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Energy Efficient Utilization in IEEE 802.15.4 based WDSN with Grid Structured Clusters using Adaptive Clustering Technique and EA-STR

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Abstract

Background/Objectives: The foremost requisite in the IEEE 802.15.4 based WDSN is to utilize the energy efficiently among the mobile sensor nodes since they are limited in their battery resource. **Methods/Statistical Analysis:** In order to utilize the energy effectively, the nodes are organized as clusters (fixed or adaptive clusters). Hence in this paper, adaptive clustering technique is adapted for IEEE 802.15.4 based WDSN which enables the nodes to change their association with different clusters over time. This enhances the nodes independency besides the conservation of energy. It further utilizes EA-STR protocol for routing the information from the member node to the cluster head. **Findings:** In the proposed technique, the clusters in the IEEE 802.15.4 based WDSN are organized in the structure of the grid and the nodes utilize the column mobility model to create mobile scenario. Further, the proposed methodology is analyzed through performance metrics such as average residual energy, Packet Delivery Ratio (PDR) and delay by varying the number of clusters from one to five, data rate from 50 kbps to 250 kbps and range from 45m to 125m. The simulation results portray that the proposed methodology with adaptive clustering and EA-STR achieves enhanced average residual energy, PDR and reduced delay thereby surpassing the performance of network with non- adaptive clustering and EA-STR. **Improvements/Applications:** In future, the proposed model can be extended by incorporating different deployment techniques and mobility models.

Keywords: Adaptive Clustering Technique, Average Residual Energy, Delay, EA-STR, PDR, WDSN

1. Introduction

Owing to the development and enhancement of Micro-Electro-Mechanical Systems (MEMSs) technology and wireless communication technology, Wireless Dynamic Sensor Networks (WDSNs) are utilized for enormous applications such as military reconnaissance, disaster management, security surveillance, monitoring the habitat, health monitoring and industrial automation etc.[1-3] Also in recent years, the applications of WDSNs have been extended to smart homes, smart farms, fire monitoring in smart cities etc. These are made possible by the introduction of IEEE 802.15.4 based WDSN, which supports low cost, low power, Low Rate-Wireless Personal Area Networks (LR-WPANs). Thus, the IEEE 802.15.4 based WDSNs have established a bridge between the physical world and the computing world.

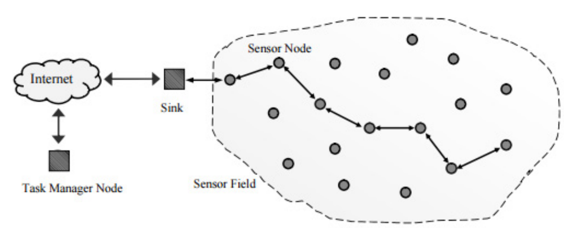

Figure 1. Components of Sensor Network.

The WDSN consists of massive number of small sized mobile sensor nodes that are distributed over a

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large area known as the sensing field. A data aggregation point known as the sink governs the entire sensing field of WDSN. The sink performs tasks such as receiving the data from the other nodes, processing them and then storing the processed data. The various components of the sensor network are depicted in Figure 1.

The sensor nodes in the WDSN are limited in their battery resource. Hence, energy efficient techniques are required to conserve the battery resource to utilize the energy efficiently for performing various functions such as sensing the physical parameters, establishing communication among the sensor nodes and computing the parameters. Several researchers have proposed various protocols for conserving the energy resources of the network. Among them, organizing the sensor nodes as cluster excels as the promising technique due to various advantages.[4] The advantages of clustering technique are listed as follows:

1.1 Increased Scalability

The clustering technique organizes the sensor nodes as different clusters and the sensor nodes are assigned with different functionalities. The size of the cluster is varied according to the terrain size. Therefore, the clustered network can be easily scaled and managed in order to respond to the events, which will be happening in the environment.

1.2 Less Load

The process of aggregating the data is known as data fusion or data aggregation. The data from multiple sensor nodes are aggregated in order to remove the redundant data transmission. This mechanism reduces the load at each sensor node and at the sink.

1.3 Less Energy Consumption

The clustering technique reduces the energy consumption significantly due the various mechanisms such as data aggregation; inter cluster and intra cluster communications.

1.4 Enhanced Robustness

The clustered network can easily adapt to the changes within the individual clusters. Therefore, the clustering techniques enhance the robustness of the entire network.

The clustered WDSN consists of Cluster Heads (CHs) and member sensor nodes. The member sensor nodes perform the function of sensing various physical parameters and the CHs aggregate the data from the member sensor nodes.

The sensor nodes in the WDSN are mobile in nature and they are liable to move away from their respective clusters. Hence in this paper, an attempt has been made to develop a model for IEEE 802.15.4 based WDSN that adapts the adaptive clustering technique to identify the nodes that move away from the cluster and to change their association from their parent cluster. By doing so, more energy can be conserved leading to an increased network lifetime. In addition to the adaptive clustering technique, the proposed methodology utilizes the Energy Aware-Shortcut Tree Routing (EA-STR) protocol, which identifies the one hop neighbor nodes based on minimum distance as well as based on the residual energy at the nodes. Thus, the route is established through the nodes that are at minimum distance as well as with sufficient energy to act as next hop node. Both these mechanisms lead to enhanced lifetime of the sensor nodes with lesser energy consumption.

The article is further organized as follows: Section 2 reviews about the routing protocols in WDSN and Zigbee wireless networks. Section 3 presents the proposed methodology. Section 4 discusses the analysis of the performance of proposed methodology through the simulation results. Section 5 finally concludes the paper.

2. Routing Protocols in WDSN and Zigbee Wireless Networks

In the WDSN, routing the information between the mobile sensor nodes has a prominent role.[5-7] The prime objective of the routing protocols proposed for WDSNs is to reduce the energy consumed by the nodes to increase the lifetime of the network. This is accomplished by selecting the path between the mobile sensor nodes and the Base Station (BS) in such a way that they consume less energy and prolong the lifetime of the network. Hence, several routing protocols such as flat protocols, location based protocols and hierarchical protocols have been proposed by various researchers to achieve lesser energy consumption in order to increase the network lifetime.

In the flat routing protocols, all the sensor nodes are at the same level in the network and they function with a common task.[8] These protocols have the advantage of reduced overhead and they maintain the infrastructure established between the nodes that are involved in communication.

In the Location based protocols, the nodes are organized based on their location in the network.[9,10] In these protocols, the distance among the nodes is computed through the signal strength. When the signal strength between the nodes is more, the distance between the nodes is less and when the signal strength between the nodes is less, the distance between the nodes is more.

In the hierarchical protocol, the sensor nodes are organized as clusters, which lead to significant savings in energy.[11-14] In the hierarchical network, each cluster has a leader known as the Cluster Head (CH). It performs special tasks such as data fusion and data aggregation. Also in the hierarchical network there are several common sensor nodes known as member nodes. Thus, the organization of clusters leads to a two-level hierarchy where the CH nodes form the higher level and the member sensor nodes of the cluster form the lower level. The member sensor nodes periodically transmit their data to their corresponding CH. The CH nodes aggregate the data transmitted by them to the BS either directly or indirectly. This mechanism decreases the total number of relayed packets.

The clustered network consists of two different communications, namely intra cluster communication and inter cluster communication. In intra cluster communication, the member sensor nodes transmit their sensed data to the CH, whereas in the inter cluster communication, the CH forward their data to the BS. Figure 2 illustrates the data communication in the clustered network.

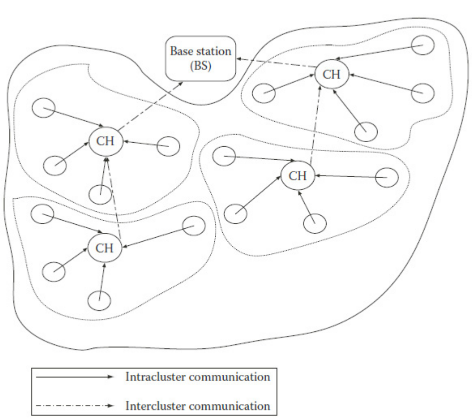

Figure 2. Data communication in the clustered network.

The different categories of hierarchical protocols are briefly described below:

2.1 Low Energy Adaptive Clustering Hierarchy (LEACH)

In LEACH protocol, the CHs are elected through a probabilistic approach.[15] At each node, a random number between '0' and '1' is generated and it is compared with the CH selection Threshold value T(n). If the number that is generated at the particular node is less than the threshold value, then that node will act as the CH for the corresponding round.

Various types of LEACH protocol are discussed as follows:

2.1.1 Centralized LEACH (C-LEACH)

In C-LEACH, the responsibility to elect the CH is bestowed with the BS for the corresponding round.[16] The BS broadcasts the CH ID to every node. If the broadcasted CH ID matches with a particular node, then it is elected as the CH of the cluster.

2.1.2 Modified LEACH (MODLEACH)

In MODLEACH, the CH in the current round is replaced with a new CH if and only if the energy of the current CH is less than the required threshold. MODLEACH utilizes two different power levels; one for transmission of data between the nodes of a cluster and another for transmitting the data from the CH to the base station.[17]

2.1.3 Vice-Cluster-Head LEACH (V-LEACH)

This protocol elects an additional CH known as the vice CH.[18] When the energy at the CH vanishes, the vice CH performs the duty of CH.

2.1.4 Optimization LEACH (O-LEACH)

In the O-LEACH protocol, the node with the highest residual energy is elected as the CH.[19] This protocol ensures fairness in the selection of CH as they dynamically change the CH after each and every round.

2.2 Power Efficient Gathering Sensor Information System (PEGASIS)

A chain structure is utilized in the PEGASIS protocol for aggregating and dispersing the data.[20] In the PEGASIS protocol, each node acts as the leader of the chain for a certain period of time. Here each node communicates only with its nearby neighbor node and rotates the chance of transmitting the information to the base station periodically.

2.3 Threshold Sensitive Energy Efficient Sensor Network (TEEN)

In TEEN, the CHs broadcast different threshold values known as hard threshold and soft threshold to its member sensor nodes.[21]

- Hard threshold is the absolute threshold value for the sensed attribute. Whenever a node senses this value, it switches on its transmitter and transmits the data to the CH.
- A small change in the value of the sensed attribute is known as the soft Threshold. This value triggers the node to turn on its transmitter in order to enable transmission.

The member sensor nodes will start to send their information to the CH only when the subsequent attribute reaches the essential hard threshold value or when the sensed value is either more than the hard threshold or when the difference between the sensed value and the SV parameter is greater than or equal to the soft threshold.

The clustering technique is also classified as fixed clusters and adaptive clusters. In the fixed clustering technique, the association of sensor nodes with the clusters will not change with the passage of time. Whereas in the adaptive clustering technique, the sensor nodes will change their association with different clusters with the passage of time. The adaptive clustering mechanism is illustrated in Figure 3.

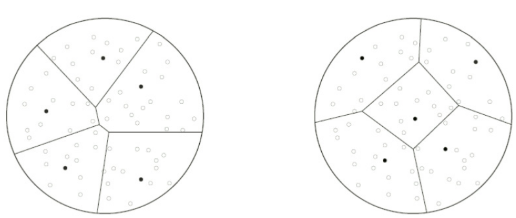

Figure 3. Adaptive clustering technique.

Apart from these deployment techniques, the sensor nodes can be deployed using three different strategies such as force based, grid based and computational geometry based deployment strategy.[22] Grid based deployment schemes outperform other schemes as they are simple and less complex.

In addition to these routing mechanisms, various authors have proposed different network routing protocols. AODV junior (AODVjr), which is known as the simplified Adhoc On demand Distance Vector (AODV) routing protocol.[23] It is a reactive protocol which identifies the path for communication on-demand through the route discovery mechanism. The route discovery mechanism adds additional overhead leading to a serious limitation. Thus, the Zigbee Tree Routing (ZTR) protocol is proposed. In ZTR, the packets are forwarded from source to the destination through the parent child relationship along the tree. ZTR also suffers from a limitation (i.e) in ZTR, the packets are routed from the child only to its parent even when the destination is at one hop distance. Thus, optimal routing path is not obtained. Subsequently, the Shortcut Tree Routing (STR) protocols are proposed to surpass the limitation of ZTR.[24] In STR, the optimal path is achieved by identifying the 1 hop neighbor nodes of a particular node. Here, the node with the smallest remaining hop count to the destination is identified as the next hop node.

In order to achieve better utilization of energy, the techniques such as organizing the nodes as clusters and routing the packets through energy aware STR are combined which is discussed in the next section.[25] The collective combination of these techniques reduces the energy consumed by the nodes and enhances the lifetime of the network.

3. Proposed Methodology

In WDSN, energy conservation at each mobile sensor node plays a vital role as they determine the lifetime of the network. Further, the mobile sensor nodes are deployed in large number in remote and hostile regions. Therefore, these nodes are inaccessible. This draws a special attention to keep intact the energy at the nodes. In order to conserve the energy at the nodes, the nodes are grouped into clusters. Clustering techniques reduce the energy dissipation, remove the redundant data transmission and increase the lifetime of the network.

In the clustering techniques, the CHs are chosen either statically or dynamically. In static clustering, as long as the network is active, the CH remains fixed. But, the CH changes after each round in dynamic clustering technique. The dynamic clustering technique prolongs the network lifetime since they rotate the chance of being the CH during each round. But, this technique does not hold good at all circumstances. Moreover, each cluster in WDSN consists of mobile member nodes and mobile CHs; there occurs two problems as follows:

- The member node may move far away from its CH.
- The CH may move far away from its member nodes.

In either case, the energy required for transmission and reception of data packets increases. The proposed methodology is therefore modeled in such a way that the sensor nodes are organized in clusters with grid structure for IEEE 802.15.4 based WDSN and it adapts the techniques such as adaptive clustering and EA-STR to preserve the energy at the mobile sensor nodes and to increase the network lifetime.

In the proposed methodology, the mobile sensor nodes pursue the column mobility model. In the column mobility model, the sensor nodes cooperate with each other and they move in certain fixed direction. Therefore, the mobile sensor nodes with column mobility model are suited for applications that require searching and scanning activities.

The proposed methodology is developed with the following assumptions:

- 10% of mobile sensor nodes in each cluster (grid) are with higher speed.
- The mobile sensor nodes belonging to one cluster (grid) do not enter into the range of the neighboring cluster (grid).

The algorithmic steps utilized by the proposed methodology are listed in Table 1, Table 2 and Table 3.

Table 1. Algorithm to select the CH

i.	Organize the mobile sensor nodes as 'a' clusters in 'p*q' topology with each cluster having 'b' mobile sensor nodes. Deploy each cluster in the grid structure of size 'x*y'.
ii.	Initialize each mobile sensor node with initial energy, energy for transmission and energy for reception.
iii.	Compute the distance between the mobile sensor nodes and set the energy level at each node for transmitting and receiving the control signals with its neighbor nodes.
iv.	Evaluate the average energy required for transmitting and receiving the control signals at each mobile sensor node.
v.	Compute the residual energy of each mobile sensor node in each cluster using Residual energy = Initial energy – [(Transmitting energy+ receiving energy+ calculated average energy) of the mobile sensor node].
vi.	In each cluster, compare the residual energy of each node and the node with the highest residual energy is choosen as the CH of the corresponding cluster.
viii.	Broadcast the ID of the CH to the member nodes of the corresponding cluster.
ix.	Schedule the member nodes with the CH using TDMA scheduling and establish the communication between the nodes accordingly.

Table 2. Algorithm for Adaptive Clustering

i.	Create lists *dist* and *separatednodes* and initialize them.
ii.	Identify the median node in each cluster and estimate the distance 'D' between the median node and the each of the remaining nodes in the cluster and append the computed distance to list *dist.*
iii.	Sort the list *dist* in descending order and identify the greatest possible distance in each cluster.
iv.	Compute the distance 'Di' between the median node in the cluster and the other nodes at regular intervals.
v.	If the calculated distance 'Di' is greater than the distance 'D', then the mobile sensor node 'i' has moved far from the respective cluster and append that node to list *serparatednodes.*
vi.	Remove the mobile sensor nodes in list *separatednodes* from the parent cluster and form the nodes in list *separatednodes* as a separate new cluster.
vii.	Calculate the residual energy using Table I for each of the node in list *separatednodes.*
viii.	Elect the mobile sensor node with highest residual energy in list *separatednodes* as the CH of the new cluster.
ix.	Broadcast the ID of the CH in the new cluster to its member nodes.
x.	Establish communication between the nodes of the new CH on the TDMA basis.

Table 3. Algorithmic steps of EA-STR

i.	Set the communication range for each mobile sensor node and initialize the list *neighbor[i].*
ii.	Calculate the distance't' between node 'i' and node 'j'.
iii.	If the computed distance 't' is less than the communication range and if the residual energy at node 'j' is at least 50% of the initial energy, then node 'j' acts as the neighbor node of node 'i'.

iv.	Append the list *neighbor[i]* for each computation.
v.	Now for each node 'k' in list neighbor[i], compute the distance between node 'k' and the CH.
vi.	Identify the node with the minimum distance to the CH and create the routing table with the shortest path.
vii.	Route the packet through the shortest path from the member node to the CH during the prescribed time.

4. Simulation Results and Discussion

The proposed methodology is developed and analyzed through simulations using ns2. The performance metrics such as average residual energy, Packet Delivery Ratio (PDR) and delay are computed by varying parameters such as number of clusters that vary from one to five, range varies from 45m to 125m and data rate ranges from 50 kbps to 250 kbps. The proposed methodology with adaptive clustering and EA-STR is examined and compared with the network using non-adaptive clustering and EA-STR.

The simulation parameters used for the simulation of the proposed methodology are given in Table 4.

Table 4. Simulation Parameters

Sl. No.	PARAMETER	VALUE
1.	Number of clusters	1,2,3,4,5 (25nodes per cluster)
2.	Number of nodes	25,50,75,100,125.
3.	Initial energy of a node	5J
4.	Topology	1500*1500(m^2)
5.	Transmission range	45m to125m
6.	Speed of the nodes	2m/s and 3m/s
7.	Mobility model	Column mobility model
8.	Simulation time	200 secs
9.	Energy for transmission	0.7J
10.	Energy for reception	0.9J
11.	PHY/MAC protocol	IEEE 802.15.4

The NAM output of the network with 50 mobile sensor nodes using non-adaptive clustering and EA-STR and adaptive clustering and EA-STR are illustrated in Figure 4 and Figure 5 respectively.

The analysis of average residual energy, PDR and delay by varying the number of clusters from one to five is depicted from Figure 6 to 8 respectively.

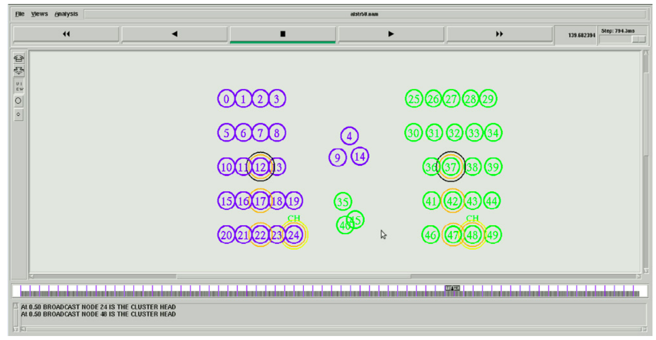

Figure 4. NAM output with 50 nodes for network using non adaptive clustering and EA-STR.

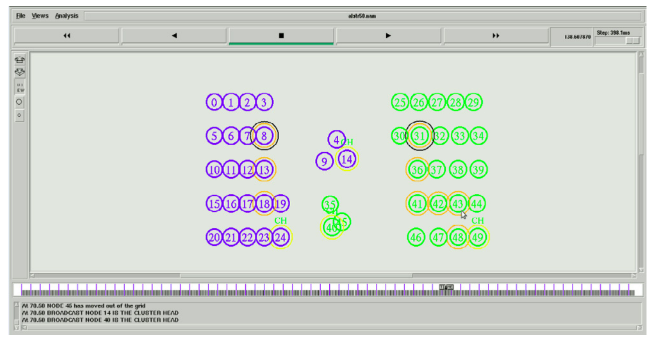

Figure 5. NAM output with 50 nodes for network using adaptive clustering and EA-STR.

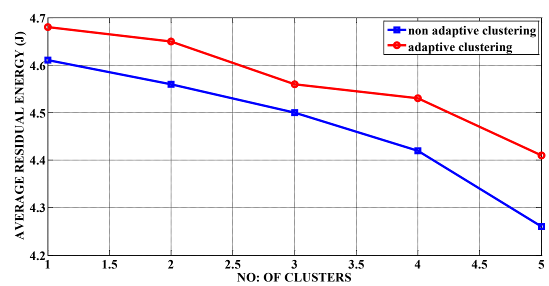

Figure 6. Average Residual Energy (J) vs No. of Clusters.

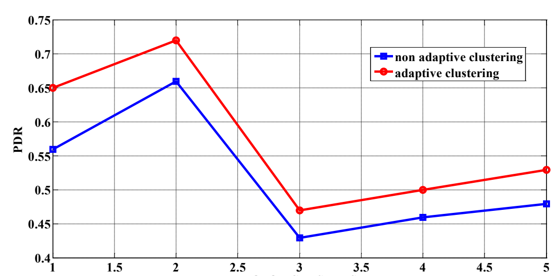

Figure 7. PDR vs No. of Clusters.

It is inferred from Figure 6 that the average residual energy decreases as the number of clusters increases. This is due to the fact, that, as the number of clusters increases, the number of packets in transmission increases leading to an increase in energy consumption. Subsequently, the average residual energy decreases. Further, Figure 7 portrays that the PDR increases between 1 and 2 no. of clusters but reduces at 3 no. of clusters and later increases. This phenomenon is due to the mobile nature of nodes. Since the nodes are mobile, the links break at certain instances. Therefore, the PDR decreases. Correspondingly in the delay analysis shown in Figure 8, the delay decreases between 1 and 2 no. of clusters, increases at 3 no. of clusters and reduces later between 4 and 5 no. of clusters.

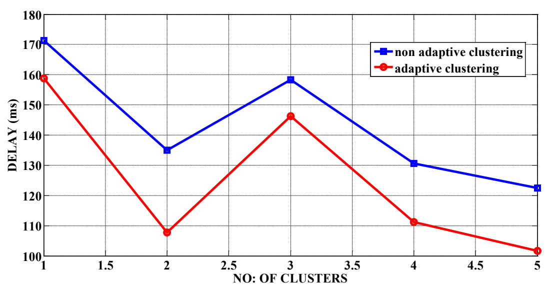

Figure 8. Delay (ms) vs No. of Clusters.

The response of average residual energy, PDR and delay with respect to the data rate varies from 50 kbps to 250 kbps are depicted from Figure 9 to 11 respectively.

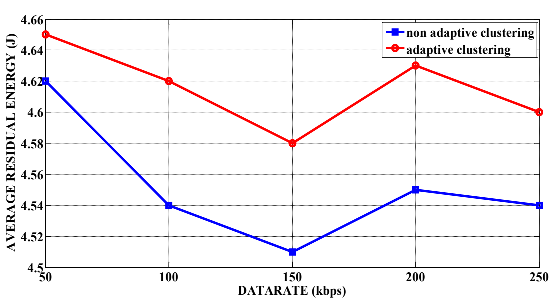

Figure 9. Average Residual Energy (J) vs Data rate (kbps).

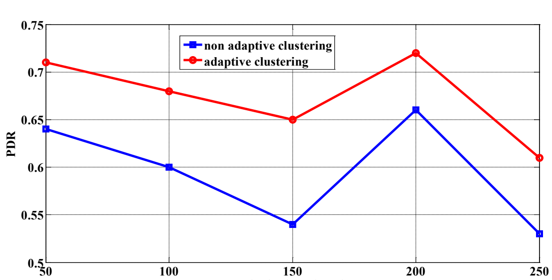

Figure 10. PDR vs Data rate (kbps).

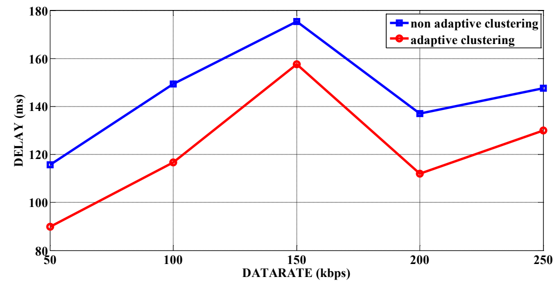

Figure 11. Delay (ms) vs Data rate (kbps).

Figure 9 portrays that as the data rate increases, the number of packets transmitted per second increases which in turns leads to a decrease in the average residual energy. Also, as the data rate increases, the network gets flooded with data packets. This causes the queue to get overwhelmed, leading to the increase in the network congestion, and hence more data packets are lost. Therefore, the PDR drops as the data rate increases and this phenomenon is illustrated in Figure 10. Moreover, from Figure 11, it is observed that the delay is less for lesser data rate. Since, the number of packets transmitted is less at lower data rates and the problem of congestion is less, the delay is reduced.

The variation of average residual energy, PDR and delay with respect to range from 45m to 125m are illustrated from Figure 12 to 14 respectively.

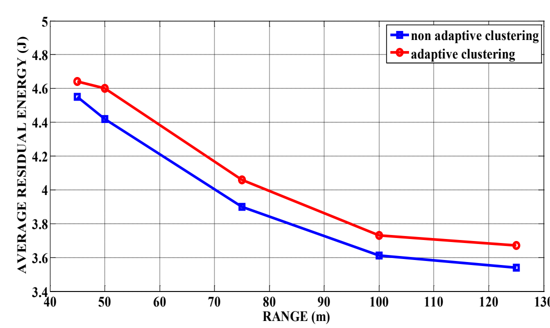

Figure 12. Average Residual Energy (J) vs Range (m).

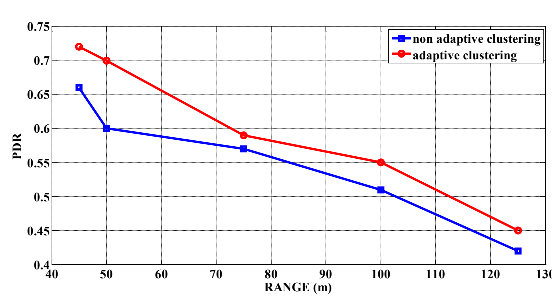

Figure 13. PDR vs Range (m).

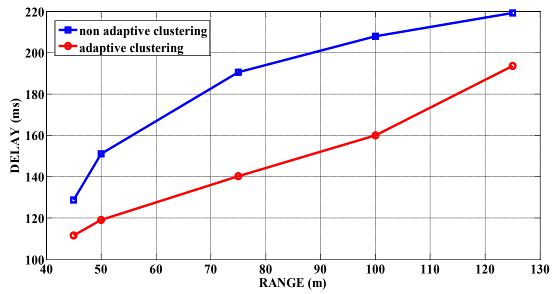

Figure 14. Delay (sms) vs Range (m).

As the range increases, the nodes consume more energy for transmission and reception. This leads to the decrease in average residual energy as portrayed in Figure 12. Further, as the range increases, the certainty of receiving the packets successfully decreases because of the more dispersed nature of the nodes. Thus, the PDR decreases with increase in range and it is illustrated in Figure 13. In contrary to the PDR, the delay increases as the range increases and it is depicted in Figure 14. This is due to the reason, that, when the range between the nodes is less, the packets travel through fewer hop counts and also the amount of interference between the nodes will be less. As a result, the probability of successful delivery of packets increases for lesser range and decreases for higher range.

5. Conclusion

IEEE 802.15.4 based WDSN is modeled as clusters with the structure of the grid. As each cluster consists of mobile sensor nodes with two different speeds, either the member node or the CH may move away from the parent cluster. The proposed methodology therefore adapts the technique of adaptive clustering to organize the nodes that move away from the cluster as separate new cluster. Further, the packets are routed from the member node to CH through the EA-STR. This mechanism in turn conserves energy. The performance of the proposed methodology is examined through simulation by using ns2. It is then compared with the performance of non- adaptive clustering and EA-STR. The evaluation of simulation results depict that by considering the number of clusters as 5, the average residual energy and PDR of the proposed methodology increases by 4% and 10% respectively and the delay of the proposed methodology decreases by 16% compared to that of the non adaptive clustering and EA-STR. Also, it is depicted through the simulation results that there is 2% and 20% improvement in average residual energy and PDR respectively and 10% reduction in delay of the proposed methodology for the data rate of 150kbps compared to that of the non adaptive clustering and EA-STR. Further, in the proposed methodology, the average residual energy and PDR is enhanced by 2% and 10% respectively and the delay is reduced by 13% for the range of 45m compared to that of the non-adaptive clustering and EA-STR. Hence, it is inferred from the simulation results that the proposed methodology with adaptive clustering and EA-STR surpasses the performance of non -adaptive clustering and EA-STR.

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