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ENERGY ANALYSIS OF MIHOP TECHNIQUE IN WSN WITH MOBILE SINK NODE

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ABSTRACT

In wireless sensor network nodes operate on batteries & it is difficult to replace & recharge the batteries of these nodes periodically. Hence to increase lifetime of these sensor nodes, energy consumption must be minimized. In this paper we discuss a network infrastructure based on the use of controllably Mobile Sink to reduce the energy consumption at the energy constrained nodes and, thus, increase useful network lifetime. A transmission scheme for energy-constrained WSNs is also proposed here. The scheme, called MIHOP (MIMO and Multi-hop), combines cluster-based virtual MIMO and multi-hop technologies. The multi hop mode is employed in transmitting data when the related sensors are located within a specific number of hops from the sink, and the virtual MIMO mode is used in transmitting data from the remaining sensor nodes. The simulation results show that the proposed scheme significantly outperforms individual virtual MIMO, multi-hop technologies, and double-string networks in terms of energy conservation. The energy consumption levels under the MIHOP scheme are approximately 12.98%, 47.55% and 48.30% less than that under virtual MIMO schemes, multi-hop networks and double string networks, respectively.

INDEX TERMS- Wireless sensor network, Energy efficiency, Mobile sink, Virtual MIMO, Multi-hop network, MIHOP

1. INTRODUCTION

Energy is a limited resource in wireless sensor network, so that energy consumption must be minimized while satisfying given throughput requirements. Moreover, energy consumption must take into account both the transmission energy and the circuit processing energy for short-range communications. In Wireless Sensor Network hundreds or even thousands of sensors are scattered over a field, from which required data may not be obtained in a timely manner. Sensors enable the acquisition of sensed data and uploading to data sinks through wireless channels without manual intervention. One of the most critical problems in WSNs is the limited energy resources of battery-operated sensor nodes. Periodically replacing or recharging the batteries of sensor nodes is difficult in given environmental limitations. An entire network would be disconnected as a result of energy depletion in the sensors. Enhancing the energy efficiency of transmission is advantageous because transceivers consume substantial energy. Hence the scheme, called MIHOP (MIMO and Multi-hop) is used which combines the advantages of multi-hop and STBC based virtual MIMO technologies. In MIHOP, a mobile sink is managed so that it moves along a prepared path and pauses at certain locations to broadcast routing information. The sensor nodes near the sink are located within a specific predefined number of hops, and constitute a multi-hop network. Each node transmits data to the sink hop by hop. The sensor nodes further from the sink may use STBC-based virtual MIMO technology to transmit data. The theoretical analysis shows that the MIHOP scheme significantly outperforms individual virtual MIMO, multi-hop schemes and double-string network in terms of energy efficiency when energy consumption in transmission and circuitry are considered.

2. RELATED WORK

Energy-constrained networks, such as wireless sensor networks, have nodes that are typically powered by batteries, for which replacement or recharging is very difficult. Finite energy can only support the transmission of a finite amount of information. Therefore, minimizing the energy consumption for information transmission becomes one of the most important design considerations for such networks. A certain amount of research has recently been done to investigate various Energy efficient transmission schemes.

[1] SUSHANT JAIN et al. analyze an architecture based on mobility to address the problem of energy efficient data collection in a sensor network. Their approach exploits mobile nodes present in the sensor field as forwarding agents.

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As a mobile node moves in close proximity to sensors, data is transferred to the mobile node for later depositing at the destination. They present an analytical model to understand the key performance metrics such as data transfer, latency to the destination, and power.

In [2] CUI Shuguang, et.al proposed MIMO systems based on Alamouti diversity schemes, which have good spectral efficiency but also more circuitry that consumes energy. They extend this energy-efficiency analysis of MIMO systems to individual single-antenna nodes that cooperate to form multiple antenna transmitters or receivers. They shows that by transmitting and/or receiving information jointly, tremendous energy saving is possible for larger transmission distance. ZHOU Zhong et al. present a clustered wireless sensor network where sensors within each cluster relay data packets to nearby clusters using cooperative communications in [3]. In this, the authors have used a cooperative transmission scheme based on distributed space-time block coding and conduct a systematic analysis on the resulting energy consumption. In

In [4] Yi Gai, Lin Zhang et al. proposed an energy model for wireless sensor networks based on the cooperative MIMO (multiple-in-multiple-out) technique, taking into consideration of both the transmission and data aggregation energy. Based on the model, two cooperative wireless sensor network schemes, namely, MIMO approach and SISO approaches are compared in this. They have shown that the overall energy consumption in the systems is related to not only the transmission range but also the correlation among the raw sensor data, and can be solved as a nonlinear programming problem. Furthermore, a critical value above which MIMO approach outperforms SISO approach is analyzed.

Yong Yuan et al. [5] proposed a novel multi hop virtual multiple-input multiple-output (MIMO) communication protocol by the cross-layer design to jointly improve the energy efficiency, reliability, and end-to-end (ETE) QoS provisioning in wireless sensor network (WSN). In the protocol, the traditional low-energy adaptive clustering hierarchy protocol is extended by incorporating the cooperative MIMO communication, multi hop routing, and hop-by-hop recovery schemes. Based on the protocol, the overall energy consumption per packet transmission is modeled and the optimal set of transmission parameters is found. Then, the issues of ETE QoS provisioning of the protocol are considered. The ETE latency and throughput of the protocol are modeled in terms of the bit-error-rate (BER) performance of each link. Then, a nonlinear constrained programming model is developed to find the optimal BER performance of each link to meet the ETE QoS requirements with minimum energy consumption. In this they employed the particle swarm optimization (PSO) algorithm to solve the problem.

3. PROBLEM DEFINITION

Energy-efficiency is one of core challenges in WSN because energy is few and hard to find out and valuable. The above literature survey shows several clustering algorithms have been proposed for purpose of reducing energy consumption and extending lifetime of sensor network. These methods have some drawbacks, as in Multi hop network when a sink is far from the sensor area or the area is so large that most sensor nodes need numerous hops to reach the sink, considerable retransmitting energy is consumed during transmission, which significantly accelerate node depletion. Also though MIMO systems consume less energy than SISO systems but deploying multiple antennas on one sensor node like in MIMO is infeasible because of the limited physical size of a node. To solve this problem, researchers proposed a cooperative (Virtual) MIMO transmission scheme. But in Virtual MIMO, when transmission distance is relatively short and below a certain threshold, the energy used by collaborating nodes accounts for a huge proportion of consumption. Again in STBC cluster based communication scheme the nodes in one cluster require extra energy as they work in conjunction. The studies discussed above motivate this work, in which a new energy-efficient transmission scheme is proposed. This proposed approach is an attempt to reduce above mentioned drawbacks and achieve efficient data transmission in Wireless Sensor Network.

4. PROPOSED METHOD

This section describes the proposed MIHOP scheme in detail, and illustrates the mobile data gathering mechanism of MIHOP.

4.1 MIHOP SYSTEM MODEL

Figure 1 illustrates the system model of MIHOP. The sink works similar to a base station that broadcasts and gathers information. In the multi-hop network formation stage, a sink broadcasts routing information packets, and the sensors that receive the packets function as first-hop nodes. These nodes rebroadcast the routing information packets in wireless channels, and the entire multi-hop network is created through the hop-by-hop routing of an algorithm. The range of a multi-hop network is limited by maximum number of hops M_H, which can be optimized according to the model proposed in Section V. This optimization minimizes energy consumption. Every two nodes with hops greater than M_H form a cluster on the basis of minimum cooperation range [6].

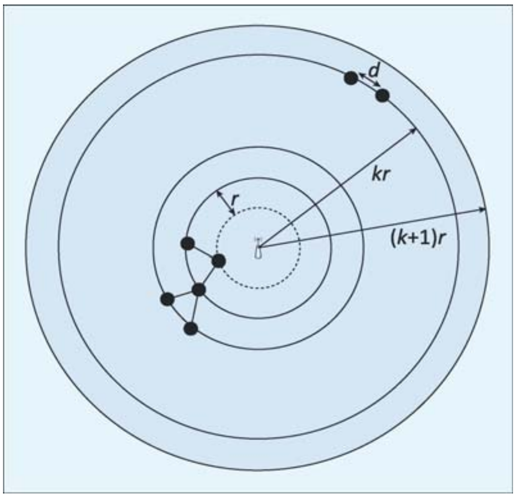

Figure 1: System model of MIHOP

The STBC-based virtual MIMO scheme proposed which is adopted for data transmission to a sink. The nodes in one cluster are assumed located on the same tier of the virtual MIMO network, and the distance between two adjacent tiers is denoted as r (Figure 1). Two nodes in one cluster should be located on the k^{th} tier and the collaboration distance between these nodes is expressed as d. The transmission distance from node to sink is denoted as k_r. Remaining single nodes can transmit data to a sink by SISO technology alone. After each sensor selects a transmission mode, the TDMA schedule is used by the sink to determine the sequence at which the sensors transmit data.

4.2 MOBILE SINK

Suppose N sensor nodes are distributed in the sensing area as shown in Figure 2, to which a mobile sink is introduced. Adaptive Motion Control algorithm is used to control the motion of the mobile node [7]. This sink is employed to enable movement along a fixed path, which is a cross path. It pauses at certain data gathering points to broadcast BEACON packets and periodically collect data from sensor nodes. The sink is equipped with two antennas, and each sensor has a single antenna for uploading data. Every packet has a fixed length of L bits. The network layer algorithms are used to select a route from the sink to each sensor in the multi-hop network.

Each sensor node maintains a parameter N_{hop}, which represents the shortest hop count to the mobile sink. The value of N_{hop} is initialized as infinite, but the N_{hop} on the mobile sink is set as 0.

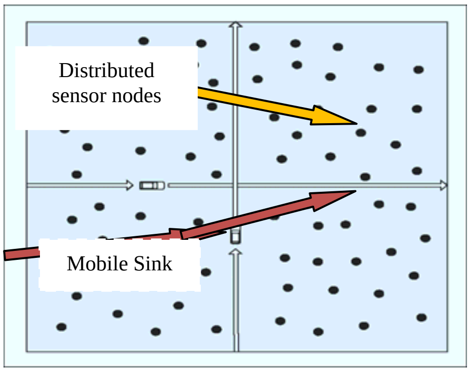

Figure 2: Movement of the mobile sink

In the training phase, the mobile sink stops at a data gathering point and broadcasts BEACON packets with MH and K. K is initialized as 0. Each sensor node receiving the BEACON packet adds 1 to K, then updates its N_{hop} into N_{hop} = min {N_{hop}, K} and rebroadcasts the BEACON with the new K. This process continues until all the nodes in the network receive a BEACON hop by hop. The mobile sink then moves onto the next point and again broadcast routing information. After the training phase, sensor nodes with N_{hop} higher than M_H form into clusters and the virtual MIMO mechanism is used to transmit data to the mobile sink. Other nodes with N_{hop} lower or equal to M_H adopt multi-hop transmission technology. Design flow for MIHOP technique is shown below:

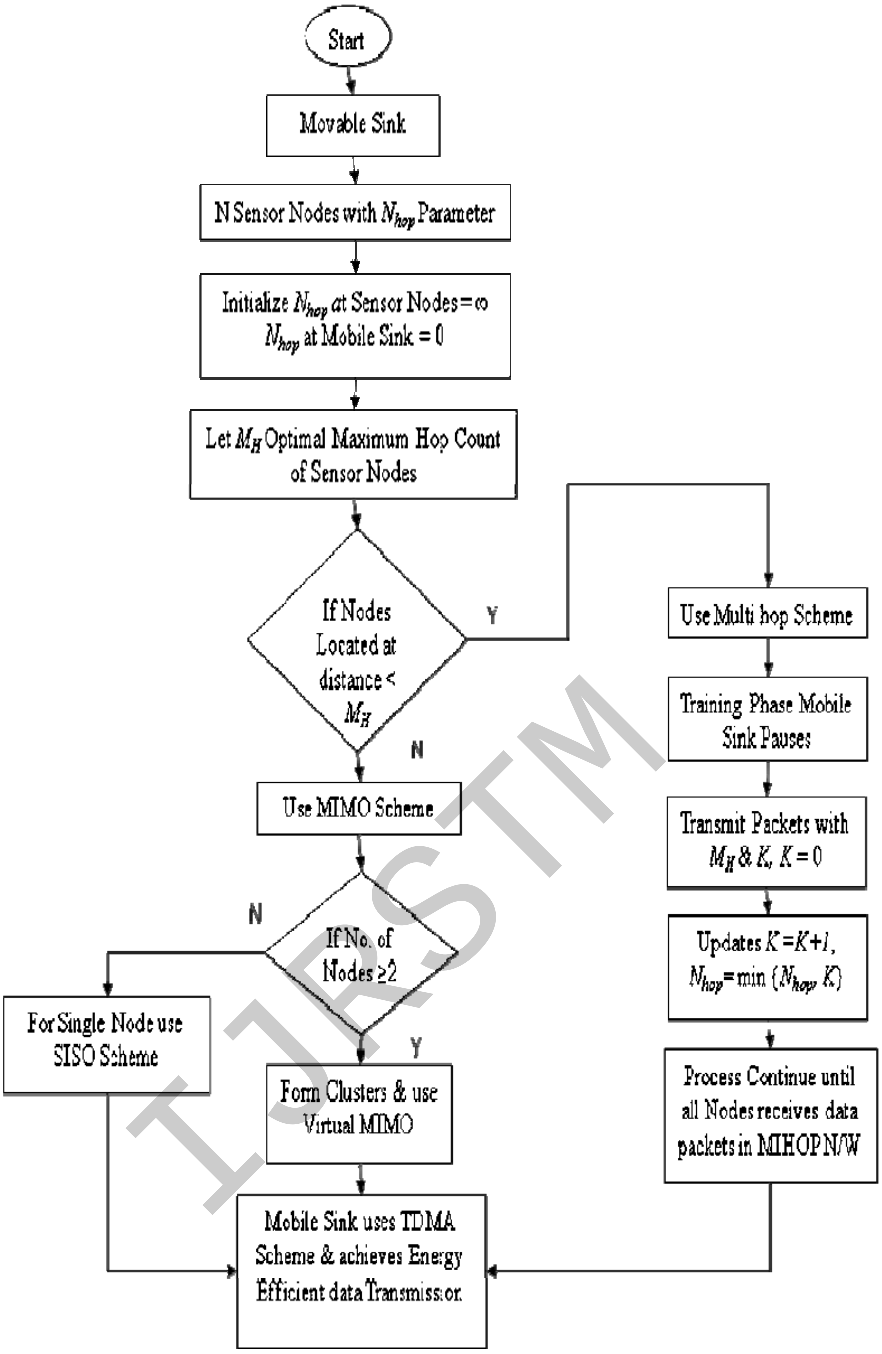

Figure 3: Design Flow for MIHOP Technique

4.3 PATH OF MOBILE SINK NODE:

By selecting cross path (X-path) of mobile sink node we can save more energy of sensor nodes since mobile sink in Cross path covered more area in less time. The different paths of mobile sink node are shown below [7].

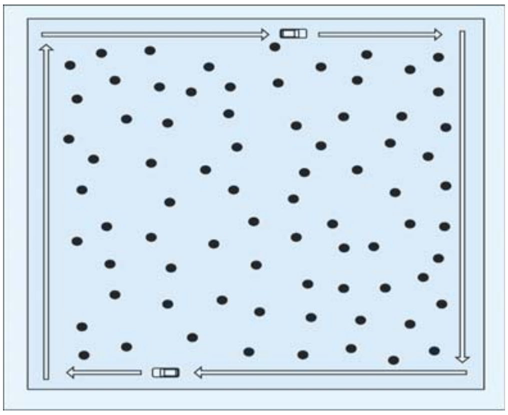

Figure 4: Rectangular path

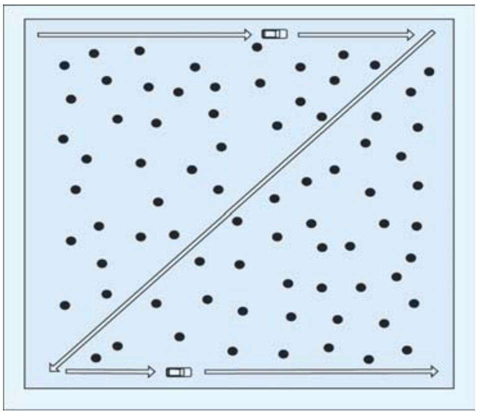

Figure 5: Zigzag path

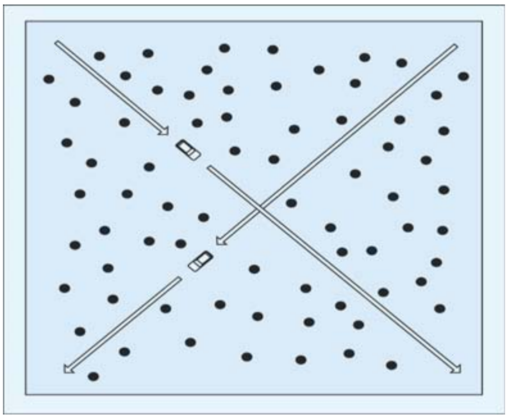

Figure 6: X path cover maximum area in less time

4.4 DIFFERENT TYPES OF MOBILITY:

Various types of mobility have been considered in the domain of wireless networks for facilitating data transfer. These can be broadly classified into three categories: random, predictable, and controlled [7].

Random mobility- Since many entities in nature move in extremely unpredictable ways, the Random Mobility Model was developed to mimic this erratic movement [8]. In this mobility model, an MN (Mobile Node) moves from its current location to a new location by randomly choosing a direction and speed in which to travel. The new speed and direction are both chosen from pre-defined ranges, [speedmin; speedmax]. Each movement in the Random Walk Mobility Model occurs in either a constant time interval t or a constant distance traveled d, at the end of which a new direction and speed are calculated. If an MN which moves according to this model reaches a simulation boundary, it "bounces" off the simulation border with an angle determined by the incoming direction. The MN then continues along this new path.

Predictable mobility was used in [9]. A network access point was mounted on a public transportation bus moving with a periodic schedule. The sensor nodes learn the times at which they have connectivity with the bus and wake up accordingly to transfer their data. However, it was assumed in [9] that the mobile node comes within direct radio range of all the static nodes, which may not be true in practice, because the trajectory of the bus may not be designed for data collection purposes. We design a network protocol which supports nodes at multiple hops from the mobile node and helps find the minimum energy route for such nodes to deliver their data to the mobile node.

Controlled mobility - The speed of the mobile node was controlled to help improve network performance. This work can be extended in three ways: First, analytically explore the energy trade-off when the energy of moving the mobile node is also considered. Second, design an enhanced communication protocol, discussing the trade-offs of the alternative approaches in the design space. Third, we consider the design of the motion control strategy in greater depth. The number of motion states used is analyzed.. Controlled mobility was also used in a mobile node is used to route messages between nodes in sparse networks. However, all nodes are assumed to have short range mobility and can modify their locations to come within direct range of the mobile node, which has long range mobility and is used for transferring data [7]. Mobile nodes in a disconnected ad hoc network modify their trajectories to come within communication range and considered moving the intermediate nodes along a route so that the distances between nodes are minimized and lower energy is used to transmit over a shorter range.

5. ENERGY CONSUMPTION ANALYSIS

Energy consumption models of virtual MIMO, multi-hop technology and SISO methods are derived. The method for determining the optimal number of hops is provided, and the energy consumption model of MIHOP is constructed.

5.1 ENERGY CONSUMPTION MODEL OF VIRTUAL MIMO TRANSMISSION:

The data transmission in virtual MIMO schemes involves two stages: intra cluster communication and long-haul MIMO transmission.

5.1.1 Energy consumption model of long haul MIMO transmission:

The Rayleigh fading with a two-ray ground reflection model is assumed for long haul virtual MIMO transmission [10]. The one-bit energy consumption of long-haul MIMO transmission E_{bt_MIMO} is given by,

$$E_{bt\_MIMO} = (1+\alpha)E_{b_{MIMO}}\frac{4\pi^2 M_l N_f}{G_t G_r \lambda^2} d^2_{MIMO} + \frac{2P_{ct}}{R_b} \quad (1)$$

Where E_{bt_MIMO} is the average energy required to transmit one bit data at a given BER, d_{MIMO} is the node-to-sink distance.

5.1.2 Energy consumption model of intra cluster communication:

An AWGN channel and free space model is used for intra cluster communication. Similarly, E_{bt_intra} denotes energy consumption for one bit intra cluster communication. It can be approximated as,

$$E_{bt\_intra} = (1+\alpha)E_{bt_{intra}}\frac{4\pi^2 M_l N_f}{G_t G_r \lambda^2} d^2_{inner} + \frac{P_{ct}+P_{cr}}{R_b} \quad (2)$$

Where Eb _ intra is the required energy per bit for a given BER requirement, which can be estimated by,

$$E_{b\_intra} = N_0(Q^{-1}(P_b))^2/2 \cdot d_{inner} \quad (3)$$

Where d_{inner} is the collaboration distance between two nodes in a cluster. Summing up the energy consumption in the two stages yields the total energy consumption of virtual MIMO in the j^{th} cluster as follows:

$$E^j_{MIMO\_C} = (d_{MIMO}) = LN\ (E_{bt\_MIMO} + E_{bt\_intra}) \quad (4)$$

Where L is the number of bits, and No. of transmitting & Receiving antennas in MIMO mode, $N = N_R = N_T = 2$.

5.2 ENERGY CONSUMPTION MODEL OF MULTI-HOP TRANSMISSION

The Rayleigh channel and a two-ray ground reflection model are used in the multi-hop network. The sensor nodes in this network not only transmit the data that they generated, but also forward data from other correlated nodes. We assume that the sensors transmit and receive data by SISO. Similar to the energy consumption model of virtual MIMO, that of the multi-hop network for one-node transmission can be described as follows:

$E^i_{Multihop} = LN\,(E_{bt\_trans} + E_{bt\_rece})$ (5)

Here, we assume that $N = N_R = N_T = 1$. E_{bt_trans} and E_{bt_rece} represent the energy consumed in transmitting and receiving data, respectively. i denotes the i^{th} node in the multi-hop network.

$$E_{bt_{trns}}(M, d_{hop}) = \sum_{k=1}^{M}((M+1-k)\left((1+\alpha)E_{b_{SISO}} \cdot \frac{4\pi^2}{G_t G_r \lambda^2} d_{hop}^2\right) + \frac{P_{ct}}{R_b})$$

(6)

$$E_{bt_{rece}}(M) - \sum_{k=1}^{M}(M-k)\frac{P_{cr}}{R_b}$$

(7)

Where M is the hop count from the mobile sink to the node, d_{hop} denotes the distance of one hop, and

$E^i_{multihop}(M, d_{hop}) = E^i_{Multihop}$

The average energy per bit E_{b_SISO} in the SISO scheme can be expressed as

$$E_{b\_SISO} = \frac{N_0}{1/(1-2P_b)^2 - 1}$$

(8)

5.3 ENERGY CONSUMPTION MODEL OF SISO TRANSMISSION

Sensor nodes that are neither in the multi-hop network nor in the virtual MIMO scheme adopt the long-distance SISO transmission scheme. The one-node energy consumption model of the SISO scheme simply includes transmission part and can be expressed as follows:

$E^i_{SISO} = LN_T\,E_{bt\_trans}$

(9)

Where E_{bt_trans} is the energy consumed in transmitting data, i denotes the i^{th} node in the SISO scheme, and $N_T = 1$. No forwarding component is found in SISO, and E_{bt_trans} can be expressed as,

$$E_{bt_{trans}}(d_{SISO}) = \left((1+\alpha)E_{bt_{SISO}} \cdot \frac{(4\pi)^2 M_l N_f}{G_t G_r \lambda^2} d_{SISO}^2\right) + \frac{P_{ct}}{R_b}$$

(10)

Where d_{SISO} is the transmission distance from the i^{th} node to the sink.

5.4 ENERGY CONSUMPTION MODEL OF MIHOP TRANSMISSION

An algorithm for determining the optimal hop count in the multi-hop network is provided. Then, the energy consumption model of the MIHOP scheme is developed.

5.4.1 Algorithm for determining the optimal hop count in multi-hop networks

Existing methods indicate that multi-hop networks are advantageous for data transmission in small areas, whereas virtual MIMO schemes are more energy efficient for large-area transmission. The MIHOP scheme determines the maximum allowable transmission distance (in a multi-hop network) at which the energy efficiency of multi-hop transmission can be maintained. Within this distance, the multi hop networks outperform virtual MIMO schemes; beyond this distance, virtual MIMO technologies exhibit better performance than do the former. As shown in Figure 1, the problem lies in identifying the optimal maximum hop count in the multi-hop network given that the transmission distance from the node in tier n to the sink is approximately estimated as n× r.

The algorithm for determining M_H is described as follows-

1. Initialize $M_H = 1$; r is a fixed value
2. While TRUE
3. If $E^i_{Multihop}(M_H,r) < E^i_{MIMO}(M_H \times r)$
4. M_H++
5. else
6. break;
7. end while.

In this algorithm E^i_{MIMO} is the energy consumption of the ith node that belongs to the jth cluster in the virtual MIMO scheme. As an extension of Eq. (10), E^i_{MIMO} can be expressed as:

$$E^i_{MIMO} = E^j_{MIMO\ c} /2 \qquad (11)$$

In the algorithm, the comparison of one node energy consumption between two transmission schemes is shown in line 3. M_H progressively increases and stabilizes at the value at which the comparison is mismatched. The final value of M_H is the optimal hop count in the MIHOP scheme.

5.4.2 Energy consumption model of MIHOP:

The total energy consumption $E_{MIHOP-total}$ of the MIHOP scheme comprises three components: the energy consumption levels of the multi-hop network, virtual MIMO scheme, and SISO scheme. N_{M1}, N_{M2}, and N_{M3} are assumed to be the number of sensor nodes in the multi-hop network, virtual MIMO scheme, and SISO scheme, respectively. N_{total} denotes the total number of nodes in the MIHOP scheme, where $N_{total} = N_{M1} + N_{M\ 2} + N_M$. If n_i indicates the ith node in different transmission modes, its energy consumption E_i can be expressed as,

$$E^i = \begin{cases} E^i_{Multihop} & \text{When } n_i \text{ is in the multi}-\text{hop network} \\ E^i_{MIMO} & \text{When } n_i \text{ is in the virtual MIMO scheme} \\ E^i_{SISO} & \text{When } n_i \text{ is in the SISO scheme} \end{cases}$$

Thus, $E_{MIHOP-total}$ can be expressed as follows,

$$E_{MIHOP\_total} = \sum_{i=1}^{N_{total}} E^i = \sum_{i=1}^{NM_n} E^i_{Multihop} + \sum_{i=1}^{NM_n} E^i_{MIMO} + \sum_{i=1}^{NM_n} E^i_{SISO} \qquad (12)$$

Where

$$E^i_{Multihop} = E^i_{Multihop}(M, d_{hop}) \quad (1 \leq M \leq M_H) \qquad (13)$$

6. RESULTS & DISCUSSION

The theoretical analysis & simulation results shows that the proposed scheme significantly gives better performance than individual virtual MIMO, multi-hop technologies, and double-string networks in terms of energy conservation. The energy consumption levels of the MIHOP scheme are approximately 12.98%, 47.55% and 48.30% less than that under virtual MIMO schemes, multi-hop networks and double string networks, respectively [7].

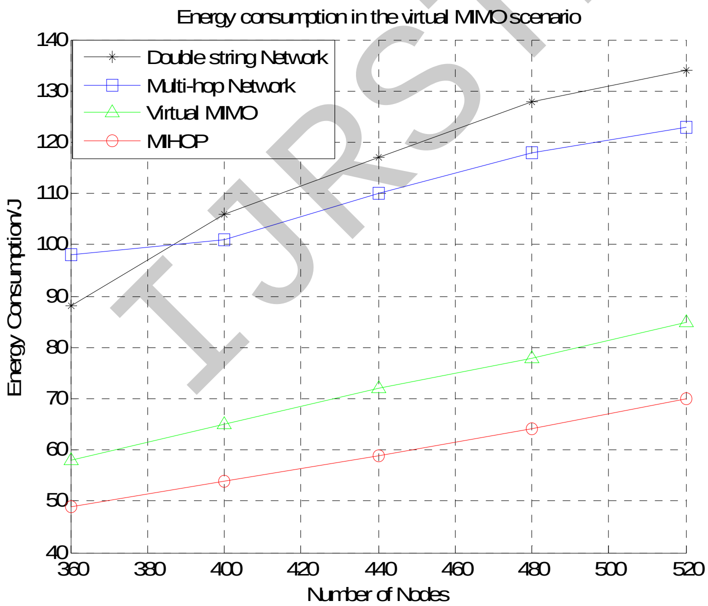

Figure 7: Energy consumption levels of different schemes

To confirm the advantes of presented by the MIHOP scheme, we propose three more simulation scenarioswith different sink movement paths. In fig.8 sink move along the boundry of arectangular area. The Energy consumption of the multi-hop scheme,virtual MIMO and double string network are 107%, 11.64% and 100.16% higher than that of the MIHOP on the average.

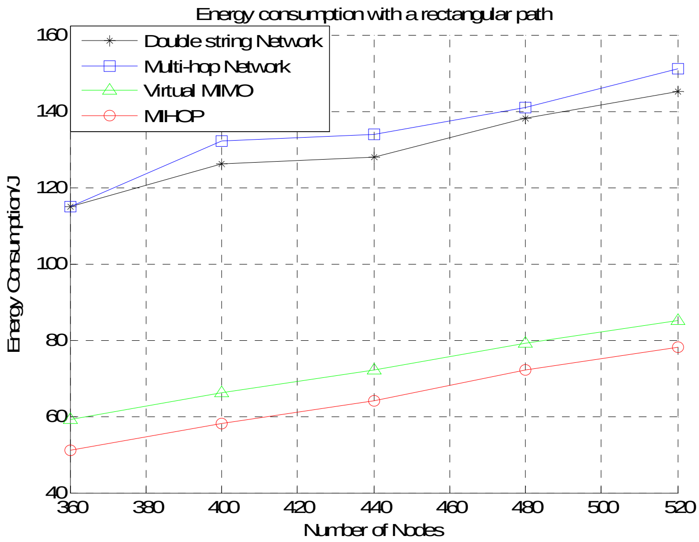

Figure 8: Energy consumption with Rectangular path

The sink travels across zigzag path in fig. 9 and the multi-hop network, virtual MIMO, and double sttring nerwork consume 93.19%,11.35% and 93.19% more than do the MIHOP scheme on the average, respectively. When sink travels along an X-path, the energy consumption of the multi-hop scheme, virtual MIMO and double-string network are 75.07%, 15.01% and 85.51% higher than that of MIHOP on average, respectively. The optimal number of hops in all cases is 2.Thus the energy efficiency of the MIHOP scheme is illustrated.

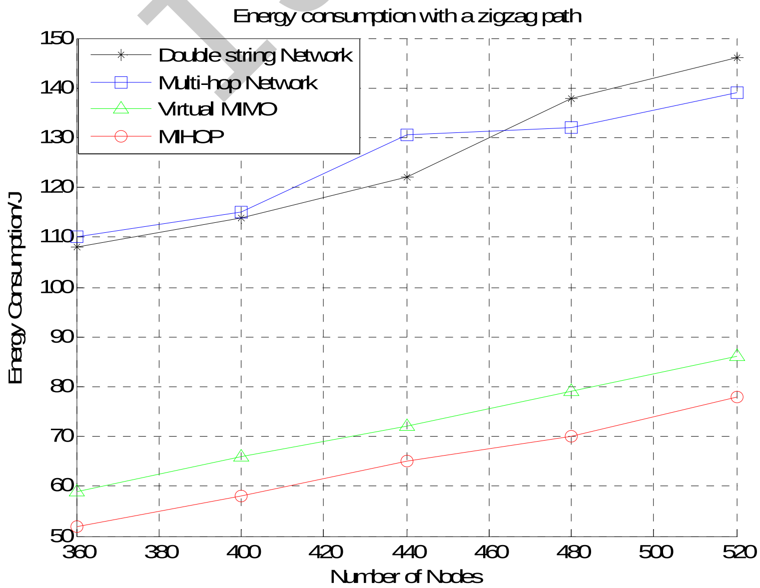

Figure 9: Energy consumption with Zigzag path

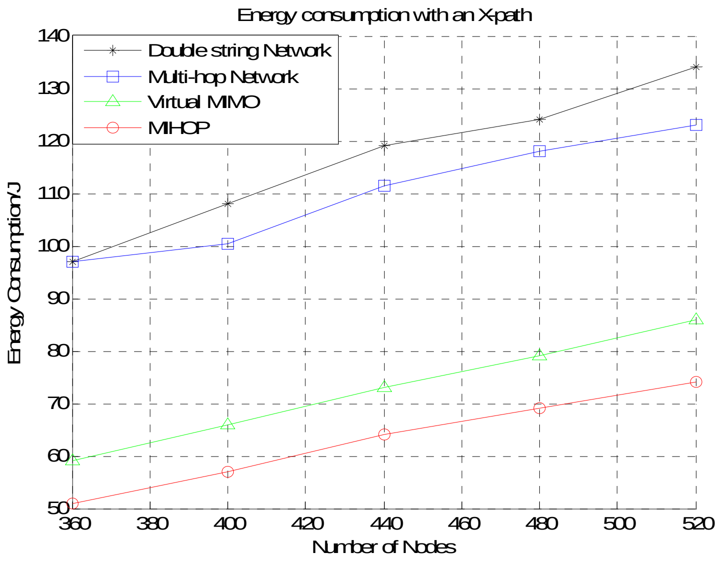

Figure 10: Energy consumption with X- path

7. CONCLUSIONS

In this paper we have extensively characterized data collection in Wireless Sensor Networks with Virtual MIMO, Multihop routing & Mobile Elements (WSN-MEs). An energy-efficient transmission scheme for mobile data gathering in WSNs is proposed. The motivation for doing this was to save energy in the embedded sensor nodes and increase the useful service time of a deployed system. The MIHOP technique combines cluster-based virtual MIMO and multi-hop technologies along with mobile sink node. The key intuition was that using a mobile node to establish shorter data routes reduces the data relaying overhead, especially at the nodes close to the data egress point in the network. The sensor nodes within two hops operate in multi-hop mode as they transmit data, and the remaining nodes operate in virtual MIMO of SISO mode. An algorithm for determining the optimal number of hops required to form a multi-hop network is derived, and the energy consumption model of MIHOP is developed. The MIHOP scheme significantly outperforms individual virtual MIMO, multi-hop technologies and double string network in terms of energy efficiency.

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