1. Introduction

With the advent of IOT (Internet Of Things), Wireless sensor networks gained more and more popularity. In the present scenario WSN has been deployed in various domains like security, monitoring, environment, tracking down enemy, military applications, agriculture, surveillance etc. In the near future WSN will be able to efficiently monitor and generate timely warnings of avalanches, tectonic-plate movements, tsunami, hurricanes, forest fires etc.

WSN offers various benefits over traditional wired networks in terms of factors like flexibility, reduction in infrastructure costs, increase in accuracy and reliability, dynamic changes in topology and scalability of devices. The disadvantages of WSN includes low bandwidth, less storage capacity, limited battery power and data processing feature, unstable link capacity and high variability in bit transfer rates and vulnerability towards interruptions during data transfer.

The functioning of WSN includes – a. sensing the data from the environment b. processing the gathered data c. Data transfer from the source node to the sink node (a base station). The transfer of data from source node to the sink node can be done in 2 ways:-

- Use of Routing protocols
- Use of Mobile Elements

Routing protocols are generally categorized into – flat, hierarchical and location aware protocols. In case of flat routing technique, all sensor nodes are supposed to have equal responsibility and power (includes Direct Diffusion, Rumor routing, Gradient based etc.). Hierarchical technique includes different responsibility for different nodes (consists of a cluster head in case of LEACH protocol and chain-formation in case of PEGASIS). Location based technique involves exploitation of the position of sensor node in order to relay data (includes GAF, GEAR, GOAFR, SPAN protocols etc.).

Routing through Mobile elements include (as shown in Figure 1)-conventional sensor nodes, assistance providing nodes (helper nodes) and base station (sink-node).

2. Mobile Elements in WSN

General scenario/problem of data transfer through Routing Protocols:
The role of routing protocols was to transfer data from source node to the sink node using intermediate nodes as a hop or relay station. This required that the node has to sense the data as well as to act as a forwarding station for other nodes. These sensor devices have limited radio power or coverage area, so there has to be a dense network of sensor nodes in order to maintain proper connectivity among the nodes. So the deployment of sensor nodes is much dense in case of using conventional routing protocols. This increases the cost of deploying sensor nodes. Also there are chances of interference due to multi-hop communication. The funneling effect further reduces the efficiency and causes energy depletion.

Using Mobile elements is lucrative from the aspect of above discussed problems as it solves the problems related to cost, connectivity and reliability.

How the problem is solved by MEs?

Problem Related to Cost and Connectivity
MEs ameliorates the situation by providing the option of sparse-deployment of nodes, since multi-hop transfer is greatly reduced by making use of MDC (i.e. mobile data collectors), MS (mobile sinks) and Re-locatable nodes. There is no need for end to end connectivity since the mobile elements helps to relay or bridge the path between sender and receiver nodes.

Problem Related to Reliability
Bandwidth is the bone of contention between intermediate nodes during data transfer through multi-hop route. Also there are fading effects and impediments which increases latency and probability of message loss. Mobile elements solve this problem by personally visiting the node that generated the data ->gathering data from that node by single hop transfer mode ->finally takes back the data to the base station or communication end points.

Figure 1. A scenario depicting data collection via Mobile Element.

Mobile Element Classification
Taking account of mobility and architecture, MEs are categorized into (as shown in Figure 2).

- **Re-locatable/Dynamic Positioning Nodes**: This idea proposed a scenario of re-locatable- nodes which are used for managing topology and re-establish network connectivity in case of faulty links. They act as bridges between nodes when the connection is unstable or about to fail. They often change the WSN topology to improve and enhance the reliability and energy efficiency. They also truncate and solve the problem of sensing-coverage i.e. covering those areas where there is inadequate density of nodes to properly detect or sense an event. Re-locatable nodes don't take active part in data collection; they are there just to provide mobility assistance to WSN. They don't carry the data themselves rather they act as a medium or relay station for forwarding data.

- **MDC (Mobile Data Collectors)**: They move in the network to gather data from the source nodes. They are of 2 types.

  - **MS (Mobile Sink)**: Mobile sink is just a case of mobile base station with stationary sensor nodes, whereby a mobile sink traverse through the entire WSN to collect data from the sensor nodes. It can either use the data autonomously or can send it to remote stations or to users via wireless communication. The route between source and MS is though multi-hop but the path is dynamic since the MS keeps changing its position.

  - **MR (Mobile Relay)**: Mobile relays act as support nodes to carry data from the stationary sensor nodes to the base station. These are not communication end-points rather they just carry data (gather data from source nodes-> store and carry to sink). A mobile relay technique was proposed called data MULE, Mule stands for-Mobile Ubiquitous LAN Extensions. In this technique, the source node waits for the mule to be in range for data communication.

  - **MP (Mobile Peers)**: Mobile peers act as both a sensor node as well as a relay node. These apart from generating their own data, store and forward data of other nodes (gathered when they were in contact with each other) to the base station. Data already transferred to the sink station is deleted or flushed out by these peer nodes. Example includes- Zebra Net project for tracking movement patterns of zebras.

The influence of mobile elements in data collection is quite remarkable and dominating as compared to static WSN when it comes to performance, data-latency and energy efficiency.
Some important terminologies with respect to data collection:

- **Contact**: When the mobile element is inside the presence detection area of the sensor node then a contact is said to have occurred.

- **Contact time**: The time for which the interacting nodes are in contact with each other is termed as contact time.

- **Residual Contact Time**: It is the amount of time in which actual data transfer takes place. (After detecting a contact, the nodes initiate data transfer. Residual contact time is a subset of the contact time).

- **Contact Area**: It is the span or area where the nodes and MEs can be in contact, generally it is a radial expansion.

Phases of Data collection in MES:

- **Discovery**: It is the detection of the contact i.e. presence of ME within the communication range of the sensor node.

- **Data Transfer**: It is the exchange of data between the interacting nodes during residual contact time.

- **Routing to the MEs**: It is the selection of a route to the destination.

Aim of all these phases is to:

- Increase number of contacts
- Increase residual contact time
- Control and reduce energy depletion
- Increase throughput
- Increase probability of data delivery

The crucial impact of mobility on data collection procedure is “controllability”

Types of mobility:

- **Autonomous** (i.e. uncontrolled) mobility
- **Controlled Mobility**

There are 2 types of autonomous mobility:

- **Deterministic** - periodicity in contacts made between sensor nodes and MEs.
- **Random** - irregular contact pattern between sensor nodes and MEs, often follow some probability distribution.

Advantages of controlled mobility over autonomous mobility:

- Contact duration can be controlled and organized.
- Residual contact time can be manipulated since the speed and trajectory of MEs is under control.

Now we will give a brief description of the protocols used in discovery phase of data collection.

There are 2 types of Discovery Protocols:

- **Mobility Independent**: No prior mobility pattern is known to the sensor nodes.

- **Knowledge based Mobility**: Having prior knowledge about mobility patterns so that the energy of sensor nodes can be conserved by letting them go in dormant status when there are no chances of MEs detection. In case of deterministic mobility, a knowledge gathering phase was proposed where asynchronous method of discovery is used to detect a ME whereby the ME periodically sends beacon messages and static sensor nodes listens to them. After the occurrence of contact, the sensor nodes record the pattern of contact time which is in turn used as a means to predict future arrivals of MEs.

Types of mobility independent discovery protocols:

- **Scheduled Rendezvous**: This is the technique where the interacting nodes define a particular time for their contact to occur. Scheduled rendezvous is like a time table system, for example- a bus has a predefined timetable to visit every bus stop on its route at a particular time-slot. These bus stands consist of sensor nodes which become active on arrival of the bus (a MDC) to exchange the data.

- **On-demand**: It uses 2 approaches:
  - **Approach Involving Different Energy Radios**: This approach makes use of different energy radio system whereby the ME uses a powerful radio for data communication and a comparatively low range.
radio for triggering the sensor nodes. The channel for communication (also termed as paging channel) is monitored by the sensor nodes to detect a ME. When the detection is confirmed, the sensor nodes activates its powerful data transfer radio for communication with the ME.

- **Harvesting Energy from Radio Event:** This approach makes use of energy harnessing; ME sends activation signals to sensor nodes where it is used to activate the transceiver of the sensor node.

- **Asynchronous:** In this technique, the ME emits signals periodically and the sensing node too wakes up in a periodic fashion to listen and respond to the advertisement signal by initiating data transfer. In case there is no detection of the discovery signal, the sensor node goes back to dormant state.

4. **Data Transfer Phase of Data Collection in MEs**

Various techniques for data transfer between sensor nodes and MEs were proposed in which indicated that speed and trajectory of ME affects data transfer. Different ideas were proposed in these papers whereby speeds ranging 30-150 cm/sec, 20-40 km/hour and 1 m/sec were used according to different scenarios. A graph between chance of message loss and distance was plotted and the resultant curve obtained was found to be parabola. A message loss function was used in the study which demonstrated that in order to minimize data loss during transfer, the trajectory of ME is to be controlled. A technique was proposed that made use of a message loss model to determine the performance of data collection via MDC. A method was developed termed as stop & wait protocol for efficient data collection and further on a protocol was coined: automatic repeat request protocol to increase the rate of successful data transfer along with a reduction in energy dissipation of sensor nodes.

5. **Routing Techniques used in Case of MEs**

Routing is divided into 2 categories based on type of mobility of the ME:
- Routing data to ME with autonomous (uncontrolled) mobility
- Routing data to ME with controlled mobility

There are 2 categories of routing mechanisms used in case of uncontrolled ME:
- **Flat Routing:** In this technique all sensor nodes have same privilege and status and no special functionalities.
- **Proxy-based Routing:** In this technique, gateways or forwarder nodes (anchor nodes or rendezvous nodes) are elected which relay data from the static sensor nodes to the mobile element.

Various flat routing techniques suggested by some authors are:

5.1 **Modified Directed Diffusion**
The earlier DD-algorithm was modified by the author to deal with mobility issues. 2 changes were proposed - a. setting up a higher priority for propagation generated by ME as compared to the other sensor nodes. b. Using acknowledgements for data transfer to the ME as a method to determine whether ME is out of contact region.

5.2 **Mobi-route Protocol**
The earlier Mint-Route protocol was modified by the author for dealing with mobility. 3 changes were proposed- a. Making use of time-out signals to determine faulty or terminated links if ME goes out of the contact area. b. Increasing tolerance towards less optimal routes in order to avoid overhead energy expenditure in rebuilding the relay tree. c. Buffering the data in order to reduce loss of data during the movement of ME.

5.3 **Energy Aware Routing to Mobile Gateway**
In this technique the author proposed that nodes can expand their transmission range up to a certain extent to deal with the mobile element which is traveling out of the contact region. The intermediate nodes can be used as forwarders or relay station if the ME is out of coverage range.

5.4 **Weighted Entropy Data Dissemination Protocol**
In this technique the entropy of the sensor nodes were exploited to elect forwarder nodes. 2 parameters were used to decide forwarder nodes- a. residual energy of sensors. b. location of mobile element.
Various proxy routing techniques suggested by some authors are:

- **Two Tier Data Dissemination Protocol**\(^{19}\). This technique involves position-aware routing and building a grid-like structure to forward data to the mobile elements. The author elaborates that the forwarding sensor nodes align themselves according to the crossing junctions of the grid network. The intersection point of grid lines denote a crossing point. During the phase of data collection, the mobile elements propagate requests flooding the network. The nodes which are closer to the ME align themselves on the crossing points and act as disseminating node to spread the request and finally allow the data from the supposed source nodes to pass through them; therefore acting as a proxy (a bridge) between ME and source sensor nodes.

- **Scalable Energy Efficient Asynchronous Dissemination Protocol**\(^{20}\). In this technique the authors proposed a measure of threshold value which is a tradeoff between power consumption for constructing D-tree (i.e., dissemination tree) and delay. The protocol uses message-catching for reducing chances of data loss. A dissemination tree consisting of sensor nodes is constructed which is used for routing the data from the sensor nodes to the ME. The mobile element when comes in contact range of a sensor node, it sends a query for subscribing i.e., joining the dissemination tree. The node which handles the initial query of the ME and acts as a rendezvous point between ME and other nodes in the network is termed as the access node from which the ME fetches the response data. A recursive operation is used by the access node to construct the d-tree. In order to mitigate data loss during transmission, caching is used. When the ME goes out of the reach and coverage of its access node and the threshold value is exceeded then another access node is assigned to the ME which satisfies the threshold value and the process goes on until the ME completes its tour of data gathering.

- **Hybrid Learning Enforced Time Domain Routing Protocol**\(^{21}\). In this technique the authors assumed that the ME follows a Gaussian mobility distribution pattern. Only those nodes which can interact with ME via one-hop routes are elected as gateways or proxy nodes. These proxy nodes record the mobility patterns of ME and deduce/predict a reinforcement value which foretells the future arriving of ME based on probability. Now this value is disseminated to the other nodes so that they can prepare to forward data to the proxy server when the ME arrives in future.

- **Maximum Amount Shortest Path**\(^{7}\) - This technique is similar to the above described protocol in which a proxy node is elected based on its distance from the ME. Lesser the distance more is the probability of becoming a proxy node. This protocol reduces the chances of bottleneck at the proxy nodes by making use of the duration of contact time. Those nodes which have varying length contact time are assigned to the same proxy node while those sensor nodes which have same length of contact time are allotted to different proxy nodes so as to mitigate bottleneck cases. Implementation of this protocol requires a GA (genetic algorithm) and ILP (integer linear programming) model.

6. **Routing Data to ME with Controlled Mobility Incorporating Motion Control**

In case of controlled mobility, the moving pattern, speed and trajectory\(^{31}\) are under control and hence data collection procedure becomes much more flexible since the routing techniques need not to work and adapt according to the autonomous ME, therefore data gathering can be optimized and contact, contact-time, residual contact time can be well controlled and manipulated.

6.1 **Motion Control Involves Controlling the Trajectory and Speed of ME.**

Trajectory is further divided into 2 parts:

6.1.1 **Static Trajectory**

In static trajectory, the path of the ME doesn’t vary with time. Mobility as well as routing is collectively used so as to improve the performance parameters and conserve energy. Various scheduling techniques are used in case of static trajectory which will be discussed in the coming sections. A network assisted navigation\(^{22}\) was proposed which determines a path from which all the nodes can interact via single hop. The authors present the concept of navigation agents. These navigation agents are those nodes from which the other sensor nodes can be reached via one-hop route. The authors computed the path along these navigation agents using traveling salesman problem.

6.1.2 **Dynamic Trajectory**

In dynamic trajectory, the path of ME can vary with time for satisfying performance parameters and freshness of
Node initiated message ferrying\textsuperscript{23} is a type of event driven dynamic trajectory in which any sensor node can initiate data transfer by sending a query to the ME. Initially the ME traverses on a default trajectory but when it receives indication from a sensor node willing to transfer data, the ME changes its track and reaches the source node to gather data. After collecting the data, the ME returns back to its original default route.

6.1.3 Speed Control in Case of Controlled ME

During the transfer of data if the speed of the ME can be controlled then the chances of data loss can be mitigated. So the residual contact time duration can be increased thereby increasing the chances of successful data transfer. Techniques for speed control like SCD i.e. stop to collect data\textsuperscript{20} was suggested by the researchers. In this algorithm following parameters are considered:

- Max Time (T): Total amount of time that can be spent by the mobile element in a tour.
- Constant speed (S): It is the constant speed with which the ME can travel while covering all the nodes in the time T.

The author species that according to the working of SCD, the speed of ME can be increased to 2*S which will let the ME complete its journey in 0.5*T. So the remaining time (T- 0.5T = 0.5T) can be used by the ME to wait and collect data from sensor nodes efficiently.

Another technique specified is ASC i.e. adaptive speed control\textsuperscript{10} which is a classification algorithm which uses parameters like amount of buffered data and percentage of data gathered to categorize nodes into 3 groups:

- **Group L (low)**: Nodes belonging to this category are those from whom meagre percentage of data is gathered so they pose a potential fresh data store which needs to be transferred to the ME and hence given more priority than other groups. Therefore the ME halts in contact regions of these groups to initiate data transfer.
- **Group M (medium)**: Nodes belonging to this category are those from whom some amount of information has been gathered already hence the ME moves with the speed S(constant speed) when it enters the contact space of this category of sensor nodes.
- **Group H (high)**: Nodes belonging to this category are those from whom significant amount of data has already been gathered therefore the ME moves with the speed 2*S when it enters the contact region of this group of nodes.

7. REA-MDG (Residual Energy Aware Mobile Data Gathering)

The idea of residual energy approach\textsuperscript{24} was coined for data gathering in case of MDC (Mobile Data Collector). In order to enhance and increase the WSN’s lifetime, the energy at each sensor node is to be conserved and carefully spent. The authors made use of spectral clustering technique to group the sensor nodes into different cluster sets and elects a cluster head for each cluster based on certain parameters of interest:

- Total number of nodes in the vicinity i.e. the neighbors.
- Total amount of residual energy the neighbor has.

A heuristic route of the MDC is selected by taking into account- timeliness (data freshness) and storage capacity (buffer) overflow at a sensor node. The authors proposed an iterative approach and divided the working of their algorithm into 4 steps:

- Use of spectral clustering (based on eigenvectors) to divide the whole WSN into different clusters.
- Selection of polling points (cluster-heads) based on above discussed parameters of interest.
- Construction of a balanced data relay tree in every cluster.
- Deciding a shortest path as a route for the MDC to gather data from all clusters.

The authors proposed the use of MDC equipped with antenna for the purpose of data gathering. A contention free transmission mechanism is obtained by assigning different time slots to the clusters. Let P be the residual power of a vertex V. The authors have made certain assumptions:

- Every sensor node is equipped with a counter device so that the residual energy can be measured.
- All sensor nodes have a communication range R which is the same for MDC as well.
- Lifetime of the WSN is dependent on the exhaustion of the first node i.e. as soon as the first node in the network expires (exhausted), the lifetime is over.
- There is an irregular distribution of residual energy in the entire network since different nodes forward different quantity of data through themselves.

So based on the above assumptions the network topology has to be dynamically changed according to the residual energy of the sensors. Therefore the authors have suggested to:
• Select path points which are the subset (say C) of the total sensor nodes (say V) employed in WSN. These path points are the cluster heads which are dynamically elected based on certain parameters discussed before.
• Dynamically construct a forwarding path (data relay route) from the remaining sensor nodes to a node in the subset C.
• Determining the tour of MDC in such a way that every node in the subset C is visited by the MDC utmost once in order to enhance the lifetime of the network.

The algorithm of REA-MDG is proved to be \textit{NP-Hard} by the authors. In order to determine the energy depletion at each sensor node, the authors have used radio energy dissipation model which makes use of parameters like:
• Amplifier energy in a free space model.
• Amplifier energy in a multipath fading channel.

In order calculate a threshold distance $d_0$ between sender and receiver.

REA-MDG algorithm has excelled LEACH protocol and SRC-WSN based on simulation results. The authors have concluded that more scalable methodology and multiple MDCs should be used in time constraint deployment.

### 8. Scheduling & Data Latency Reduction Techniques used in Case of Data Collection by MEs

During data collection procedure, the MEs visit the respective regions of the WSN to gather the data but it is known that the sensor nodes sense and recognize the data at different rates which signifies that the ME (may be a MS (Mobile Sink) or MR (Mobile Relays like MDC)) has to visit some sensor nodes more often and quickly than the other nodes so that the problems related to data loss like buffer overflow and energy depletion at the sensor node is mitigated. This requires some \textit{scheduling techniques which guide the tour of the ME} so that the freshness of data and timeliness parameters is maintained along with minimum data loss during data collection.

#### 8.1 Mobile Element Scheduling Technique (MES)\textsuperscript{25}

This technique suggested scheduling with respect to controlled mobility paradigm. The authors showed the difference between MES and TSP (Travelling Salesman Problem) whereby in TSP every node is visited only once where as in MES, the MDC can visit a node multiple times depending upon the frequency with which it (sensor node) collects the data. When the ME visits the sensor node for data collection, the \textit{re-visit time} is updated which denotes the time period before which the ME must visit the sensor node in order to prevent data loss due to buffer overflow at the sensor node. These re-visit times are also termed as deadlines which are updated in a dynamic fashion during the data gathering phase as elaborated by the authors. ILP is used for implementation of this scheduling technique and the algorithm is found out to be \textit{NP-Complete}. Two parameters are involved- cost matrix $[1..N][1..N]$ and buffer-overflow-time vector $[1..N]$ which determines the time required to traverse from one node to the next node and the time duration after which the buffer storage at the node will overflow respectively. The authors assumed that:

• The cost matrix and buffer-overflow-time consists of integer entity only.
• The buffer space of all the sensor nodes begin consuming up at the same time.
• The time required in transfer of data from the node to ME is negligible.

For updating the deadline value of the buffer, the authors proposed EDF (\textit{Earliest Deadline First}) algorithm in which input was – cost matrix, buffer-overflow-time and start node. Certain initializations were made:

• Current-time $= 0$
• current-node$= \text{start node}$,
• deadline $[1..N] = \text{buffer-overflow-time [1..N]}$

Steps of EDF:

• Selection of the next node whose deadline is nearest.
• Stop the process if deadline $[j]$ is less than the summation of current-time and cost $[\text{current-node}][j]$
• Else if the condition in step (ii) is false then update the following values:- current-time$= \text{current-time} + \text{cost [current-node][j]}$, current-node$= j$, deadline $[j] = \text{current-time} + \text{buffer-overflow-time}$

\textbf{Some of these Scheduling Techniques Proposed by Various Authors are Given Below:}
So the authors proposed the above min-weighted-sum-first algorithm and simulations showed that it performed well and computational cost was less.

8.2 Partition-based Scheduling Technique (PBS)

This method proposed a partitioning technique to divide the sensor nodes into different groups depending upon 2 parameters:

- Buffer-overflow time
- Distance metric which denotes distance of ME from that node.

Then the trajectory of the mobile element is devised so that there is minimum message-loss and buffer-overflow problems can be mitigated.

8.3 Multi-hop Route to the Mobile Element (MRME)

This idea proposed a Differentiated Message Delivery (DMD) technique which is a modification to PBS stated earlier. This technique included priority of the message to be transferred to the ME. It introduced new parameter known as- UM (urgent message) which are less often generated as compared with normal messages but they need special attention by the ME in terms of quick data gathering because these messages are more important and possess critical information which needs prompt response and hence must be delivered to the mobile element within the deadline specified so a multi-hop routing method is used in this technique. The authors showed that these UMs are less frequently produced therefore using a multi-hop mechanism to relay these UMs to those nodes which are most likely to be visited by the ME, will not cause any significant impact on WSN lifetime. Also the authors suggested that in case the transfer of UMs (to the nodes which are likely to be visited) take more time than their deadlines, then MRME algorithm reduces the buffer-overflow-time of some nearby nodes and minimizes the speed of ME to increase the chances of successful relay of UMs to these nodes.

8.4 Data Mule Scheduling Technique (DMS)

DMS proposed a scheduling technique in case of Data Mules proposed earlier in Jain et al. to optimize the moving pattern of mule in order to reduce message loss and reduce latency in data transfer. The authors formulated path selection problem (as shown in Figure 3) also termed as Label-Covering Tour (LCT) in order to calculate an optimized route for the data mule so that latency is mitigated to a greater extent. The DMS algorithm consists of following steps:

- Selection of path: It is a process of choosing an optimal path for the data mule.
- Speed control mechanism: It is a process of determining the magnitude of speed with which the mule traverses the path.
- Job scheduling: It is a process of selecting sensors which will exchange data with the mule at a stipulated time.

The authors proved this algorithm to be NP-Hard. An approximation algorithm was also suggested in this paper which made use of Euclidean distance as a cost metric and ILP (Integer Linear Programming) to calculate the lower bound of the problem. The algorithm was also applied in case of several data mules. Simulation results showed that this algorithm outperformed the previous ones and was successful in case of larger communication ranges. A semi-online algorithm was also proposed by the authors in case of scenarios where the communication range was not completely known in advance. The semi-online algorithm is more realistic and is best suited for uncertain locations and environment.

8.5 Latency Reduction Technique

A technique for lowering latency in case of data collection in WSN with Mobile elements was proposed. A combine-skip-substitute algorithm was proposed by the authors to optimize the tour and decrease tour-length so as to mitigate data collection latency using a progressive optimization approach. The algorithm uses a combination approach to group together all the nearby sensor nodes...
which are elected as cluster-head of their respective clusters and then finally skip and substitute other nodes in the region. The authors have modified Welzl's algorithm to combine and group nodes within a radius \( r \). This algorithm takes the following inputs: a. communication range \((r)\) between mobile element and sensor nodes. b. A subset of sensor nodes \((s)\). The output given by modified Welzl algorithm is- center point and radius \( r \) of the disc only when the subset \( s \) is covered completely by a disc of radius \( r \), else it returns false. To implement skip and substitute the authors used binary search method. The simulation results demonstrated that it out-performed various other heuristic approaches used earlier.

9. **Fuzzy Logic Implementation for Energy Conservation in WSN-ME**

The cluster heads play a vital role in data transfer as they are the one who are responsible for relaying data of all their cluster members to the base station or MDC. So the energy of these cluster heads must be maintained and conserved in order to mitigate energy depletion in WSN.

The authors proposed the use of fuzzy logic\(^{30}\) to manage the movement patterns of the mobile base-station in order to collect data from the static cluster heads such that the energy at the cluster heads is maintained. The authors made use of parameters like: energy of the cluster, size of the cluster and the distance of base station from the cluster head so as to assign a critical degree to the cluster head. Then the tour of base station is devised in such a way that the base station visits those cluster heads which are having a higher value of critical degree. Assumptions made in this approach are:

- Base station is mobile.
- All other sensor nodes are stationary.
- The sensors can adjust their transmission power according to their distance from the base station.
- All nodes in the WSN are of equal energy (homogeneous).

The authors used LEACH protocol to form clusters. Status packets are proposed in this paper which consists of information like-

- **Cluster head location**- the farther a cluster head is from the base station, greater is the energy consumption for data transfer hence more will be the critical value.
- **Number of members in cluster**- more the number of cluster members, greater will be the energy consumption for forwarding and collecting data by the cluster head hence more will be the critical value.
- **Energy of cluster head**- lesser the residual energy of the cluster head, greater will be the critical value.

All the cluster-heads send their respective status packets to the base station. The base station has to determine the cluster head with the most critical degree based on the values in the status packets and then plan a tour to it. To implement fuzzy logic: fuzzy rules, fuzzifier, fuzzy inference engine along with defuzzifier was used. The authors used **Mamdani method as a technique for fuzzy inference** and for defuzzification they used **center averaging technique**. To derive membership functions for cluster head's residual energy, distance from BS and number of cluster members; certain parameters were used like: initial energy of the cluster head, proximity from base station and density of network. It was found that membership function for:

- Cluster head proximity is directly proportional to the position of base station
- Cluster head's residual energy is directly proportional to the initial energy.
- Number of cluster members is dependent on the density of WSN.

**How the base station moves?**

The authors gave the following **steps for movement control of base station**:

- Formation of cluster and sending the status packet to base station for analyzing critical values
- Then the base station moves to a new location.
- Broadcasting the new address of base station in the entire network.
- Finally the cluster heads adjust their power needed for data transmission and begin data transfer.

The simulation results showed that this fuzzy scheme was efficient in terms of load distribution, lifetime of the network and the amount of residual energy of the complete network.

Similar techniques like **connectivity based data collection**\(^{32}\) and **Efficient Data Harvesting Mechanism**\(^{33}\) makes use of the level of connectivity between different sensor nodes in order to control the movement of
mobile sink and reducing multi-hop transmissions. In order to increase the lifetime of the wireless sensor network a novel technique called Energy aware Data Aggregation with Sink Relocation (EDASR)\(^\text{10}\) was proposed in which the base station changes its position according to the residual energy of the sensor nodes. It consists of 2 phases:

- Transmission range adjustment.
- Mechanism to relocate the sink based on residual energies of the sensor nodes.

10. Conclusion

This paper has given extensive information about mobility in WSN. All the existing concepts and theories related to WSN-ME are efficiently covered in this paper. It will give an insight to the readers and enthusiastic researchers and equip them with a good knowledge-base to carry on further work in this domain. The basic idea that this paper conveys is that energy has to be conserved at each and every level: be it at the static sensor node level, at the path selection level, at the job-scheduling level, delay mitigation level, clustering level, motion control level or residual energy level. So the future research problems will aim at optimizing energy consumption during all the phases of data collection and development of energy efficient algorithms which assist in reducing the overall energy depletion during data transmission.

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