International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)
Web Site: www.ijettcs.org Email: editor@ijettcs.org, editorijettcs@gmail.com
Volume 4, Issue 3, May-June 2015 ISSN 2278-6856

Energy Efficiencies for V-BLAST-modified OSIC-based Cooperative MIMO Scheme

Xing ZOU

[1]Shanghai institute of satellite engineering, Shanghai, 200240, China

Abstract

For energy-constrained distributed wireless sensor networks (WSNs), good bit-error-rate (BER) performance of V-BLAST detection in long-haul communication for cooperative multiple input multiple output(CMIMO) can significantly cut down the overall power consumption. In this paper, we propose a modified layered OSIC scheme to use parallel interference cancellation to replace part of successive interference cancellation, meanwhile **we employ post-cancellation and pre-cancellation to refine the coarse results. Detailed steps are described as follows, firstly, according to the complexity formulas we choose the optimal number of transmit layers to be detected by the modified layered OSIC scheme and the remaining transmit layers then be detected by ML scheme to give better BER performance. Simulation and analysis indicate that via using the proposed OSIC method, a certain number of pseudo inverse operations are saved while improving a better BER performance. We still adopt the proposed OSIC method in the long-haul communication for WSNs, based on this new method, the modulation size are selected with respect to achieving the lowest energy consumption. Numerical results show that significant energy savings can be received by the proposed OSIC method for distributed WSNs.**

Keywords: Wireless Sensor Networks, Cooperative multiple-input-multiple-output, detection method

1. INTRODUCTION

In the energy-constrained distributed WSNs, cooperative multiple input multiple output communication has been becoming the primary way to offer significant energy saving, even when we take the local energy cost into account[1-3]. Instead of STBC scheme, especially simple Alamouti multi-access encoding scheme, we adopt V-BLAST processing into the cooperative MIMO communication in this paper. Owing to there is no joint encoding requirement in V-BLAST processing, this eliminates energy consumed in the local processing and in the local communication steps involved in Alamouti scheme.

To minimize the total energy consumption of a cooperative MIMO for distributed WSN,V-BLAST detection method in long-haul communication can be taken into consideration due to good BER performance can significantly cut down the overall power consumption of the network. Due to ML scheme detects all sub-stream symbols jointly by exhaustive search, which make it outperform other non-linear detection methods. However, computational complexity of ML scheme is increased exponentially according to the number of transmit antennas as well as the modulation size. V-BLAST detection is a familiar non-linear detection methods for the spatial multiplexing (SM) MIMO system, the performance of V-BLAST, namely the ZF-OSIC detection, is not be optimal due to noise enhancement caused by nulling operation and error propagation caused by interference cancellation in already detected layers. Most of the incorrect detections for the OSIC receiver are taken place at lower SNR transmit layers and it is necessary to improve the detection of lower SNR transmitted symbols by using ML detection[4]. The complexity of the conventional algorithm is mainly caused by the calculation of pseudo-inverse operation[5], A modified layered OSIC algorithm is proposed in this paper, instead of calculating the Pseudo-inverse in each layer, we firstly choose p layers to use the modified parallel interference cancellation to replace part of successive interference cancellation, then use post-cancellation and pre-cancellation to refine the coarse results, and then proceed ML method to execute the remaining layers. p is chosen according to a complexity formula, which has a good balance between the performance and the complexity. Paper literally describes the BER simulation for three detective methods and analyze the relation between BER and energy consumption in long-haul communication for WSNs. We still evaluate the energy efficiencies of V-BLAST-modified layered OSIC-based cooperative MIMO scheme in distributed WSNs. The dependence of energy efficiencies on system parameters such as transmission distance, constellation size (modulation rate) is investigated.

The remainder of this paper is organized as follows: In section II, we briefly describe the conventional and the proposed OSIC algorithm and present the simulation result among three detection methods. Section III describes the energy analysis of the non-cooperative system and cooperative system. Section IV gives the energy efficiency of rate optimized implementation of the V-BLAST-scheme based cooperative MIMO architecture in WSNs as well as the reference SISO architecture. Some concluding remarks are demonstrated in section V.

2. CONVENTIONAL V-BLAST RECEIVER AND PROPOSED DETECTION ALGORITHM FOR WIRELESS SENSOR NETWORKS

The better the performance of detection method is, the less power consumption the overall CMIMO in WSNs receive, V-BLAST detection method of cooperative MIMO system is becoming a hotspot of research for long-haul communication in WSNs. The realization of conventional V-BLAST receiver is based on the symbol cancellation in each selected layer to improve the performance as well as maintaining relatively low operation complexity[6]. The picked symbol cancellation order is dependent to the maximum post detection SINR induced by the particular subset of transmit antennas in this paper. The transmitted symbol with the smallest post detection SINR is a decisive factor of the error performance of the system[7].

From what have been described above, we may safely draw the conclusion that the performance of V-BLAST detector is seriously influenced by the smallest post detection SINR layers in which symbol detection may be inaccurate because of systematic cumulative errors from previous layers. In this paper, ML detection is executed for lower SINR transmit layers to maximize the probability of correct detection. We should not assign large number of layers to be detected by ML algorithm due to the complexity of it will grow exponentially lie on the number of layers to be detected. In our proposed method, p transmit layers was detected by a modified layered OSIC scheme then we employ ML method to detect the remaining layers (p is calculated according to a certain formula).The complexity of the conventional algorithm is mainly caused by the calculation of Pseudo-inverse operation[5], to make a further complexity saving in the p layers, we merge some layers in modified layered OSIC scheme, which greatly reduces the pseudo-inverse operation.

2.1Conventional V-BLAST Detection Algorithm for Wireless Sensor Networks

At the initialization stage, i -th detection stage of nulling matrix of ZF filter is evaluated by

$$G_i = ((H_i)^H H_i)^{-1} (H_i)^H \qquad (1)$$

where H_i is the channel coefficients, which may not be square such as $m \times n$,the pseudo-inverse operation computation will be used in (1) under the condition $m \geq n$, $(\square)^H$ indicates conjugate transpose. We use the minimum squared Euclidean norm of $(G_i)_j$ to suggest the optimal ordering

$$\mu_i = \underset{j \notin \{\mu_1 \mu_2, \ldots, \mu_{i-1}\}}{\arg\min} \left\|(G_i)_j\right\|^2, \ j = 1,2,..., N_t \qquad (2)$$

where $(G_i)_j$ denotes the j- th row of matrix G_i ; $(G_i)_{\mu_i}$ can be used to null all but the optimally ordered layer μ_i signal. Then the detected symbol can be received by

$$\hat{s}_{\mu_i} = Q([(G_i)_{\mu_i} r_i]) \qquad (3)$$

where $Q(\square)$ is the QAM slicer for signal constellation in use. We regard the detected layer as interference, which must be canceled to improve detection of subsequent layers by

$$r_{i+1} = r_i - \hat{s}_{\mu_i} (H_i)_{\mu_i} \qquad (4)$$

where $(H_i)_{\mu_i}$ is μ_i -th column of H_i . Once the layer μ_i is detected, the channel matrix H_i should be changed by removing the μ_i th column into H_{i+1}

$$H_{i+1} = null \left\langle H_i \right\rangle_{\mu_i} \qquad (5)$$

where $null\langle \cdot \rangle_{\mu_i}$ indicates the operation of mulling μ_i -th column vector. The process (1)-(5) repeat with $i = i+1$ until all the symbols are detected[8].

2.2 Proposed OSIC algorithm for Wierless Sensor Networks

Initialization: At the initialization stage□we set $i=1$ and

$$H(1) = H \text{ , } y(1) = y \text{ , } G_1 = H^+ .$$

Parallel slicing: The ZF nulling matrix is calculated by (1) and the p layers are chosen by (p is received in II-C)

$$[\mu_1, \mu_2, \cdots, \mu_p] = \underset{\{\mu_1, \mu_2, \cdots \mu_p\} \in j}{\arg\min} \left\|G_1\right\|^2, \ j = 1,2,..., N_t \qquad (6)$$

Assume signals in p layers can be “coarsely” calculate by (7)

$$[\tilde{s}^{(1)}, \tilde{s}^{(2)}, \cdots, \tilde{s}^{(p)}]^T = Q([(G_1)_1^T, (G_1)_2^T, \cdots, (G_1)_p^T]^T r) \quad (7)$$

To improve the results of the merged detection, we can cancel the mutual interferences for layer 1~p, we define m , and $m = 0,1,2,\cdots, p$, by

$$\tilde{r}_m = r - \sum_{l=0}^{m-1} \hat{s}^{(1+l)} H_{1+l} - \sum_{l=m+1}^{p-1} \tilde{s}^{(1+l)} H_{1+l} \qquad (8)$$

and produce the detected symbol as

$$\hat{s}^{(1+m)} = Q(\left[G_{1+m}\right] \tilde{r}_m) \qquad (9)$$

Before proceeding ML detection, we have to cancel the p layers detected symbols to improve the detection of subsequent layers.

$$r_{i+1} = r_i - \sum_{i=1}^{p} \hat{s}^{(i)} H_i \quad (10)$$

ML Detection for the remaining layers:

$$\hat{s}^{\{p,\dots,M\}} = \arg\min_{x \in S} \left\| r_p - \tilde{H}x \right\| \quad (11)$$

In the parallel slicing, partial layers can be removed from the received signal in parallel for the number of p, if little perform loss due to partial simultaneous interference cancellation, we still use post cancellation and pre-cancellation to refine our results as well as the ML detection in the smallest post detection SINR layers.

2.3 Complexity Analysis and Finding Optimal p

The complexity of ML, ZF-OSIC and proposed layered OSIC detections are analyzed in this subsection. For ML detections, total complexity can be stated as follows [4]

$$S^M M^2 + S^M M \quad (12)$$

where S is the modulation constellation size, ML method has $S^M M^2$ multiplications operations and $S^M M$ square operations. We can clearly notice that, the complexity of it will grow exponentially lie on the number of layers to be detected and the constellation size S.

As for the complexity of conventional ZF-OSIC, the Pseudo inverse operation of channel matrix $((H^H H)^{-1} H^H)$ takes $4M^2 + 2NM^2$ operations [9] and M will change in each layer. Furthermore, the complexity of ordering and interference cancellation is $2MN + (N-1)M + MN$. Thus, the total complexity of ZF-OSIC is

$$\left(\sum_{m=0}^{M} 4m^2 + 2Nm^2\right) + 2MN + (N-1)M + MN \quad (13)$$

We can combine and drive formula (12) and (13) to figure up the total complexity of the proposed method with p layers for the parallel slicing and $(M-p)$ in ML method:

$$\left(\sum_{m=0}^{p} 4p^2 + 2Np^2\right) + 2Nt + N(t-1)t + 2(N-1)t + (t-1)t + S^{(M-t)}(M-t)^2 + S^{(M-t)}(M-t) \quad (14)$$

We exhibit the results of complexities of conventional ZF-OSIC, ML methods and our proposed method in Table. I. In this table, we use various constellation modes for 4×4 MIMO system with different number of selected transmit layers p for ZF-OSIC block for Fig. 1.

We send 1000 symbols for each antenna and use 16QAM and QPSK modulation. From the Table. I, the best layer number p is 3 when focusing on 16QAM and QPSK, so the data in the receiver was detected in the proposed layered OSIC for 3 layers and 1 layer ML algorithm after the Rayleigh channel. Numerical result is presented in Fig. 1.

Fig.1 indicated that ML detection in remaining layers bring the performance of new method outperforms the conventional one while saving a considerable amount of complexity, which due to the proposed parallel slicing can reduce the complexity of calculating pseudo-inverse and complexity of ML detection will not surprisingly increase when the number of layers is chosen according to table I. We still notice that the improved layered OSIC scheme needs less SNR than conventional one in the condition of the same BER. For example, focus on the group of curve for 16QAM, when the system BER is 0.01, the required SNR of the three detection schemes are 18dB, 23dB and 25dB, respectively. The saving SNR can greatly influence the energy efficiency, which will analyze elaborately in the following parts.

Table.1 Complexity of different detection methods with different modulation size（4x4）

Detection Method	16QAM	8PSK	QPSK	BPSK
ZF-OSIC	700	700	700	700
ML	3.0924e+11	1.2080e+09	4718592	18432
p=1	49555	6547	1171	499
p=2	1968	816	528	456
p=3	503	487	479	475
p=4	520	520	520	520

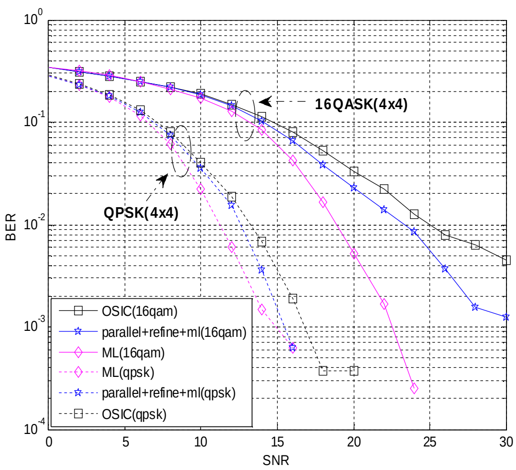

Fig.1. BER of different detection methods

3. ENERGY ANALYSIS OF THE PROPOSED SCHEME

We consider a model of CMIMO system for distributed WSN, in which each sensor node has a single antenna and all nodes are uniformly distributed in space. We assume that WSNs made of a collection of low-end data collecting nodes (DCNs) that are connected to a high-end data gathering node (DGN), which was shown in Fig. 2. Specifically, the cooperative procedure can be divided into the long-haul communication and the local communication. In Fig. 2, Cluster A includes N_T data collecting nodes, and cluster B includes one data gathering node and N_R-1 assisting nodes. In the long-haul communication, a set of data collecting nodes transmit their data simultaneously to the nodes in cluster B. At the receiver side, there are N_R-1 local sensors close to data gathering node, so in the local communication, assisting nodes firstly quantize the received samples (q bits per sample) and use time-division multiple access (TDMA) to send these bits to the data gathering node. Then the data gathering node combines these sample values with its own received signal to proceed with the detection process.

In the following subsections, we firstly analyze the energy evaluation of non-cooperative system, then cooperative system efficiencies are described in detail in formulas which depend on the energy analysis in III-A.

3.1 Non-cooperative system

To keep things simple, the digital signal processing blocks (coding, pulse-shaping, digital modulation, combination, detection ...) are not taken into consideration[10]. Total power consumption of typical non-cooperative system consists of two major components: the power consumption of the power amplifier P_{PA} and the power consumption of the circuit power P_C .

P_{PA} is dependent on the transmit power P_{out} , and P_{out} can be calculated as follow:

$$P_{out}=\frac{(4\pi)^2 d^k M_l N_f}{G_t G_r \lambda^2}\times \bar{E}_b R_b \qquad (15)$$

where d is the transmission distance; k is the signal attenuation parameter, $k=2$ denotes the free-space propagation; M_l is the link margin compensating the hardware process variations and other additive background noise or interference; N_f is given by $N_f = N_r / N_0$ where N_r is the power spectral density of the total effective noise at the receiver input and N_0 is the single- sided thermal noise PSD at the room temperature. G_t G_r are the gain of transmit and receive terminal, respectively; λ is the carrier wavelength; $\bar{E}_b$ is the average energy per bit required for a given BER; R_b is the bit rate of each node.

P_{PA} can be evaluated according to the formula

$$P_{PA}=N_T(1+\alpha)P_{out} \qquad (16)$$

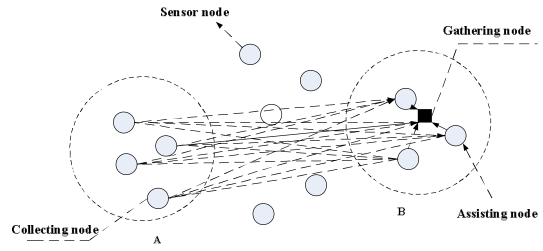

Fig.2. Cooperative MIMO based on V-BLAST for WSN

where $\alpha=\varepsilon/\eta-1$, η is the rain efficiency of the RF power amplifier and ε is the peak-to-average ratio (PAR) that depends on the modulation scheme and the constellation size, for the M-ary QAM systems $\varepsilon=(M+2\sqrt{M}+1)/(M-1)$.

The power consumption P_C in circuit module can be written as:

$$\begin{aligned} P_C \approx\ & N_t(P_{DAC}+P_{mix}+P_{filt}+P_{synth}) \\ & +N_r(P_{synth}+P_{LNA}+P_{mix}+P_{IFA}+P_{filr}+P_{ADC}) \end{aligned} \qquad (17)$$

where P_{DAC} , P_{mix} , P_{filt} , P_{synth} , P_{LNA} , P_{IFA} , P_{filr} and P_{ADC} are the power consumption values for the D/A converter, the mixer, the active filters at the transmitter side, the frequency synthesizer ,the low noise amplifier ,the intermediate frequency amplifier ,the active filter at the receiver side and the A/D converter, respectively, N_t N_r is the number of transmitter and receiver antennae.

Once $\bar{E}_b$ is known, we can derive the total energy consumption per bit for a fixed rate M-QAM system can be calculated by (16) and (17):

$$\begin{aligned} E_{bt} &= \frac{P_{PA}+P_C}{R_{bt}} \\ &= \frac{3c_1}{\eta}\frac{(M+1-2\sqrt{M})}{M-1}d^k \bar{E}_b + \frac{P_C}{R_S M_t \log_2(M)} \end{aligned} \qquad (18)$$

we assume that the symbol rate of each individual sensors is R_s ,we set $R_S = B$, $R_{bt}=N_T R_S \log_2 M$, B is the transmission bandwidth, $\bar{E}_b$ is the average energy per bit. From formula (18), we know that the energy saving problem can be reduced to a problem of choosing appropriate modulation rates for different distances when the number of antennas are fixed.

We use formula $S/N=(E_b/N_0)(R_b/B)$ to indicate the relationship between signal to noise ratio (SNR) and

E_b / N_0 in communication system, where N_0 is the power spectral density in single side band of noise, R_b / B on behalf of the frequency efficiency for a fixed modulation size. Here we invert the formula $S / N = (E_b / N_0)(R_b / B)$ into (19).

$$E_b = (S / N) N_0 \left(\frac{R_b}{B} \right)^{-1} \quad (19)$$

So when we receive S / N, E_b can be calculated in (19), then E_{bt} in (18) can finally be achieved

3.2Cooperative MIMO system

In the long-haul communication, a set of DCNs transmit their data simultaneously to the nodes in cluster B. We assume that each collecting node has L bits data to be transmitted, according to our model in Fig.2, the total energy is dependent on the total energy consumption per bit in the long-haul communication by

$$E_{coopTx} = N_T L E_{bt}^{(L)} \quad (20)$$

At the receiver side, in the local communication, assisting nodes firstly quantize the received samples (q bits per sample) and use time-division multiple access (TDMA) to send these bits to the DGN. Then the DGN combined these sample values with its own received signal to proceed with detection process, the total energy is dependent on the total energy consumption per bit in the local communication by

$$E_{coopRx} = \frac{(N_R - 1) q L}{\log_2 (M)} E_{bt}^{(l)} \quad (21)$$

Total energy consumption per bit in the long-haul communication $E_{bt}^{(L)}$ and the total energy consumption per bit in the local communication $E_{bt}^{(l)}$ can be calculated like non-cooperative MIMO system.

Finally, the total energy consumption of cooperative MIMO system is

$$E_{total}^{mimo} = E_{coopTx} + E_{coopRx} \quad (22)$$

4.NUMERICAL RESULTS

In this section, we evaluate the proposed OSIC scheme in WSNs and study the selection of optimal modulation size for the proposed model, then we employ the simulation of energy efficiency to illustrate the results achieved previously.

We assume

$B = 10kHZ$, $f_c = 2.5GHZ$, $P_{mix} = 30.3mW$, $P_{filt} = 2.5mW$, $P_{filr} = 2.5mW$, $P_{LNA} = 20mW$, $P_{synth} = 50mW$, $P_{DAC} = 15.4mW$, $P_{ADC} = 6.7mW$, $P_{IFA} = 3mW$, $M_l = 40dB$, $N_f = 10dB$, $G_t G_r = 5dBi$, $\eta = 0.35$ in all simulations in this paper.

We use the results in Fig.1 (SNRs corresponding to three detection schemes for the fixed system BER of 0.01 is 18dB, 23dB and 25dB in 16QAM). The total energy consumptions of three detection methods can be calculated in (22) and are shown in Fig.3. We make the value of constellation size fixed (16QAM), the average BER is 0.001 in local communication and the sensors within a cluster is chosen to be 20m, 16000 bits were transmitted in per antenna.

Fig.3 illustrates that the proposed approach consumes less power consumption than the conventional one as well as greatly outperforms SISO from the origin. Thus the proposed method in cooperative MIMO can significantly save more sending power when compared with other means, that is, new method can be used to prolong the life cycle of the energy-constrained wireless sensor networks.

The dependence of total energy consumption per bit on the incremental value of constellation size b for four diverse transmission distances in both conventional detection and the proposed method are shown in Fig.4. We suppose that bits in the local communication are firstly executed with QPSK modulation and then transmit over Rayleigh channel and in long-haul communication the Rayleigh channel was considered.

From Fig.4 we notice that one optimal modulation size can be chosen for various transmition distance to receive the minimal total energy per bit E_{bt} for conventional OSIC and the proposed schemes. We can further notice that the more distance the long-haul communication increases, the larger energy the whole network consumes, still, the communication for long distance requires larger value of modilation size when compared to short ones. Total energy consumption per bit for the poposed OSIC method is less than the conventional one all way through when we forcus on two lines in one fixed distance, which matches the result we have discussed in Fig.3.

We further study the result in Fig.4, and portray Fig.5 to describe the dependence of total energy consumption per bit on the incremental transmission distance for diverse modulation size (including BPSK QPSK and 16QAM) for the proposed scheme–based cooperative MIMO and SISO model.

In Fig.5, the bold solid red line with star symbols indicates the total energy consumption per bit while using the optimal modulation method, namely, the lower bound of total energy consumption in the cooperative MIMO system. We can notice that when d is small, the SISO system is more energy-efficient than MIMO due to extra circuit consumption and cooperative consumption, when d is getting larger, the total energy saved by MIMO technique can not only remedy the extra cooperative energy cost but receive a lot of surplus energy. So based on our assumptions, when $d < 14$ m, the adoption of SISO using 16QAM is chosen and when $15 < d < 29$ m, we use cooperative MIMO technique using 16QAM to transmit and $d > 29$ m,CMIMO using QPSK is adopted for saving over-all energy.

Based on Fig.6 we conclude that even consider both circuit and transmission power consumption term, the modified OSIC can provide significant energy saving compared to the conventional one. d_L needs to be at least 21m to justify the use of cooperative MIMO in optimal rate and the critical distance needs to be increased to 31m in the case of the fixed-rate employing QPSK modulation.

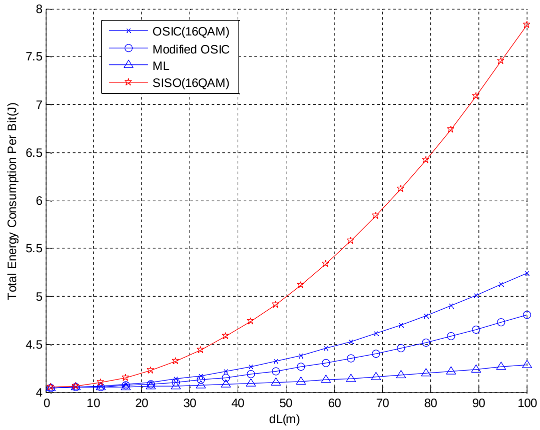

Fig.3. Total energy vs. distance of WSN in the local Rayleigh channel

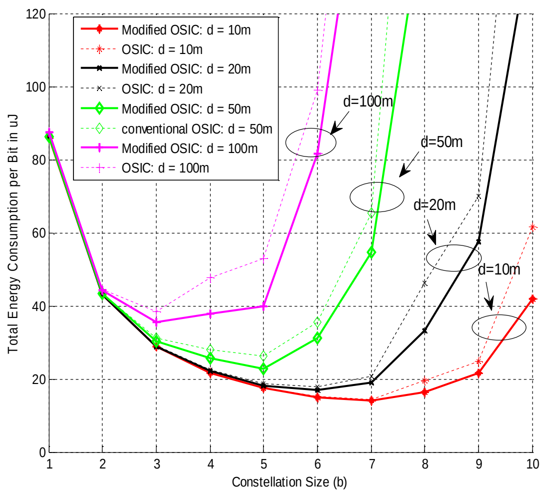

Fig.4. Total energy consumption per bit E_{bt} vs. M-QAM constellaton size for 4x4 cooperative MIMO in conventional OSIC detection and the proposed method

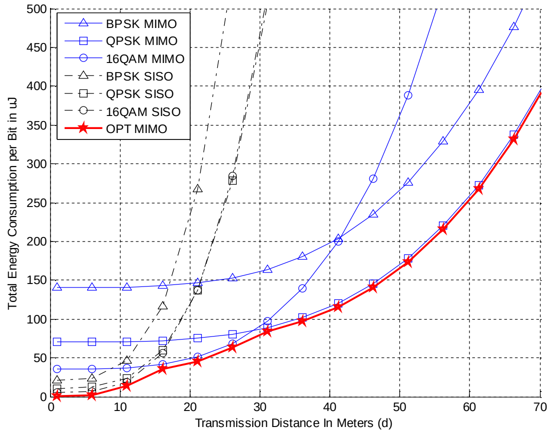

Fig.5. Total energy consumption per bit E_{bt} vs. transmission distance for 4x4 cooperative MIMO in proposed method for viable modulation sizes

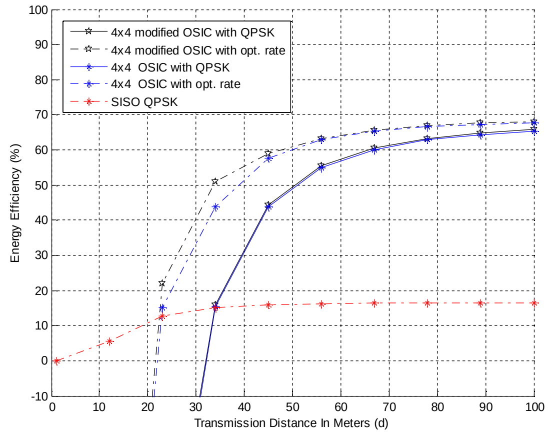

Fig.6 Energy efficiency of both modified OSIC and conventional OSIC method for QPSK and variable-rate

5. CONCLUSIONS

We proposed a modified OSIC algorithm that can significant save more energy than conditional one when we adopt the proposed method in WSNs. Moreover, the simulation results indicate that there must have an optimal rate for each transmition distance to minimize the total energy, and for achieving the maximum energy efficiency proposing an opyimal scheme whose canstellation size is considered.

References

[1] Xiaohua L, Mo C,and Wenyu L, "Application of STBC-encoded cooperative transmissions in wireless sensor networks", IEEE Signal Processing Letters, 2005, 12(2): 134-137.

[2] Jayaweera S.K ,and Chebolu M.L, " Virtual MIMO and Distributed Signal Processing for Sensor

Networks-An Integrated Approach", IEEE International Conference on Communications (ICC 05), May 2005: 1214~1218.

[3] Maung Sann Maw,Hajima Suzaki and Iwao Sasse, "Reduced Complexity Scheme for MIMO Receiver with Combined ZF-OSIC and ML Detection", IEEE Symposium on Computer and Informatics,2012.pp.92-96.

[4] P.Wolniansky, G.Foshini, G.Golden, and R.Valenzuela, "V-BLAST: an architecture for realizing very high data rates over rich-scattering wireless channel", In Proceeding of signals, Systems and Electronics,1998.pp.295-300.

[5] Xiaohua L, Mo C,and Wenyu L, "Application of STBC-encoded cooperative transmissions in wireless sensor networks", IEEE Signal Processing Letters, 2005, 12(2): 134-137.

[6] Jayaweera S.K ,and Chebolu M.L, " Virtual MIMO and Distributed Signal Processing for Sensor Networks-An Integrated Approach", IEEE International Conference on Communications (ICC 05), May 2005: 1214~1218.

[7] Dah Chung Chang, "Spatial-Division Multiplexing MIMO Detection Based on a Modified Layered OSIC Scheme", IEEE Transaction on Wireless Communications, VOL.12, NO.9, September 2013.

[8] Chung-Wen and His-Pin Ma, "A low complexity scalable MIMO detector," IWCMC Interference Wireless Communication and Mobile Computing Conference on 2006, pp.605-610.

[9] Chung-Wen and His-Pin Ma, "A low complexity scalable MIMO detector," IWCMC Interference Wireless Communication and Mobile Computing Conference on 2006, pp.605-610.

[10] Tuan-Duc Nguyen, Oliver Berder and Oliver Sentieys, "Cooperative MIMO Scheme Optimal Selection for Wireless Sensor Networks", IEEE Vehicular Technology Conference, April 2007:pp 85-89.