Energy efficient Wireless Sensor Networks using Cooperative MIMO

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Abstract - In wireless sensor network, sensor nodes are generally powered by batteries, which are not easy to replace. Hence, it is very important to use energy efficient techniques to minimize the energy consumption. Mainly, the MIMO technique which is a proven scheme to minimize the energy consumption of a wireless sensor network. However, it is not practical to install multiple antennas in one sensor node because sensor node is smaller in size. Neighbors nodes at transmitter and receiver cooperate with the source and destination nodes to form a cooperative MIMO system. In this paper, the energy efficiency of SISO (single input single output), cooperative MISO (multi-input single-output) and MIMO (multiple input multiple out) in WSNs at different constellation size are investigated. This comparison helps us to choose, according to the distance between the source and the destination, the appropriate cooperative technique.

Keywords: Cooperative MIMO, energy efficiency, wireless sensor networks

I. INTRODUCTION

In sensor networks, where the nodes operate on batteries so that energy consumption must be minimized, while satisfying given throughput and delay requirements. The total energy consumption includes both the transmission energy and the circuit energy consumption. Multi-input–multi-output (MIMO) systems can support higher data rates under the same transmit power budget and bit-error-rate performance requirements as a single-input single-output (SISO) system. An alternative view is that for the same throughput requirement, MIMO systems require less transmission energy than SISO systems. However, direct application of multiantenna techniques to sensor networks is impractical due to the limited physical size of a sensor node which typically can only support a single antenna. Fortunately, if we allow individual single-antenna nodes to cooperate on information transmission and/or reception, a cooperative MIMO system can be constructed such that energy-efficient MIMO schemes can be deployed [1, 2, 3]. Energy-efficient communication techniques typically focus on minimizing the transmission energy only, which is reasonable in long-range applications where the transmission energy is dominant in the total energy consumption. However, in short-range applications such as sensor networks where the circuit energy consumption is comparable to or even dominates the transmission energy, different approaches need to be taken to minimize the total energy consumption. Here, the circuit energy consumption includes the energy consumed by all the circuit blocks along the signal path: analog to digital converter (ADC), digital to analog converter (DAC), frequency synthesizer, mixer, lower noise amplifier (LNA), power amplifier, and base band DSP [1]. Binary phase-shift keying (BPSK) based systems, where we show SISO systems may be more energy-efficient than MIMO systems when transmission distance is short. We then show that if we allow the constellation size to be optimally chosen, the energy efficiency of MIMO systems can be dramatically increased. For the data transfer in sensor networks, we show that if we allow the cooperation among sensors for information transmission and/or reception, we can reduce energy consumption, as well as transmission delay over some distance ranges. In other words, under the same BER and throughput requirement, MIMO systems require less transmission energy than SISO systems. However, if we consider both the
transmission energy and the circuit energy consumption then for short distance SISO system is more energy-efficient but long distances MIMO system is more energy efficient [1]. MIMO techniques can be used to increase data rate using spatial multiplexing and bit error rate (BER) can be improved by using spatial diversity. [3].

For $b = 1$, M-ary QAM system reduces to a BPSK system [2].

II. ENERGY CONSUMPTION OF MIMO SYSTEM

The total power consumption of this RF system along the signal path consists of two components: the power consumed in the amplifiers $P_{PA}$ and the power consumed in all the other circuit blocks $P_C$ [5]. The first term $P_{PA}$ is decided by the transmitting power $P_{trans}$

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

Where $\alpha = (\xi / \eta) - 1$, $\eta$ is the drain efficiency of the RF power amplifier and $\xi$ is the Peak to-Average Ratio which depends on the modulation scheme and the associated constellation size.

When squared power path loss is considered, $P_{out}$ can be calculated by the link budget relationship as

$$P_{out}(d) = \frac{E_b R_b (4\pi^2 d^{4k} M_k E_b)}{G_r \lambda^2}$$

Where $E_b$ is the mean required energy per bit at the receiver for a given BER requirement $R_b$ is the bit rate of the RF system. “d” is the transmitting distance. $G_r$ and $G_t$ are the antenna gain of the transmitter and the receiver respectively. $\lambda$ is the wavelength of the signal, $M_k$ is the link margin compensating the hardware process variations and other additive background noise or interference, $N_f$ is the receiver noise figure defined as $N_f = N_s / N_0$ with $N_s$ as the power spectral density of the total effective noise at input of the receiver and $N_0$ as the power spectral density of the single-sided thermal noise.

$P_C$ can be expressed as

$$P_C = N_f(P_{DAC} + P_{mix} + P_{filt}) + 2P_{synth} + N_R(P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC})$$

where $P_{DAC}$, $P_{mix}$, $P_{LNA}$, $P_{IFA}$, $P_{filr}$, $P_{ADC}$ and $P_{synth}$ are the power consumption values for the digital-to-analog converter, the mixer, the low-noise amplifier, the intermediate frequency amplifier, the active filters at the transmitter side, the active filters at the receiver side, the analog-to-digital converter, and the frequency synthesizer, respectively. [2]

Finally, the total energy consumption per bit can be expressed as

$$E_{pb} = \frac{P_{PA} + P_C}{R_b}$$

III. SIMULATION ANALYSIS

Hardware of a wireless sensor node is energy efficient, i.e., various components of sensor node are designed to consume lesser energy. For Simulation analysis, MAT LAB tool has been used [2,7].

<table>
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<th>Table 1: Simulation Parameters</th>
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<tr>
<td>Wavelength ($\lambda$)</td>
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<tr>
<td>Drain efficiency factor( $\alpha$)</td>
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<tr>
<td>$G_t G_r$</td>
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<tr>
<td>Noise power density($N_o$)</td>
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<tr>
<td>Bandwidth (B)</td>
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<tr>
<td>$P_{mix}$</td>
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<td>$P_{IFA}$</td>
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<td>$P_{syn}$</td>
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<td>$P_{filr}$</td>
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<td>$N_f$</td>
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<td>$P_{ADC}$</td>
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Fig.1 shows BPSK modulation. The result shows that the total energy consumption of MIMO is less than MISO for $d > 23$ and for $d < 23$ MISO consumes less energy than MIMO if $k=2$. Further, for $d < 3$, SISO is better than MIMO i.e. SISO consumes lesser energy than MIMO but for $d > 3$, MIMO consumes less energy than SISO if $k=2$.

Fig.2 shows 4-QAM modulation. The result shows that the total energy consumption of MIMO is less than MISO for $d > 15$ and for $d < 15$ MISO consumes less energy than MIMO if $k=2$. Further, for $d < 2$, SISO is better than MIMO i.e. SISO consumes lesser energy than MIMO but for $d > 2$, MIMO consumes less energy than SISO if $k=2$. 

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consumes less energy than MIMO if k=2. Further, MIMO better than SISO.

IV. CONCLUSION

In this paper, we have evaluated the energy efficiency of cooperative MIMO system and compared it to a traditional SISO and MISO schemes at different constellation size. Despite the extra energy consumption at emission and reception sides, Cooperative MIMO proves its energy efficiency better in wireless sensor networks, especially in large distances. Simulation results prove that the cooperative MIMO approach seems better than the traditional SISO technique and Cooperative MISO for long distances. We can also compare this scheme according to different parameters like training overhead factor, pathloss component etc.

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