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Energy efficient wireless sensor network using DSC-MIMO

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Abstract. A wireless sensor network consists of small sensor nodes, which operate with battery. In WSN, replacement of battery in sensor nodes is not an easy task. So, there is a requirement of energy saving schemes in wireless sensor network that can efficiently reduce power consumption. In high node density wireless sensor network, data collected by sensor nodes are highly correlated which is directly sent to sink node decreases the energy efficiency. For increasing the energy efficiency of wireless sensor network, we introduce distributed source coding (DSC) based on Virtual MIMO. In DSC-MIMO, distributed source coding compresses the redundant source data before transmitting it to virtual MIMO link. The simulation results show that DSC-MIMO reduces power consumption and increases the energy efficiency of wireless sensor network at different constellation size.

Keywords: Wireless Sensor Network (WSN), Distributed Source Coding (DSC), Multiple Input Multiple Outputs (MIMO), Single Input Single Output (SISO), DSC-MIMO, Sensor nodes

1. Introduction

DSC compresses the output of different correlated sensors that do not communicate with each other. It decreases the total amount of data in the whole network while the transmission cost within a cluster can be reduced by performing the optimal intra-cluster rate allocation. To save bandwidth and energy multiple, sensor nodes may detect a target and send correlated sensor data to an information sink for joint decoding. Therefore, different data values may be sent to the base station through different routes. By exchanging the computational complexity of the encoder for the decoder, DSC transfers the burden of computing and processing from the sensor nodes to the base station (sink). The low-complexity encoder is critical for increasing the lifetime of a sensor node. Encoding operations consume low battery energy.

Multiple-Input Multiple-Output (MIMO) system can increase the radio channel capacity, the performance of bit error rate and the transmission distance by the transmission of information. But WSN nodes are relatively small in size, and it is not easy to install multiple antenna systems on a single sensor node. Applying directly the MIMO technique to wireless sensor network is not practical. To solve this problem, the researchers propose virtual MIMO technology. In virtual MIMO technology a single antenna sensor node shares antennas with other sensor nodes to implement virtual multi-antenna system and then communicates with the multi-antenna systems [7, 8]. Virtual MIMO allows wireless sensor network to give a similar effect to MIMO communication and reduces the network energy consumption. In recent years, researchers have made a lot of good virtual MIMO communication schemes, such as CMIMO, CCP and MIMO-CCRN etc. Therefore, virtual MIMO communication technique, solves the problem of energy consumption in sensor network, but cannot solve the low energy

ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION
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ORIGINAL ARTICLE

efficiency situation in the large-scale high-density WSN [1]. To solve this problem, we introduce distributed source coding (DSC) into the WSN based on virtual MIMO [2].There are different types of a MIMO system like single-user MIMO, multi-user MIMO and cooperative MIMO. For long distances MIMO is better than SISO system, whereas short distances SISO is better than MIMO[6].

2. Data compression using Distributed Source Coding

Distributed source coding is used, if there is a correlation between a set of sources. This is exactly the case in the typical wireless sensor network, where the correlation is often high between neighboring nodes. Each individual node is compressing their own data based on observations done by other sensors and not only on its own localized data, hence the term distributed. To exploit this correlation and remove the redundancy, each node has to know about data sending by other sensors. This can be done in two ways. First, the sensors can communicate with each other, or second, they could avoid using this Scheme. The first option gives an extra unwanted overload on sensor network and requires more data processing in each node. The point of distributed source coding in sensor network is exactly the opposite of first scheme. Therefore, second scheme is preferred to reduce the processing amount and thus the energy consumption. Suppose X and Y are two sensor nodes. Sensor node X is the input of the encoder which compresses the data of sensor node X i.e. correlated between sensor nodes X and Y. Sensor node Y is transmitting uncompressed data to decoder as shown in Fig-1.The more data correlation between source nodes, the more compresses the data of sensor node X.

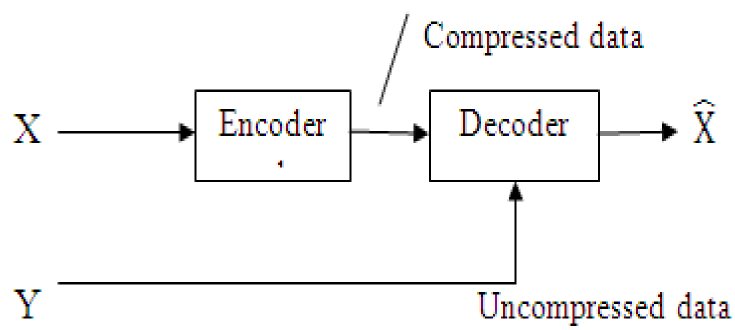

Figure.1. Data compression using Distributed source coding

Slepian and Wolf shows that this data compression can be fully blind manner in wireless sensor network, i.e. Sensors have only the knowledge of the local data. Therefore, sensors compress the data without the knowledge of the data of the other sensors, and without degrading network performance [11]. Therefore Distributed source coding is an important alternative approach to data compression and increase energy efficiency of wireless sensor network.

According to Slepian and Wolf theorem efficient compression of two or more sources can be achieved by separate encoding and joint decoding. Slepian and Wolf gives lossless compression theoretical limit of DSC for two related sources using information entropy, called S-W limit. [2].

Slepian-Wolf coding theorem is resolved by the following equations given below:-

AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Journal of Engineering Technology (ISSN: 0747-9964)
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ORIGINAL ARTICLE

$$R(X_1) \geq H\left(\frac{X_1}{X_2}\right) \qquad \text{----------} \ (1)$$

$$R(X_2) \geq H\left(\frac{X_2}{X_1}\right) \qquad \text{----------} \ (2)$$

$$R(X_1) + R(X_2) \geq H(X_1) + H(X_2) \ \text{-----} \ (3)$$

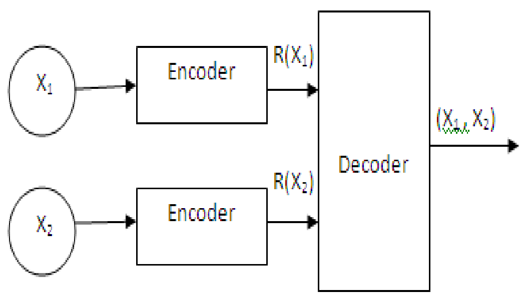

Figure.2. Two correlated sources using Slepian-Wolf coding

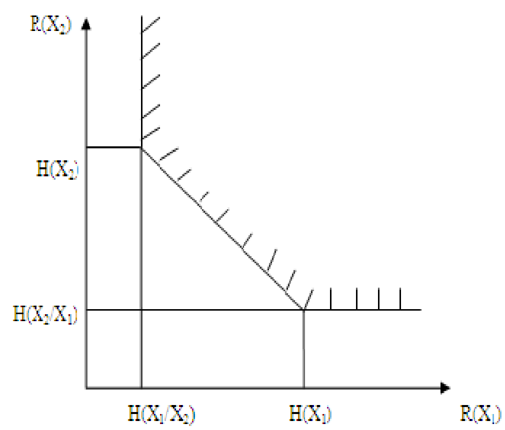

Figure.3. Rate region for slepian –wolf encoding

Where X_1 and X_2 are two independent sources and $R(X_1)$ and $R(X_2)$ is its information rate.$H(X_1)$, $H(X_2)$ are entropy and $H(X_1/X_2)$ and $H(X_2/X_1)$ are conditional entropy.

In the recent research work done in the area of wireless sensor network using Distributed source coding like turbo code, LDPC code, Raptor code, etc are discussed below. By using these codes and algorithm to increase energy efficiency, save power and bandwidth of wireless sensor network.

There are various Distributed source coding like turbo code, LDPC code, Raptor code, etc.

Table1. Comparison of LDPC code, Turbo code and Raptor code

AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.268-277

ORIGINAL ARTICLE

S.N.	LDPC code	Turbo code	Raptor Code
1	The performance of LDPC code is better than Turbo code and close to Slepian–Wolf theorem. But LDPC is suitable where length of less than 10000 bits is used. The LDPC code has the property to protect unequal error. Before decoding communication occurs between decoder and each decoder independently decoding their data. If an error occurs in one decoder, it does not affect the other one [4, 5].	According to Slepian–Wolf theorem, Distributed source coding compresses the same extent of the output of two correlated sensors without loss of any information that communicate with each other or not and decompression occur at a joint decoder. In distributed source coding scheme pixel values of correlated images is encoded by modulo encoding. Then the resulting symbol is encoded in binary and no binary turbo codes. Turbo codes have larger saving rate than modulo encoding are achieved alone, without any loss of information. Therefore turbo code is used for correlated images in distributed source coding [6].	WSN architecture, the systematic Raptor code outperforms the best implementations based on state of the art LDPC and Turbo codes in terms of compression rate. Compared to the non-systematic version, the systematic Raptor code has a very low BER when long source words are used, while the non-systematic code reaches BERs close to zero when small code words are used [3].
2	Therefore, LDPC code is suitable if sensor nodes transmit two or more than two correlated data of length less than 10000 bits [4].	If sensor nodes have two or more than two correlated images, then Turbo coding is used. Turbo coding is complex when the large gain is required [6].	Raptor code is used for a better compression rate in wireless sensor network [3].

3. DSC-MIMO

DSC-MIMO compresses the redundant source data using DSC before transmitting it to virtual MIMO link. Data compression can decrease the data length and increase the energy efficiency. DSC-MIMO does not need the cluster heads to gather the information from source nodes, which decreases the frequencies of data passing on and saves energy. Researches indicated that in long-distance data transmission virtual MIMO is more suitable than SISO for energy efficiency and data transfer delay. By using a virtual MIMO method can save the energy consumption, but it cannot resolve the energy efficiency issue in high-density WSN caused by high correlation source data. Aiming at this issue, we use distributed source coding (DSC), which can compress the high correlation source data before transmitting, into the virtual MIMO link and then propose a new communication technique, called DSC-MIMO, which can increase energy efficiency and decrease communication energy consumption. The concept of DSC-MIMO depends on cooperative group (CG) and DSC. Each CG, collected of two correlative source nodes, DSC first compresses the source data, then sends the compressed data to virtual MIMO link to the next hop receiver without transferring data to the cluster head (CH), which can decrease transferring times of source data and increase the energy efficiency [1,2].

There are two types of DSC:-

(i)Asymmetric Distributed Source Coding (ii) Symmetric Distributed Source Coding

In asymmetric DSC, different bitrates are utilized in coding the input data sources .For asymmetric DSC scheme, the most illustrative is distributed source coding (DSC) using syndromes (DISCUS). In DISCUS, one source sends its syndromes to achieve data compression; another source transmits its raw data directly as side information. At the receiving end, compressed data are recovered by the decoder through joint decoding, using the

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.268-277

received side information and the syndromes. Researchers have proposed, a number of asymmetric DSC schemes using turbo codes and low-density parity check (LDPC) on the basis of DISCUS.

In symmetric DSC, same bitrates are utilized in coding the input data sources. For symmetric DSC scheme, the most illustrative is the technique proposed by Sartipi .In Sartipi's technique, First two sources are encoded using LDPC code, then one source sends their parity bits, only the first half of the information bits, and the other source sends their parity bits, the second half of the information bits. The decoder recombines the two parts of information bits and then uses message passing decoding algorithms to recover the original data [1].

Table2. Comparison of MIMO, DSC and DSC-MIMO

S.N.	MIMO	DSC	DSC-MIMO
1	In same transmitted power, MIMO system can give more data rates and bit-error-rate performance than SISO system. The MIMO system requires less transmission energy than a SISO system for same throughput [7, 8]. Therefore a MIMO system reduces the power consumption in Wireless sensor network. But if sensor nodes have redundant data, then MIMO system cannot solve redundancy problems in sensor network.	If sensor nodes have redundant data, then we use distributed source coding. DSC compresses the output of different correlated sensors without communicating with each other. It reduces the total amount of data on the whole network and increase energy efficiency of wireless sensor network [2].	In DSC-MIMO technique, Both MIMO and DSC techniques are used. DSC-MIMO compresses the redundant source data using DSC before transmitting it to virtual MIMO links. DSC-MIMO reduces power consumption and also increases energy efficiency in wireless sensor network [1].
2	In virtual MIMO technology a single antenna sensor node shares antennas with other sensor nodes to implement virtual multi-antenna system, and then communicates with the multi-antenna systems. Virtual MIMO allows sensor network to give a similar effect to MIMO communication, and reduces the whole network energy consumption.	DSC is based on the theorem Slepian-Wolf. According to this theorem efficient compression of two or more sources can be achieved by separate encoding and joint decoding. There are various Distributed source coding like turbo code, LDPC code, Raptor code, etc [11].	In DSC-MIMO, One of DSC methods like LDPC code, Turbo code, Raptor code, etc. are chosen with a MIMO system according to our requirement. DSC-MIMO is better techniques than DSC or MIMO techniques used alone.[2]

4. Energy consumption of DSC-MIMO

Power consumption of RF system can be divided into two parts: the power consumed in the amplifiers(P_{PA}) and the power consumed in all the other circuit blocks (P_C) .

$$P_{PA}(d) = (1 + \alpha)P_{out}(d) \qquad (4)$$

ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION
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ORIGINAL ARTICLE

Where $\alpha = \xi / \eta - 1$, η - Drain efficiency of the RF power amplifier, ξ -Peak to-Average Ratio .η and ξ depends on modulation scheme and the associated constellation size.

$$P_{out}(d) = \overline{E_b} R_b \frac{(4\pi)^2 d^k M_l N_f}{G_t G_r \lambda^2} \qquad (5)$$

Where R_b-bit rate of the RF system, d- Transmitting distance, G_t – Gain of transmitting antenna, G_r -Gain of receiving antenna, λ - wavelength of the signal , M_l -link margin compensating the hardware process variations and other additive background noise or interference, N_f -receiver noise figure defined as $N_f = N_S/N_O$ with N_S as the power spectral density of the total effective noise at input of the receiver and N_O - power spectral density of the single-sided thermal noise , E_b - Energy per bit at the receiver for a given BER that can be calculated by following equation:-

$$\overline{P}_b = \frac{1}{2^{N_T N_R}} \left(1 - \frac{1}{\sqrt{1 + 2N_{o/\ \overline{E_b}}}}\right)^{N_T N_R} \times \sum_{k=0}^{N_T N_R - 1} \frac{1}{2^k} \binom{N_T N_R - 1 + k}{k} \left(1 + \frac{1}{\sqrt{1 + 2N_{o/\ \overline{E_b}}}}\right)^k \quad (6)$$

Where $\overline{P}_b$ -Given BER, N_T -Number of sending nodes, N_R - Number of receiving nodes and N_o – noise power density

$$P_C = N_T(P_{DAC} + P_{mix} + P_{filt}) + 2P_{synth} + N_R(P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC}) \qquad (7)$$

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

Now Total energy consumption per bit $E_{pb} = \frac{P_{PA} + P_c}{R_b}$ (8)

Compression rate (%)= $\frac{\text{Total length of data after compression}}{\text{Total length of data before compression}}$ x 100 (9)

For Intracluster Communication

In Intracluster communication, the nodes, belonging to a Cooperative Group, exchange their data after DSC using SISO mode. Therefore, energy consumption for transmitting 1-bit original source information is

$$E_{pb\_DSC}^{SISO}(d) = R_{DSC} E_{pb}(d)|_{N_T=1, N_R=1} \qquad (10)$$

Where R_{DSC} is the compressing rate of DSC and it is equal to 75%

For Intercluster Communication

In the intercluster communication, every Cooperative Group communicates with the next hop Master Cooperative Group through a 2 × 2 virtual MIMO link. Therefore, energy consumption for transmitting 1-bit original source information is

AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.268-277
ORIGINAL ARTICLE

$$E_{pb}^{MIMO}(d) = \frac{R_b^{eff}}{R_b}\left[E_{pb}(d)|_{N_T=2,N_R=2}\right]R_{DSC} \quad (11)$$

Where R_b^{eff} is effective bit rate, which is expressed –

$$R_b^{eff} = \frac{F-pN_T}{F}R_b \quad (12)$$

Where F - block size of space-time coding and p - training overhead factor.

5. 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.

Table3. Simulation Parameter

Wavelength (λ)	0.125 m
Drain efficiency factor(α)	0.47
$G_t G_r$	5 dBi
Noise power density(No)	-174 dBm/Hz
Bandwidth (B)	10 KHz
P_{mix}	30.3 mW
P_{IFA}	2 mW
P_{syn}	50 mW
P_{filr}=P_{filt}	2.5 mW
P_{LNA}	20 mW
N_f	10 dB
M_l	40 dB
P_{DAC}	15.43 mW
P_{ADC}	6.62 mW

Figure-4, 5, 6 shows the energy consumption per bit of DSC-MIMO, CMIMO, DSC-SISO and SISO at different constellation size. SISO is used for intracluster communication and MIMO is used for intercluster communication. The simulation results show that energy consumption per bit of DSC-MIMO is less than CMIMO, SISO. Therefore, energy efficiency of DSC-MIMO is more than CMIMO, SISO. The reason is that DSC in DSC-MIMO compresses the correlated source data and reduces the length of the transmission data.

Figure-4 shows the energy consumption per bit in different transmission modes at constellation size b=1 bit /symbol. The simulation result shows that energy consumption per bit in different transmission modes is more than energy consumption per bit in different transmission modes at constellation size b=2 and b=4 bits per symbol.

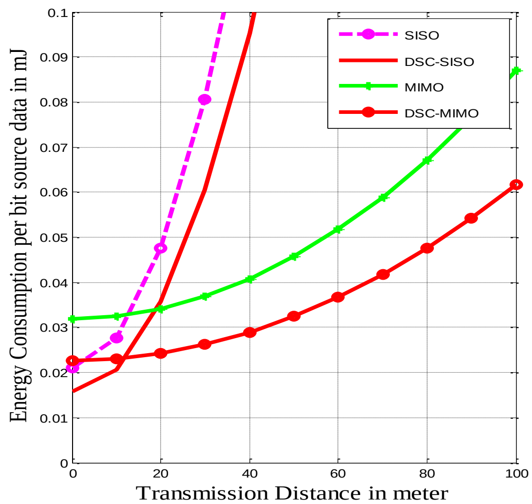

Figure.4 The energy consumption per bit of DSC-MIMO, CMIMO, DSC-SISO and SISO at constellation size b=1 bit /symbol

Figure-5 shows the energy consumption per bit in different transmission modes at constellation size b=2 bits /symbol. The simulation result shows that energy consumption per bit in different transmission modes is less than energy consumption per bit in different transmission modes at constellation size b=1 but more than energy consumption per bit in different transmission modes on constellation size b=4 bits per symbol.

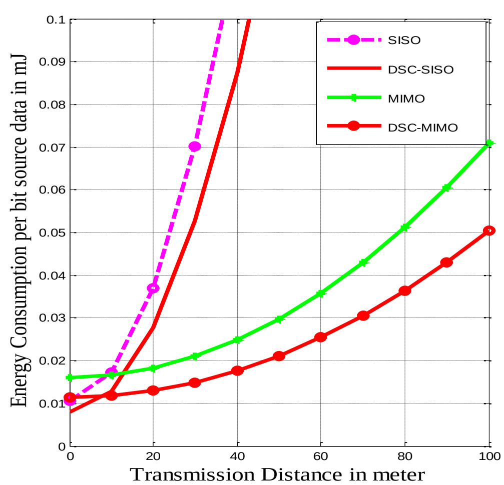

Figure.5 The energy consumption per bit of DSC-MIMO, CMIMO, DSC-SISO and SISO at constellation size b=2 bits /symbol

Figure-6 shows the energy consumption per bit in different transmission modes at constellation size b=4 bit /symbol. The simulation result shows that energy consumption per bit in different transmission modes is less than energy consumption per bit in different transmission modes at constellation size b=1 and b=2 bits per symbol.

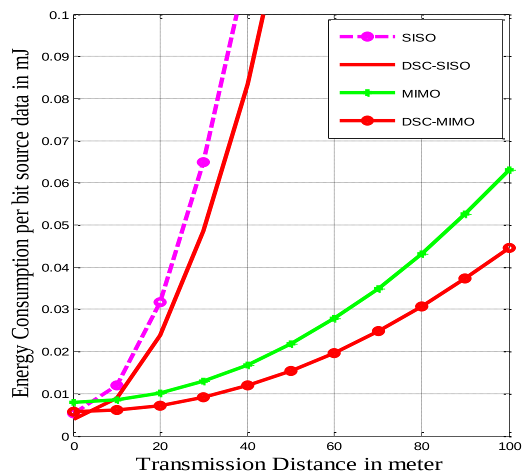

Figure.6. The energy consumption per bit of DSC-MIMO, CMIMO, DSC-SISO and SISO at constellation size b=4 bits /symbol

In this paper, simulation results also prove that energy consumption per bit decreases for increasing constellation size. Therefore, energy efficiency increases for increasing constellation size.

6. Conclusion

In this paper, we propose DSC-MIMO, which is very appropriate for wireless sensor network. In this method, the DSC first compresses source data collected by adjacent nodes and reduce the length of data then send data to virtual MIMO link. DSC-MIMO uses cooperative groups instead of cluster head. Sensor nodes send data directly to cooperative group instead of cluster head, which can reduce the forwarding times of source data and energy consumption and enhance energy efficiency. By comparing DSC-MIMO with CMIMO and SISO we see that DSC-MIMO is higher energy saving and has more energy efficiency than CMIMO and SISO. In this paper, simulation results also prove that energy consumption per bit decreases for increasing constellation size.

Finally, One of DSC methods like LDPC code, Turbo code, Raptor code, etc. based on MIMO system can be adopted according to our requirements. DSC-MIMO techniques enhance energy efficiency, save power and bandwidth of wireless sensor network.

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