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A cooperative tranmission strategy on WSN based on virtual MIMO

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Abstract. For the wireless sensor network (WSN), this article proposes an efficient cooperative transmission strategy based on virtual MIMO. It cooperates together on STBC coding in the inner-cluster, while the inter-cluster makes use of the V-BLAST scheme. The information coming from multiple clusters are extracted by configuring multiple receive antennas at the DGN (Data Gathering Node) whose energy and processing power are not constrained. To decrease the complexity of DGN, furthermore, a decoding scheme based on block QR decomposition by using Gram-Schmidt orthonormalization is introduced. The simulation results show that the proposed strategy can increase the efficiency of WSN, while the reliability is conserved.

Keywords: WSN, DGN, QR, Orthonormalization, Virtual MIMO.

1. Introduction (Use "Header 1" Style)

WSN is a hot topic in borne and abroad academic circle now due to its potential in applications of military and civil areas. At the same time, multiaerial system based on MIMO can provide diversity gain and multiplexing gain, it has emerged as the de facto standard of future wireless PCS. But the size of the WSN sensor node is very small; multiple antennas can't be fixed in it. The advantage of MIMO transmission can't be reflected in WSN. In order to solve this problem, this article proposes a virtual MIMO communication architecture that cooperates among sensor nodes. In fact, multiple sensor nodes fixed single antenna cooperates and becomes a VAA in the way of MIMO. Considering the communication cost and transmission performance, this article put forward a solution of physical layer. [1] It takes advantage of STBC and V-BLAST and preserves the advantage of high-efficiency energy. It extends space time coding to multiple clusters and greatly improves the network throughput. Furthermore, it can avoid MAC control among the clusters in traditional program, decreases complex processing of DCN nodes and optimizes the character of high-efficiency energy. The design philosophy of algorithm focus on the complexity is transferred from DCN to DGN, this complies with the design character of WSN and the energy is efficient.

2. System Model and New Transport Policies

A common WSN model is composed of a DGN and a cluster of DCN. It studies the distributed coding and the energy efficiency of signal. [2] For the model, some lower-end DCN connect with a high-end DGN by means of wireless link, and the data convergent point is the centre of data fusion. It is as follow Fig. 1.[1]

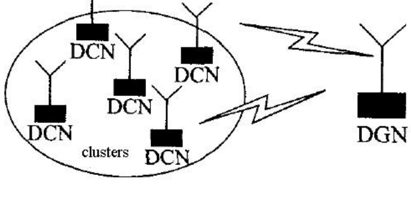

Fig. 1: Basic WSN model.

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The transmission based on virtual MIMO serves the functions as follows: if some cluster will send a data to DGN and the distance between them is very close. Firstly, DCN in the clusters broadcasts data to other DCN in way of TDD, the process is called transmitted local communication. After this step, all DCN of the clusters have the same data. Then, all DCN dispatch the signal to DGN simultaneously, the signal is encoded with special space time coding. It is called the long distance transmission. In order to communicate with other clusters, the data need to be sent alternately in time-sharing format; it would decrease the efficiency of communication.

This article applies a different communication scheme. Every cluster sends the data to DGN independently and the coding adopts STBC in the cluster. It can keep all advantages. The interference among clusters is removed by multiple antennas fixed on DGN. This strategy is regarded as the application of SDMA in WSN; a cluster is corresponding with a user. The system diagram is as shown in Fig.2. In theory, the space time coding applies V-BLAST code scheme in the clusters, but it makes DGN to configure many antenna for separating these information. To do so, cost of manufacture would sharp increase, and the system bit error rate gets quite large. For this reason, this article makes use of STBC code scheme.

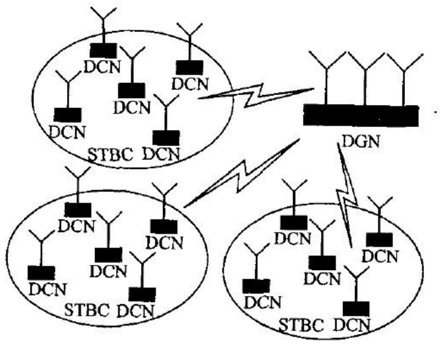

Fig. 2: The transmission model based on multi-cluster.

For the sake of argument, assuming the number of clusters communicated with DGN is n_c , every cluster has n_t sensor node participant communication. DGN configures n_r antennas. In order to differentiate the signal coming from every cluster, it must meet $n_r \geq n_c$. For conforming to the size of WSN clusters and simplifying the design of transmitter, the data is modulated and sent in way of PAM. The constellation points expresses as the set Q. Assuming the information sent by cluster k expresses as $X_k = (x_1, \cdots, x_{n_t})^T \in Q^{n_t}$, where $(\bullet)^T$ shows transposed vector. After these steps, all DCN in the clusters get X_k , the space time coding rate is 1. The time slot sending a coding block is $T = n_t$. the corresponding space time coding matrix is as follow.

$$C_k = \begin{bmatrix} x_{1k} & -x_{2k} & -x_{3k} & -x_{4k} \\ x_{2k} & x_{1k} & x_{4k} & -x_{3k} \\ x_{3k} & -x_{4k} & x_{1k} & x_{2k} \\ x_{4k} & x_{3k} & -x_{2k} & x_{1k} \end{bmatrix} \qquad Y_r = \sum_{k=1}^{n_c} H_{rk} X_k + N_r \quad (1 \leq r \leq n_r) \quad (1)$$

Where h_{rkt} is the channel ratio between the r^{th} antenna of DGN and the t^{th} sending antenna of the k^{th} cluster. In the condition of strong scatter communication, h_{rkt} modelling is average 0. The variance of Gaussian random variable is 1.

3. Decoding Strategy

Please acknowledge collaborators or anyone who has helped with the paper at the end of the text.

Searching the optimal solution is also equal to searching $\widehat{X}$, so as to:

$$\widehat{X} = \arg\min_{X \in Q^{n_c n_t}} \|Y - HX\| \qquad (2)$$

The way of Brute-force can achieve the optimal ML performance, but the complexity is $O\left(\|Q\|^{n} c^{n} t\right)$. Obviously, when the size of signal constellation and the number of clusters are more, the complexity is greater. This is impossible in the factual WSN, so some good ways of detecting are demanded.

3.1. The Way of Linea Decoding Based on ZF/MMSE

The clearest measure of solving is that the signal received is processed with linear weighted by weight matrix W, then it can get the X estimation.

$$\widehat{X} \approx WY \qquad (3)$$

When applying the ZF criterion $W = \left(H^T H\right)^{-1} H^T$, the MMSE criterion, $W = \left(H^T H + \sigma^2 I\right)^{-1} H^T$

Above two ways all don't consider the special structure of equivalent channel matrix; it needs to compute the inverse matrix of $n_c n_t$ matrix. The pre-process complexity of algorithm is very more. For ZF algorithm, it can increase the influence of noise and decrease the BER performance of system. [3]

3.2. The Decoding Algorithm of block QR based on Gram-Schmidt Orthogonalization

Firstly, the continuous disturbance offset algorithm based on QR decomposition is introduced. The equivalent channel matrix H is decomposed with QR,

$$H = QR \qquad (4)$$

Where Q is the orthogonal matrix of $Tn_r \times n_c n_t$, R is the upper triangular matrix of $n_c n_t \times n_c n_t$. The both sides of equation simultaneously left multiply Q^T. Because Q is the orthogonal matrix, $\widehat{N}$ is still Gaussian noise which average is 0 and variance is 1. R is the upper triangular matrix, the i^{th} element of $\widehat{Y}$ only depends on sending signal of the i^{th} layer and lower layer .

$$\widehat{y}_i = r_{ii} x_i + \sum_{j=i+1}^{nT} r_{ii} x_j + \widehat{n}_i \qquad (5)$$

Suppose that x_i is the current signal detected. And $\widehat{y}_i$ includes lower interference than y_i. Because the interference from $x_j\left(j = 1, \cdots, i-1\right)$ is suppressed, the 2nd part in the right-hand-side of equation expresses the interference from other layer, it can be offset with the signal detected.

Above the decoding algorithm based on QR decomposition don't consider the special structure of channel matrix. The process of QR decomposition can be simplified by means of the equivalent channel matrix H. For the sake of argument, it can do as following: [3]

$$Q = \left(q_{11}, q_{12}, \cdots, q_{1n_c}, \cdots, q_{k1}, \cdots, q_{kt}, \cdots, q_{kn_t}, \cdots, q_{n_c 1}, \cdots, q_{n_c n_t}\right) 1 \le k \le n_c, 1 \le t \le n_t$$
$$H = \left(h_{11}, h_{12}, \cdots, h_{1n_c}, \cdots, h_{k1}, \cdots, h_{kt}, \cdots, h_{kn_t}, \cdots, h_{n_c 1}, \cdots, h_{n_c n_t}\right) 1 \le k \le n_c, 1 \le t \le n_t \qquad (6)$$

$$R = \begin{bmatrix} R_{11} & \cdots & R_{1,n_c-1} & R_{1,n_c} \\ 0 & \ddots & \vdots & \vdots \\ \vdots & \ddots & R_{n_c-1,n_c-1} & R_{n_c-1,n_c} \\ 0 & \cdots & 0 & R_{n_c n_c} \end{bmatrix} \qquad (7)$$

For the diagonal sub matrix:

$$R_{k,k} = \begin{bmatrix} r_{(k_1,1),(k_2,1)} & \cdots & r_{(k_1,1),(k_2,n_t-1)} & r_{(k_1,1),(k_2,n_t)} \\ 0 & \ddots & \vdots & \vdots \\ \vdots & \ddots & r_{(k,n_t-1),(k,n_t-1)} & r_{(k,n_t-1),(k,n_t)} \\ 0 & \cdots & 0 & r_{(k,n_t),(k,n_t)} \end{bmatrix}, 1 \le k \le n_c \qquad (8)$$

H is QR decomposed with the orthogonal way of improved Gram-Schmidt. It can seem from formula (8), the equivalent channel vector $\left(h_{k1},\cdots,h_{kt},\cdots,h_{kn_t}\right)$ is orthogonal in k cluster, and the matrix Q can be directly obtained according H orthogonalization. [4] That is:

$$q_{11}=\frac{h_{11}}{\left\|h_{11}\right\|_F},\cdots,=\frac{h_{1t}-\sum_{j=1}^{i-1}\left(q_{1j},h_{1t}\right)q_{1j}}{\left\|h_{1t}-\sum_{j=1}^{i-1}\left(q_{1j},h_{1t}\right)q_{1j}\right\|_F}=\frac{h_{1t}}{\left\|h_{1t}\right\|_F}=\frac{h_{1t}}{\left\|h_{11}\right\|_F},\cdots,$$

$$q_{kt}=\frac{h_{kt}-\sum_{i=1}^{k-1}\sum_{j=1}^{n_t}\left\langle q_{ij},h_{kj}\right\rangle q_{ij}-\sum_{j=1}^{i-1}\left\langle q_{kj},h_{kt}\right\rangle q_{1j}}{\left\|h_{kt}-\sum_{i=1}^{k-1}\sum_{j=1}^{n_t}\left\langle q_{ij},h_{kj}\right\rangle q_{ij}-\sum_{j=1}^{t-1}\left\langle q_{kj},h_{kt}\right\rangle q_{1j}\right\|_F}=\frac{h_{kt}-\sum_{i=1}^{k-1}\sum_{j=1}^{n_t}\left\langle q_{ij},h_{kj}\right\rangle q_{ij}}{\left\|h_{kt}-\sum_{i=1}^{k-1}\sum_{j=1}^{n_t}\left\langle q_{ij},h_{kj}\right\rangle q_{ij}\right\|_F}=\frac{h_{kt}-\sum\sum\left\langle q_{ij},h_{kj}\right\rangle q_{ij}}{\left\|h_{kt}-\sum_{i=1}^{k-1}\sum_{j=1}^{n_t}\left\langle q_{ij},h_{kj}\right\rangle q_{ij}\right\|_F},$$

$$1\leq k\prec n_c,1\leq t\leq n_t \qquad (9)$$

Above the equation, the conclusion is drawn as fellow:

$$\left\langle q_{kj},h_{kt}\right\rangle=0,\ 1\leq j\leq t\leq n_t \quad (10)$$

The element of upper triangular matrix R , $r_{(k_1,n_t),(k_2,n_t)}$ can be understood as the projected length of equivalent channel vector $h_{k_2t_2}$ in t_2 antenna of k_2 cluster.

$$r_{(k_1,n_1),(k_2,n_2)}=\left\langle q_{k_1,n_1},h_{k_2,n_2}\right\rangle \quad (11)$$

From what have been discussed above, after QR decomposition, the feedback factor among the signal components of same cluster is 0. They aren't interfered each other, so the way of parallel processing can greatly speed up. Assuming the sending signal of clusters $k+1,\cdots,n_t$ has been judged as $\left(\widehat{X}_{k+1}^T,\cdots,\widehat{X}_{n_c}^T\right)^T$.

4. Simulation Data

From what have been discussed above, after QR decomposition, the feedback factor among the signal components of same cluster is 0. They aren't interfered each other, so the way of parallel processing can greatly speed up. Assuming the sending signal of clusters $k+1,\cdots,n_t$ has been judged as $\left(\widehat{X}_{k+1}^T,\cdots,\widehat{X}_{n_c}^T\right)^T$.

When simulating, the sending data is modulated by 4PAM constellation. The transmission power of all antennas is equal for short. The communication nodes of every cluster are also equal. The antenna of DGN is equal to the number of cluster.

Firstly, when applying STBC coding of 2 antennas, the BER performance characteristic of single cluster compares with that of multiple clusters, as seen the Fig.3. [5]

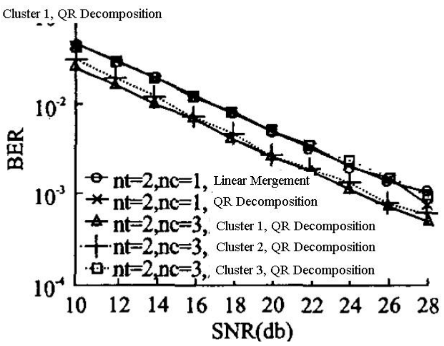

Fig. 3: BER of single cluster and multi-cluster ones.

As can be seen from Fig.3, the simultaneous transmission of multiple clusters doesn't cause the function deterioration. For the transmission scheme of 3 clusters based on STBC with 2 antennas, the 3rd cluster firstly t detected has the same BER performance with the STBC coding scheme of single cluster with 2 antennas. It's because the disturbing coming from other clusters is held back. Fig.3 also shows that the 2nd cluster and 1st cluster have better BER performance than 3rd cluster in the transmission scheme of 3 clusters. Because the 3rd cluster is offset by disturbing, multiple receiving antennas of DGN bring out array gain.

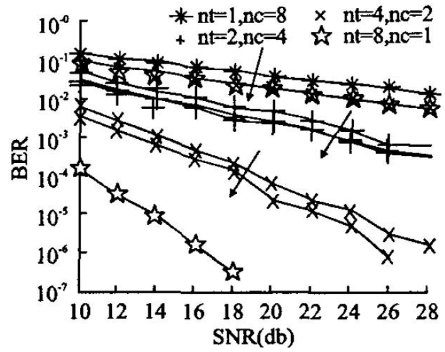

Fig. 4: The BER of cluster when using different clustering strategies.

And Fig.3 shows that the decoding strategy based linear mergence has the same performance with that based on QR decomposition in the condition of single cluster. This is due to the orthogonal structure of equivalent channel matrix can eliminate the disturbing among antennas through QR decomposition. It gains the same ends as linear mergence strategy. The size of cluster has a great influence on BER and transmission rate. Assuming there are 8 DCN around DGN, they examine the size of cluster separately, their value are 8, 4, 2 and 1. The performance chart is as fellow Fig.4.

Fig.4 clearly expresses the effect of BER performance as diversity gain. The nodes of participant STBC coding in the clusters is more, their diversity gain is larger and their performance of BER is better. Moreover, the corresponding total transmission efficiency becomes small accordingly. In the same cluster, the latter cluster detected could obtain higher array gain and its BER performance is better.

5. Conclusion

This article proposes a efficient transmission strategy of virtual MIMO in connection with sensor network. It extends the space time coding strategy from single cluster to multiple clusters. The strategy can greatly improve the transmission rate of network system in the condition of preserving the BER performance. Depending on the different application, the system can apply the size distribution strategy of the different cluster to achieve optimal performance. The QR decomposition decoding strategy based on Gram-Schmidt takes full advantage of the special structure of channel matrix coming along with new transmission strategy. Further, it decreases the complexity of DGN decoding. The transmission strategy makes advanced multiaerial MIMO and wireless sensor network combined more closely and firmly. A new approach is proposed for developing sensor network.

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