message retransmission is proportional to the network size and deployment topology policies. Fig. 14, make it clear that data redundancy in CREEC, BATR, EEDCP-TB, PEGASIS and LEACH routing schemeis very challenging issues is due to participation of huge number of active sensor nodes for sensing tasks in dense deployment. In our proposed scheme, ANSA plays an important role to reduce high overlapping data redundancy by appointing least amount of active sensor nodes in each cluster with satisfying coverage to watch an event. Total number of active sensor nodes appointed in each cluster in ANSA formally can be expressed as

$$\mathrm{DR}_{\mathrm{ANSA}} = \sum_{SN=1}^{N} \mathrm{DR}_{\mathrm{NS-SLN}=\mathrm{AN}}^{\mathrm{cluster}(i)} \tag{57}$$

where SLN indicates the number of sensor nodes in sleeping mode and AN shows the number of active sensor nodes to watch the phenomenon in cluster *i*.

Furthermore, this huge amount of redundant data generated in the network raises the congestion management issues which deteriorates data quality and further leads to data packet loss in the network. Since a node is equipped with limited buffering memory capacity, if not utilizes effectively network has to face excessive energy consumption issues in term of data retransmission due to buffer overflow and congestion management issues. As shown in Fig. 15, all routing schemes try to achieve their maximum level of congestion management between sensor nodes 1 and 200. In the beginning when sensor node deployment density is between 20 and 100 as shown in Fig. 16, the performance of the LEACH and PEGASIS is found poorer than all other routing schemes while EEDCP-TB overlaps some regions of LEACH and PEGASIS when node density is between 72 and 100. In the mean while, the performance of EDHRP is found more robust in term of congestion management than all other routing schemes while BATR and CREEC overlap each other's in some regions to get better stability in congestion management.

As shown in Fig. 17, when node density increases between 100 and 200, the performance of all routing schemes for congestion management is rapidly decreasing. Here the most rapid decrease is observed in LEACH and PEGASIS routing schemes than others. However, in term of congestion management the performance of EDHRP is observed more superior than all other routing schemes in the network when network density is very high in large network deployment. To manage congestion issues in EDHRP, ANCF, ANSA and ANRA routing algorithms play important role to handle entire network traffic and energy consumption load evenly in the network in distributive manner. Thus the entire network traffic is conveyed through multiple data paths by taking into account the link quality among sensor nodes in the network, which leads to the least amount of congestion management issues in EDHRP compared to other routing schemes.

5.3. *Delay and setup robustness*

Delay is another factor affecting entire network performance and in our scheme numerically it can be defined as

$$T_{\mathrm{avg}}^{P_i} = TDP_{Sn_i}^{\mathrm{Source}} + T\sum_{i=1}^{n} RDP + TDP_{Sn_i}^{\mathrm{Sink}} \tag{58}$$

where $T_{\mathrm{avg}}^{P_i}$ is the average time to send a data packet/request can be measured as the sum of $TDP_{Sn_i}^{\mathrm{Source}}$ is the time when a source generates data packets, $T\Sigma_{i=1}^{n} RDP$ is the time taken by relaying data packets and $TDP_{Sn_i}^{\mathrm{Sink}}$ is the time when data packets reached successfully at the sink. Fig. 18 shows that the delay increases with the increase in number of sensor nodes in the network from 1 to 200 and then after reaching at steady state it starts to increase more rapidly due to increase in the number of sensor nodes died in the network. In the beginning, when network size is small between sensor nodes 25 and 100 as shown in Fig. 19, CREEC, BATR, EEDCP-TB, PEGASIS and LEACH routing schemes overlap each other's and try to achieve the level of

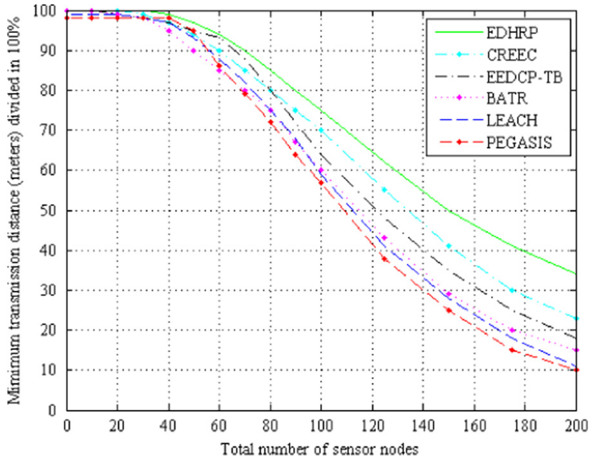

Fig. 11. Minimum transmission distance vs total number of sensor nodes between 1 and 200.

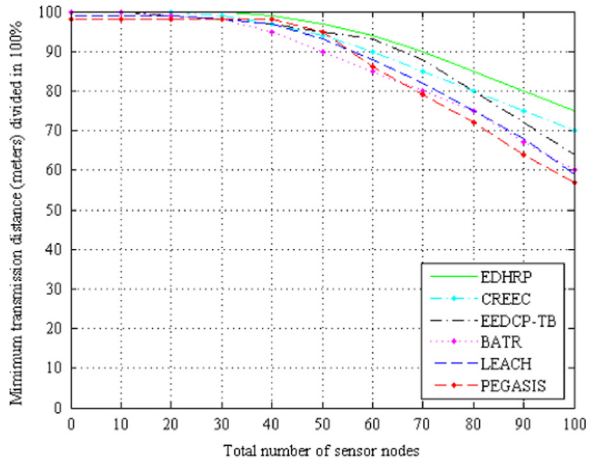

Fig. 12. Minimum transmission distance vs total number of sensor nodes between 1 and 100.

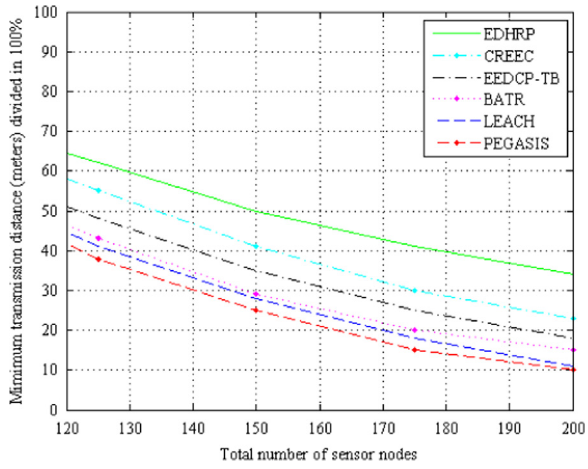

Fig. 13. Minimum transmission distance vs total number of sensor nodes between 120 and 200.

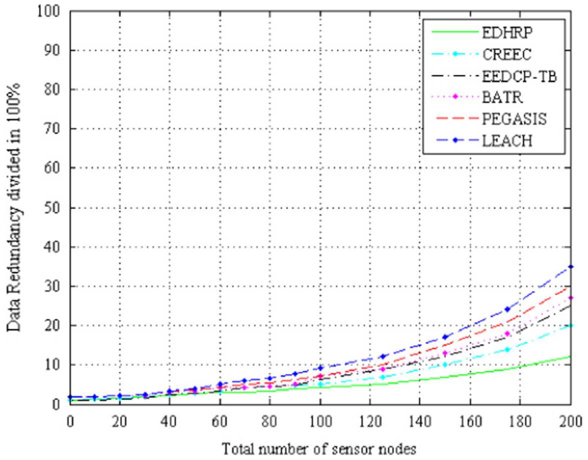

Fig. 14. Data redundancy vs total number of sensor nodes between 1 and 200.

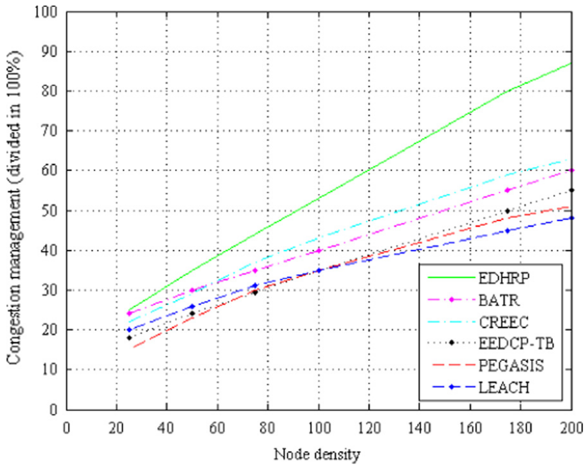

Fig. 15. Congestion management vs node density between 1 and 200.

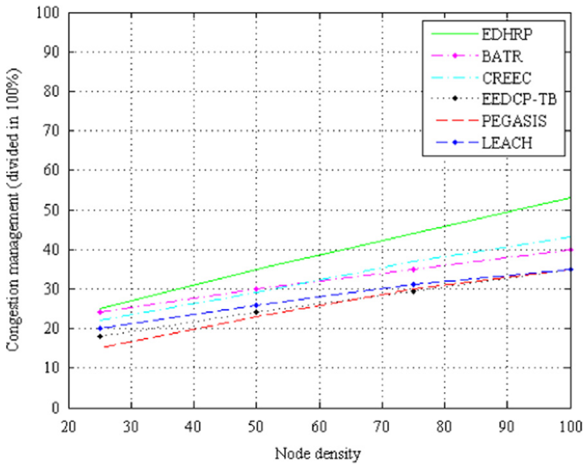

Fig. 16. Congestion management vs node density between 20 and 100.

minimum delay during involving new sensor nodes in the network. In the beginning, the performance of the EEDCP-TB is more outstanding than BATR to achieve a minimum level of E2E delay by taking into account new sensor nodes in the network, which is found relatively higher in the EEDCP-TB, PEGASIS and LEACH routing protocols. However, with the passage of time when the network size grows up between sensor nodes 100 and 200 as shown in Fig. 20, the level of minimum delay of BATR becomes better than EEDCP-TB because of forwarding data packets through different paths in term of a route node failure. In the meanwhile the performance of the CREEC is observed better in term of achieving a minimum delay level than all other routing schemes except EDHRP as shown in Fig. 20. Here, it is realized that for small or large size dense network deployment, the performance of EDHRP in term of achieving a minimum level of delay is remarkable by keeping its graphs at minimum delay level than all

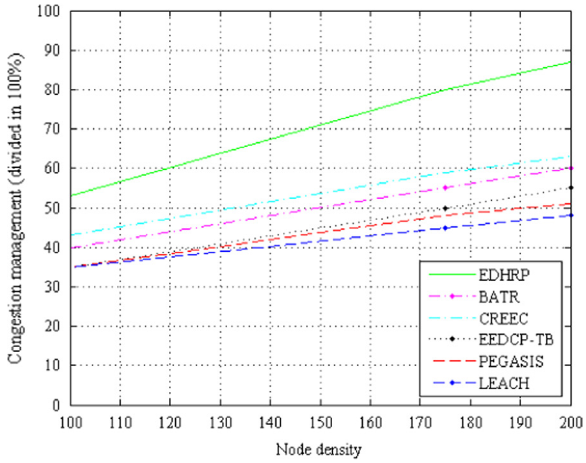

Fig. 17. Congestion management vs node density between 100 and 200.

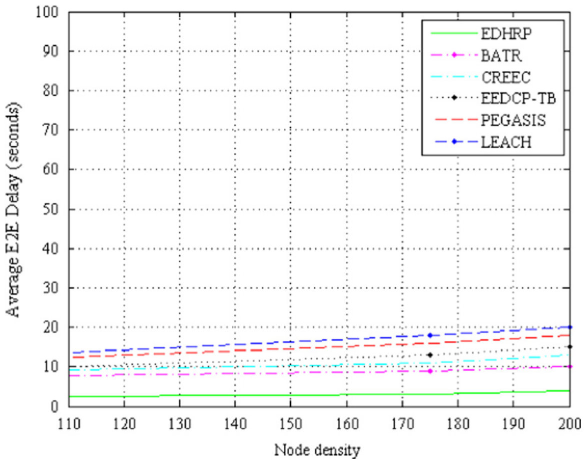

Fig. 20. Average E2E delay vs node density between 100 and 200.

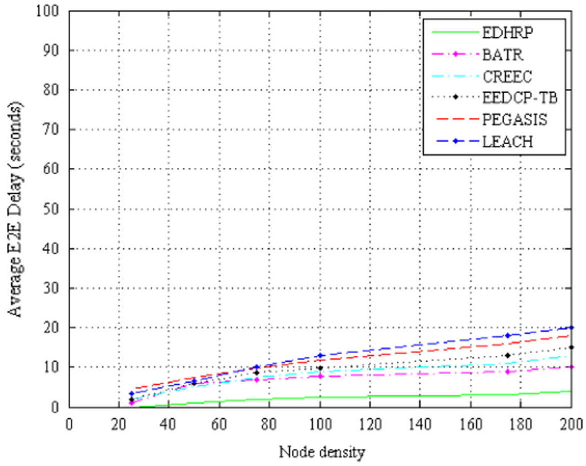

Fig. 18. Average E2E delay vs node density between 1 and 200.

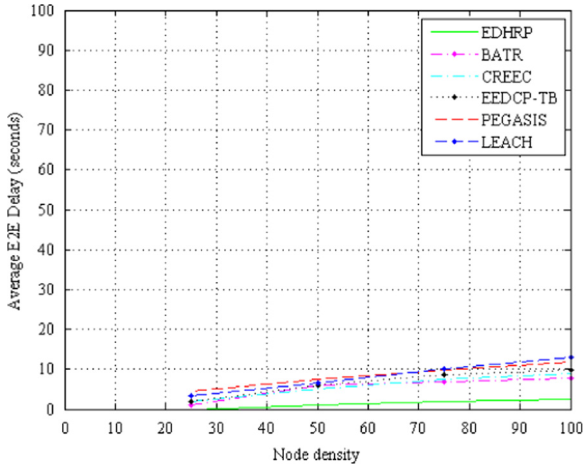

Fig. 19. Average E2E delay vs node density between 25 to 100.

other routing schemes as shown in Figs. 18–20, respectively. One of the main reasons, which causes more delay in CREEC, BATR, EEDCP-TB, PEGASIS and LEACH routing schemes is their routing table cost in terms of updating and route finding. Furthermore, link reliability also plays an important role in minimizing network delay which saves valuable amount of time during finding new data paths. One of the main reasons of increasing delay in LEACH and PEGASIS is their certain amount of holding time, which is based on the depth difference between a sending and a receiving node. In both routing schemes, when a node received a data packet from its neighbors, first it calculates the next hop node distance level by taking into account the threshold value and if the calculated value of a node is higher than threshold value then it routes the data packet. However, most of the time it is noticed that while routing data packets both scheme do not take into account the node distance level appropriately and spend a notable amount of time to perform a number of calculations. Therefore, at each hop data packets are received and hold for a significant amount of time. The major issue which increases delay in CREEC is its number of calculations to establish a data path in term of a single path node failure and most of the time it fails to find an appropriate next hop node in the routing chain to convey robust information which leads to high E2E delay in the network. The other main of increasing delay in EEDCP-TB routing scheme is its deliberated algorithm which holds information while finding an appropriate next hop sensor node to convey robust data delivery at the second level hierarchy. However, this holding is considered as the minimum than BATR. In terms of achieving minimum delay level graphs, BATR utilizes its alternative data paths finding technique to route information in term of route failure. However, still BATR faces a significant amount of delay due to its making decision for finding next hop node to convey robust information in term of a single route node failure over dense deployment. Furthermore, in CREEC, BATR, EEDCP-TB, PEGASIS and LEACH routing schemes unnecessary multi-hop data packet transmissions also increases the network E2E delay.

In terms of achieving a minimum delay level in EDHRP, ANRA plays an important role towards higher link reliability among nodes and CHs with the least expense of managing routing table cost to convey robust information from the source to destination. Since each sensor node in ANRA is responsible to maintain two hop neighbor node information with increasing priority which helps it to find next hop node in an effective and robust manner to convey data packets. In a case when a single route node fails to deliver robust information, the sender waits for a specific amount of time if it does not receive any acknowledgement message from its receiver node, it forwards its information to the next hop node which has a second priority level in the routing table. Thus, the network has to face the minimum network delay problem in dense network deployment.

Setup robustness is directly linked to number of sensor nodes involved in the system and can be numerically defined as

$$S_{RB} \in SN \tag{59}$$

As shown in Fig. 21 setup robustness in all routing schemes increases linearly when the system includes sensor nodes between

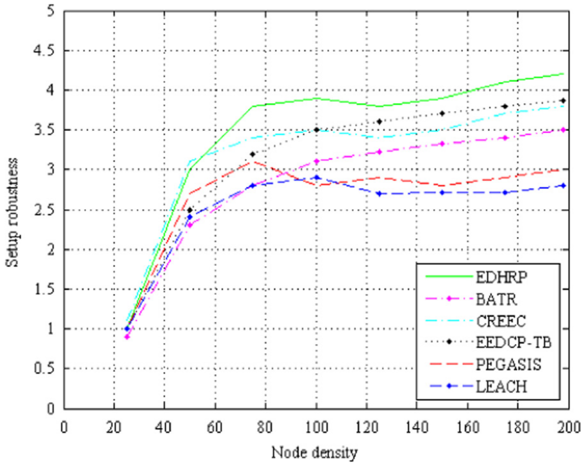

Fig. 21. Setup robustness vs node density between 1 and 200.

20 and 50. In the beginning when network density is small, the performance of CREEC is observed better than BATR, EEDCP-TB, PEGASIS and LEACH routing schemes where PEGASIS outperforms LEACH, BATR and EEDCP-TB. However, with the passage of time when node density increases between 80 and 200, all routing schemes try to keep their maximum level of setup robustness. At the moment it is observed that LEACH rapidly loss its robustness level even fails to maintain its robustness stability compared to PEGASIS. The CREEC after reaching its maximum level of setup robustness loses its stability more rapidly and performs poorer than EDHRP and EEDCP-TB routing schemes. Here it is detected that the better performance of EEDCP-TB is due to its embedded lightweight algorithm which adopts new sensor nodes rapidly in the system with the expense of delay and high energy consumption among sensor nodes. The overall setup robustness performance of EDHRP in term of low or high density network is found more robust than all routing schemes. In EDHRP, the implementations of light weight algorithms ANCF, ANSA and ANRA play important roles to adopt a new number of sensor nodes in the system in more a robust manner due to their design flexibility of memorizing information at each stage. In EDHRP total number of control message overheads required to setup a robust network formally can be described as

$$\mathrm{OH}_{\mathrm{EDHRP}} = \sum_{SN=1}^{N} \mathrm{OH}_{\mathrm{NS-SLN=AN}}^{\mathrm{cluster}(i)} \tag{60}$$

while for the robust network setup, least amount of sensor nodes are required can be numerically shown as

$$\mathrm{SR}_{\mathrm{EDHRP}} = \sum_{SN=1}^{N} \mathrm{SR}_{\mathrm{NS-SLN=AN}}^{\mathrm{cluster}(i)} \tag{61}$$

As unnecessary multi-hop data packet transmission also increases the network end-to-end delay and reduce the energy consumption, so, the least amount of sensor nodes involved in packets transmissions from the sensing region toward sink can be formally expressed as

$$\mathrm{MHDT}_{\mathrm{EDHRP}} = \sum_{SN=1}^{N} D_{\mathrm{NS-SLN=ANR}}^{\mathrm{cluster}(i)} \tag{62}$$

where ANR indicates the number of sensor nodes involved in routing to convey robust information toward the sink.

Network lifetime can be formally defined as

$$\mathrm{NLT} \in \mathrm{SN}_{\mathrm{alive}} \tag{63}$$

Furthermore, network life also depends on the network energy can be numerically indicated as

$$\mathrm{NLT} \in \mathrm{ESN}_{\mathrm{alive}} \tag{64}$$

where NLT denotes network lifetime, $\mathrm{SN}_{\mathrm{alive}}$ indicates number of sensor nodes alive in the system and $\mathrm{ESN}_{\mathrm{alive}}$ is the energy level of the sensor nodes in the deployed network.

5.4. Network lifetime

In our experiments, we viewed that CREEC performs better in term of network lifetime by consumption least amount of energy, however still like PEGASIS, BATR and EEDCP-TB, it is facing unnecessary multi-hop long distance data packet transmission issues. Furthermore, in most cases where the network is deployed densely, CREEC fails to maintain its stability period and selects next hop nodes having the least amount of residual energy, thus link reliability becomes a major challenging issue strongly needed to be solved to improve network lifetime performance. Like CREEC in BATR, EEDCP-TB, PEGASIS and LEACH routing schemes, one of the main reasons of decreasing network lifetime more rapidly is due to their unreliable link quality and long distance communication among sensor nodes which further leads to congestion and delay management issues in the network. Figs. 22 and 23 make it clear that EDHRP outperforms all other routing schemes in term to achieve higher network lifetime in the dense deployed network by keeping a number of sensor nodes alive in the network than all other routing schemes. In EDHRP, stable link

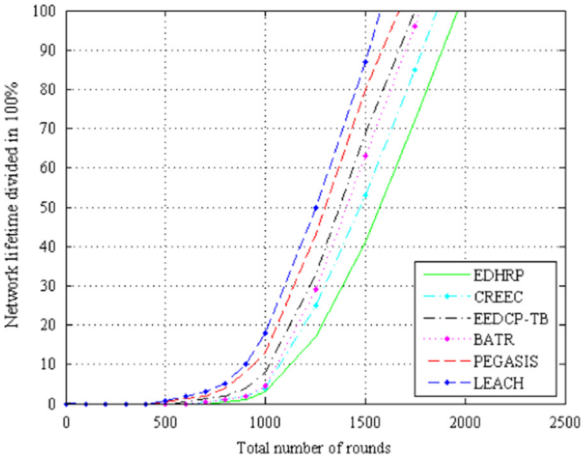

Fig. 22. Network lifetime vs total number of rounds between 1 and 2000.

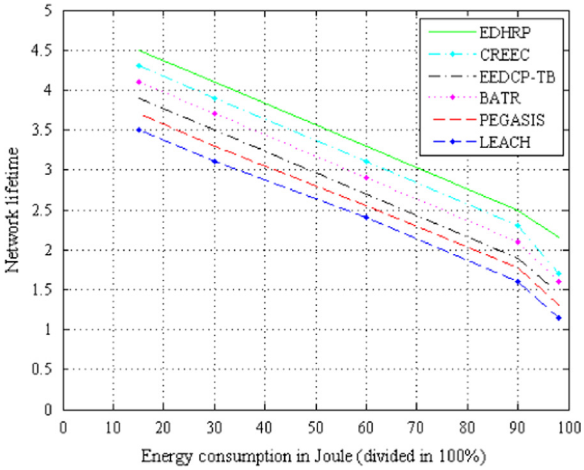

Fig. 23. Network lifetime vs energy consumption in joule between 1% and 100%.

reliability among sensor nodes plays an important role in maximizing network lifetime by minimizing overall network energy consumption. For achieving superior network lifetime profile in EDHRP, ANCF and ANRA play important roles by providing a robust and reliable clustering architecture. In ANSA and ANRA link quality is measured by a cost effective check mechanism based on the minimum distance between each set of node pair. In EDHRP, ANSA is responsible to increase the network lifetime by distributing energy load evenly in the cluster network by appointing least amount of sensor nodes as active node with satisfy network coverage for close sensing by considering node residual energy and minimum transmission distance among sensor nodes and CHs. Furthermore, in EDHRP to distribute energy load evenly in the entire network, ANRA plays an important role towards higher link reliability among CHs with the least expense of managing routing table cost to convey robust information from the sensing region to destination. After receiving information each cluster head looks into its own routing table and select the next hop with the minimum transmission distance with high residual energy. In term of a route failure, routing table helps ANRA to find a next hop node with second higher priority to avoid further delay and energy consumption which ultimately affect in an increasing network lifetime. Furthermore, a details comparison of the network lifetime among all routing schemes in terms of first node died, last node died and total number of rounds is given in detail n Table 4.

Table 4
Network lifetime comparison between various routing schemes in terms of first node died (FND), last node died (LND) and total number of rounds (R.No's).

Protocol name	First node died vs last node died vs round numbers				
EDHRP	CREEC FND = LND > R. No's >	BATR FND > LND > R. No's >	EEDCP-TB FND > LND > R. No's >	PEGASIS FND > LND > R. No's >	LEACH FND > LND > R. No's >
CREEC	EDHSR FND = LND < R. No's <	BATR FND = LND > R. No's >	EEDCP-TB FND > LND > R. No's >	PEGASIS FND = LND > R. No's >	LEACH FND > LND > R. No's >
BATR	EDHSR FND < LND < R. No's <	CREEC FND = LND < R. No's <	EEDCP-TB FND > LND > R. No's >	PEGASIS FND = LND > R. No's >	LEACH FND > LND > R. No's >
EEDCP-TB	EDHSR FND < LND < R. No's <	CREEC FND < LND < R. No's <	BATR FND < LND < R. No's <	PEGASIS FND < LND > R. No's >	LEACH FND > LND > R. No's >
PEGASIS	EDHSR FND < LND < R. No's <	CREEC = < LND < R. No's <	BATR = < LND < R. No's <	EEDCP-TB FND > LND < R. No's <	LEACH FND > LND > R. No's >
LEACH	EDHSR FND < LND < R. No's <	CREEC < < LND < R. No's <	BATR < < LND < R. No's <	EEDCP-TB FND < LND < R. No's <	PEGASIS FND < LND < R. No's <

6. Conclusion

In this paper we proposed an energy efficient clustering based routing scheme to handle the clustering, sensing and routing issues in highly dense deployed WSNs. In this scheme, first, we proposed an energy efficient cluster formation algorithm called Active Node Cluster Formation (ANCF). The core aim to propose ANCF algorithm is to distribute heavy data traffic and high energy consumption load evenly in the network by offering unequal size of clusters in the network. In the developed scheme each cluster head (CH) is appointed near to the sink and sensing event while the remaining set of the cluster heads (CHs) are appointed in the middle of each cluster to achieve the highest level of energy efficiency in dense deployment WSNs. Second, we proposed a lightweight sensing mechanism called Active Node Sensing Algorithm (ANSA). The key aim to purpose ANS algorithm is to avoid high sensing overlapping data redundancy by appointing a set of active nodes in each cluster with satisfy coverage near to the event. Third, we proposed an Active Node Routing Algorithm (ANRA) to address complex inter and intra cluster routing issues in highly dense deployment based on the node dominating values. Our extensive experimental studies show that the proposed scheme outperformed existing routing techniques in terms of energy efficiency, end-to-end delay, data redundancy, congestion management and setup robustness. In our future work, we are going to investigate its performance in more complicated sparse heterogeneous scenarios, consisting nodes of different capabilities to demonstrate the strength of the scheme in terms of various performance metrics.

Acknowledgments

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