Efficiency of Wireless Sensor Network with MIMO Techniques

P. Sudhakara Rao, A. Narmada

Abstract— ***A performance analysis of the energy efficiency of Wireless Sensor Network with different types of MIMO techniques is carried out in this paper. MIMO concept is integrated with WSN and performance of such network is analyzed and experimented in this paper with respect to different energy consumptions viz., transmit energy consumption and total energy consumption. It is concluded that WSN with BPSK-MIMO outperforms WSN with SISO. The results published in this paper show that the integration WSN with BPSK-MIMO can achieve better performance metrics.***

Keywords—***Wsn,Mimo,Siso,Bpsk,Distributed Processing***

I. INTRODUCTION

There is lot of research attention towards WSN even though they have lot of energy constraints. WSN consists of sensors that are battery operated, with parallel and distributed processing abilities. The sensor nodes form vital part in collecting remote data and communicating it to the central processing unit in multiple hops. The essential aim of WSN is to collect remote data from difficult and hash radio environments so as to facilitate the end user with reliable information. Hence the methodologies to reduce energy consumption are vital to the successful operation of WSN as WSN are battery operated [1-6].

The major power consumption of traditional WSNs is due to asymmetrical transmitting patterns and internal circuits. Traditional energy optimization techniques may not be effective to reduce the unusual power consumptions of WSNs. Multiple Input and Multiple Output (MIMO) techniques can be one such methodology to help reduce energy consumption of WSNs which include layered space time architectures, smart antenna schemes and various virtual coalition algorithms. However the MIMO technique has a drawback of requiring complex circuitry to implement coalition algorithms which prevented the integration of WSN [1-5].

II. RELATED WORK

The recent research analysis on MIMO show that the cooperative MIMO techniques enhance the data rates of WSN thereby enhancing the efficiency based on overall energy consumption [6].

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Virtual coalition with cooperative MIMO methodologies leads to many benefits like better energy efficiency, better data rates etc. There may be significant overheads due to MIMO based implementation as discussed in [7].

This paper deals with better methodologies to save energy, enhance throughput and hence improving many other vital performance metrics of WSN.

The model of the proposed system is explained in section III, the analytical methods of the proposed system are explained in section IV and section V represents the conclusion.

III. MODEL AND DESCRIPTION OF THE SYSTEM

The proposed model is based on connecting two wireless sensor nodes with a communication link that is characterized by flat fading and narrow band filtering. The proposed model assumes WSN can either be MIMO or Single Input Single Output (SISO). The base band signal processing blocks of the unit consume negligible energy and hence this energy is assumed to be zero in the proposed model in order to simplify the mathematical analysis. N_T and N_R represent the number of transmitting and receiving antennas respectively.

The total energy consumption is due to two parts viz., power consumption due to all the power amplifiers P_{PA} and the power consumption due to circuit blocks P_C. The amount of transmitted power P_{out} depends of power amplifier power efficiency and its energy consumption and hence the overall power consumption due to the power amplifiers is interpreted in equation (1)

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

Where $\alpha = \varepsilon/\eta - 1$, η: RF power amplifier Energy efficiency and ε: the peak-to-average ratio which depends on two factors viz., modulation scheme and constellation size. M-QAM is assumed in this model [9], therefore

$$\varepsilon = 3\frac{M - 2\sqrt{M} + 1}{M - 1} \text{-----(2)}$$

Link budget calculation can be used to calculate the transmit power P_{out}

$$Pout = \frac{(4\pi)^2 d^k M_l N_f}{G_t G_r \gamma^2} \bar{E}_b R_b \text{------(3)}$$

d:the distance of transmission

k: attenuation of the signal

G_t: Gain of transmitting antenna

G_r: Gain of the receiving antenna

Γ: wave length of the carrier

M_l: the link margin

N_f: Noise figure of the receiver

E_b: Energy consumed per bit

R_b: Bit rate of the system

Receiver noise figure N_f is given by

$\frac{N_f}{N_o}$

N_f : Power spectral density (PSD) of the system

N_o : Thermal noise PSD(single sided)

The antenna patterns including that of MIMO systems, share the synthesizer frequency, [6] hence the total power consumption is estimated as

$$P_C \approx N_T(P_{DAC} + P_{mix} + P_{filt}) + 2P_{synth} + N_R(P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC}) ----(4)$$

P_{DAC} : Power consumption of DAC

Pmix : Power consumption of mixer

Pfilt : Power consumption of filter

Psynth: power consumption of frequency synthesizer

P_{LNA} : power consumption of low noise amplifier

P_{IFA}: power consumption of intermediate frequency amplifier

P_{ADC}: power consumption of ADC

The energy consumed to process one bit of a fixed rate system is formulated using (1) and (4):

$$E_{bt} = \frac{P_{PA} + P_C}{R_b} \quad \text{-------(5)}$$

Based on the above assumptions the time signal of MIMO receiver in discrete domain can be expressed as

$$y(i) = H(i)\,x(i) + n(i) \text{------(6)}$$

y(i) represents the received signal vector using BPSK-MIMO virtual coalition antenna arrays

x(i) represents the transmitted signal vector using BPSK-MIMO virtual coalition antenna arrays

n(i) represents vector of additive noise at receiver using BPSK-MIMO virtual coalition antenna arrays

H(i) : Matrix of order $N_R \times N_T$ that represents complex fading coefficients of the proposed virtual MIMO system.

H(i) also interprets random signal attenuation of square law path loss from equation (1). Rayleigh flat fading model is assumed in this work. Further it is also assumed that the noise is independent of time.

The virtual coalition of cooperative MIMO, which is the basic concept of the proposed work is realized by adopting simple Alamouti scheme with 2X1 MISO array of antennas to implement MIMO technique.

Let c(i) and c(i+1) denote inputs of space-time block encoder, then according to the Alamouti technique, $x(k)=[c(i),c(i+1)]$, $x(k+1)=[-c^*(i+1), c^*(i)]^T$, * denotes complex conjugate

IV. ANALYSIS OF WSN WITH MIMO TECHNIQUE FOR A CONSTANT BIT RATE SYSTEM

A. Cooperative MIMO with Alamouti Scheme (BPSK with 2X1 MISO)

The signal-to-noise ratio of the Alamouti method for the proposed work with 2X1 BPSK MIMO array can be represented as

$$SNR_i^{(2X1)} = \|H(i)\|_F^2$$

where $\|H(i)\|_F$ is the Frobenius norm of the matrix H(i).

Based on the above analysis using Alamouti scheme, the average Bit Error Rate of a MISO system is expressed as in equation (7)

$$\vec{P}_b = \frac{1}{2^{N_T}}\left(1 - \frac{1}{\sqrt{1+\frac{1}{E_b/2N_o}}}\right)^{N_T} X \sum_{k=0}^{N_T-1}\frac{1}{2^k}(N_T-1+k,k)\left(1 + \frac{1}{\sqrt{1+\frac{1}{E_b/2N_o}}}\right)^{k} ---7)$$

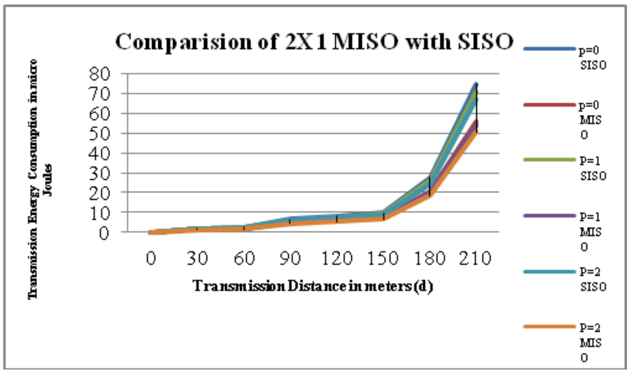

Figure 1: Comparison of 2X1 MISO Vs SISO Energy consumption at transmitter section for BPSK

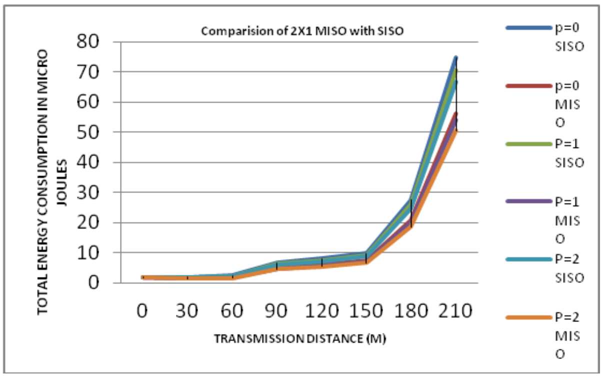

Figure 2: Comparison of 2X1 MISO Vs SISO Energy consumption for BPSK at virtual coalition array of the system

With little modifications to equation (7), required average energy per bit $\vec{E}_b$ for a given Bit Error Rate can be obtained. According to the Alamouti scheme for 2X1 BPSK-MIMO system and by inverting equation (7) is further simplified to

$$\vec{P}_b = \frac{1}{4}\left(1 - \frac{1}{\sqrt{1+\frac{1}{E_b/2N_o}}}\right)^2\left(2 + \frac{1}{\sqrt{1+\frac{1}{E_b/2N_o}}}\right) --- (8)$$

Energy per bit E_b was estimated based on simulation in contrary to the existing analytical methodologies. In order to simplify the analysis and reduce the complexity of the proposed methodology, it is assumed that the receiver has the knowledge of Channel State Information (CSI). The training overhead that is required to train the system initially is very negligible and it is also assumed to be zero to further simplify the analysis. But MIMO based methodologies certainly require more training than SISO based methodologies and hence neglecting this overhead may result in additional energy consumption and more distortion in terms of comparison results which is also neglected in order to simply the analysis..

Further if training symbols and data symbols consume the same quantum of transmission energy, more number of training symbols are required than the number of transmitting antennas. In addition to this number of training bits is a function of Signal to Noise Ratio at the time of operation of the system.

This extra energy component may be compensated when it is assumed that each block consists of F symbols and $_pN_T$ training symbols are included in order to train the antenna arrays of cooperative MIMO as a result of virtual coalition at both transmitter and receiver.
Equation (9) formulates the effective bit error rate of the system as mentioned below.

$$R_b^{eff} = \frac{F - pN_T}{F} R_b - - - (9)$$

By replacing R_b in equation (5), the updated values of energy consumption for 2X1 MISO can be evaluated.

B. Analysis of conventional WSN with Single antenna Array (SISO)

The Signal to Noise Ratio of the receiver of BPSK-SISO system can be expressed as

$$SNR_i^{SISO} = |H(i)|^2 \frac{\overleftrightarrow{E_b}}{N_0}$$

Thus, the average Bit Error Rate of a BPSK SISO system in flat Rayleigh fading is expressed as

$$\overleftrightarrow{P_b} = \frac{1}{2}\left(1 - \frac{1}{\sqrt{1 + \frac{1}{E_b/N_0}}}\right) -----(10)$$

The average energy required ber bit can be obtained by inverting above equation (10) leading to equation (11) for a given bit error rate,

$$\overleftrightarrow{E_b} = \frac{N_o}{\frac{1}{\left(1 - 2\overleftrightarrow{P_b}\right)^2} - 1} ---------(11)$$

The equation (9) gives the effective bit error rate by making $N_T = 1$. In order to ease the analysis, the details of simulated values of transmission energy and total energy of 2X1 MISO and SISO are depicted in figure 1 and 2 respectively for different values of transmission distance ranging from 0 to 210 meters.
The assumptions n all the simulations are described below. The bandwidth is 10 kHz, cutoff frequency is 2.5 GHz, power consumed at mixer is 30.3 mW, Filter power consumption is 2.5 mW, , Power consumed at Low Noise Amplifier is 20 mW, Power Consumed at synthesize is 50 mW, M_l = 40 dB, N_f = 10 dB, G_tG_r = 5 dBi and η = 0.35. Also, in all simulations we have set $\kappa = 2$.
Figure 1 and 2 describe the comparison of energy parameters 2X1 BPSK-MIMO and conventional WSN-SISO at transmitter and receiver antenna arrays respectively. It is observed that the energy efficiency of 2X1 BPSK-MIMO system is better than that of conventional WSN-SISO system and efficiency improves with number of training parameter (distance in this case)

V. CONCLUSION

This paper published the results of comparison of both systems viz., 2X1 BPSK-MIMO and conventional WSN-SISO. Figure 1 and 2 describe the comparison of energy parameters 2X1 BPSK-MIMO and conventional WSN-SISO at transmitter and receiver antenna arrays respectively. It is observed that the energy efficiency of 2X1 BPSK-MIMO system is better than that of conventional WSN-SISO system and efficiency improves with number of training parameter (distance in this case). From the analysis presented in sections III and IV, it can be concluded that there is an extra overhead in case of 2X1 BPSK-MIMO due to the additional training methodologies. But from the comparison results s shown in figure 1 and 2 it can be concluded that even with the extra energy overhead 2X1 BPSK –MIMO system with multiple antenna arrays at transmitter and receiver outperforms conventional WSN-SISO system if the design is carried out judiciously.

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