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# MOBILE ENTITIES IN WIRELESS SENSOR NETWORKS: THEORY AND PERFORMANCE ANALYSIS

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*Abstract*

***Wireless Sensor Network (WSN) is a collection of intelligent sensors that can communicate to form a self-organizing network and can function without human intervention for a long amount of time. Traditionally, WSN was static, but due to the necessity of today's applications, there has been a paradigm shift from a static WSN to dynamic WSN. This dynamism can be realized by adding mobility to static WSN. Mobility can be added by introducing extra elements called Mobile Entities (MEs) like Mobile Sinks (MSs), Mobile Cluster Heads (MCHs), Mobile Relays (MRs) and Mobile Sensor Nodes (MSNs). Adding MEs to WSN has attracted much research interests because it can significantly improve the capability and functionality of the WSN by making it flexible to failures, ease data collection, increase energy efficiency, enhance connectivity, improve coverage and prolong network lifetime, so the full potential of MEs can be harnessed to yield maximum benefits in static WSN. The goal of this paper is to present a comparative study and performance analysis of few of the possible MEs in literature and based on the results and analysis the best ME can be chosen for the desired application.***

*Keywords:*

***Mobile Sink, Mobile Cluster Head, Mobile Relays, Network Lifetime, Theory, Metrics, Algorithms, Analysis, Simulations***

## 1. INTRODUCTION

WSN has become a promising technology in recent years and are applied in a variety of applications such as environmental monitoring, surveillance, event detections, wild animal tracking and in healthcare [2-6]. WSN are applicable where structured communications cannot be established in hostile and inaccessible terrains. The WSN can penetrate into such environment and can monitor and report an event which otherwise would be impossible. This is due to the recent advancement in Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated the development of smart sensors. A smart sensor [1] is a low power device equipped with one or more sensors, a processor, memory, power supply, radio and an actuator. These sensors are limited in processing capabilities, computing resources and are inexpensive. Once deployed the sensors sense, measure and gather information from the environment and transmit the sensed data to a base station from which the data is taken, processed and analyzed by field experts to take necessary decisions. The sensors derive its power from the battery whose energy is very limited. The sensor will fail if the battery is drained of its energy, which will need a replacement, but replacing the battery is a daunting task as the sensors are deployed in hostile environment. This condition will result in death of many sensors which will lead to network failure. This problem can be solved by using energy scavenging methods where the sensors rely on other secondary sources like solar cells as suggested in [7], but scavenging power from solar cells may not be a source of continuous power because solar cells cannot obtain power during cloudy days or during the night. So, once the sensor nodes are deployed in the field, the lifetime of the battery has to be extended through careful energy conservation schemes. A detailed comprehensive taxonomy on the energy conservation schemes is given in [7]. Power-saving strategies can be applied at the different layers of the protocol stack as given in [1]. The solution to conserve energy can either be done at the hardware or at the communication level of the network architecture. At the communication level, the network failure can be avoided by adding extra mobile elements called Mobile Entities to the static network. In this paper, some of the possible MEs that can be added to the static WSN are identified and their performances are compared and analyzed.

## 2. BACKGROUND AND RELATED WORK

The advantages of adding MEs into WSN are manifold. First, since sensors are deployed randomly, it is not possible to cover all the locations in the area to be monitored. To make this happen, the MEs can be moved to the necessary points in the monitoring area to get better samples of the data. Second, due to sparse deployment of sensors, the network is not properly connected. To correct this, necessary MEs can be moved to the necessary location for repair of broken or island of networks. Third, MEs can physically transport energy to regions where energy availability is scarce thereby balancing the energy consumption in the network. Further the MEs can also be used to share the workload of sensors with lesser energy. Some of the possible MEs identified and considered in this paper are the MS, MR and MCH. The detailed study of each of the MEs is described in the following sections.

### 2.1 MS APPROACH

The sink is a data collection point in the network, which receives the data sent by the sensors regularly or during an event. The sensed data is processed by the sink and sent to the base station for further action. In static WSN, the sink is placed at the center of the network region. Due to this, the sensors surrounding the sink will soon deplete their energy and die because these sensors have to transfer their own data and also forward the data for the other nodes to the sink. This will result in network partitioning where the sink will not be available to the other sensors. The authors in [8] define this as sink neighborhood problem. To prevent the early death of sensors at the sink neighborhood, an MS can be deployed which changes its location efficiently to collect data. Each time the MS changes its location the sink neighborhood also changes and thus enhances the network lifetime when compared to the static sink.

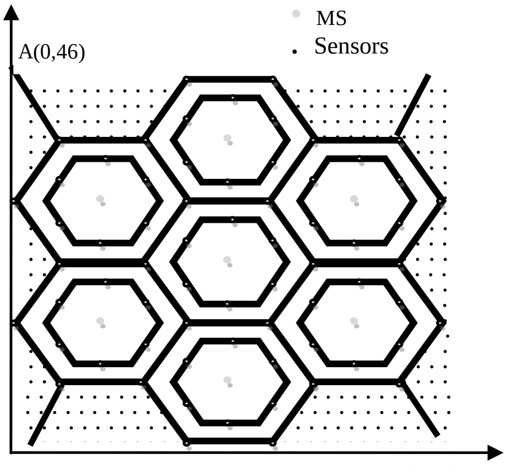

Fig.1. Hexagonal tiling for MS

The authors in [11] studies about the improvement of static sink over multiple MSs. The network area is divided into hexagonal tiling with large number of sensors and multiple MSs as in Fig.1. The MSs are interconnected at all times. First, the MS moves on a predetermined path along the perimeter of the hexagonal tiling and stops at the hexagon corners. This shows an improvement of 3.48 times over static sink. Network lifetime is further improved by 4.86 times when the MS stops at multiple locations in the hexagon. Since predetermined path is not energy conscious, the MS is made to move autonomously towards energy-rich nodes within each cluster.

In this distributed algorithm, the data-gathering period is organized into rounds of time T. At start of each period, clusters are formed with MS as the cluster-head. Data is sent along the tree formed during the cluster phase. The MS decides to move to a new location based on the energy of its 1-hop neighbors. If at least p% of the 1-hop sensors has less than the threshold energy $E_{th}$, the MS decides to move. The new location should have energy at least greater than the current location by $E'_{th}$ where, $E'_{th} = E_{th} + \alpha$ where, $0 < \alpha < 1$. If the new location is decided, the MS checks for the interconnectivity with other MSs and if it is connected the MS moves to the new location for the next data-gathering round. If there is no suitable location then the overall energy of the network is reduced, so the threshold energy is reduced by $E_{th} = E_{th} * \beta$ where, $0 < \beta < 1$. The results prove that predetermined and autonomous moving of multiple MSs increase the network lifetime significantly.

In half-quadrant-based moving strategy (HUMS) as presented in [12], the MS moves proactively towards the highest residual energy node in order to balance uneven energy depletion. The data-gathering period is divided into three phases. The first phase consists of the MS broadcasting a notification message to inform the sensor nodes of its position. In the second phase, the sensor nodes report their data to the MS in a multi-hop manner.

The MS determines and arrives at the new position in response to the residual energy status of the network during the third phase. The MS reaches its new position before the next data-gathering period begins. The MS always chooses the node with highest residual energy called as *movedest* to be its next location. The nodes with less energy called the quasi-hotspots are also considered in this algorithm. To make a decision to move, the MS sets up a coordinate system as in Fig.2, which will take its current position as the origin and divides the coordinate system into eight half-quadrants. The MS selects one of the eight quadrants which is free of quasi-hotspots and moves into it while making its way to the *movedest*. The precise sojourn position is calculated using the Minimum-Influence Position Selection (MIPS) algorithm.

The MS chooses four points in the arc of the selected sector and compares the composite force of all the quasi-hotspots in the network with the points in the arc. At the end, it selects the point which has the minimum composite force as the sojourn position. The main idea is that the MS while moving towards the highest residual energy node should always move away from quasi-hotspots. Simulation results show that this strategy not only extends network lifetime but also provides scalability and topology adaptability.

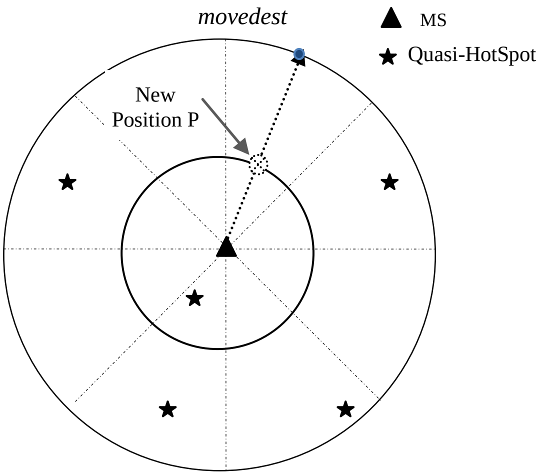

Fig.2. Eight sectors for the MS

In [10] an analytical model for load distribution in WSN using MS which changes location based on route traces is proposed. The lifetime maximization problem is formulated into a min-max problem. The mobility pattern is controlled and predictable. The best and the optimum strategy that maximizes the network lifetime is when the MS moves along the periphery of the network. This scheme improves lifetime without sacrificing latency.

The above-mentioned studies indicate the advantages of using the MS. The design issues to consider when building applications using MS are the reporting of MSs location to the nodes, its speed and multiple MSs coordination.

## 2.2 MR APPROACH

MR is a special node that has the same capability of a sensor node but with extra energy-provisions and higher buffer capacities. The functionalities of a MR are manifold. First, MRs are exploited to transport messages from the sensors to the sink.

Second, MRs are used to relieve the routing and transporting workload of regular nodes. Furthermore, the MR provides fault tolerance, network connectivity and improves network lifetime and scalability.

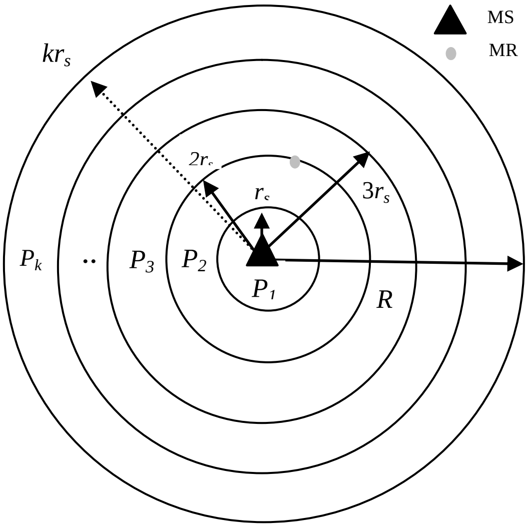

Fig.3. Network divisions for MR

In [13] a heterogeneous architecture with one energy-rich MR and a large number of static nodes is proposed as in Fig.3. The MR is introduced to lift the burden of the bottle-neck nodes around the static sink. The MR moves around the 2-hop distance from the sink and shares the load of the bottle-neck nodes to increase the lifetime of the bottle-neck nodes. A single MR increases the lifetime of the network by a factor of four when compared to a static network. The proposed joint routing and mobility algorithm routes the packet to the MR which in turn sends it to the sink. This algorithm requires that all the nodes need to know the location of the MR and achieves an upper bound on the network lifetime. Since the MR stays only within the 2-hop distance from the sink, it is enough that only the nodes within this region know about the location of the MR. So, Aggregation Routing Algorithm with Limited Nodes (ARALN) is designed which gives the same performance as the joint routing and mobility algorithm. Even though MR increases the network lifetime, the study shows that the MS always outperform the MRs. Therefore, in a densely deployed sensor field of radius R hops, we require O(R) MRs to achieve the same performance as the MS.

In [14] a three-tier architecture is proposed and analyzed to collect sensor data in sparse sensor networks. The bottom tier consists of the sensors, the middle tier the MULEs (Mobile Ubiquitous LAN Extensions) and the top tier consists of the wired access points which can be set up at convenient locations. The MULEs, which acts as MR, moves randomly to collect the data from the sensors, buffer and drop the packets at the wired access points. The sensors do not send the data by means of multi-hop communication to the sink, but passes the data to the MULEs as they pass by, which will result in considerable energy savings. The performance metrics observed are the data success rate, which is the fraction of generated data that reaches the access points, and the required buffer capacities on the sensors and the MULEs. This approach increases the latency of the packets as the sensors has to wait for a MULE to pass by its location.

The design issues for a MR are data collection by MR and its delivery to the sink, MR location information, speed of MR, number of MRs involved and their coordination.

### 2.3 MCH APPROACH

The problem of unequal energy distribution in the network can also be resolved by an MCH. The network is divided into clusters with an MCH for each cluster. Each sensor in the cluster is responsible for detecting and delivering the sensed data to the MCH. The MCH moves within its own cluster to change its neighborhood nodes so as to avoid the fixed set of sensors to continuously forward data to the MCH which may otherwise result in network partitioning. Thus an MCH can regulate the flow of energy among the sensors in the cluster and thus increase total network lifetime.

The idea of a MCH for enhancement of network lifetime using MCHs (LIMOC) in a WSN is given in [15]. The low-energy static sensor nodes sense physical parameters and route the data to the higher energy-rich nodes called MCHs which transmits data directly to the BS. Three mobile strategies are discussed based on (i) event, (ii) residual energy and (iii) combination of both (i) and (ii) i.e., hybrid mobility. The hybrid strategy makes moving decision based on the event as well as the residual energy. This strategy outperforms the other two by balancing the overall residual energy of the network. The MCH thus increases the network lifetime by about 75% compared to the other existing strategies.

The design issues of MCH strategy comprise of formation of clusters, choosing the MCH, cluster stability and coordination among MCHs.

## 3. CHARACTERESTICS OF WSN WITH MEs

The functionality of a WSN can certainly be enhanced by adding MEs to it. Any MEs whether it is MS, MR or MCH have certain common characteristics which are formulated below and compared in Table.1.

### 3.1 ARCHITECTURE

The heterogeneous WSN consists of few MEs and a large number of static nodes. This architecture can either be flat or hierarchical. The advantages of a hierarchical architecture are that it scales well with network size. The hierarchical architecture consists of the following tiers: Sensor tier, ME tier and base station tier. The ME tier is composed of MEs like MCHs, MSs or the MRs.

### 3.2 MOBILITY PATTERN

The mobility pattern of an ME can be classified into random, predetermined and autonomous. In random pattern, an ME moves in any of the four directions with equal probability without energy consciousness. This is applicable for delay tolerant networks. In a predetermined pattern, the ME moves in a predefined trajectory in concentric circles or along the hexagonal tilings, etc. This pattern too is not energy conscious and inflexible since the path has to be redesigned when there is a change in network size. In autonomous pattern, the ME takes the movement decisions based on the network conditions like energy, distance to move from the current to the new location, load, etc.

### 3.3 ALGORITHMS FOR MEs

The algorithms that can be used with MEs can be centralized, distributed or localized. In the centralized algorithm, all nodes send their data to the ME, which processes the data, takes decision, and sends back the output to the other nodes for further action. The centralized algorithm causes energy loss, undue delay due to the large network size. In distributed algorithms, various nodes along with ME involve in computation to make a decision. The computation at these nodes still depends on information sent by nodes that are located far from it. This reduces the execution time but the energy consumed for communication is still high.

A new class of algorithms called localized algorithms which are a special type of distributed algorithms are proposed where an ME makes a decision based on just the local (e.g., nearest neighbors) information. This reduces the flow of redundant information which enhances energy efficiency and thus results in longer network lifetime.

### 3.4 COMMUNICATION TO AN ME

The communication between the nodes and the ME can be either single or multi-hop. In single-hop communication, the nodes directly communicate with an ME. In multi-hop communication the nodes communicate with an ME through the intermediate nodes using a routing algorithm.

### 3.5 DATA AGGREGATION BY AN ME

The ME can be used to aggregate the similar data. The data generated by the sensors are redundant and can be aggregated by an ME using functions like suppression, compression, minimum, maximum and average. Thus sending the aggregated data reduces the number of transmissions and thereby reduces the energy consumption.

### 3.6 ROUTING WITH ME

The sensors route the data to the sink using multi-hop communication. This can be done independent of the ME using the shortest path or energy- aware routing algorithms. The MEs can also be jointly considered for routing and mobility.

Table.1. Characteristic Features of Various MEs

| Parameters | [10] | [11] | [12] | [15] | [13] | [14] |
|---|---|---|---|---|---|---|
| **Mobile entity** | MS | MS | MS | MCH | MR | MR |
| **Focus** | Load balancing | Avoid energy holes | Avoid quasi-hot spots | Avoid multi-hop communication | Maximization of network lifetime | Architecture for data-gathering |
| **Strategy** | Move the MS to spread the bottleneck nodes around the network | Move MS to zones of higher energy | MS moves away from quasi-hot spots | MCH approaches the sensors to collect data | MR takes the role of bottle neck nodes | MR to collect data as it nears sensors |
| **Parameters Considered** | Network lifetime, Load balancing | Network lifetime, Coverage, Time delivery | Network lifetime, Topology | Network lifetime | Network lifetime | Data success rate, Latency |
| **Architecture** | Flat | Flat | Hierarchical | Hierarchical | Flat | Hierarchical |
| **Mobile Pattern** | Periphery movement | Based on zones with high energy | Based on highest energy node | Based on residual energy& events | Concentric circles | Random walk |
| **Algorithm** | Distributed | Distributed and localized | Distributed and localized | Distributed and localized | Centralized | Centralized |
| **Multi-hop Communication** | Yes | Yes | Yes | Yes | Yes | No |
| **Data Aggregation** | No | No | No | Yes | Yes | No |
| **Routing** | MobiRoute | Shortest path routing | Location-based routing | Shortest path routing | Joint Routing and mobility | MR collect data directly from sensors |
| **Buffer capacities** | High | Medium | High | Medium | Medium | Very High |
| **Speed of ME** | Adaptive | Constant | Constant | Constant | Constant | Constant |
| **Number of MEs** | Single | Multiple | Single | Multiple | Single and Multiple | Multiple |
| **Applications** | Delay tolerant | Periodic data-gathering | Periodic data-gathering | Event Driven | Data Logging | Delay tolerant |

### 3.7 BUFFER CAPACITIES

The sensors are constrained in their resources and have a limited amount of memory. Hence they have a finite buffer capacity of temporary storage for small number of packets. Insufficient buffer capacity may result in the loss of data packets. MEs are not resource constrained and is designed to have high buffer capacity to move around the network to collect the data from the sensors.

### 3.8 MEs SPEED

The speed of an ME can either be constant or adaptive. When the speed of the ME is constant, it moves around the network with fixed speed to collect data periodically and returns to the starting point before the deadline is missed. In adaptive movement of the ME, it can either slow or increase the velocity according to the parameters of the network. In reality, the speed of the ME is limited, so it can result in longer delay for data collection which causes the sensors to lose their data packets. Data latency and packet loss is directly controlled by the speed of the ME.

### 3.9 NUMBER OF MEs

The number of MEs in the network can be single or multiple. A single ME in a network is easy to handle and maintain. If there are multiple MEs, they have to interact with each other and stay connected. The cooperation of MEs causes additional overhead.

### 3.10 APPLICATIONS WITH MEs

The WSN applications can be of three types, one is time-driven networks, where the data is gathered periodically and sent to the sink at regular intervals. Second is an event-driven network where nodes collect data only when an event happens. For example, fire in forest monitoring, gas leaks in industries, etc. Third is the query-driven network where the data is queried whenever it is needed. For example, to get the data about the region in a monitoring area where the temperature is above 45 degree. In all these applications, MEs can be added to enhance the functioning of the network.

Thus, the different characteristic features of various MEs considered from literature are enumerated in Table.1.

Table.2. Description of Performance Metrics

| Sl. No. | Performance Metrics | Description |
|---|---|---|
| 1 | Network Lifetime | This is the lifetime of the network until the death of the first sensor node. |
| 2 | Energy consumption per node | This is the total communication energy the node consumes in a time period for transmission and reception. |
| 3 | Residual energy per node | This is the amount of energy remaining in a node at a given time. |
| 4 | Data Latency | This is the time delay between the data generated at the source node and the data packets received at the sink. |
| 5 | Packet Delivery Ratio | This is the percentage of packets generated at the sensor nodes that are successfully delivered to the sink. |
| 6 | Route Dilation | This is the average path length used for routing of the proposed scheme to the optimal scheme. |
| 7 | Total Overhead | The overhead incurred for building routes, finding exact sojourn position, managing the mobility of the ME during the network operation time. |
| 8 | Network Coverage | The maximum area a network can efficiently monitor the service area with the deployed sensors. |
| 9 | Network Scalability | The ability of the system to retain all its functionality with the increase of network size. |
| 10 | Network Flexibility | The adaptability of the system to changes in the network, i.e., failure of a node, displacement of a node, topology changes, etc. |

Table.3. Performance Analysis of Various MEs

| Performance Parameters | [10] | [11] | [12] | [15] | [13] | [14] |
|---|---|---|---|---|---|---|
| **Network Lifetime** | 400% | 35 rounds | 59830 seconds | 2.5E-08 seconds | 130% | 175 time units |
| **Energy Consumption per Node** | 0.2 joules | 0.21 joules | $7.27*10^5$joules | 6180 milli joules | Medium | Low |
| **Residual Energy per Node** | Medium | High | High | 12,500 milli joules | $E_{re}(k, r)$ | Low |
| **Data Latency** | 0.212 seconds | Medium | Medium | 101time units | Medium | High |
| **Route Dilation** | 500% | Variable | Variable | Variable | 2(spr) | NA |
| **Network Scalability** | Low | -15 rounds | -45.5 seconds | High | 300% | 130% |
| **Network Flexibility** | Low | 18 rounds | 70.28 seconds | Medium | High | 98.96% |

## 4. PERFORMANCE ANALYSIS OF MES

The performance metrics of MS, MR and MCH are briefed in Table.2 and some of the metrics are analyzed and compared in Table.3. Based on the performance comparison, the best ME can be chosen for the desired applications.

### 4.1 DISCUSSION ON MS

[10] considers the optimal strategy of moving MS along the periphery. The energy consumption is 0.2 joules for each node in a data-gathering round. Network lifetime is improved by 400% over static network with a data latency of 0.212 seconds. The proposed routing strategy with MS yields 500% improvement over shortest path routing. This strategy can be applied to delay tolerant networks.

The distributed and localized algorithm by [11] increases the number of rounds by 35 rounds over the static network with an average energy consumption of 0.21 joules per node for a single round. Network lifetime is directly proportional to different network shapes and inversely proportional to the network size. The distributed algorithm with additional time-delivery requirement increases the delivery rate at the cost of network lifetime. The algorithm proposed is suitable for periodic data-gathering applications.

[12] method gives a significant increase in network lifetime of 59830 seconds over static network. It also gives better network flexibility and adaptability to irregular-shaped networks. The energy consumption per node is $7.27*10^5$ unit joules for a round. The energy consumption rate is directly proportional to the size of the network. This algorithm is suitable for periodic data-gathering applications and for networks that are scalable and flexible. The optimal periphery strategy in [10] outperforms HUMS and distributed and localized algorithm in [11]. The total overhead is high in the other two algorithms because it involves position notification of the MS to the sensors. The sensors also have to send extra packets to the MS to make decisions regarding its movement to new location and its exact sojourn position.

### 4.2 DISCUSSION ON MR

The single mobile relay proposed in [13] can at most improve the network lifetime by 130% over the static network. The network lifetime can be asymptotically improved by $4M$ times, where $M$ is the number of MRs in the network. The joint mobility and routing algorithms with one MR can asymptotically achieve the upper bound of lifetime four times that of static network. Routing dilation is two times that of shortest path routing (spr). The residual energy is given by [13] as $E_{re}(k, r)$, where $k$ is the ring in which the sensor lies and r is the transmission range of the sensor. This approach provides good network scalability and flexibility. Since the MR moves in a predetermined path the issues relating to energy are not considered.

The MR presented in [14] can be used in delay tolerant applications because of its high latency and poor packet delivery ratio. This algorithm provides good improvement in network scalability by 130% and network flexibility by 98.96%. Network lifetime increases by 175 time units over static network. This algorithm has not considered the issues relating to energy consumption. The sensors send the data directly to the MULEs through 1-hop communication, so the routing dilation parameter is not applicable (NA) in this application. Increasing the buffer capacity, the number of MULEs will definitely increase the data success rate and decrease latency in the network.

### 4.3 DISCUSSION ON MCH

The controlled and the hybrid mobility of the MCH proposed by [15] increases the residual energy by 75% over the existing approaches. The energy consumption per node is 6180 milli joules and network lifetime improvement over static network is 2.5E-08 seconds. The network lifetime can further be increased by aggregating the data at the MCH. This approach achieves better network scalability and network coverage. The total overhead is higher because of cluster head election, cluster formation, cluster maintenance, cluster head cooperation, etc. This approach is best suited for event-driven and query-driven applications.

## 5. SIMULATIONS

In this section, we exhibit the simulation setup and the results. The algorithms considered are developed using MATLAB. In all the simulations, we consider ideal MAC layer where there is no collision or retransmission of packets so as to avoid wastage of energy in this layer. The energy model used is the ideal radio model. Since we have considered ideal MAC and radio model, it can be assumed that if the node $n_i$ is within the radio range of the node $n_j$, both the nodes can communicate without packet loss.

The simulation is carried out with 100 sensors uniformly and randomly deployed in a square field of 100 m × 100 m. The sensors at the time of deployment have the initial energy of 5 joules each. Each sensor generates one packet (1000 bits) every round. The simulation parameters are listed in the Table.4.

Table.4. Parameters and values for Simulation

| **Parameters** | **Value** |
|---|---|
| Area side | 100 m, 100 m |
| Number of sensor nodes | 100 |
| Node Deployment | Random and uniform |
| Sensor Transmission radius | 10 m |
| Sink communication range | 20 m |
| Initial energy in each node | 5 J, 3 J |
| $E_{elec}$ | 50 nJ/bit |
| $E_{amp}$ | 100 pJ/bit/m$^2$ |
| Data Size | 1000 bits |
| Data routing | Shortest path routing |

The energy model described is very similar to [18], where the energy is utilized only for receiving and transmitting. The transmission energy requires additional energy to amplify the signal according to the distance from the destination. The energy consumption formula for transmitting *k*-bit data packet from a sensor $n_i$ to $n_j$, is given by Eq.(1).

$$E_{tx} = k.E_{elec} + k.E_{amp}.d_{ij}^2 \tag{1}$$

$$E_{rx} = k.E_{elec} \tag{2}$$

The parameters, $E_{elec}$ is the energy consumed to run the transmitter or receiver circuitry, $E_{amp}$ is the energy required for the transmitter amplifier, and $d_{ij}$ is the distance between $n_i$ and $n_j$. The energy consumed in receiving a *k* bit data packet is given by Eq.(2). The energy consumption of the sensors in the network is examined and recorded for every data-gathering round. In a data-gathering round, each sensor generates one packet and all the packets are relayed to the sink for processing.

The network region is divided into 10 × 10 cells and the average energy consumption for the cell is calculated. Fig.4 shows the snapshot of energy expended for a round in a static network where the sink is placed in the middle of the network. We infer from the figure the energy expended by the sensors near the static sink is high, and they tend to die faster resulting in early failure of the network.

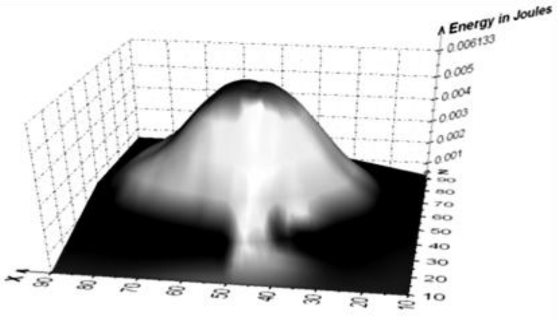

Fig.4. Energy distribution graph for static sink

The Fig.5 shows the snapshot of energy distribution when a multiple MSs [11] are added to the network. This graph clearly shows the equal distribution of energy expended throughout the network during a data-gathering round. We define the network lifetime as the time until which the first sensor runs out of energy in the network as given in [19].

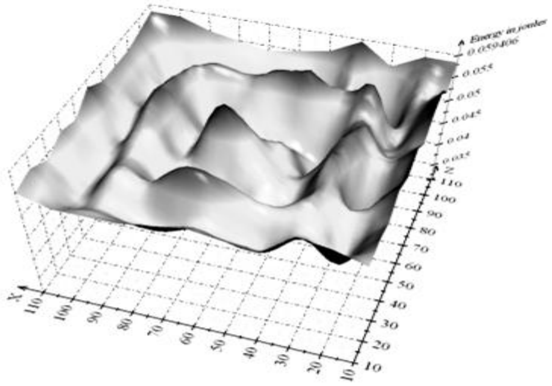

Fig.5. Energy distribution graph for Network with an ME

The network lifetime is compared for various MEs in Fig.6. The initial energy of all the sensors is considered to be 3 J. The MR is moved in a predetermined way as in [13], the MS moves in a distributed way to the highest residual energy node avoiding the quasi-hotspot as in [12] and the MCH moves in hybrid mobility considering the residual energy as well as the event as in [15]. The graph shows that the MEs significantly extend the network lifetime over the static network and the MS outperforms the MR and MCH.

The Fig.7 shows the average residual energy of the network of 200 sensors with 3 J of initial energy after 25, 50, 75, 100, 125, 150, 200 and 250 rounds respectively. The average residual energy drops suddenly in the static sink. In the case of MR and MCH the energy decreases gracefully. The degradation of residual energy in the case of the MS is minimum and constant. The MS is able to balance the energy consumption among the nodes and prolong the network lifetime.

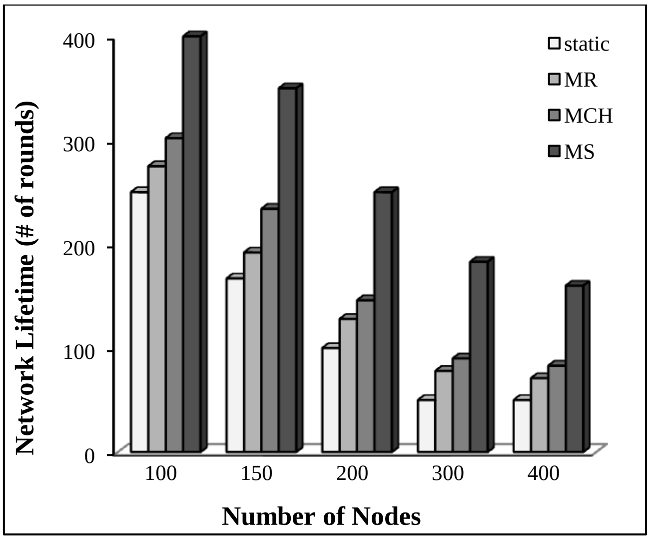

Fig.6. Network Lifetime for different MEs

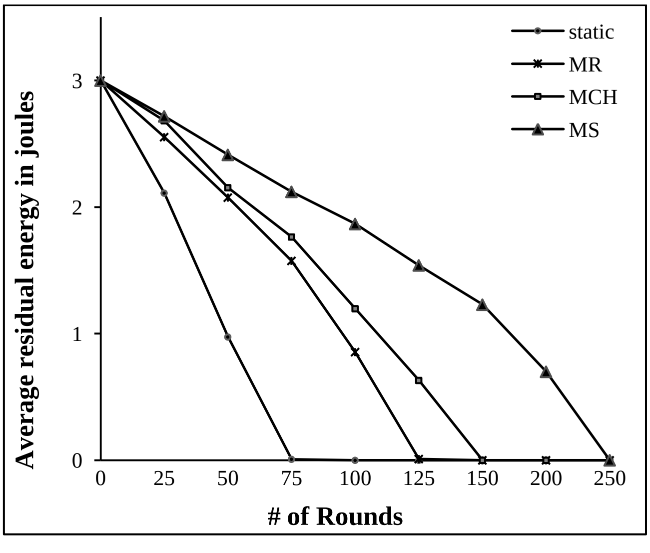

Fig.7. Average Residual Energy vs. Number of Rounds

## 6. CONCLUSION

The performance analysis of various MEs is given in Table.3. The analysis and the simulation results show that adding MEs to a static network definitely improve the performance of a network when compared to a static network. Out of the three MEs, MS outperforms MR and MCH. MS balances the energy consumption in the network and increases network lifetime, whereas MR and MCH increases energy efficiency and adapt to changing network topology. Though the MS increases the network lifetime, in certain applications MS is not feasible since the MS acts as a gateway and it also causes more routing overheads. So to increase the performance, MR or MCH has to be realized. It should be noted that failure of MS may result in network failure but even if an MR or MCH fails, the basic network functionalities will still be working, but it may not avail the services of MR or MCH. To conclude the above study, the MEs can definitely be added to a static network to improve the lifetime. Further it can also be useful to improve the tracking quality, reduce estimation error, to improve coverage, ease data-gathering and to keep the network connected.

## REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, “Wireless sensor networks: A survey”, *IEEE Communications Magazine*, Vol. 40, No. 8, pp. 102-114, 2002.

[2] K. Yunseop, R. G. Evans and W. M. Iversen, “Remote Sensing and Control of an Irrigation System Using a Distributed Wireless Sensor Network”, *IEEE Transactions on Instrumentation and Measurement*, Vol. 57, No. 7, pp.1379-1387, 2008.

[3] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk and J. Anderson, “Wireless sensor networks for habitat monitoring”, *Proceedings of the 1st ACM International workshop on Wireless Sensor Networks and Applications*, pp. 88–97, 2002.

[4] A. M. Mielke, S. M. Brennan, M. C. Smith, D. C. Torney, A. B. Maccabe and J.F. Karlin, “Independent sensor networks”, *IEEE Magazine on Instrumentation and Measurement*, Vol. 8, No. 2, pp. 33-37, 2005.

[5] G. Werner-Allen, J. Johnson, M. Ruiz, J. Lees and M. Welsh, “Monitoring volcanic eruptions with a wireless sensor network”, *Proceedings of the second European Workshop on Wireless Sensor Networks*, pp. 108–120, 2005.

[6] H. Baldus, K. Klabunde and G. Muesch, “Reliable Set-Up of Medical Body-Sensor Networks”, *Proceedings of First European Workshop on Wireless Sensor Networks*, pp. 353-363, 2004.

[7] Giuseppe Anastasi, Marco Conti, Mario Di Francesco and Andrea Passarella, “Energy Conservation in Wireless Sensor Networks: a Survey”, *Ad Hoc Networks*, Vol. 7, No. 3, pp. 537-568, 2009.

[8] S. Cui, A. J. Goldsmith and A. Bahai, “Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks”, *IEEE Journal on Selected Areas in Communications*, Vol. 22, No. 6, pp. 1089–1098, 2004.

[9] Stefano Basagni, Alessio Carosi, Emanuel Melachrinoudis, Chiara Petrioli and Z. Maria Wang, “Controlled sink mobility for prolonging wireless sensor networks lifetime”, *Wireless Networks*, Vol. 14, No. 6, pp. 831-858, 2008.

[10] Jun Luo and Jean-Pierre Hubaux, “Joint Sink Mobility and Routing to maximize the Lifetime of Wireless Sensor Networks: The Case of Constrained Mobility”, *IEEE/ACM Transactions on Networking*, Vol. 18, No. 3, pp. 871-884, 2010.

[11] M. Marta and M. Cardei, “Improved sensor network lifetime with multiple mobile sinks”, *Pervasive and Mobile Computing*, Vol. 5, No. 5, pp. 542-555, 2009.

[12] Y. Bi, L. Sun, J. Ma, N. Li, I. A. Khan and C. Chen, “HUMS: An autonomous moving strategy for mobile sinks in data-gathering sensor networks”, *EURASIP Journal on Wireless Communications and Networking*, 2007.

[13] Wei Wang , Vikram Srinivasan and Kee-Chaing Chua , “Extending the Lifetime of Wireless Sensor Networks Through mobile relays”, *IEEE/ACM Transactions on Networking*, Vol. 16, No. 5, pp. 1108-1120, 2008.

[14] Rahul C. Shah, Sumit Roy, Sushant Jain and Waylon Brunette, “Data MULEs: Modeling and analysis of a three-tier architecture for sparse sensor networks”, *Ad Hoc Networks*, Vol. 1, No. 2-3, pp. 215-233, 2003.

[15] Torsha Banerjee, Bin Xie, Jung Hyun Jun and Dharma P. Agrawal, “Increasing lifetime of wireless sensor networks using controllable mobile cluster heads”, *Wireless Communications and Mobile Computing*, Vol. 10, No. 3, pp. 313-336, 2010.

[16] Wei Wang, “Increasing Lifetime of Wireless Sensor Networks”, Ph.D. diss., Department of Electrical and Computer Engineering, National University of Singapore, 2008.

[17] Banerjee T. Agrawal, “Increasing Lifetime of Wireless Sensor Networks Using Controllable Mobile Cluster Heads”, Ph.D. diss., Department of Computer Science, University of Cincinnati, Cincinnati, OH, 2009.

[18] W. Heinzelman, “Application-specific protocol architectures for wireless networks”, Ph.D. diss., Massachusetts Institute of Technology, 2000.

[19] J. H. Chang and L. Tassiulas, “Energy conserving routing in wireless Ad-Hoc Networks”, *IEEE Proceedings of the Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, Vol. 1, pp. 22-31, 2000.