Optimized CMIMO-SM for saving energy in Wireless Sensor Network

Wided ABIDI† and Tahar EZZEDINE††

National Engineering School (ENIT) of Tunis

Summary

Spatial Modulation (SM) is a recently proposed technique that increases the overall spectral efficiency therefore the energy consumption on Wireless Sensors Network is minimized. In addition, this technique can improve the capacity of CMIMO schemes by using the transmit antenna index and amplitude/phase modulation to transmit information bits. For this reason, combining CMIMO scheme to SM can achieve energy-efficiency improvement [1]. The main idea introduced in this paper is based on CMIMO-SM scheme by optimizing the constellation size b for minimizing the energy consumption. At first time, we present the system model of CMIMO-SM concept used. Then, we elaborate the proposed scheme and examine its performance by numerical simulations. The results show an important savings of total energy consumption.

Key words:

Wireless Sensors Network (WSN), Spatial Modulation (SM), Cooperative Multiple Input Multiple Output (CMIMO), Energy efficiency

1. Introduction

In wireless sensors network (WSN), sensor nodes operate on batteries but this one is energy limited. In addition, it could be difficult or impossible to recharge or replace it. Therefore saving energy consumption in wireless sensors network (WSN) is a critical issue. Several researches on multiple input multiple output (MIMO) technique show the performance of this one to reduce energy. But direct application of this technique to wireless sensors network is impractical due to the size of the sensor node. Typically, the sensor node is a tiny device which can't support more than one antenna. As a solution, we need to allow cooperation between devices for transmission information. Hence, the use of cooperative MIMO (CMIMO) scheme is necessary.

In other side, a new approach "spatial modulation" [3, 4, 5] is developed recently which increases the spectral efficiency. Only one antenna remains active during transmission which can effectively avoid the inter-channel interference (ICI). To get advantages of these both techniques CMIMO and SM, a new approach named CMIMO-SM is proposed by Yuyang Peng and Jaeho Choi in [1]. Based on this scheme, since that the total energy consumption is function of constellation size b, we have find an optimal value for b which minimizes this energy for each transmission distance d.

In this paper, we first represent the related work in section 2. Then, we present the system model used in section 3 as well as the CMIMO-SM and its application. The energy consumption model is detailed in section 4. In section 5, we present the optimization algorithm. Simulations results are shown and discussed in section6. Finally, section 7 concludes with insights for future researches in reducing energy consumption in WSN.

2. Related work

In [2], Cui and al proposed the CMIMO concept for the first time for single hop transmission in WSN. In [3], a new technique "Spatial Modulation (SM)" is proposed to minimize the energy consumption by improving the spectral efficiency. In [1], the authors are relied to [2] and [1] to propose a new approach combining the CMIMO concept with SM to reduce energy consumption. The authors of [4] are discussed challenges, opportunities and issues related to the implementation of SM–MIMO.

3. System Model

We consider a wireless sensors network divided into many clusters where each node is equipped with only one antenna. Cooperative Multiple Input Multiple Output (CMIMO) and Spatial Modulation (SM) are the practical techniques to transmit information, provide high spectral efficiency and avoid Inter-Channel Interference (ICI) by using only one active antenna during the transmission.

In our proposed model, we denote Mt and Mr the number of transmit and receive antennas respectively. The cardinality of the signal constellation diagram is denoted by M where M = 2b and b is constellation size. Besides, we named the data flow inside the cluster 'local transmission' and between two clusters 'long-haul transmission'.

At the transmitter, the information to be transmitted is divided into blocks of log (M) +log (Mt) bits. Each block is then mapped into two sub-blocks : 1) a symbol that was

Manuscript received October 5, 2016
Manuscript revised October 20, 2016

chosen from a constellation diagram and 2) a unique transmit antenna number that was chosen from a set of transmit antennas [3]. Then each sensor broadcasts its data to other nodes in the same cluster. Due to the principle of SM, only one antenna is active during transmission. For that, information are transmitted from the the appropriate antenna aver MIMO channel to the receiver. At reception, there is one destination node and Mr - 1 nodes join the cooperative reception.

4. Energy consumption model

From [2], the total average power consumption of our model is composed of two components: the power consumption of all the power amplifiers PPA and the power consumption of all the circuit blocks Pc. PPA depends on the transmit power Pout and calculates as follows:

$$P_{PA} = (1+\alpha)\overline{E_b}\, R_b \frac{(4\pi d)^2}{G_t G_r \lambda^2} M_l N_f \qquad (1)$$

where $\overline{E}_b$ is the required energy per bit at the receiver for a given BER requirement, 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 compensating the hardware process variations and other additive background noise or interference, and N_f is the receiver noise figure defined as $N_f = N_r/N_0$ with $N_0 = -171$ dBm/Hz the single-sided thermal noise Power Spectral Density (PSD) at room temperature and Nr is the PSD of the total effective noise at the receiver input. $\alpha = \xi|\eta - 1$ with η the drain efficiency of the RF power amplifier and ξ the Peak-to-Average Ratio (PAR). For MQAM, $\xi = 3(M^{1/2}-1)/(M^{1/2}+1)$.

Concerning the total circuit power consumption, the relation is given by :

$$P_c = M_t (P_{DAC} + P_{mix} + P_{filt}) + 2P_{syn} + M_r (P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC}) \qquad (2)$$

Where P_{DAC}, P_{mix}, P_{LNA}, P_{IFA}, P_{filt}, P_{filr}, P_{ADC}, and P_{syn} 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 receiver side, the ADC, and the frequency synthesizer, respectively. The values of P_{DAC}, P_{ADC}, and P_{IFA} are calculated in the same way as in [6].

The total energy consumption per bit is given by :

$$E_{bt} = \frac{P_{pa} + P_c}{R_b} \qquad (3)$$

By combining (1) and (3), we have the total energy consumption per bit as follows :

$$E_{bt} = (1+\alpha)\overline{E_b} \frac{(4\pi d)^2}{G_t G_r \lambda^2} M_l N_f + \frac{P_c}{R_b} \qquad (4)$$

Given that the parameter $\overline{E_b}$ is defined by the bit error rate $\overline{P_b}$ and the constellation size b and according to [2], we can write $\overline{E_b}$ as follows :

$$\overline{E_b} = \frac{2}{3}\left(\frac{P_b}{4}\right)^{\frac{-1}{M_t}} \frac{2^b - 1}{b^{\frac{1}{M_t}+1}} M_t N_0 \qquad (5)$$

According to (4) and (5) and since $b = \frac{L}{B\,T}$ the total energy consumption per bit can be rewritten as :

$$E_{bt} = x\, d^2 \frac{2^b - 1}{b^2} + y\, \frac{1}{b} \qquad (6)$$

With coefficients x and y defined as :

$$x = \frac{8}{3\,P_b}(1+\alpha) N_0 \frac{4\pi^2}{G_t G_r \lambda^2} M_l N_f \qquad (7)$$

$$y = \frac{P_c}{B} \qquad (8)$$

As detailed in [1], the total energy consumption per bit for CMIMO-SM is calculated as follows :

$$E_{btcsm} = E_l + E_{lh} \qquad (9)$$

Where E_l is the energy consumption for the local phase and E_{lh} is the energy consumption for the long-haul phase and are calculated according to (4).

For the local phase, there are two components: (1) energy consumption of data exchange inside cluster in transmitter side E_i^t and (2) energy consumption of data collection for joint detection inside cluster in receiver side E_j^r. For this phase communication, SISO communication is used i.e $M_t = M_r = 1$.

For the long-haul energy consumption, CMIMO-SM is used therefore only one antenna is active during each time instant i.e $M_t = 1$ in the circuit power consumption since. Each sensor node has Ni bits to transmit and the energy consumption per bit E_l can be written as follows :

$$E_l = \frac{\sum_{i=1}^{M_t} N_i E_i^t + \sum_{j=1}^{M_r - 1} E_j^r \sum_{i=1}^{M_t} N_i}{\sum_{i=1}^{M_t} N_i} \qquad (10)$$

After adding E_{lh} to E_l, the energy consumption per bit can be expressed as

$$E_{bt,csm} = \frac{\sum_{i=1}^{M_t} N_i E_i^t + E_{lh} \sum_{i=1}^{M_t} N_i + \sum_{j=1}^{M_r-1} E_j^r \sum_{i=1}^{M_t} N_i}{\sum_{i=1}^{M_t} N_i} \qquad (11)$$

Where E_i^t, E_j^r and E_{lh} can be calculated according to (6).

4. Optimization Algorithm

Since E_{bt} is function of the constellation size b for various transmission distances d (equation (6)), we can find an optimal value for b which minimizes this total energy consumption for each transmission distance d.
Assuming that b is a discrete variable, the optimization problem is not convex. In this paper, brute-force search is used to find the optimal b

$$\begin{aligned} &\text{minimize} \quad E_{bt} \\ &\text{subject to} \quad b - b_{min} \geq 0 \\ &\qquad\qquad b_{max} - b \geq 0 \end{aligned} \tag{12}$$

By using the log-barrier functions [12], the unconstrained problem is rewritten as :

$$\text{Minimize } tE_{bt} - \sum_{i=1}^{m} \ln(b_{max} - b_i) \quad i=1,\ldots,M_t \tag{13}$$

Where t > 0 is a weighting factor.

The algorithm [6] for minimizing Ebt is :

Given a strictly feasible b0, t := t0 > 0, step size $\mu > 1$, tolerance ϙ > 0, we run

Algorithm

1)Compute b* by minimizing $tE_{bt} - \sum_{i=1}^{m} \ln(b_{max} - b_i)$ starting from b_0

2) Update: $b_0 = b^*$

3) Quit if m/t < ϙ

4) Otherwise set t = μ t and go back to step 1)

Note that $b_0 = b_{max}$ is the feasible point and to solve the problem in step 1) Gaussian- Newton method [12] is used.

Table 1 summarizes optimized constellation sizes for each transmission distance d :

Table 1 : OPTIMIZED CONSTELLATION SIZE CMIMO-SM

d (m)	$b_{CMIMO-SM}$
1	16
5	12
10	10
20	8
40	7
70	5
100	5

5. Simulations and numerical results

The results are obtained using a MATLAB simulator tool which is licensable software. The simulation results are shown below.

In this simulation, these values have been used : $G_tG_r = 5$ dbi ; M_l =40db; N_0 = -171 dB/Hz; f_r=2,5 GHz; N_f=10 dB; λ=0,12 m; η=0,35; P_b=1e-3; L_i=20 Kb; P_{syn}=50 mW; P_{mix}=30 mW; P_{LNA}=20 mW; $P_{filt}=P_{filr}$=2,5 mW; P_{IFA}=3 mW; P_{DAC}=6,698 mW; P_{ADC}=15,437 mW; E_{ch}=28 µJ/bits/signals; E_{da}=5 nJ/bits/signals; $L_{ch=8}$; $L_{c=8}$; $n_{t=10}$; f_{cor}=1 MHz; l_0=50 µm; L_{min}=0,5 µm; $n_1=n_2$=10; B=10 kHz; C_p=1 pF; β=1; V_{dd}=3V

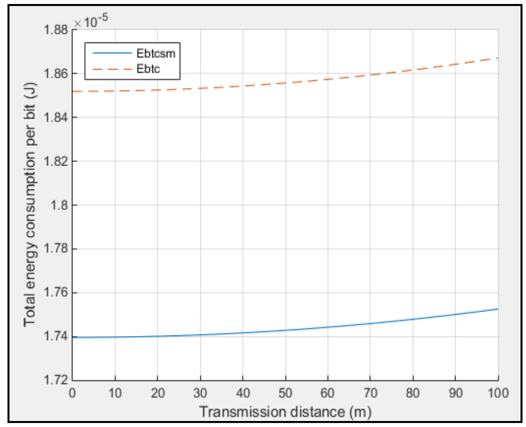


Fig. 1 : Total energy consumption per bit over d for 4 bits transmission

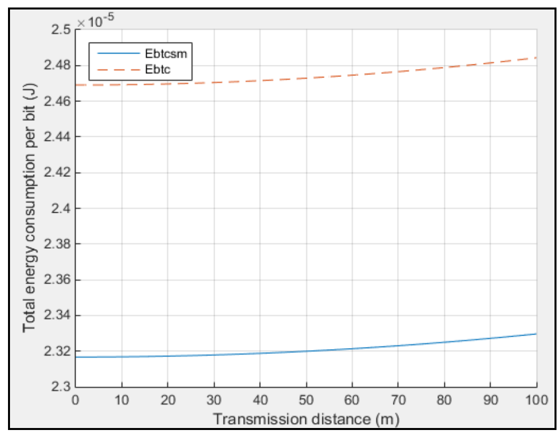


Fig. 2 : Total energy consumption per bit over d for 3 bits transmission

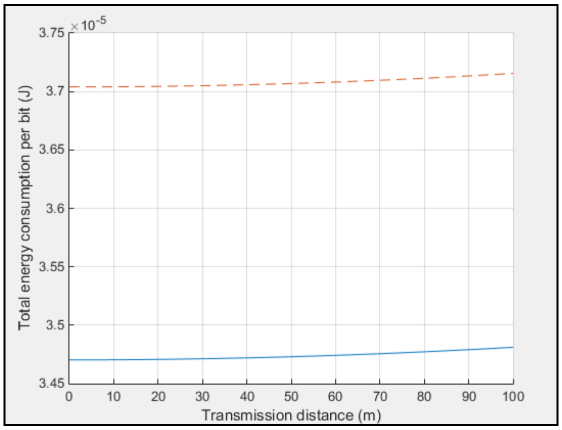


Fig. 3: Total energy consumption per bit over d for 2bits transmission

Fig.1, Fig.2 and Fig.3 show that the CMIMO-SM is a performed scheme to reduce energy consumption compared with traditional scheme CMIMO. For this reason, we are based on this technique CMIMO-SM and have found the optimal constellation size b that minimized the total energy consumption.

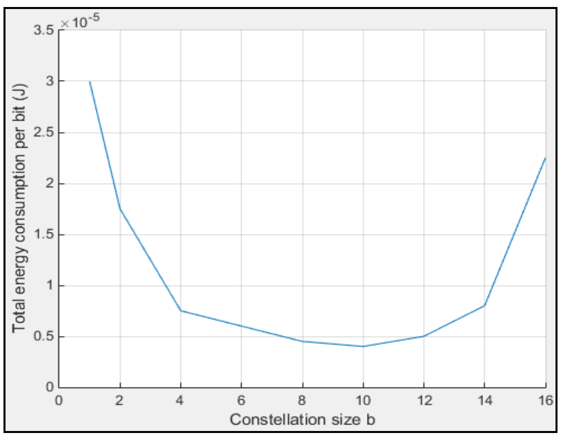


Fig. 4 : Total energy consumption over b CMIMO-SM 2*2

we can see in Fig.4 that the energy decrease when b=10 i.e the optimal constellation size bopt = 10.
This value of constellation size saves a large amount of energy.

References

[1] Y.Peng, J.Choi “A New Cooperative MIMO Scheme Based on SM for Energy-Efficiency Improvement in Wireless Sensor Network” The Scientific World Journal, vol.2014, ArticleID 975054, 10 pages

[2] S. Cui, A. J. Goldsmith, and A. Bahai, “Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks,” IEEE Journal on Selected Areas in Communications, vol. 22, no.6, pp. 1089–1098, 2004.

[3] R. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn, and S. Yun, “Spatial modulation,” IEEE Transactions on Vehicular Technology, vol. 57,no.4, pp. 2228 –2241, July 2008.

[4] M.Di Renzo, H.Haas, A.Ghrayeb, S.Sugiura, L.Hanzo, “Spatial Modulation for Generalized MIMO: Challenges, Opportunities, and Implementation,” Proceedings of the IEEE, Vol. 102, No. 1, January 2014.

[5] M.Di Renzo, H.Haas, P.Grant, “Spatial Modulation for Multiple-Antenna Wireless Systems: A Survey,” IEEE Communications Magazine, vol. 49, no.12, pp.182-191, December 2011.

[6] S. Cui, A. J. Goldsmith, and A. Bahai, “Energy-constrained modulation optimization,” IEEE Transactions onWireless Communications, vol. 4, no. 5, pp. 2349–2360, 2005.

[7] S. Cui, A. J. Goldsmith, and A. Bahai, “Modulation optimization under energy constraints,” Proceedings of ICC’03, Alaska, U.S.A, May, 2003. Also available at http://wsl.stanford.edu/Publications.html

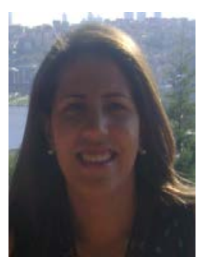
[8] S. Cui, A. J. Goldsmith, and A. Bahai, “Energy Consumption and Optimization in MIMO Systems” Department of Electrical Engineering, Stanford University, Stanford, CA, 94305

[9] M. Riduan Ahmad, Eryk Dutkiewicz, Xiaojing Huang and M. Kadim Suaidi (2010). “Cooperative MIMO Systems in Wireless Sensor Networks,” Radio Communications, Alessandro Bazzi (Ed.), ISBN: 978-953-307-091-9, InTech, DOI: 10.5772/9462. Available from:http://www.intechopen.com/books/radio-communications/cooperative-mimo-systems-in-wireless-sensor-networks

[10] Y. Y. Peng, J. H. Choi, "Energy Efficient Multi-Hop Wireless Sensor Networks with CMIMO-SM Scheme", Applied Mechanics and Materials, Vol. 666, pp. 322-326, 2014 http://www.scientific.net/AMM.666.322

[11] Lifetime and energy optimization in multi-hop wireless sensor networks with spatial modulation based cooperative MIMO Article first published online: 23 SEP 2015 http://onlinelibrary.wiley.com/doi/10.1002/tee.22155/full

[12] S. Boyd, L. Vandenberghe, Convex Optimization, Cambridge Univ. Press, Cambridge, U.K., 2003.



Wided ABIDI received engineering degree in Electrical Engineering in 2007 and Master's degree in electronics and telecommunication in 2009 from National Engineering School of Monastir (ENIM). From 2012 to now , preparing my PhD in Telecommunications.