Comparative analysis of co-operative mimo based wireless sensor network

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***Abstract*— In wireless sensor network, all nodes are battery operated and because of which energy management is necessary at all stages of the system. The energy consumption needs to be minimized while maintain the other requirements of the network. In conventional wireless sensor network, MIMO is not suitable because of its higher power consumption. To create high speed wireless sensor network, MIMO is necessary. In this paper, the analysis of non-cooperative and cooperative MIMO techniques is discussed with suitable modulation and data rate. The total energy consumption includes both transmission energy and circuit energy consumption. The non-cooperative MIMO is analyzed for cluster based wireless network where power consumption is higher compared to cooperative MIMO technique. The proposed cooperative MIMO technique provides good energy efficiency when distance between source node and destination node is kept higher. The paper includes simulation results to demonstrate energy efficiency of the cooperative MIMO based wireless sensor network.**

***IndexTerms*— WSN, SISO, MISO, Cooperative MIMO**

I. Introduction

Multi-antenna systems have been deployed intensively in recent years due to increase the channel capacity in fading environment. Multi antenna system may improve the channel capacity and may reduce the multipath fading effect. It has been shown that Multi-Input Multi-Output (MIMO) systems can support higher data rates under the same transmit power resources and bit-error-rate performance requirements as a Single-Input Single-Output (SISO) system. Another view is that for the same throughput requirement, MIMO systems require less transmission energy than SISO systems. Direct application of multi-antenna techniques to sensor networks is unreasonable due to the limited physical size of a sensor node which typically can only support a single antenna. Allowing individual single-antenna nodes to cooperate on information transmission and reception, cooperative MIMO system can be constructed such that whole network become energy efficient. In wireless communications, the main objectives are to increase throughput and transmission quality. MIMO systems can take advantage of the shortage of a wireless channel, the multipath and turn it into advantage. In MIMO systems, random fading and multipath delay spread can be used to increase throughput. MIMO systems offer increase in capacity without the need to increase bandwidth or power. One obvious disadvantage of MIMO is that they contain more antennas. MIMO increases complexity, volume, and hardware costs of the system compared to SISO. With reference to SISO, MIMO system has better energy efficiency and throughput. The energy efficiency is compared over various transmission distances. In the traditional approach, the multi-hop transmission techniques are used to reduce the transmission energy consumption by dividing the long transmission channel into multiple short transmissions. The result is that system performance is improved or less energy is needed for data transmission.

The unstable growth of Multiple Input Multiple Output (MIMO) systems has permitted for high data rate and wide variety of applications. Recent advances in wireless communication systems have contribute to the design of multi-user scenarios with MIMO communication. These communication systems are referred as multi-user MIMOs. MIMO system model is showing in Figure 1. It present a communication system with N_T transmit antennas and N_R receive antennas.

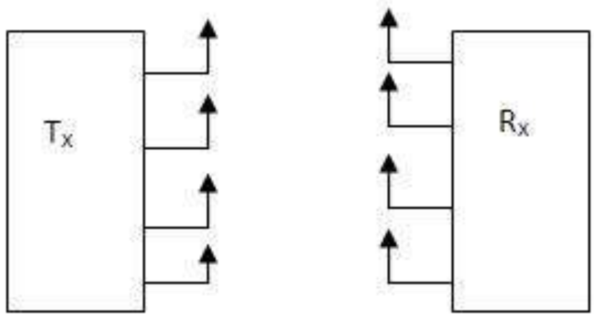

Fig. 1 MIMO system model

II. BASIC OF WIRELESS SENSOR NETWORK

A sensor network is an infrastructure comprised of measuring, computing, and communication elements that gives an administrator the ability to instrument, observe, and react to events and phenomena in a specified environment [1]. The administrator typically is a civil, governmental, commercial, or industrial entity.

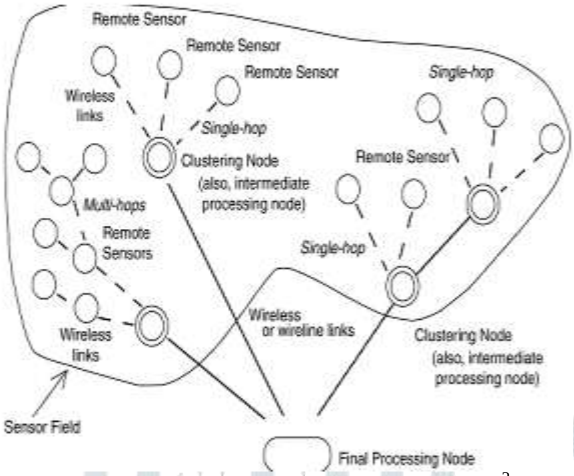

Fig. 2 Typical Sensor Network Arrangements [2]

The environment can be the physical world, a biological system, or an information technology (IT) framework. Network sensor systems are seen by observers as an important technology that will experience major deployment in the next few years for a embarrassment of applications, not the least being national security. In sensor network, elements and design principles need to be placed in the context of the C1WSN sensor network environment, which is characterized by many of the following factors: large sensor population, large streams of data, incomplete/uncertain data, high potential node failure; high potential link failure, electrical power limitations, processing power limitations, multi hop topology, lack of global knowledge about the network, and limited administrative support for the network. Sensor network developments rely on advances in sensing, communication, and computing. As noted, to manage scarce WSN resources adequately, routing protocols for WSNs need to be energy-aware. Data-centric routing and in-network processing are important concepts that are associated intrinsically with sensor networks. The end-to-end routing schemes that have been proposed in the literature for mobile ad hoc networks are not appropriate WSNs; data-centric technologies are needed that perform in-network aggregation of data to yield energy-efficient dissemination. A sensor network is composed of a large number of sensor nodes that are closely deployed. A sensor node typically has embedded processing capabilities and onboard storage; the node can have one or more sensors operating in the acoustic, seismic, radio (radar), infrared, optical, magnetic, and chemical or biological domains [2].The node has communication inter-faces, typically wireless links, to neighbouring domains. The sensor node also often has location and positioning knowledge that is acquired through a global positioning system (GPS) or local positioning algorithm. Figure 2 depicts typical WSN arrangement. Although in many environments all WNs are assumed to have similar functionality, there are cases where one finds a heterogeneous environment in regard to the sensor functionality. In sensor networks, fine-grained time synchronization and localization are needed to detect events of interest in the environment under observation.

III. COOPERATIVE AND NON COOPERATIVE TRANSMISSION

Non cooperative transmission means, source node is direct transmit data to destination node. As data transmission follow path as, source node transmit data to its neighbour node and that neighbour node retransmit data to destination node is called cooperative transmission. In the cooperative transmission, distance between transmit data and number of transmit bits are decrease than non-cooperative transmission technique. Figure 3 show the concept of cooperative and non-cooperative technique.

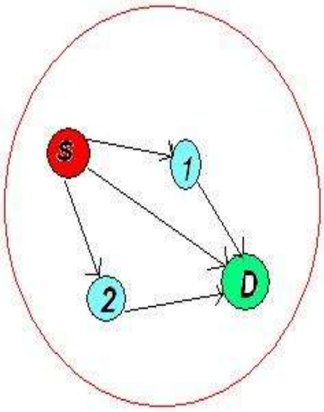

Fig. 3 cooperative and non-cooperative transmissions

As shown in figure 3, source node S transmits data direct to destination node D is non-cooperative transmission. Source node transmits data to either node (1 or 2) and node (1 or 2) retransmit data to destination node that is cooperative transmission.

IV. Cooperative MIMO Based Wireless Sensor Network Model

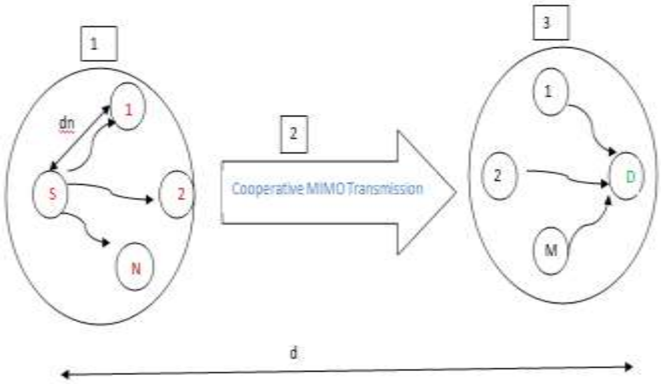

Fig.4 Cooperative MIMO transmission scheme

The MIMO technique can exploit diversity gain of the [3]. the principle of cooperative MIMO transmission space–time coding technique to increase the system performance or to reduce the transmission consumption for the same bit-error-rate requirement using STBCs was presented in, As illustrated in Figure 4, the cooperative MIMO transmission from source node S to destination node D over a transmission distance *d* is composed of the following three phases:(1) local data exchange;(2) cooperative MIMO transmission; (3) cooperative reception. In the local data exchange at the transmission side, the source node S must cooperate with its neighbors and replace its data to perform MIMO transmission in the next phase. Node S can transmit the transmission bits to the other $N - 1$ cooperative transmission nodes. The distance between cooperating nodes *dn* is usually much smaller than transmission distance *d*. In the cooperative MIMO transmission phase, after $N – 1$ neighbor nodes have received the data from source node S, *N* cooperative transmission nodes will modulate and encode their received bits to the quaternary phase-shift keying (QPSK) STBC symbols and then simultaneously transmit to the multi destination nodes similar to traditional MIMO systems. Finally, in the cooperative reception phase at the reception side, cooperative neighbor nodes of destination node D receive the MIMO modulated symbols and then sequentially retransmit them to destination node D for joint MIMO signal combination and data decoding. In a cooperative MIMO system, the decoder at destination node D requires the analog value of received signals at all cooperative nodes for the space–time combination. So, each cooperative node must transmit its received value through a wireless channel to destination node D. One of the following three cooperative reception techniques can be used for this retransmission procedure as: (1) quantization (2) combine and forward (3) forward and combine

V. Energy Consumption MIMO Model

A. Non Cooperative System

The energy model is used with same system parameter for energy evaluation of cooperative MIMO system. The typical RF system block of transmitters and receivers is shown in figure 5, where M_t and M_r indicate for the number of transmitter and receiver antennas, respectively.

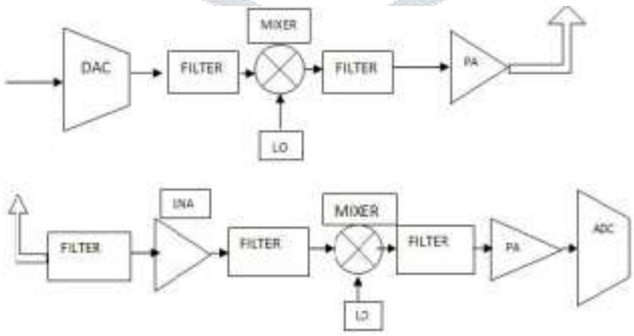

Fig. 5 Transmitter and Receiver blocks

The following is the system model proposed in below equation [3] [4]. The total average power consumption of a signal path is divided into the power consumption of the power amplifiers and the power consumption of the rest of the circuit components. The power consumed by the power amplifier depends on the transmitted power and is given by

$$P_{out} = E_b R_b \frac{(4\Pi d)^2}{G_t G_r \lambda^2} M_l N_f \tag{1}$$

Where E_b is the required energy per bit at the receiver for a given BER requirement and calculate as

$$E_b = \frac{M_t N_f}{P_b^{\frac{1}{dr}}} \tag{2}$$

Diversity gain, dr, and the multiplexing gain, r, is given by

$$d_r = (M_t - r)(M_r - r) \tag{3}$$

$$r = \frac{R_b}{B \log_2 M} \tag{4}$$

Where M is constalation size, B is cut-off bandwidth, R_b is the bit rate, d is the transmission distance, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, λ is the carrier wavelength, M_l is the link margin and N_f is the receiver noise figure given by $N_f = N_r / N_o$ where N_r is the single-sided thermal noise power spectral density and N_o is the power spectral density of the total effective noise at the receiver input. It is assumed that the channel experiences square-law path loss. The power consumption of the power amplifiers is approximated as:

$$P_{PA} = (1+\alpha) P_{out} \tag{5}$$

$$\alpha = \left(\frac{\xi}{\eta}\right) - 1 \tag{6}$$

Where η the drain efficiency of the RF power amplifier and ξ the peak-to-average ratio express as:

$$\xi = 3\frac{M - 2\sqrt{M} + 1}{M - 1} \tag{7}$$

M_t is the no. of transmitter antennas and M_r is the no. of receiver antennas. The local oscillator (LO) used by all the RF chains is the same. The power consumption of the circuit components other than the power amplifier is given by

$$\begin{aligned} P_c = {} & M_t (P_{DAC} + P_{mix} + P_{mod} + P_{filt}) + 2P_{syn} \\ & + M_r (P_{ADC} + P_{mix} + P_{demod} + P_{filr} + P_{LNA} + P_{IFA}) \end{aligned} \tag{8}$$

where P_{DAC}, P_{mix}, P_{LNA}, P_{IFA}, P_{filt}, P_{filr}, P_{ADC}, P_{syn}, P_{mod}, P_{demod} are the power consumption values for the DAC, the mixer, the low-noise amplifier (LNA), the intermediate frequency amplifier (IFA), the active filters at the transmitter side, the active filters at the receiver side, the ADC and the frequency synthesizer, modulation demodulation respectively. The total energy consumption per bit for a fixed rate system is given by

$$E_{bt} = \frac{P_{PA} + P_c}{R_b} \tag{9}$$

The energy consumption of traditional MIMO system E_{MIMO} can be obtained as

$$E_{MIMO} = N_b E_{bt} \tag{10}$$

B. Cooperative MIMO System

The extra energy of the local cooperative data exchange is depend on the number of cooperative antennas and the local inter-node distance d_n between two cooperative nodes at both transmitter and receiver sides. d_n is expected to vary from 1 to 10 meter depending on the geographical configuration of the network. Assumption that N_b bits to transmit from source node to destination node separate by distance d (d >> d_n) and there are M_t nodes and M_r nodes to cooperate at transmitter and receiver sides respectively.

In the transmission side, node S must firstly broadcast its N_b bits to M_t-1 cooperative nodes. For the short distance d_n, SISO is more energy efficient technique in local data exchange and cooperative reception phase. Based on non-cooperative transmission model calculate energy per bit consumption for local data exchange transmission E_{bcoTx}. The extra cooperative energy consumption in the transmission side calculate as

$$E_{coTx} = N_b E_{bcoTx} \tag{11}$$

After receiving N_b bits from source node S, M_t cooperative nodes will be modulate using QPSK and then transmit simultaneously to destination node. In the receiver side, M_r-1 cooperative nodes firstly receive the MIMO modulated symbols, quantize one STBC symbol to Nsb bits and then retransmit their quantized bits respectively to the destination node D using SISO transmission. The extra cooperative energy consumption in the receiver side E_{coRx} is dependent on M_r, N_{sb} and the energy consumption per bit SISO E_{bcoRx}. E_{coRx} can then be calculate as

$$E_{coRx} = N_{sb}(M_r - 1) N_b E_{bcoRx} \tag{12}$$

The transmission and circuit power of cooperative MIMO can be calculate as non-cooperative MIMO system. The total energy consumption of cooperative MIMO system is

$$E_{total} = E_{coTx} + E_{MIMO} + E_{coRx} \tag{13}$$

VI. SIMULATION RESULTS

The simulations were performed in MATLAB® tool using the parameters presented in table 1. The local distance between cooperative nodes is d_n=5m and N_{sb}=10.

Simulation Parameter	Value
Constellation Size ,M	M=4 for QPSK
Noise power	-120dBm
Carrier frequency	2.4GHz
B	200KHz
R_b	9.6 kbit/s
G_t, G_r	5 dB
n	0.35
M_l	40dB
N_f	10dB
P_{MOD}, P_{DEMOD}	30mW
P_{DAC} , P_{ADC}	40mW
P_{mix}	30.3mW
P_{filt} , P_{filr}	2.5mW
P_{syn}	50mW
P_{LNA}	20mW
P_{IFA}	3mW

Table 1 Simulation Parameter

A. SISO vs multihop SISO

On Fig.6 show that traditional SISO is less energy-efficient than the multi-hop SISO as distance increase between source node and destination node. If increase hop than multi-hop SISO technique is consumed less transmitted energy over SISO, but time delay is increase.

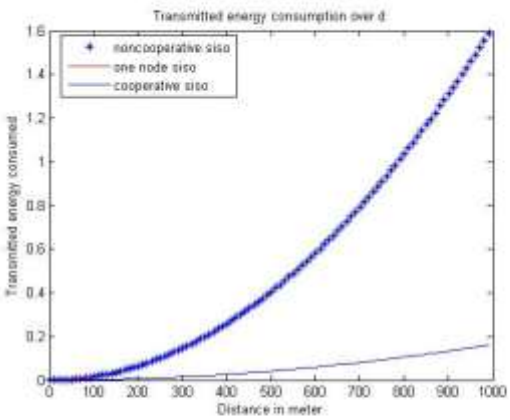

Fig. 6 Transmitted energy consumption of SISO and multi-hop SISO systems

B. Cooperative MIMO vs MISO and MIMO

For long range data transmission in typical WSN, multi-hop SISO technique has been used to reduced transmission energy. The figures from 7 to 10 and table 2 are representing that SISO is good energy efficient for small distance around 5 to 10 meter compare to other techniques. But as distance increase around 100m, the traditional MISO is consumed less energy than traditional SISO and MIMO. Also MISO system receiver antennas are reduced to 1 compared to MIMO. But above 500m distance MIMO system is less energy consumed than MISO. As distance greater than 1000m cooperative MIMO approach is around 52% less energy consumed than traditional MIMO approach. As cooperative MIMO take more time delay than MIMO, but only focus on energy than cooperative MIMO is good than other techniques. Also, the Figure -11 shows analysis of various MIMO system channel capacity. Among that MIMO system has good channel capacity compare to SISO and MISO.

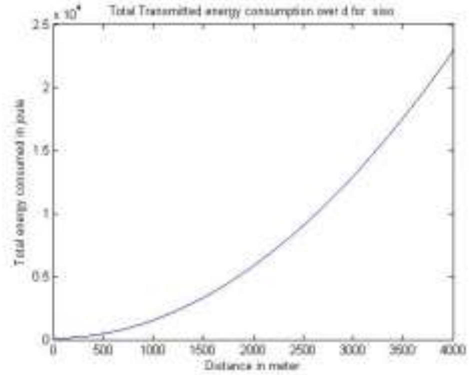

Fig. 7 Total energy consumption of SISO

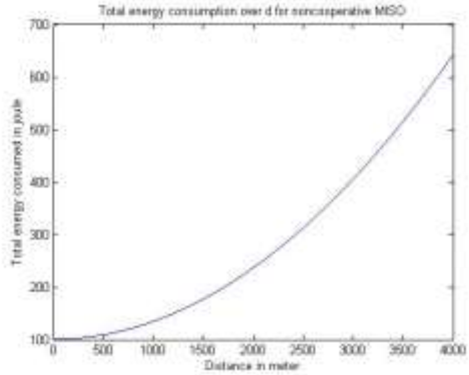

Fig. 8 Total energy consumption of MISO

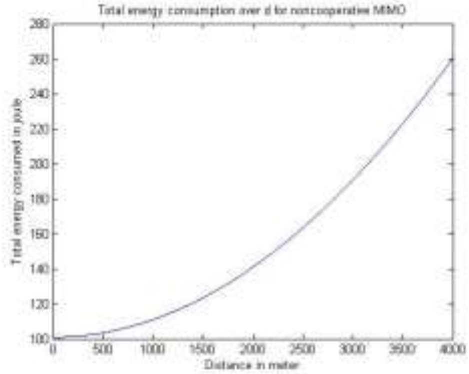

Fig. 9 Total energy consumption of MIMO

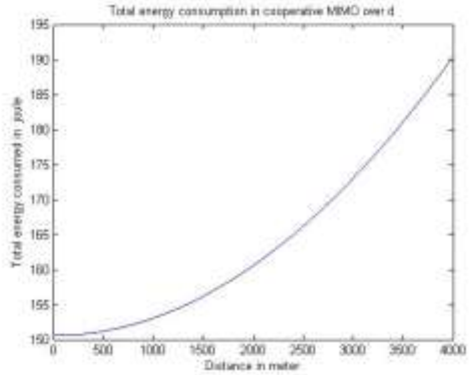

Fig. 10 Total energy consumption of cooperative MIMO

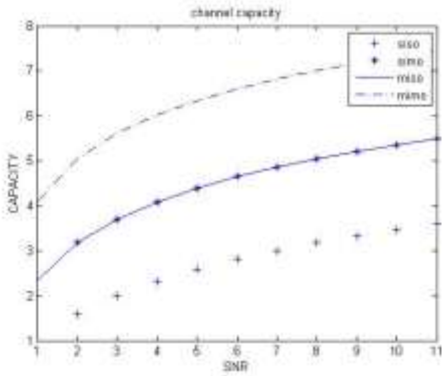

Fig. 11 Comparison of channel capacity of various systems

Total energy (joule)	SISO	MISO	MIMO	COP-MIMO
D=50m	103.79	100.62	100.93	150.56
100	114.49	100.87	101	150.58
500	456.93	108.99	103.40	151.18
1000	1527.06	134.38	110.88	153.05
1500	3310.60	176.69	123.33	156.16
2000	5807.5	235.92	140.78	160.52
2500	9017.9	312.07	163.20	166.13
3000	12941.7	405.15	190.61	172.98
3500	17578	515.15	223	181.08
4000	17578.9	642.08	260.38	190.2268

TABLE 2 Total energy consumption (j) analysis over distance (m) to various techniques

VII. CONCLUSION

As shown into the Simulation results, the MIMO communication system provides better energy efficiency for high speed wireless sensor network. It also provides good channel capacity. Cooperative techniques can exploit the transmission diversity gain to increase the performance or reduce the transmission energy consumption of the system. Cooperative MIMO transmission also reduces latency in the network. Cooperative MIMO is more energy efficient than SISO and traditional multi-hop SISO technique for a long range transmission.

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