Energy Efficient Data Gathering with Mobile Element Path Planning and SDMA-MIMO in WSN

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Abstract

Wireless Sensor Network (WSN) is a network which depends on the intermediate node to relay the data so the energy of the nodes near to the sink node is exhausted very quickly, as a result network gets disconnected. To overcome this problem and to prolong the lifetime of the network, we propose Wireless Sensor Network with multiple SenCar. It has high data gathering rate and shortest path with low time latency model which uses mobile nodes to collect the data. Also a mobility model of the nodes (SenCar) is proposed to move in the network and cover the whole network area. Further we compare the simulation results with existing protocols and find that the proposed model gives better results in terms of throughput, residual energy and lifetime of the networks. The lifetime of sensor network depends on the operation time of individual sensor nodes. Therefore, a model, which defines the amount of power consumed in each action of a sensor node, influences the lifetime of networks to a great degree. The multiple SenCars eliminates this problem and efficient data gathering is made possible with high channel capacity. The OQPSK (Offset Quadrature Phase Shift Keying) modulation and demodulation reduces the bit error rate as well as increase the signal strength at the nodes of the networks. This model is applicable to different networks which all are connected by the multiple SenCars.

1. Introduction

In this paper, we consider a wireless sensor network that consists of a large number of sensors and a limited number of mobile data collectors called SenCars. In such a network, SenCars take over the burden of routing from sensors, roaming over the sensing area and collecting data from nearby sensors via short-range wireless communications. We present a series of efficient mobile data gathering schemes in such sensor networks, which aim to prolong network lifetime and shorten data gathering latency.

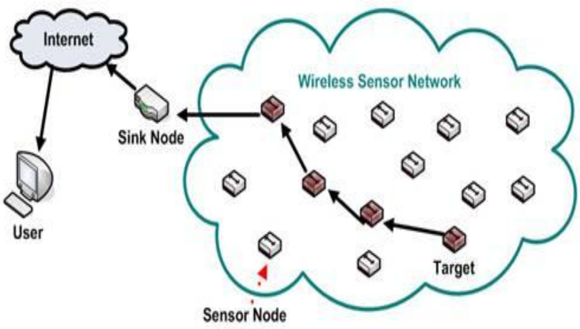

Figure 1. Typical wireless sensor network

1.1. Node neighborhood problem

Previously, Sensor nodes used to communicate with sink node by multi-hop [2], [5] mechanism as in fig. 1. Various existing energy efficient techniques concern the delivery of the sensed data from the sensor to the node, which generally improves the burden to the nodes that are closer to the node. More specifically, when a node is statically placed, the sensor nodes that are the neighbor of node tend to deplete their energy faster than other nodes. They consume energy to communicate their own data as well as they relay the data of other node [8], [12] and the node gets isolated from the rest of the network due to early death of its neighbors when most of the sensor nodes are still fully operational. This problem, termed as "Node Neighborhood Problem" [11] which leads to a premature disconnection of the network. To overcome this problem we need to make the network dynamic. As sensor network deployed for risk management and disaster management, we cannot make all the sensor nodes as mobile node because we cannot access all sensors for the renewal of energy and it is also not possible to establish a path in order to collect the data.

1.2. Energy efficient data collection

In the proposed model we consider a large number of sensor nodes placed at uniformly in the service area, for collecting data or monitoring events. Data collected by a many SenCars travelling through proposed mobility model in the monitored region. Here we assumed that the node has no significant resource limitation, i.e. computational, memory, and communication capabilities. Node is able to directly communicate wirelessly with a subset of one hop reachable nodes. Each sensor node in the network is equipped with a given buffer space that is utilized to store data for later retrieval by the mobile node. We use OFDM technology to enhance secure and energy efficient communication. SenCar changes its position randomly according to the proposed mobility model. Before changing the position, SenCar halts for some fixed amount of time called a pause time to collect the data from the corresponding node within its range. Before changes its position it broadcast another beacon frame to reset the sensors. We follow the last step to reduce the packet drop. Mobile node needs the energy efficient and relative motion of the node. Our proposed model provides the relative random motion of the node. We need mobile node because it resolves the energy efficient data collection in sensor network and overcome the node neighborhood problem. It also avoids the multi hop communications [5] and the threats arise in the multi hop communications.

2. Block diagram

The block diagram in figure 2 given below explains various steps included in the proposed method.

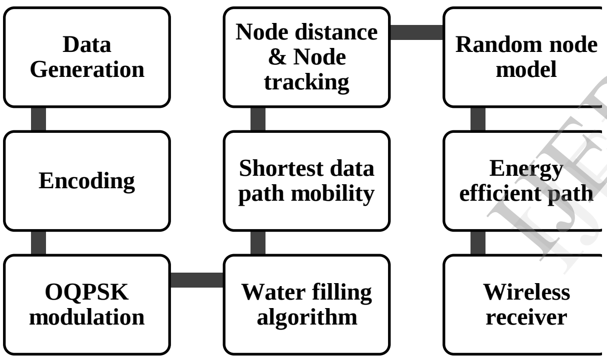

Figure 2. Block diagram of the proposed system

The efficient data gathering with mobile element data path planning in a Wireless Sensor Network involves a series of steps. Initially the raw data generated by the sensors are encoded and modulated. We proposed OQPSK (Offset Quadrature Phase Shift Keying) modulation scheme so as to avoid non-linearity. Because QPSK or Quadrature Phase Shift Keying used in previous methods involves the splitting of a data stream $m_k(t)=m_0,m_1,m_2,m_3,m_4,m_5,\ldots$ into an in-phase stream $m_I(t)=m_0,m_2,m_4,\ldots$ and a quadrature stream $m_Q(t)=m_1,m_3,m_5,\ldots$ Both the streams have half the bit rate of the data stream $m_k(t)$, and modulate the cosine and sine functions of a carrier wave simultaneously. As a result, phase changes across intervals of $2T_b$, where T_b is the time interval of a single bit of the $m_k(t)$. This may make us susceptible to non-linearities, which may be prevented using linear amplifiers but they are more expensive and power consuming. A solution to the above mentioned problem is the use of OQPSK. OQPSK modulation is such that phase transitions about the origin are avoided. In OQPSK, the phase transitions take place every T_b seconds. In QPSK the transitions take place every $2T_b$ seconds.

Next capacity calculation for every node is done for power allocation, using water filling algorithm. Then node localization is done which means, determining the geographical location of each node in the system. Based on the capacity of the nodes polling points are selected. The SenCar gathers data only at these polling points. Very few nodes are selected as polling points so the SenCar need not travel to all nodes. Thus the travelling distance known as tours of the SenCars are reduced. Further, with the use of multiple SenCars provides division of entire sensing region into sub-regions, with small tours for each SenCar used within each sub-region to obtain energy and time efficiencies. Each node will have its own coverage area within which it could transmit data in a single hop. When the SenCar comes into this coverage zone, it sends a beacon to alert the node so that it comes to active state and starts transmitting data. Very little time is needed for the SenCar to pause at the polling point because, data transmission occurs at very high speed for data gathering. After that, next beacon is sent so that the node stops sending data packets and goes to sleep state. Still sensing function of the sensor nodes continues. It comes to active state only during data transmission which saves lot of energy.

3. Proposed model

3.1. Space Division Multiple Access

SDMA 2.0 supports several advanced multi-antenna techniques including single and multi-user MIMO (spatial multiplexing and beam forming) as well as a number of transmit diversity schemes. In single-user MIMO (SU-MIMO) scheme only one user can be scheduled over one resource unit, while in multi-user MIMO (MU-MIMO), multiple users can be scheduled in one resource unit. Therefore we can take Space Division Multiple Access (SDMA) = allocating an angle direction sector to each user.

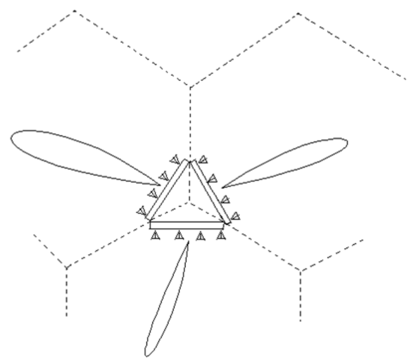

Figure 3. Allocating an angle direction sector to each user

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The Rayleigh-distribution is a well known estimation of the PDF (Probability Density Function) of the fading statistics in a radio channel; Since the MIMO system architecture uses the independent fading between different antenna-elements. All signals are transmitted from all elements once using single-hop and the receiver solves a linear equation system to demodulate the message as below.

3.2. MIMO linear equation system

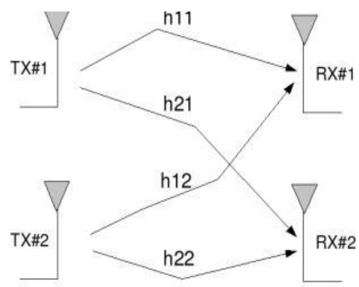

Figure 4. MIMO–two transmitting antennas and two receiving antennas (Tx=2, Rx=2)

The received signal in the first time slot is,

$$\begin{bmatrix} y_1^1 \\ y_2^1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1^1 \\ n_2^1 \end{bmatrix} \quad (1)$$

Assuming that the channel remains constant for the second time slot, the received signal is in the second time slot is,

$$\begin{bmatrix} y_1^2 \\ y_2^2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} -x_2^* \\ x_1^* \end{bmatrix} + \begin{bmatrix} n_1^2 \\ n_2^2 \end{bmatrix} \quad (2)$$

Where,

$$\begin{bmatrix} y_1^1 \\ y_2^1 \end{bmatrix}$$

is the received information at time slot 1 on receive antenna 1, 2 respectively,

$$\begin{bmatrix} y_1^2 \\ y_2^2 \end{bmatrix}$$

is the received information at time slot 2 on receive antenna 1, 2 respectively,

h_{ij} is the channel from i^{th} receive antenna to j^{th} transmit antenna, x_1, x_2 are the transmitted symbols,

$\begin{bmatrix} n_1^1 \\ n_2^1 \end{bmatrix}$ is the noise at time slot 1 on receive antenna 1, 2 respectively, and

$\begin{bmatrix} n_1^2 \\ n_2^2 \end{bmatrix}$ is the noise at time slot 2 on receive antenna 1, 2 respectively.

Combining the equations at time slot 1 and 2,

$$\begin{bmatrix} y_1^1 \\ y_2^1 \\ y_1^{2*} \\ y_2^{2*} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1^1 \\ n_2^1 \\ n_1^{2*} \\ n_2^{2*} \end{bmatrix} \quad (3)$$

Also,

$$H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix} \quad (4)$$

To solve for $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$, we know that we need to find the inverse of H.We know, for a general m x n matrix, the pseudo inverse is defined as,

$$H^+ = (H^H H)^{-1} H^H \quad (5)$$

The Term,

$$(\mathbf{H^H H}) = \begin{bmatrix} |\mathbf{h_{11}}|^2 + |\mathbf{h_{21}}|^2 + |\mathbf{h_{12}}|^2 + |\mathbf{h_{22}}|^2 & \mathbf{0} \\ \mathbf{0} & |\mathbf{h_{11}}|^2 + |\mathbf{h_{21}}|^2 + |\mathbf{h_{12}}|^2 + |\mathbf{h_{22}}|^2 \end{bmatrix} \quad (6)$$

Since this is a diagonal matrix, the inverse is just the inverse of the diagonal elements, i.e

$$(\mathbf{H^H H})^{-1} = \begin{bmatrix} \frac{\mathbf{1}}{|\mathbf{h_{11}}|^2 + |\mathbf{h_{21}}|^2 + |\mathbf{h_{12}}|^2 + |\mathbf{h_{22}}|^2} & \mathbf{0} \\ \mathbf{0} & \frac{\mathbf{1}}{|\mathbf{h_{11}}|^2 + |\mathbf{h_{21}}|^2 + |\mathbf{h_{12}}|^2 + |\mathbf{h_{22}}|^2} \end{bmatrix} \quad (7)$$

The estimate of the transmitted symbol is,

$$\widehat{\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}} = (H^H H)^{-1} H^H \begin{bmatrix} y_1^1 \\ y_2^1 \\ y_1^{2*} \\ y_2^{2*} \end{bmatrix} \quad (8)$$

In order to separate the data flows from different sensors, the Mobile sink needs to make the receive beam forming If there exists beam forming vector $u_1=[u_{11},u_{12}]$ and $u_2=[u_{21},u_{22}]$ that makes $u_1h_2*=0$ and $u_2h_1*=0$ we finally obtain,

$$u_1 y = u_1 h_1 * d_1 + u_1 h_2 * d_2 + u_1 n = u_1 h_1 * d_1 + u_1 n,$$
$$u_2 y = u_2 h_1 * d_1 + u_2 h_2 * d_2 + u_2 n = u_2 h_2 * d_2 + u_2 n \quad (9)$$

According to the channel state, the data from different sensors are intelligently separated by the mobile sink without introducing co-channel interference. The u_1 can be any vector lying in V_1 which is the space orthogonal to h_2.

However, to maximize the received signal strength, u_1 should lie in the same direction as the projection of h_1 onto V_1. u_2 should be similarly chosen. In practice, u_1 and u_2 can be unit vectors because increasing the length of them will not increase the signal-to-noise ratio. Based on these selection criteria, the normalized beam forming vectors can be expressed as follows

$$u_1 = \left(h_1 - \frac{\langle h_1,h_2\rangle}{\langle h_2,h_2\rangle} h_2\right) / \left| h_1 - \frac{\langle h_1,h_2\rangle}{\langle h_2,h_2\rangle} h_2 \right|,$$

$$u_2 = \left(h_2 - \frac{\langle h_1,h_2\rangle}{\langle h_1,h_1\rangle} h_2\right) / \left| h_2 - \frac{\langle h_1,h_2\rangle}{\langle h_1,h_1\rangle} h_1 \right| \quad (10)$$

To ensure that the mobile sink can successfully receive the data simultaneously transmitted by the two sensors, the following criteria must be satisfied

$$SNR_1 = \frac{|u_1 h_1^*|^2 . P_t}{|u_1|^2 N_0} \geq \delta_0,\; SNR_2 = \frac{|u_2 h_2^*|^2 . P_t}{|u_2|^2 N_0} \geq \delta_0 \quad (11)$$

Where SNR_1 and SNR_2 are the signal-to-noise ratio (SNR) of the received data from the two sensors, respectively, P_t is denoted as the transmitting power of each sensor, N_0 is the variance of the background noise, and δ_0 is the SNR threshold for the mobile sink to correctly decode the received data.

Thus the SDMA-MIMO combined concept could be further extended for more number of transmitting and receiving antennas (Tx=n, Rx=n, where, n=3,4,…) as shown in below figures.

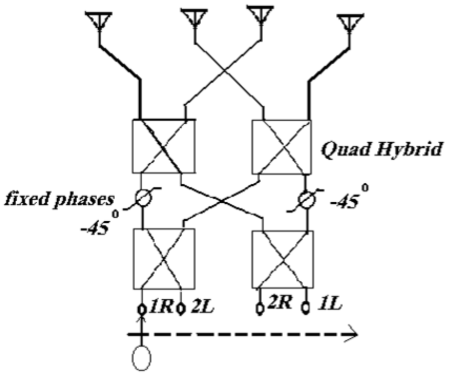

Figure 5. Four element SDMA smart array antenna

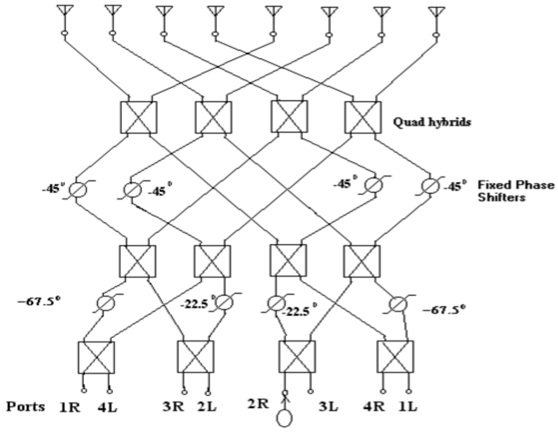

Figure 6. Eight element SDMA smart array antenna

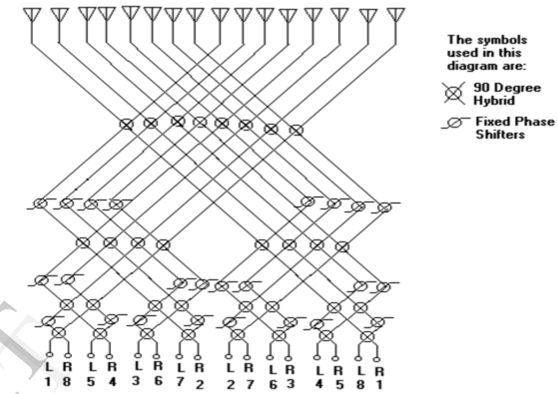

Figure 7. Sixteen element SDMA smart array antenna

This way, the concept of MIMO combined with SDMA concept (SDMA-MIMO) can be extended to any number of input and output antennas. This achieves good energy efficient data gathering in the region of WSN considered.

4. Travelling salesman problem (TSP)

So far we have explained how SDMA with the linear decorrelator works. In this section, we formally formulate the problem of mobile data gathering with SDMA-MIMO technique. The various objectives of the proposed system include:

- SenCar moving path planning with relays.
- Single-hop data gathering.
- Mobile data gathering with controlled mobility and SDMA technique.
- Bounded relay hop mobile data gathering scheme.

The user input data tells the number of nodes, the connections between these nodes (and its distance). Then we need to find the shortest distance that the SenCar need to travel to visit all nodes. But there are some restrictions:

- The travel must start and end at the same node.
- We must visit each node only once.
- We must visit at least 2 nodes.

- The connections are unidimentional so we can only travel at one direction on each connection.

To overcome the TSP problem, in the proposed model we assume that the Sensor nodes have enough energy, memory and processing power.

For the data gathering in WSN we find the best mobile element path which will visit all the polling points and returns to the starting point. During pause time at the polling points SenCar communicates with the neighbors in three step process.

- In initial step it broadcasts a beacon frame to alert the neighbor nodes in the range to transmit data packet. Every node sets to send the packet to the sink.
- In the second step every node that have set, they send their data packets to sink with one hop.
- In the third step sink broadcasts a beacon frame to its neighbors to stop sending the data packet, which reduces the packet drop.

4.1. Flow chart

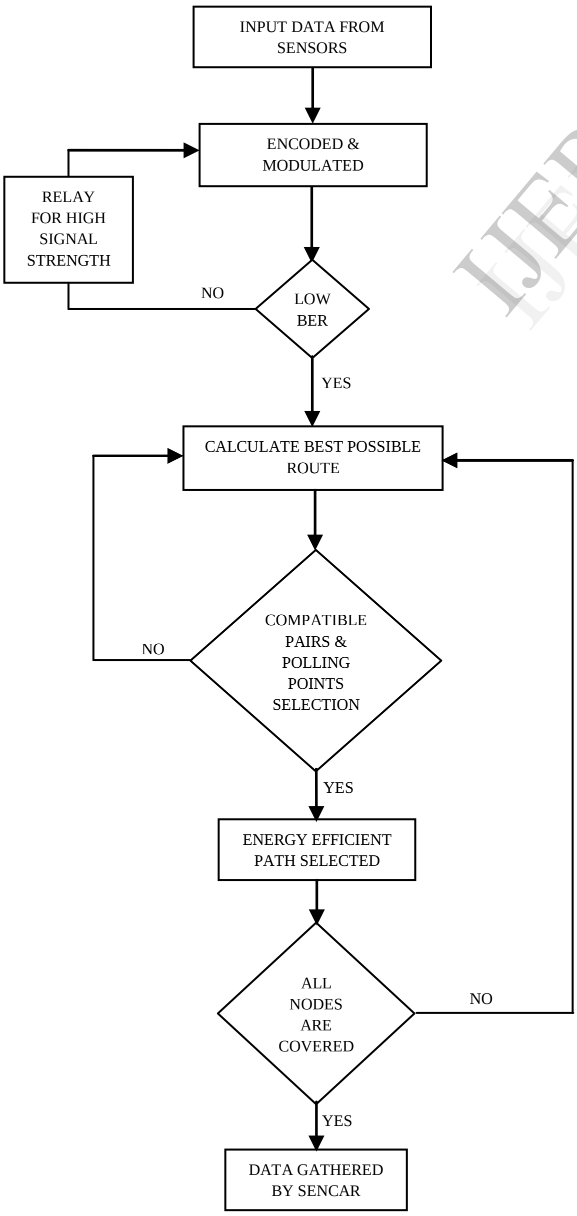

Figure 8. Flow chart of the proposed system

4.2. Proposed system architecture

Based on all the above discussions the final proposed system architecture can be given as in figure 9 below.

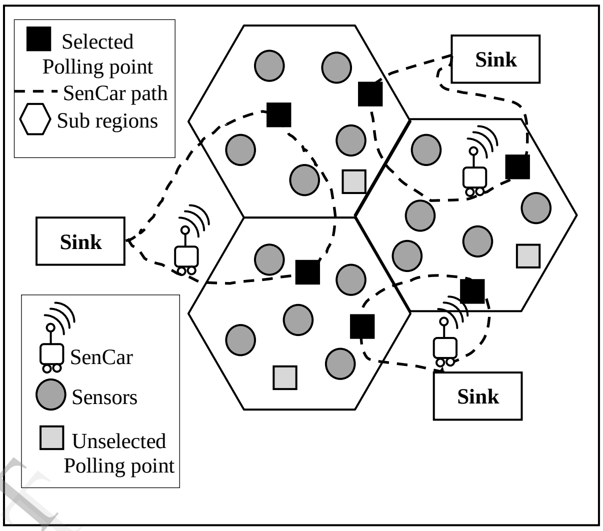

Figure 9. Architecture of the proposed system

5. Performance evaluation

Extensive MATLAB simulations were conducted to evaluate the performance of the proposed algorithms. In this section, the simulation results presented as below.

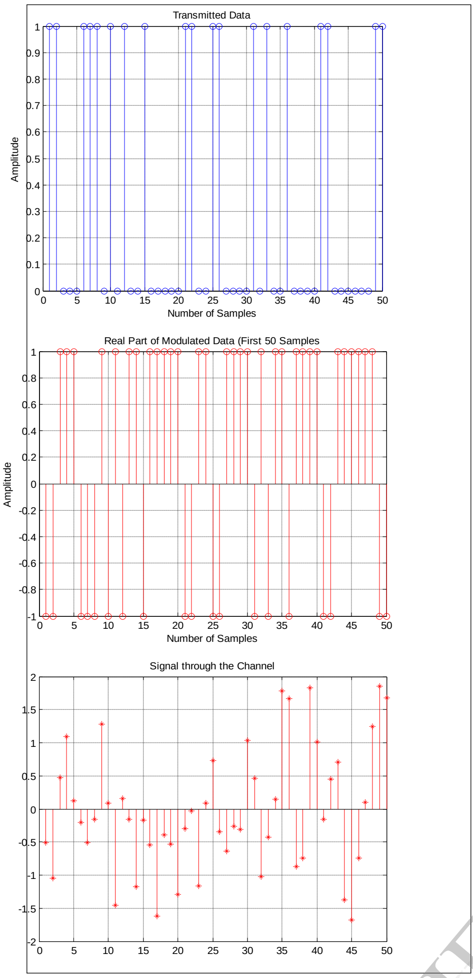

Figure 10a. Transmission results

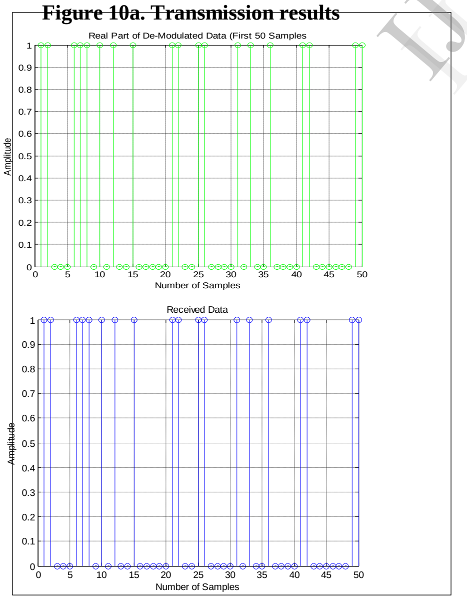

Figure 10b. Received output results

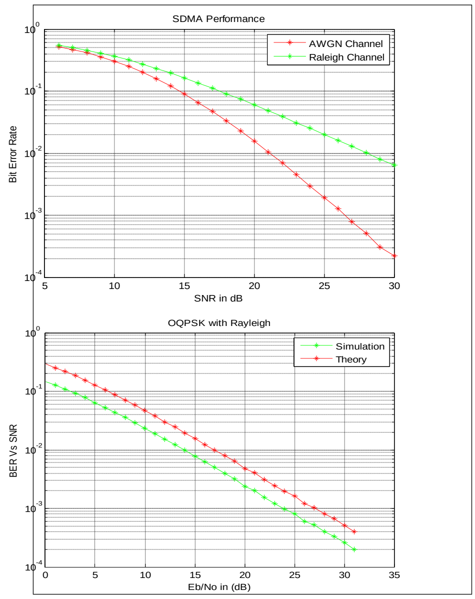

Figure 10c. Performance comparison

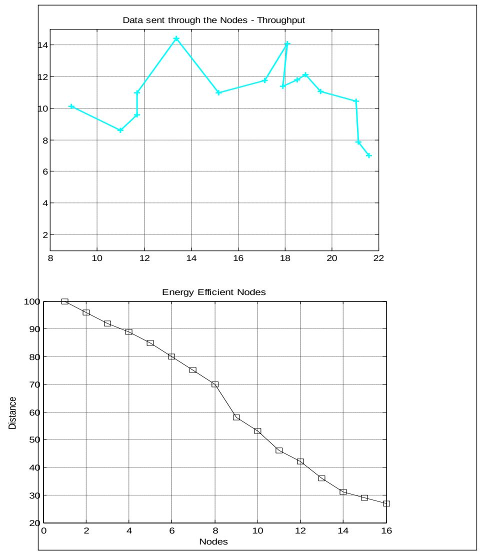

Figure 10d. Throughput calculation

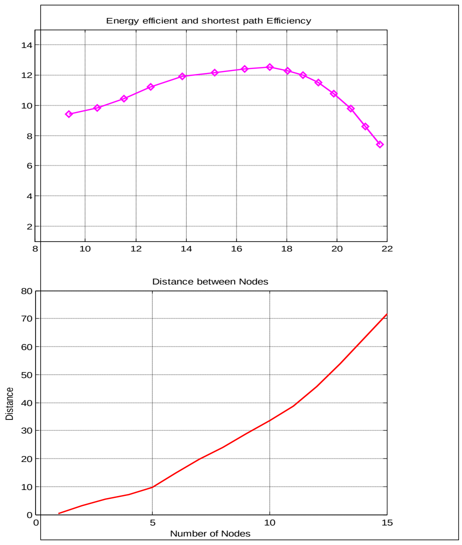

Figure 10e. Energy efficient Path

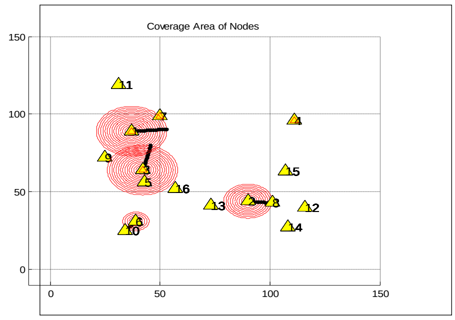

Figure 10f. Final coverage area

6. Conclusion

Deployment of many SenCars in the sensing fields to find optimal data gathering. The concept of multiple point to multiple point, enables free communications between any two nodes in network to fulfill quicker, convenient and economical data transmission which involves the automatic mapping and improved power saving. Minimizing the maximum data gathering time among different regions to prolong the network lifetime and shorten data gathering latency among different regions is obtained using proposed method. The simulation results demonstrate that the proposed algorithms can achieve very high energy efficiency and much shorter data gathering time than other compared schemes.

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8. Biographies

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