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PERFORMANCE EVALUATION OF MMS ROUTING FOR CAMPUS MONITORING WIRELESS SENSOR NETWORK

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ABSTRACT

In this paper, MMS (Multiple Mobile Sinks) routing algorithm which handles the sink node mobility is proposed in order to handle the overhead mobility, with maximum lifetime and energy efficiency, reduced end to end delay amidst topology changes for assured security for monitoring campus and environment control applications. In this MMS routing, multiple mobile sinks are used to collect the data from the wireless sensor network which is deployed around entire campus like university. The mobility of sinks makes the transmission of data from source node to sink node easier by reducing the number of intermediate router nodes. For each mobile sink, a particular region like department block is allotted and the performance of MMS routing with respect to region of interest and the total area of interest are studied. The impact of different mobility models are analyzed with MMS routing and found that the wind mobility model provides better performance. To enhance the performance of MMS routing, security is incorporated as a part of routing to avoid unauthorized data. This is achieved by using SSCA algorithm. The proposed algorithm is simulated using Matlab and Omnet++. Simulation results prove that MMS routing is well suited for monitoring class rooms or blocks as well as environment control applications.

Keywords: Multiple Mobile Sinks (MMS), symmetric ciphering, wind mobility.

1. INTRODUCTION

Recent advances in Wireless Communications and Electronics have enabled the development of tiny, low cost, low power, multifunctional sensors which are capable of sensing and data processing. These sensors have the ability to communicate either among them or directly to an external base station. Densely deployed sensor nodes can be networked in many applications like disaster assistance, environment control, intelligent buildings, preventive maintenance, facility management, logistics, telemetries, precision agriculture, military command control, medicine and healthcare.

A Wireless Sensor Network (WSN) contains hundreds or thousands of sensor nodes. In WSNs the network layer is used to implement the route to the sink node or base station to transmit the data. Unlike Mobile AdHoc Networks and Cellular Networks, routing in WSN is challenging due to the usage of large number of sensor nodes which leads to a high overhead ID maintenance. Thus the traditional IP based routing protocols cannot be applied to WSNs. Moreover in WSNs, the data is more important than sender's ID. It requires the flow of data from group of sensor nodes to the sink. In WSNs, sensor nodes require careful resource management, application specific design requirements and network dynamics leading to frequent topology changes. Also, position awareness of sensor nodes is important because data collection is based on the location.

Many new algorithms have been proposed for the routing problems in WSNs in the past decade. Even then, the mobility for sensor nodes is an issue under consideration. Routing protocols need to be improved or new protocols are to be developed to address higher topology changes and higher scalability. Routing techniques that explicitly employ fault tolerance in efficient manner are under investigation. Also current routing protocols optimize the limited capabilities of the nodes and the application specific nature of the networks.

2. RELATED WORK

Jonathan Henderson introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a cluster-based protocol, which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as cluster heads and rotates this duty to evenly distribute the energy spent among the sensors in the network. The cluster head nodes compress the data received from the sensor nodes belonging to that cluster and send the aggregated packet to the base station. Because of the aggregated data, the numbers of data transmission to the base station get reduced. LEACH uses TDMA/CDMA MAC protocol to reduce collisions. However, data collection is centralized and performed periodically. LEACH uses a TDMA/code-division multiple access (CDMA) MAC to reduce inter-cluster and intra-cluster collisions. Therefore, this protocol is well suited for constant monitoring applications. Authors found, based on their simulation model that only 5 percent of the total number of nodes need to behave as cluster heads. The operation of LEACH is split into two phases, the setup phase and the steady state phase. In the setup phase, cluster heads are elected and the clusters are formed. In the steady state phase, the data transfer from the cluster heads to the base station takes place. To minimize overhead the duration of the steady state phase is longer than the setup phase. Although LEACH is able to increase the network lifetime, there are still a number of issues. The issues are: it is not applicable to networks deployed in large area, dynamic clustering in this protocol brings extra overhead and there is the possibility that the cluster heads are concentrated in one part of the network; hence, some nodes are not connected to the network.

Wang (2007) proposed a Local Update-based Routing Protocol (LURP). Using this protocol the mobile sink needs only to broadcast its location information within a local area instead of the entire sensor network, as it moves. Their routing mechanism functions in various steps. At the beginning, the destination area or local area is set. Here the position of the mobile sink is at center with a predefined radius. Their static sensor nodes that located inside the destination area will route packets to the sink using a topology based routing scheme. After that nodes that are outside the destination area will route packets toward the center using a geographic routing scheme. Each time the mobile sink moves out of the current destination area, it needs to broadcast its location to the entire network. As the mobile sink moves inside its destination area it needs only to update its location inside its destination area.

3. SYSTEM DESCRIPTION

In Multiple Mobile Sinks (MMS) routing two, three or more sinks are used to collect the data from the network and the gathered data are directly forwarded to the base station. The sample wireless sensor network structure is shown in Fig.1. In the campus WSN, sensor nodes are deployed at the individual blocks and the mobile sink is carried by the respective in-charges who move around the campus. The following conditions are considered for MMS routing. All sensor nodes are static, homogenous and are aware of their geographic locations with low cost localization algorithm and they use the same geographic locations as their identity. It is also considered that there are no collisions between sensor nodes and the sink nodes during the movement of mobile sinks. At any time, all sensor nodes are linked with anyone of the sink node. Also data packets are generated in regular intervals by the sensor nodes. A step by step procedure of MMS routing is given in four steps below.

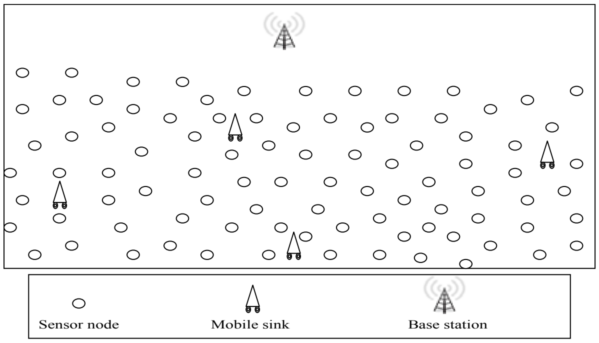

Figure-1. Campus wireless sensor network with mobile sinks.

Step-1: Determination of master node

Initially all sink nodes ie; in-charges in each block, send energy request message to the sensor nodes which reside in the sink's coverage area. In other words sinks broadcast the energy request message to single hop nodes. The sensor nodes present in the sink's coverage area, reply with the available energy information. After a preset delay, sinks identify the nodes with higher energy and set those nodes as master nodes. Master node is nothing but the dissemination node which is used to inform sink's location to all other nodes in the network except the single hop nodes which reside in the sink's coverage area. Let S_1, S_2, S_3, S_4, S_5, S_6 and S_7 be the single hop sensor nodes present in the coverage area of one sink node. Based on the request received from the sink node, all nodes in the coverage area i.e; S_1 to S_7 send their available energy to the sink node. From the reply message received from the single hop nodes, the sink node determines the master node that is the node with highest available energy. Since all single hop nodes sent their location as ID, the sink node identifies the ID of the master node from the energy reply message. ID is nothing but x and y coordinates representing the location of the sensor node.

Step-2: Information about Sink's location

The technique used to inform sink's location is flooding. In flooding, after getting the sink's location every node rebroadcasts the same message until all the nodes in the network know the sink's location. Some nodes may receive multiple messages due to flooding as stated by Linliang (2009). The nodes broadcast the sink's location only once even though they receive multiple messages. This reduces the reception of multiple messages. Sink's location is sent to all sensor nodes via flooding technique. Message flow diagram to inform all the sensor nodes about sink's location is shown in Fig.2. Sink's location information is stored or updated by each sensor node in destination location field allotted by the memory. Initially the destination location field in memory is empty. After the reception of the sink's location, the field is filled. In the network, when two or more sink nodes are present at the same time and even if any sink node changes its position then that sink's location must be updated. At every sensor node, the new location is compared with the present location and if found that the new location is closer than the present location then it is updated or else the present location continues. Thus irrespective of sink nodes the sensor nodes are with the nearest destination sink node. Let MS_1, MS_2, MS_3, and MS_4 be the mobile sink nodes in the wireless sensor network. For an example S_{15} is the source node with data and its location is (15, 15). (20, 40) is stored as the destination location which is the location of MS_3. Consider the location of mobile sink MS_1 is changed from (70, 35) to (50, 20). For S_{15}, the destination location (20, 40) is closer than (50, 20). So destination location is not updated by S_{15}. Next consider the location of the mobile sink MS_2 which is changed from (55, 45) to (30, 25). Since new location of MS_2 is closer than the present destination location stored in the memory, the destination location is updated by the sensor node S_{15}.

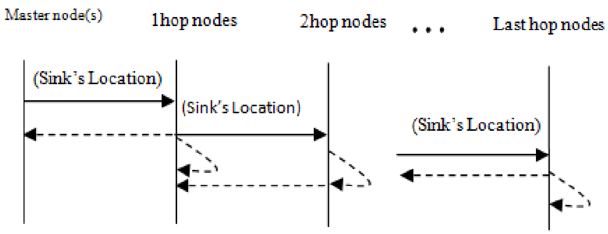

Figure-2. Message flow to inform Sink's location.

Step-3: Transmission of data

The sensor node with a sensed data is said to be the source node. The data from the source node has to be forwarded to the sink node via router sensor nodes. For this, as stated by Seada (2004) Geographic Forwarding Geocast (GFG) method is used. In GFG, the data is forwarded from the source node with the knowledge of node's geographic location as mentioned by Yan Yu (2001). Let S_s is the source node whose location is (5, 50) and the nearest sink is MS_2 and its location is (20, 40). The data from S_s is transmitted to MS_2 via router nodes S_{20}, S_{23} and S_7.

Step-4: Information about new location of sink

After a preset delay the sink node is moved to the new location. The new location of the sink node is informed to all the sensor nodes using step-1 and step-2. The sensor nodes are continued with step-3 after step-2 since the new location is known only at step-2.

3.1 RoI consideration in MMS routing

In MMS routing, all sink nodes are allowed to move in the entire sensing field which is considered as Area of interest (AoI). Data are generated at regular intervals of time. Sink nodes change their location at regular intervals of time. The data from the source node is forwarded to the sink node present in the nearest geographic location. But to improve the performance of MMS routing, each sink node is defined with its region to move which is considered as Region of interest (RoI) in the sensing field. Sink nodes are moved only in their defined region. It is not necessary that there must be only one sink in RoI, it can be even more. In other words two or more sink nodes are possible to be defined with same region. Moreover data are generated randomly. Route request message is sent by the source node to the sink node whose location is stored in the source node. Number of route requests received by the sink node from any of the quadrant in the region is more than a threshold value then the sink node move towards that quadrant. Number of route requests received by the sink node from the same region is less than a threshold value then the sink node remains in the same position. After sending the route request the source node waits for a new sink's location update message until preset delay ends. If new location is received by the source node then it updates the location. Otherwise the source node sends the data to the sink node whose location is already stored. For example, if AoI is divided into two RoIs with four mobile sinks MS_1, MS_2, $MS_3$and MS_4, then RoI_1 is the defined region for MS_1 and MS_2. The RoI_2 is the defined region for Ms_3 and MS_4. Let, initially the mobile sink MS_1 is present in the first quadrant of RoI_1, four source nodes are present in the second quadrant of RoI_1. The source nodes send the route request message to MS_1. Since location of MS_1 is stored in the source nodes. After receiving the multiple route requests the MS_1 decides to move to the second quadrant. The new location of the MS_1 is sent to all the nodes. After updating the new location of the sink node, the source nodes transmit the data to the sink node. Likewise AoI is divided into four or more RoIs based on the number of sinks. In this scenario, every mobile sink node is defined with a particular region. In other words only one sink node is present in any RoI. The RoI corner coordinates are stored in the mobile sink node in the case of rectangular or square sensing field. Also every sink node calculates its quadrant in the RoI using its location. So at any time, the mobile sink nodes are known with their RoI and their quadrants. Since corner coordinates are known by sink node, the mobility is easily restricted within the area. RoI consideration is only for the mobile sink nodes not for sensor nodes. So any mobile sink node can receive data from the sensor node residing in other RoI.

Since area of travel is reduced for the mobile sink node the energy spent for location update is reduced. Moreover increased location update interval cause reduced energy spent. Also mean end to end delay is reduced in RoI consideration compared to basic MMS routing which in turn reduces the number of dropped packets. Altogether the overall performance of MMS routing is better with the consideration of RoI.

3.2 Mobility consideration in MMS routing

In MMS routing, all sink nodes are allowed to move in the entire sensing field in random mobility pattern. Data are generated at regular intervals. Sink nodes change their location at regular intervals. The data from the source node is forwarded to the sink node present in the nearest geographic location. In the present study, the memory-less model is compared with memory based model. Among the memory-less model, random way point mobility model is selected for comparison. Also among the memory based model, geographic based mobility model is selected for comparison. Again from the geographic based model, circular path mobility model and wind mobility model are selected. These three mobility models are used in MMS routing and the MMS routing performance is compared. In the random way point model, the new position of the mobile sink node is determined with random velocity and random direction. The random way point mobility model with sixteen static positions are considered. These static positions are nothing but the pause time during mobility. Based on this model the time taken to reach each static position is calculated. Also energy spent to reach the positions is determined. Since new location of the sink node is independent on present location, memory is not required to hold the present location during new location determination. Because of this, random way point mobility is considered to be a memory less model.

Also the mobility model for sink nodes is described as pathway mobility to obtain the impact of geographic based mobility model in MMS routing. Among the geographic based models, circular and octagon paths are selected. Mobility path of mobile sinks are selected without overlapping the paths of other mobile sinks as well as with overlapping in their paths. In the circular mobility, the sink nodes follow the circular path. Data are collected during the pause time or at static position by the sink nodes. Let x, y are the coordinates of the initial position, 'r' is the radius of the circular path and the sink nodes move with a velocity, v (m/sec) then the next static position is obtained using the equations

$$x(new) = x + r\cos(\alpha) \tag{1}$$

$$y(new) = y + r\sin(\alpha) \tag{2}$$

Here x (new), y(new) coordinate indicate the next static position and 'α' is the suspended angle between previous and new position. In the same way the circular path mobility path of two or more sinks with 16 static positions are considered. According to this scenario, during mobility, the sink node remains static for sixteen times per cycle. Number of static positions is varied depends on the density of the sensor nodes. Since data are collected only at the static positions which are also called as collection points. Different mobile sinks with and without overlapping in their paths are used in MMS routing. Network performance is same in both scenarios. Wind mobility model is the model used to enhance the lifetime of the network. Wind mobility is nothing but the mobility in which direction of movement is based on the eight standard directions.

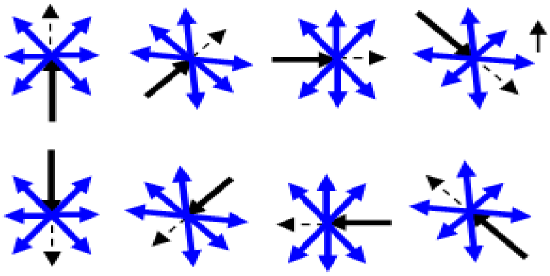

Figure-3. Possible directions of wind flow based on eight standard directions.

If wind flows from one direction the possible next flow directions are represented in Figure-3. In the figure, the black arrows show the present direction of the wind. The blue arrows show the possible next flow directions. The dotted black arrows show the next flow direction indicating that it is same as the present direction. Let the sink nodes travel towards North direction. The next possible direction can be any one of the six directions SE, E, NE, NW, W and SW. Since wind cannot blow immediately backwards at a same time with the same speed, the South direction is neglected from the possible directions. Moreover if it follows the same North direction, the length of movement will be increased rather there is no change in the direction. So this direction is also omitted in the possible next directions of movement. The same modeling technique is incorporated for mobile sinks. If a mobile sink travels in one direction after its waiting time in the static position, it can select any one of the six possible directions of movement. Difference in angle with respect to the present direction will be either 45°or 90° or 135° in either clockwise or anticlockwise directions.

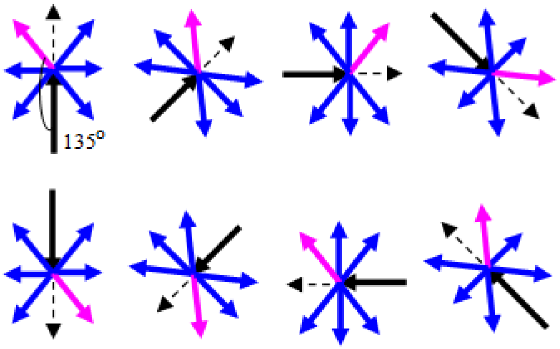

Figure-4. 135° Directions – Anticlockwise.

For the analysis, angle difference of 135° is considered since 90° gives only rectangular or square paths and 45° gives a near location to the present location. For the standard eight directions, the possible 135° directions are shown in Fig.8 and Fig.9. In both figures, the pink lines show the selected next directions. Suppose the eight directions are followed either in clockwise or anticlockwise direction. They move in one by one in order with equal time and speed then the mobility path will look like an octagon with equal sides. It is similar to circular mobility but gives notable difference in energy spent for mobility and location update. The octagonal mobility paths of a two or more sinks with 16 static positions are considered. The same direction of movement is followed for the immediate next movement and after two movements again directions are changed in 16 static positions strategy. In case, if only 8 static positions are followed then the angle of direction is changed every time after the wait time in the static position.

3.3 Security in MMS routing

Wireless sensor network is mainly used for data collection. If any attacker nodes present inside the network, they will send the false data to sink nodes which may in turn shutdown the entire network as explained by Chris Karlof (2003) and Dirk Westhoff (2006). In MMS routing, locations of sink nodes are informed by the master node to all nodes by means of flooding without any security verification. In order to avoid the inclusion of unauthorized data, Simple Symmetric Ciphering with Authentication (SSCA) algorithm is used with routing. By this secure routing, the sink's location is securely transmitted to all the nodes. To achieve this, two simple algorithms are stored in all the sensor nodes and the sink nodes. One of the algorithms is simple symmetric ciphering algorithm and another one is authentication algorithm. Before deployment, all the sensor nodes and the sink nodes are known with the symmetric key. The same key is used for authenticity.

The step by step procedure for SSCA algorithm in the MMS routing is given below.

Step-1: Determination of master node

Initially all sinks send energy request message to the sensor nodes which reside in the sink's coverage area. In other words sinks broadcast the energy request message to single hop nodes. The sensor nodes present in the sink's coverage area, reply back with the available energy information. After a preset delay, sinks identify the nodes with higher energy and set those nodes as master nodes. Master node is nothing but the dissemination node which is used to inform sink's location to all other nodes in the network except the single hop nodes which reside in the sink's coverage area. Based on the request received from the sink node, all nodes in the coverage area send their available energy to the sink node. From the reply message received from the single hop nodes, the sink node determines the master node that is the node with highest available energy. Since all single hop nodes sent their location as ID, the sink node identifies the ID of the master node from the energy reply message.

Step-2: Information about Sink's location

Sink nodes' location information is encrypted by sink nodes and is given to the master node. Master node is the sensor node which floods the location information of the sink node to the entire network. The technique used to inform sink's location is flooding. In flooding, after getting the sink's location every node rebroadcasts the same message until all the nodes in the network know the sink's location. The message flow to inform sink's location is shown in Figure-5.

$$\text{Sink node} \xrightarrow{E_K(\text{Sink's Location})} \text{Master node}$$

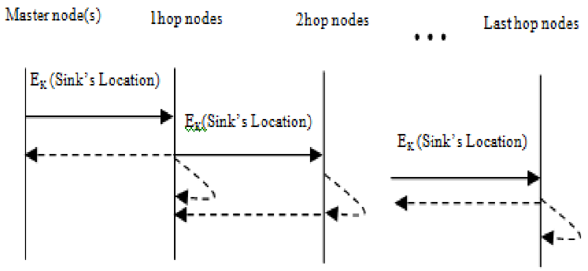

Figure-5. Encrypted message flow to inform sink's location.

Sink's location is encrypted using Simple Symmetric Ciphering algorithm. The encryption algorithm is as follows:

- $LMS \oplus K' = IMO1$
- Complement the IMO1 = IMO1'
- $IMO1' \oplus K = IMO2$
- $IMO2 = IMO2(1) \parallel IMO2(2) \parallel IMO2(3) \parallel IMO2(4)$
- $IMO2(1) \oplus K \parallel IMO2(2) \oplus K' \parallel IMO2(3) \oplus K \parallel IMO2(4) \oplus K' = EO1 \parallel EO2 \parallel EO3 \parallel EO4 = EO$
- $EO = EK(LMS)$

where L_{MS} is the Mobile Sink's location, IMO is the intermediate output and IMO_1' is its complement form. Also K and K' are the true and complement form of 80-bit key. $IMO_{2(1)}$, $IMO_{2(2)}$, $IMO_{2(3)}$ and $IMO_{2(4)}$ are obtained by dividing the IMO_2 into 4 equal parts and they represents first, second, third and fourth parts respectively. EO is the encrypted output and is obtained by concatenating EO_1, EO_2, EO_3 and EO_4. In other words EO is the encrypted form of sink's location.

Step-3: Transmission of Data

All sensor nodes receive the encrypted form of mobile sink's location already by flooding. At every node it is decrypted using the algorithm given below. Decryption algorithm is the reverse of encryption algorithm used in the previous step. The Decryption algorithm is as follows:

- $E_K(L_{MS}) = EO$
- $EO = EO1 \parallel EO2 \parallel EO3 \parallel EO4$
- $IMO2(1) = EO1 \oplus K; IMO2(2) = EO2 \oplus K'; IMO2(3) = EO3 \oplus K; IMO2(4) = EO4 \oplus K'$
- $IMO2(1) \parallel IMO2(2) \parallel IMO2(3) \parallel IMO2(4) = IMO2$
- $IMO2 \oplus K = IMO1'$

- Complement the IMO1'

where L_{MS} is the Mobile Sink's location, DO is the decrypted output. In other words it is the sink's location.

Once decryption is performed then the sensor node knows about the sink's location. Then the data from the source node is forwarded to the sink node via router sensor nodes. Initially the source sensor node verifies authenticity of its single hop neighbouring nodes. Authentication is done with the help of intermediate results of same simple symmetric ciphering. D_{AU} is calculated at the source sensor node as,

$D_{AU} = IMO_1 \| L_{MS} \| IMO_2$ and is transmitted for authentication verification as, $IMO_1 \| L_{MS} \| IMO_2 \| L_{SN} = D_{AU} \| L_{SN}$ where L_{SN} is the location of the sensor node.

Let S_S be the source sensor node and it has one hop neighbours, S_A, S_B and S_C sensor nodes. Also S_B present in the forward path towards the sink's location. Initially S_S verifies the authenticity of S_A, S_B and S_C sensor nodes. Also S_A, S_B and S_C sensor nodes verifies authenticity of S_S.

If D_{AU} (single hop node) = D_{AU} (source sensor node) then the single hop node belongs to the same network.

If D_{AU} (single hop node) $\neq$ D_{AU} (source sensor node) then the single hop node does not belong to the same network. So it can be an attacker node.

Once authenticity is verified, the source sensor node forwards the data to the authenticated single hop node in the forward path of sink's location. Here if S_S, S_A, S_B and S_C sensor nodes are authenticated then S_S forwards the data to S_B sensor node. Since S_B is present in the forward path towards sink's location.

Step-4: Information about new location of sink

After a preset delay the sink node is moved to the new location. The new location of the sink node is informed to all the sensor nodes using Step-1 and Step-2. The sensor nodes are continued with Step-3 after Step-2 since the new location is known only at Step-2. To perform the Step-3, source node finds the authenticated neighbor in the forward path from the list of authenticated nodes which are stored already in the sensor node. In Simple Symmetric Ciphering with Authentication algorithm, the key used for encryption and decryption are same and is given to the nodes before deployment which avoids the key theft by the attacker because key distribution is the major problem in the network. Since authenticity is verified for all the nodes it is not possible to include the false data by the attacker. For an attacker it is hard to find the symmetric key and the determination of sink's location information. So by this simple SSCA algorithm it is easy to avoid the false data inclusion.

3.4 Metrics evaluation

WSN is considered with side length 'L' and 'N' number of sensor nodes randomly distributed. It is assumed that the sink changes its position 'm' number of times within a time period 'T'. Radius of the destination area is given by 'R' in case of single mobile sink (LURP)

- LS =DO= IMO1 $\oplus$ K'

and 'r_1' and 'r_2' are the radius of the coverage area in case of two mobile sinks (MMS). It is also continued for three and more mobile sinks. The velocity of the mobile sink is given by 'v'. The energy spent to update the new location of the sink in each node is considered as 'h' joules. Thus the total cost to update the new location of the sink is given by (3) (Wang 2007).

$$E = mnh + \left(\frac{T}{t}\right)Nh \tag{3}$$

where 'n' is the number of nodes in the coverage area of the sink and 't' is the period of time consumed by the sink to move out of the coverage area. Here 'n' is equal to number of single hop nodes with respect to the mobile sink node. Also 'm' is the number of times the sink changes its position. The value t increases with increase in 'R' or 'r_1' and 'r_2' and decreases with 'v' which is expressed in (4).

$$t \propto \frac{R}{v};\ t = \alpha\frac{R}{v} \tag{4}$$

where α is the proportionality constant. Also m depends on 'T' and 'v'. ie; as 'T' increases 'm' increases and also as 'v' increases 'm' increases which is given in (5).

$$m \propto Tv;\ m = \beta Tv \tag{5}$$

where β is the proportionality constant. Now the energy consumption for update can be rewritten as in (6).

$$E = \left(\frac{\beta Tv\pi R^2}{L^2} + \frac{Tv}{\alpha R}\right)Nh = NhTv\left(\frac{\pi R^2\beta}{L^2} + \frac{1}{\alpha R}\right) \tag{6}$$

For minimum energy computation,

$$\frac{dE_1}{dR} = 0 \text{ which gives } R^3 = \frac{L^2}{2\pi\alpha\beta}\text{, thus } R = \sqrt[3]{\frac{L^2}{2\pi\alpha\beta}}$$

$$E = \left(\sqrt[3]{\frac{\pi}{4\alpha^2\beta^2L^2}}m + \frac{T}{t}\right)Nh$$

$$= \left(4^{\frac{-1}{3}} m\left(\frac{\pi}{\alpha\ \beta^2L^2}\right)^{\frac{1}{3}} + \frac{T}{t}\right)Nh$$

Thus for the large networks, energy decreases with increase in length of the network. With a single mobile sink strategy, the energy spent for updating the new location of the mobile sink in each node in the network is given in (7).

$$E_1 = NhTv\left(\frac{\pi R^2\beta}{L^2} + \frac{1}{\alpha R}\right) \tag{7}$$

Energy spent for the above derived with two mobile sink is given in (8).

$$E_2 = \frac{N}{2}hTv\left(\frac{r_1^2\pi\beta}{LL_1} + \frac{1}{r_1\alpha}\right) + \frac{N}{2}hTv\left(\frac{r_2^2\pi\beta}{LL_2} + \frac{1}{r_2\alpha}\right) \tag{8}$$

Thus the generalized equation for cost update is derived and is as (9).

$$E_n = \frac{N}{n}hTv\sum_{i=1}^{n}\left(\frac{r_i^2\pi\beta}{LL_i} + \frac{1}{r_i\alpha}\right) \tag{9}$$

The same radio model as stated in [7] is used with E_{elec}=50nj/bit as the energy being dissipated to run the transmitter or receiver circuits and E_{amp}=100pJbit/m2 as the energy dissipation of the transmission amplifier. The energy cost of transmission and reception for common sensor nodes is calculated as shown in (10) and (11).

$$E_{Tx}(k,d) = E_{elec} * k + E_{amp} * k * d^{\lambda} \tag{10}$$

$$E_{Rx}(k) = E_{elec} * k \tag{11}$$

with 'k' is the length of the message in bits, 'd' is the distance between transmitter and receiver nodes and 'λ' is the path- loss exponent.The costs for every location update of each sink for AoI routing and RoI routing are given in (12) and (13).

$$E_{AoI} = mnh + \left(\frac{T}{t}\right)Nh \tag{12}$$

$$E_{RoI} = NhTv((\pi R^2\beta)/L_1^2) + (1/\alpha R) \tag{13}$$

The energy spent to update the locations of the sink nodes each time is determined and the cost for one full cycle (either 8 stop points or 16 stop points) is calculated. For random way point mobility, the energy spent is given in (14).

$$E_n = \frac{N}{n}hTv\sum_{i=1}^{n}\left(\frac{R_i^2\pi\beta}{L(rand(v,d))} + \frac{1}{R_i\alpha}\right) \tag{14}$$

For circular mobility the energy spent is given in (15).

$$E_n = \frac{N}{n}hTv\sum_{i=1}^{n}\left(\frac{R_i^2\beta}{r^2L} + \frac{1}{R_i\alpha}\right) \tag{15}$$

For wind mobility the energy spent is given in (16).

$$E_n = \frac{N}{n}hTv\sum_{i=1}^{n}\left(\frac{R_i^2\pi\beta}{La^2(2+2\sqrt{2})} + \frac{1}{R_i\alpha}\right) \tag{16}$$

The total energy spent for executing SSCA algorithm is the energy spent for secure routing (E_S) which is given in (17).

$$E_S = e_E + e_D + e_A + e_M \tag{17}$$

where 'e_E' is the energy spent for encryption at the sink node, 'e_D is the energy spent for decrypting the sink's location information in the sensor nodes, 'e_A' is the energy spent for authentication verification by the node with its neighboring nodes and 'e_M' is the energy spent to store and to check the authenticated nodes in its memory. Here 'e_E' is same as 'e_D'. The energy for encryption is spent only once at each mobile sink while updating the new location whereas the energy for decryption is spent by all the nodes for every update. That is given in (18) as mentioned by Nesrine (1997).

$$e_D = N e_E \tag{18}$$

Further 'e_A' can be determined based on the total number of nodes in the forward path or the hops.

4. SIMULATION RESULTS

Simulations for all the three scenarios are carried out with m = 30, v = 10 m/s, L= 500m and alpha = 2. The energy spent to update the location of the sink and average delay over number of nodes for MMS algorithm with two, three and four sinks are determined and is compared with LURP. Simulations are carried out in OMNeT++ 4.1 IDE with MiXiM Framework and also using Matlab. MiXiM is a mixed simulator for wireless and mobile networks using OMNeT++ simulation engine. Using this only the networks can be simulated not the individual nodes. Each sensor node is designed by understanding the logical layers of WSN and is developed as a NED file using the supporting files. Sensor nodes are combined to form the WSN. Sub modules of individual nodes as well as sub modules of the compound modules like NIC are defined. Tables-I, II, III and IV are given the values of network settings, physical layer parameters, channel control parameters and battery parameters respectively.

Table-1. Network settings.

S. No.	Network settings	Value
1	Playground size X	500m
2	Playground size Y	500m
3	Sensor nodes	>100
4	Sinks	2/3/4
5	Sink mobility	RM/CM/WM
6	Sensor node mobility	null

Table-2. Physical Layer Parameter.

S. No.	Physical layer parameters	Value
1	Transmitter power	1.0mW
2	Sensitivity	-85dBm
3	Path loss alpha	2
4	Thermal noise	-110dBm
5	SNIR threshold	4dB

Table-III. Battery parameters.

S. No.	Battery parameters	Value
1	Battery capacity	25 mAh
2	Mean time to failure	-1s
3	Battery resolution	1s
4	Usage Cpu active	7.6 mA
5	Usage Cpu sleep	0.237 mA
6	SNIRthreshold	4dB
7	Publish time	20s
8	Usage radio_idle	0.37mA
9	Usage radio_recv	19.47mA
10	Usage radio_sleep	0.02mA

Table-4. Channel control parameters.

S. No.	Channel control parameters	Value
1	Carrier frequency	2.4GHz
2	pMax	2.0mW
3	sat	-85dBm
4	alpha	2
5	Number of channels	27

The output obtained for energy spent to update the new location of the sink with respect to number of sensor nodes deployed in the sensing field is shown in Figure-6. When LURP is used, the energy spent to update the new location of the sink is reduced atleast by 1mJ from MMS with two mobile sinks scenario for 5000 nodes deployment. This deployment. This reduction in energy spent is because of only one mobile sink and all the nodes have to update only one mobile sink's location. Similarly when MMS with three or four mobile sinks are used the energy spent to update new location of the sink is increased at least by 2mJ or 3mJ from LURP. But the energy spent to update the destination area in LURP is higher than MMS due to the consideration of single hop coverage area of a mobile sink in MMS routing. Moreover the overall energy spent for updating the new location is compensated by reducing the number of updates. Thus the overall energy spent for location update for one complete cycle is almost equal in MMS routing compared to LURP. This is shown in Figure-7. Since the number of new locations of a mobile sink per cycle is high in LURP ultimately the number of updates for LURP is also high compared to MMS. Moreover the number of updates is less when MMS routing is used with more sinks. This is shown in Fig.8. Since in LURP local area is set as the destination area, radius of the destination area is high. Moreover within the destination area there will be a multihop communication. But in MMS routing, since the destination area is considered to be the coverage area of the mobile sink, the radius of coverage area will be low. Moreover there will be only single hop communication. The number of new locations required to the area in one cycle with respect to radius is shown in Figure-9. The energy spent will be more in LURP if the radius is lower or higher than certain limit. The optimum value for radius is calculated around 75m based on the output obtained by the LURP authors. LURP spent more energy in accordance with the selection of destination area of the mobile sink node because it is not possible to select the optimum radius always. But in MMS depends on the characteristics of the node there will be a change in the radius of coverage. Since single hop communication is performed within the coverage area it is not necessary to worry about the selection of optimum radius of coverage. So MMS routing can be used for different types of applications. Energy spent for communication from a single source node to mobile sink node is shown in Figure-10. Since number of hops in MMS is reduced, energy spent for communication is reduced. Also changes in total energy spent due to the changes in velocity are shown in Figure-11. Moreover if the velocity of the mobile sink is increased the total energy spent is more. One of the causes for this action is because of the energy spent for mobility. The energy spent for location update with respect to time to reach the new location and due to the changes in the number of nodes is shown in Figure-12 and Figure-13.

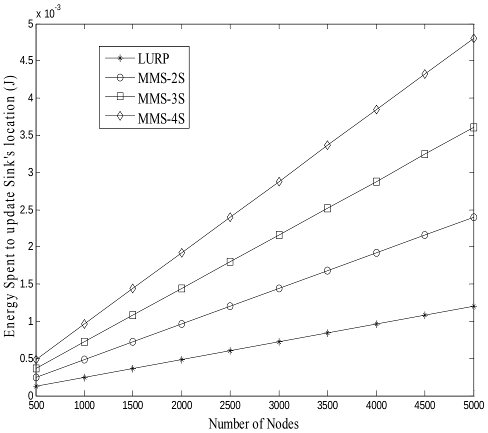

Figure-6. Energy spent to update Sinks' location.

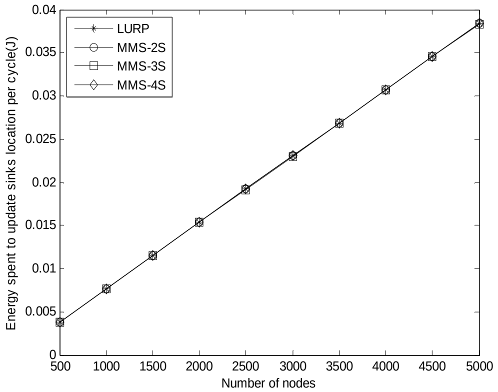

Figure-7. Energy spent to update Sinks' location for one cycle.

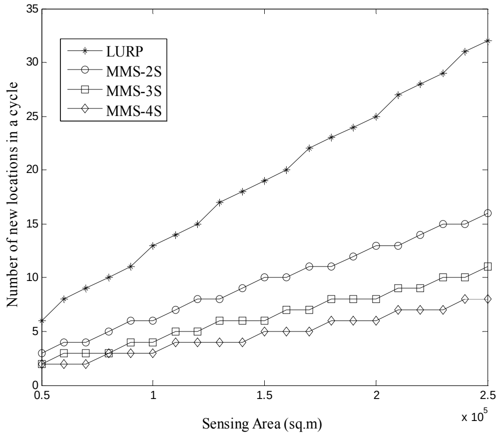

Figure-8. New locations in one cycle w.r.to sensing area.

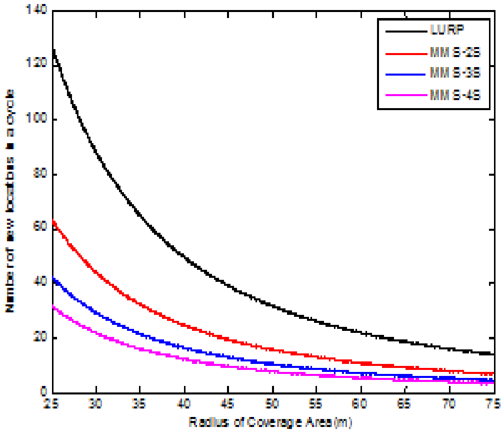

Figure-9. New locations w.r.to radius of coverage/destination.

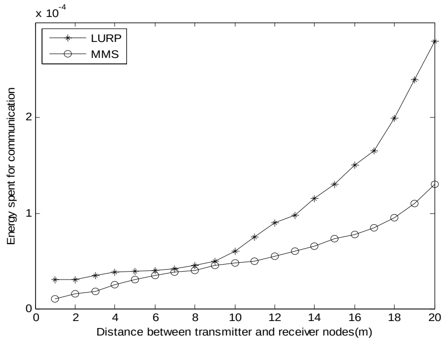

Figure-10. Energy spent for communication.

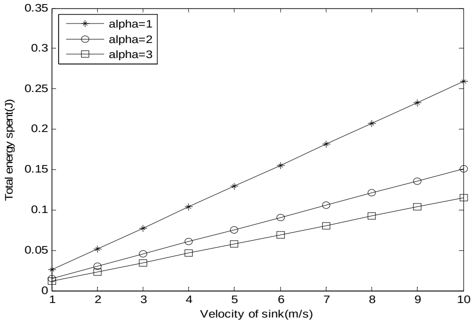

Figure-11. Total energy spent w.r.to velocity.

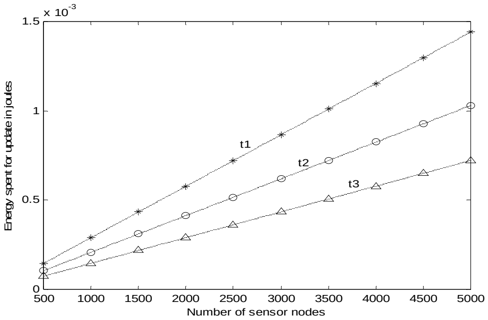

Figure-12. Energy spent for update w.r.to time

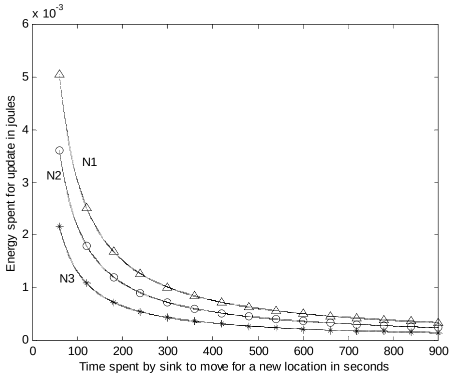

Figure-13. Energy spent for update.

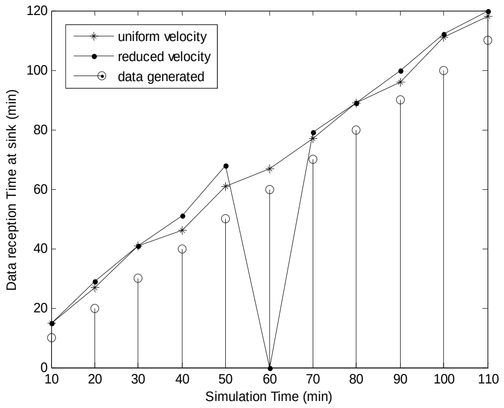

Figure-14. Variations in data reception time.

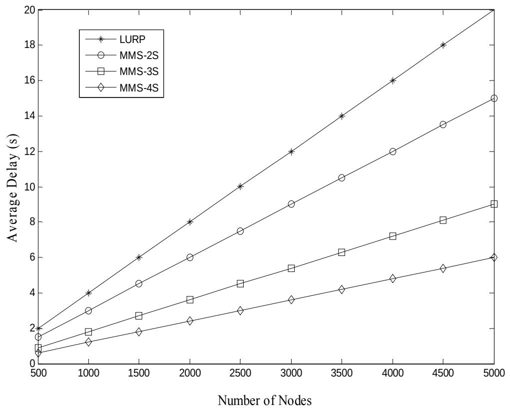

Figure-15. Average delay.

However there is a packet loss due to the increase in the speed of the mobile sink which is shown in Figure-14. From the figure it is observed that if uniform velocity is maintained the data in the queue are transmitted to mobile sink node one by one. When the velocity is increased then the wait time in the static positions are more. This implies that the mobile sink can receive almost all the data in the queue. When the velocity is decreased then the wait time in the static positions are less. This implies that the mobile sink cannot receive all the data in the queue. There is a data loss due to the low wait time of the mobile sink in each static position. During simulation, at 60 min the data loss occurrence is shown in Figure-14. It is observed from the output that if uniform velocity is maintained for all mobile sinks the data loss is considerably reduced.

The output obtained using MMS routing and LURP for average delay is shown in Figure-15. The average delay is determined by taking mean value of the end to end delay in the network. From the Figure-15 it is observed that in MMS routing delay is very much reduced because the number of hops required to transmit a data is reduced. The hop reduction due to the presence of multiple sinks ultimately results in reduced average delay in the wireless sensor network. From Figure-16 and Figure-17 it is seen that total energy spent by the network for MMS routing is again reduced in the region of interest. These two results are obtained with rectangular sensing field. First result depicts that irrespective of applications where the network is used the energy spent will be more with increase in the number of nodes using MMS routing. But the energy spent is reduced in the region of interest compared to that of the area of interest. The role of velocity with which the sink moves to the new position in a rectangular field is shown in the Figure-23. From the result, it is clear that the energy spent for routing as well as location update will be more with the increase of velocity either in the area of interest or in the region of interest. But the energy spent is remarkably reduced in the second case. From Figure-18 and Figure-19 it is seen that total energy spent for routing and updating the sink's position is reduced in the region of interest. These two results are obtained with circular sensing field. First result depicts that whatever may be the scenario the energy spent will be more with increase in the number of nodes. But the energy spent is reduced in the region of interest compared to that of the area of interest. From the result it is clear that the energy spent for routing as well as location update will be more with increase of velocity either in the area of interest or in the region of interest. But the energy spent is remarkably reduced in the second case. Also the energy spent is reduced in circular sensing field compared to rectangular field. This is due to the nature of the coverage area of the mobile sink node. The outputs obtained for various mobility models are discussed below. In the random way point mobility, the time taken to reach the data collection points is not uniform. But in circular and wind mobility models, the time taken to reach the data collection points are uniform which are shown in Figure-20 to Figure-21. Moreover, if the velocity is increased the time taken to reach the new location is reduced. The results for circular and wind mobility with respect to different velocity are measured. The time taken to reach the next data collection point for the Random way point Mobility (RM), Circular Mobility (CM) and Wind Mobility (WM) are shown in Figure-22. For the same three mobility models, the average remaining energy after one cycle is shown in Figure-23. From the figure it is observed that after one cycle, the available energy is more for wind mobility model compared to circular mobility. But in the random way point mobility, energy is decreased drastically due to non deterministic collection point. From the Figure-24, it is observed that number of dropped packets is more if the radius of the circular path is very high or very low and this parametric change is same for wind mobility. But in wind mobility the overall dropped packets are reduced when they are compared with circular mobility.

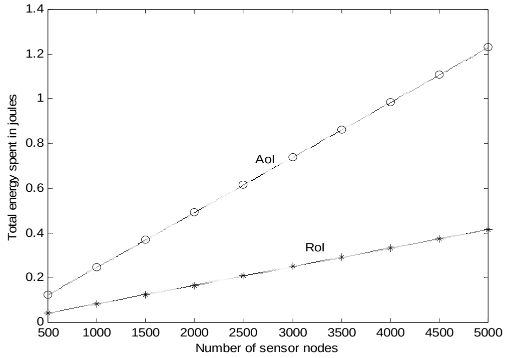

Figure-16. Total energy spent – rectangular.

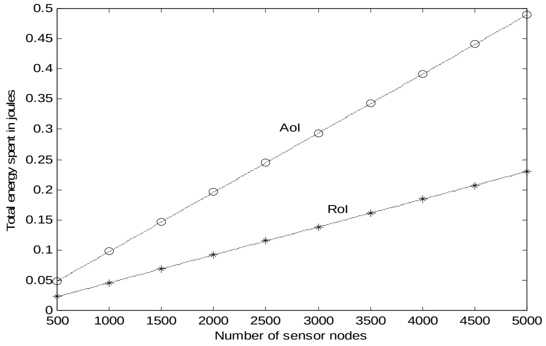

Figure-17. Total energy spent – circular.

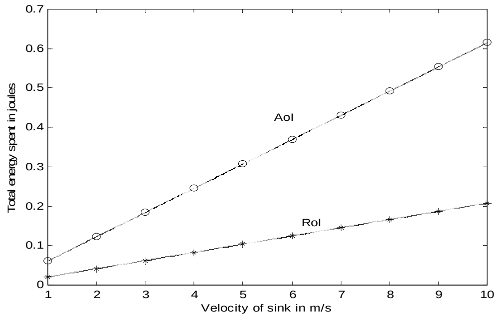

Figure-18. Total energy spent - rectangular.

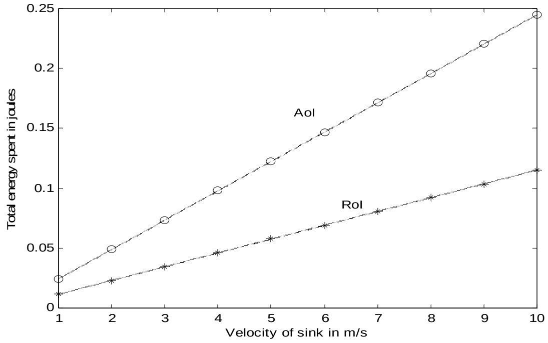

Figure-19. Total energy spent – circular.

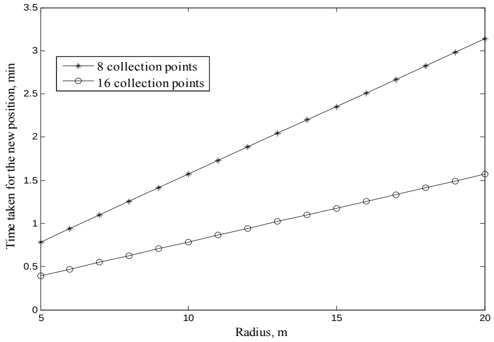

Figure-20. Time taken using circular mobility with 5m/min.

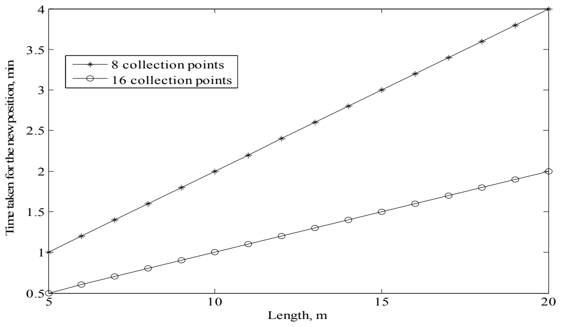

Figure-21. Time taken using wind mobility with 5m/min.

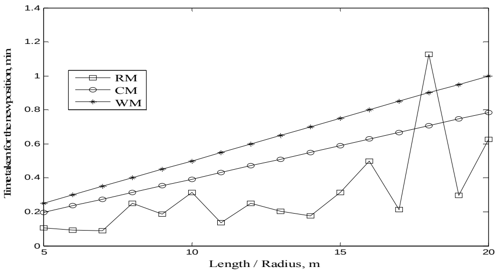

Figure-22. Time delay for location change.

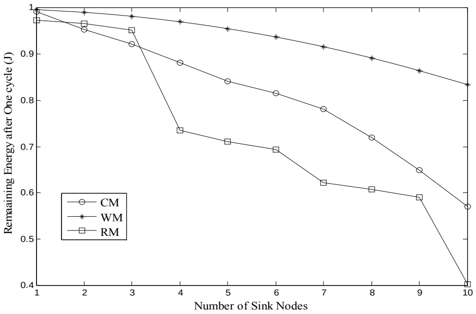

Figure-23. Average remaining energy after a cycle.

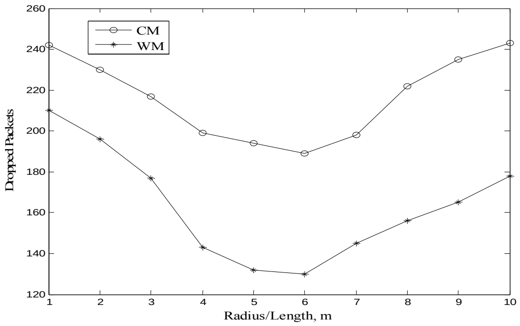

Figure-24. Dropped packets.

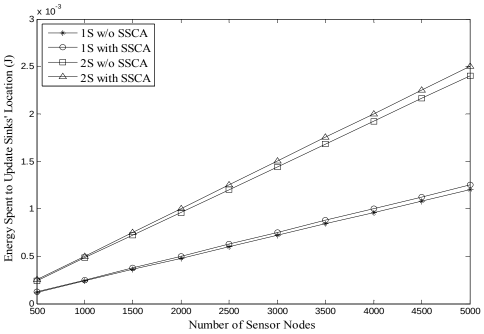

Figure-25. Energy spent for SSCA.

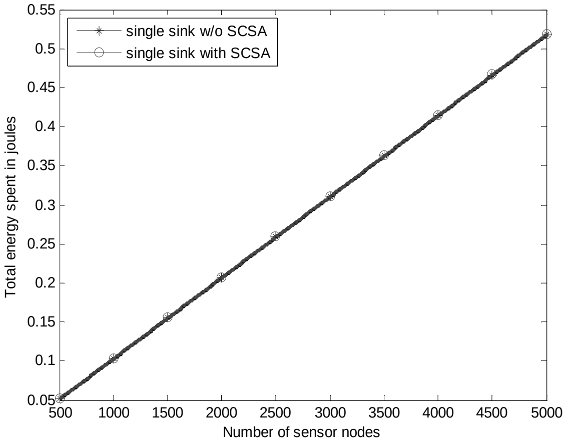

Figure-26. Total energy spent.

The outputs obtained for MMS routing with the addition of SSCA algorithm is shown in Figure-25 and Figure-26. From the figure it is clear that SSCA algorithm took only 0.1mJ at maximum for execution. Moreover Figure-26 shows that the total energy spent with and without SSCA in MMS routing are the same. Thus the MMS routing is well suited to collect more data for long time using multiple mobile sinks defining a particular region for each mobile sink in the sensing field. Wind mobility model in MMS routing provides low dropped packets with low energy spent. Further secure routing is achieved in such a way by avoiding inclusion of false data using SSCA algorithm. Results depicts that the SSCA algorithm consumes less energy but by which low cost security can be established.

5. CONCLUSIONS

Since the mobility of sinks make the transmission of data from source node to sink node easier by reducing the number of intermediate router nodes. For each mobile sink, a particular region is allotted and the performance of MMS routing with respect to region of interest and the total area of interest were studied. The impact of different mobility models are analyzed with MMS routing and found that the wind mobility model provides better performance. To enhance the performance of MMS routing, security is incorporated as a part of routing to avoid unauthorized data. This is achieved by using SSCA algorithm. From the results it is understood that MMS routing can be used for reducing the end to end delay in the sensor networks. Further it is felt that this network is best suitable for a long time campus monitoring and environment control applications. Within a short period more data can be collected from large number of source nodes using multiple mobile sinks. It is also seen that either the AoI or RoI can be selected depending upon the application. For the energy constraint situations, it is always better to go with the RoI. Again it is observed that the wind mobility model applied on the sink collects more data with minimum time than that of random way point and geographic based circular pathway mobility. Furthermore it is found that by including SSCA algorithm in MMS routing, unauthorized data inclusion can be avoided and the energy spent for the execution is also very low.

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