Selective Decoding Schemes and Wireless MAC Operating in MIMO Ad Hoc Networks

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Abstract: **Problems encountered in IEEE 802.11 medium access control (MAC) design are interferences from neighboring or hidden nodes and collision from simultaneous transmissions within the same contention floors. This paper presents the selective decoding schemes in MAC protocol for multiple input multiple output ad-hoc networks. It is able to mitigate interferences by using a developed minimum mean-squared error technique. This interference mitigation combined with the maximum likelihood decoding schemes for the Alamouti coding enables the receiver to decode and differentiate the desired data streams from co-channel data streams. As a result, it allows a pair of simultaneous transmissions to the same or different nodes which yields the network utilization increase. Moreover, the presented three decoding schemes and time line operations are optimally selected corresponding to the transmission demand of neighboring nodes to avoid collision. The selection is determined by the number of request to send (RTS) packets and the type of clear to send packets. Both theoretical channel capacity and simulation results show that the proposed selective decoding scheme MAC protocol outperforms the mitigation interference using multiple antennas and the parallel RTS processing protocols for the cases of (1) single data stream and (2) two independent data streams which are simultaneously transmitted by two independent transmitters.**

Index Terms: **Alamouti code, maximum likelihood (ML) decoding, medium access control (MAC).**

I. INTRODUCTION

With the lack of any infrastructure support of ad hoc networks, nodes in these networks must use a medium access control (MAC) protocol to reserve local access to wireless medium. In IEEE 802.11 standard, one of the two MAC protocols called the distributed coordination function (DCF) uses the carrier sense multiple access with collision avoidance (CSMA/CA) as the medium access method. The exchange of the handshake frames (request to send (RTS)/clear to send (CTS)) in the CSMA/CA algorithm can prevent the collision from a hidden station being outside transmission range that acquiring the channel. However, the use of handshaking cannot perfectly solve the hidden node and the exposed node problems [1]. Moreover, 802.11-MAC allocates spectrum inefficiency because it does not allow a pair of simultaneous transmissions. Therefore, one of the goals in this paper focuses on developing a MAC protocol to increase the concurrent transmission opportunities.

In order to improve the performance of wireless communication systems limited by multi-path fading and interferences, space-time codes on multiple transmit antennas can be combined with multiple receive antennas to minimize the effects of multi-path fading and to substantial increase channel capacity [2]. As a result, a coded multiple input multiple output (MIMO) sytem is a promising technique to offer reliability and achievable transmission rates. Recently, a lot of MAC protocols exploit the advantages of MIMO technique to improve the performance of the IEEE 802.11 standard in ad hoc networks [3]–[9]. A MAC protocol termed NULLHOC [3] designed for multipath MIMO communication channels cancels interferences by direct nulls toward other users involving in existing communication sessions. The accuracy depends on the appropriate transmit and receive weights selection in order to ensure that the signal is received with a certain gain or perfectly null. The attractive one is mitigation interference using multiple antennas (MIMA-MAC) [4] which is capable of simultaneously receiving data from two transmitters. It can mitigate interferences from neighboring nodes by employing the spatial multiplexing offered by the MIMO systems. However, in order to successfully separate all the data streams at receiver, the MIMA-MAC method uses only half of the transmit antennas for data transmission and the number of antennas on transmitters must be less than that on receivers. Hence, the channel resource is not always fully utilized. Parallel RTS processing (PRP-MAC) [5] developed an algorithm to maximize the number of transmitted data streams regardless of collision of the RTS packets, transmission demands and the number of antennas at each nodes. Although, the number of transmit antennas is maximized in single stream situation, it still uses a half of the transmit antennas for two transmission demands. Thus, the problem of the number of transmit antenna still remains and the channel capacity of the system is limited. More importantly, these methods do not incorporate diversity gains obtained from coding for MIMO communication systems.

In this paper, we developed a MAC protocol called the selective decoding scheme (SDS-MAC) for MIMO ad hoc networks. At transmitter, data streams are encoded by the Alamouti code and modulated by the orthogonal frequency division multiplexing (OFDM) [10]. Note that the OFDM is a promising technique for future broadband wireless standard to combat intersymbol interference. At receiver, the minimum mean-squared error (MMSE) interference canceller and three maximum likelihood (ML) decoding computation schemes which are applied from the decoding schemes in [11] for the point-to-point communication are presented. The decoding scheme selection corre-

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sponds to the number of transmission demands by neighboring nodes. Transmission demand can be determined after receiving the CTS packets. This allows either two simultaneous transmissions to one destine node or two pairs of transmitters and receivers communicate simultaneously.

The paper is organized as follows. Related work in Section II is first briefly analyzed for the comparison. In Section III, we describe the MMSE interference cancellation of the MIMO system. Its application to the SDS-MAC protocol is presented in Section IV. Section V proposes the frame structures of the SDS-MAC protocol. Theoretical channel capacity in Section VI is used for numerical evaluation. In Section VII, the simulation results are shown. Both numerical and simulation results are compared to the MIMA-MAC and the PRP-MAC protocols. Finally, conclusion is given in Section VIII.

II. ANALYSIS OF RELATED WORK

MAC protocols for MIMO ad hoc networks have been proposed to develop the IEEE 802.11 wireless ethernet technologies. As previous work, it would be helpful to summarize the MIMA-MAC system and PRP-MAC system.

A. Mitigation Interference Using Multiple Antennas-MAC Protocol (MIMA-MAC)

The operation in the MIMA-MAC protocol uses the fixed-size frame which consists of 2 contention slots, 2 training slots, a data slot and 2 acknowledgement slots. Each contention slot is divided for the RTS and CTS packets. This designed framing enables the MIMA-MAC protocol to have simultaneous communication of two pairs of transmitters and receivers. However, it is not efficient since the frame still contains 2 contention slots, 2 training slots and 2 acknowledgement slots for single communication pair. The frame cannot be adapted to the number of transmission demands.

In the physical layer, transmitter in the MIMA-MAC system always use only half of the transmit antennas for data transmission even if there is only one active transmitter at a time. The reason of using only half is to cancel interference induced by two active transmitters at a time. Due to using a zero-forcing (ZF) receiver as an interference canceller, the number of transmit antennas must be less than the number of receive antennas in order to separate all the data streams at receiver.

B. Parallel RTS Processing-MAC Protocol (PRP-MAC)

PRP-MAC redesigned the two contention slots so that the protocol can adapt to the number of transmission demands. Instead, the first contentions slot divided into two subslots is for the RTS packets transmitted from the first transmitter and the second transmitter, respectively. In the second contention slot, the CTS packets are transmitted. The number of slots for the CTS packet is not fixed but determined by the number of RTS packets in the previous contention slot. This technique reduces the number of training slots and acknowledgement slots if only one pair of transmission happens.

In the physical layer, the PRP-MAC protocol has resolved the problems of MIMA-MAC protocol. The number of transmit antennas used for transmission in case of a pair of communication

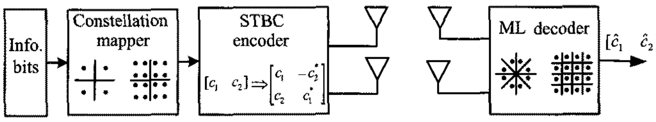

Fig. 1. Conventional MIMO system using the Alamouti code.

is not only half but total. The problem still however remains for the two pairs of communications either two transmitters to the same receiver or two transmitters to different receivers.

III. MMSE INTERFERENCE CANCELLATION IN MIMO LINKS

The MIMO system using the Alamouti code [12] is shown in Fig. 1. It is equipped with two transmit and two receive antennas. In the Alamouti coding, a block of two symbols $[c_1\ c_2]$ are taken in each encoding operation. At the first symbol period, c_1 and c_2 are transmitted from the first and the second antennas, respectively. In the next symbol period, $-c_2^*$ and c_1^* are transmitted instead. The superscript * denotes the complex conjugate. The receiver uses an ML decoder to obtain estimates $[\hat{c}_1\ \hat{c}_2]$.

Recently, attempts to mitigate interferences induced in MIMO links have been actively made [13]. Consider two synchronous co-channel terminals. Each terminal uses the transmitter scheme shown in Fig. 1. They are communicating with the same node which has two antennas for reception. Let h_{ij} be the fading channel coefficient between the ith transmit antenna of the first terminal and the jth receive antenna and let g_{ij} represent the fading channel coefficient between the ith transmit antenna of the second terminal and the jth receive antenna, $i = 1, 2$ and $j = 1, 2$. $[c_1\ c_2]$ and $[s_1\ s_2]$ represent two symbols encoded and transmitted from the first and the second terminals, respectively. The received signals over two consecutive symbol periods at the first receive antenna r_{11}, r_{12} and the second receive antenna r_{21}, r_{22} are expressed as

$$r_{11} = h_{11}c_1 + h_{21}c_2 + g_{11}s_1 + g_{21}s_2 + n_{11}, \quad (1)$$

$$r_{12} = -h_{11}c_2^* + h_{21}c_1^* - g_{11}s_2^* + g_{21}s_1^* + n_{12}, \quad (2)$$

$$r_{21} = h_{12}c_1 + h_{22}c_2 + g_{12}s_1 + g_{22}s_2 + n_{21}, \quad (3)$$

$$r_{22} = -h_{12}c_2^* + h_{22}c_1^* - g_{12}s_2^* + g_{22}s_1^* + n_{22}. \quad (4)$$

Let's define $\mathbf{r}_1 = [r_{11}\ r_{12}^*]^T$, $\mathbf{r}_2 = [r_{21}\ r_{22}^*]^T$, $\mathbf{c} = [c_1\ c_2]^T$, $\mathbf{s} = [s_1\ s_2]^T$, $\mathbf{n}_1 = [n_{11}\ n_{12}^*]^T$, and $\mathbf{n}_2 = [n_{21}\ n_{22}^*]^T$. Equations (1) and (2), and (3) and (4) can be rewritten in the matrix forms as follows

$$\mathbf{r}_1 = \mathbf{H}_1\mathbf{c} + \mathbf{G}_1\mathbf{s} + \mathbf{n}_1, \quad (5)$$

$$\mathbf{r}_2 = \mathbf{H}_2\mathbf{c} + \mathbf{G}_2\mathbf{s} + \mathbf{n}_2 \quad (6)$$

where $\mathbf{n}_1$ and $\mathbf{n}_2$ are complex Gaussian random vectors with zero mean and covariance $N_0\mathbf{I}_2$ and $\mathbf{I}_2$ is an identity matrix of size 2. $\mathbf{H}_j$ and $\mathbf{G}_j$ are the channel matrices between the two terminals and the jth receive antenna given by

$$\mathbf{H}_j = \begin{bmatrix} h_{1j} & h_{2j} \\ h_{2j}^* & -h_{1j}^* \end{bmatrix}, \mathbf{G}_j = \begin{bmatrix} g_{1j} & g_{2j} \\ g_{2j}^* & -g_{1j}^* \end{bmatrix}.$$

We defined $\mathbf{r} = [\mathbf{r}_1^T\ \mathbf{r}_2^T]^T$, $\acute{\mathbf{c}} = [\mathbf{c}^T\ \mathbf{s}^T]^T$ and $\mathbf{n} = [\mathbf{n}_1^T\ \mathbf{n}_2^T]^T$. Then, the matrix representation of the overall received signal

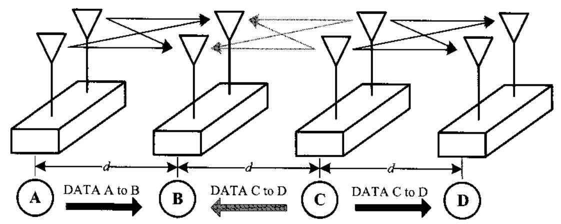

Fig. 2. Topology of an ad-hoc network with an inter-distance between nodes = *d*.

vector is

$$\mathbf{r} = \begin{bmatrix} \mathbf{H}_1 & \mathbf{G}_1 \\ \mathbf{H}_2 & \mathbf{G}_2 \end{bmatrix} \begin{bmatrix} \mathbf{c} \\ \mathbf{s} \end{bmatrix} + \begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \end{bmatrix} \tag{7}$$

$$= \mathbf{H}\acute{\mathbf{c}} + \mathbf{n}. \tag{8}$$

Assuming that we are interested in decoding signals from the first terminal, namely, c_1 and c_2. In the MMSE interference cancellation technique, the cost function is a difference between a linear combination of the received signals and the decoded symbols expressed as [11]

$$J_k(\boldsymbol{\alpha}_k, \boldsymbol{\beta}) = \|\boldsymbol{\alpha}_k^* \mathbf{r} - \boldsymbol{\beta}^* \mathbf{c}\|^2, \quad k = 1, 2 \tag{9}$$

where $\boldsymbol{\alpha}_k = [\alpha_{k,1}\ \alpha_{k,2}\ \alpha_{k,3}\ \alpha_{k,4}]$ and $\boldsymbol{\beta} = [\beta_1\ \beta_2]$ are chosen such that $\mathbf{E}\{J_k(\boldsymbol{\alpha}_k, \boldsymbol{\beta})\}$ is minimized. When the coefficients $\beta_1 = 1$, $\beta_2 = 0$ and $\beta_1 = 0$, $\beta_2 = 1$, the optimum weights are

$$\boldsymbol{\alpha}_1 = \mathbf{M}^{-1}\mathbf{h}_1, \quad \boldsymbol{\alpha}_2 = \mathbf{M}^{-1}\mathbf{h}_2$$

where $\mathbf{h}_p$ is the pth column of $\mathbf{H}$ and $\mathbf{M} = \mathbf{H}\mathbf{H}^* + (1/\Gamma)\mathbf{I}_4$, $\Gamma = E_s/N_0$ is the signal to noise ratio (SNR). Consequently, the minimized error function according to the weights $\boldsymbol{\alpha}_1$ and $\boldsymbol{\alpha}_2$ are

$$J_1(\boldsymbol{\alpha}_1) = \left\|\boldsymbol{\alpha}_1^* \mathbf{r} - c_1\right\|^2, \ J_2(\boldsymbol{\alpha}_2) = \left\|\boldsymbol{\alpha}_2^* \mathbf{r} - c_2\right\|^2.$$

It is important to mention that the minimized error functions in both cases allow us to cancel interference without regarding to another symbol. To decode the sent symbols, the ML is performed by the computation of

$$\hat{\mathbf{c}} = \arg\min_{\hat{\mathbf{c}} \in \boldsymbol{C}} \left(\left\|\boldsymbol{\alpha}_1^* \mathbf{r} - \hat{c}_1\right\|^2 + \left\|\boldsymbol{\alpha}_2^* \mathbf{r} - \hat{c}_2\right\|^2 \right) \tag{10}$$

where $\boldsymbol{C}$ is a set of all possible symbols and $\hat{\mathbf{c}} = [\hat{c}_1\ \hat{c}_2]$ is a pair of estimated symbols.

IV. SELECTIVE DECODING SCHEMES (SDS)

Consider the topology shown in Fig. 2 which consists of nodes with multiple antennas. There are three cases: (1) DATA A to B only happens; (2) DATA A to B and DATA C to D concurrently happen. The shaded arrow in Fig. 2 indicates the interference to node B while DATA C to D is connecting and (3) DATA A to B and DATA C to B are concurrently connecting to node B. In physical layer, OFDM is added at the transmitter as seen in Fig. 3. The OFDM concept can be found in [10], According

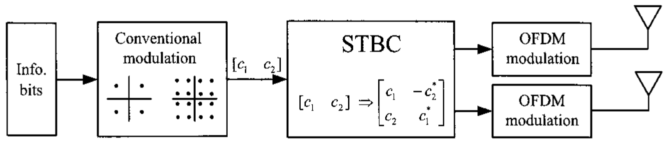

Fig. 3. SDS-MAC transmitter.

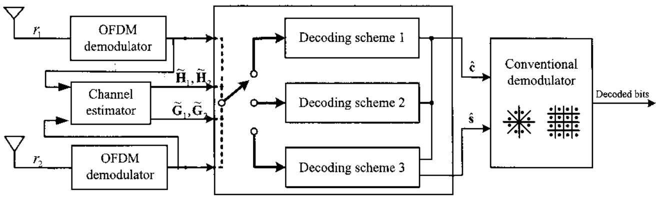

Fig. 4. SDS-MAC receiver.

to Fig. 4, three decoders are presented to increase the receiver capability which it can receive two data streams simultaneously.

1. **Decoding scheme 1** is used when the transmission of DATA A to B happens. In this case, only one data stream is transmitted. The ML decoding rule is

$$\hat{\mathbf{c}} = \arg\min_{\hat{\mathbf{c}} \in \boldsymbol{C}} \left(\left\|\mathbf{r}_1 - \mathbf{H}_1\hat{\mathbf{c}}\right\|^2 + \left\|\mathbf{r}_2 - \mathbf{H}_2\hat{\mathbf{c}}\right\|^2 \right). \tag{11}$$

2. **Decoding scheme 2** is used when two data streams are simultaneously transmitted and aim to different destinations. This is for DATA A to B and DATA C to D concurrently happen. The MMSE interference canceller pre-multiplies the received signal vectors by $\boldsymbol{\alpha}_1$ and $\boldsymbol{\alpha}_2$ as

$$\tilde{r}_1 = \boldsymbol{\alpha}_1^* \mathbf{r}, \ \tilde{r}_2 = \boldsymbol{\alpha}_2^* \mathbf{r}. \tag{12}$$

Denote $\tilde{r}_1$ and $\tilde{r}_2$ as the decision variables. The ML decoding rule is

$$\hat{\mathbf{c}} = \arg\min_{\hat{\mathbf{c}} \in \boldsymbol{C}} \left(\left\|\tilde{r}_1 - \hat{c}_1\right\|^2 + \left\|\tilde{r}_2 - \hat{c}_2\right\|^2 \right). \tag{13}$$

3. **Decoding scheme 3** is presented in order to decode two data streams simultaneously transmitted to the same destine node (DATA A to B and DATA C to B). After calculating (13), it decodes the symbol vector, $\mathbf{s}$, transmitted from the second terminal by computing $\mathbf{x}_1 = \mathbf{r}_1 - \mathbf{H}_1\hat{\mathbf{c}}$ and $\mathbf{x}_2 = \mathbf{r}_2 - \mathbf{H}_2\hat{\mathbf{c}}$, followed by

$$\hat{\mathbf{s}} = \arg\min_{\hat{\mathbf{s}} \in \boldsymbol{S}} \left(\left\|\mathbf{x}_1 - \mathbf{G}_1\hat{\mathbf{s}}\right\|^2 + \left\|\mathbf{x}_2 - \mathbf{G}_2\hat{\mathbf{s}}\right\|^2 \right). \tag{14}$$

V. SDS-MAC TIME LINE OPERATIONS

Fig. 5 shows the time structure of the SDS-MAC protocol. It is assumed that all nodes are perfectly synchronized. It consists of five types of slots. Each slot has two time segments except the data transfer slot. The tasks of each slot are briefly explained as follows.

i) Contention slot: In this slot, the transmitters send the RTS packet to alert the receivers for connection establishment. The transmitters having data to send must contend to acquire

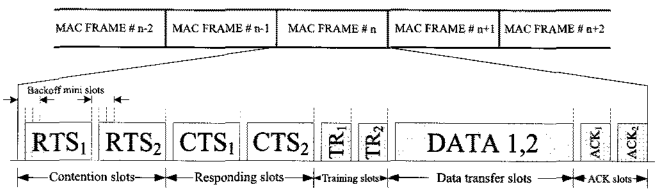

Fig. 5. Time line of SDS-MAC protocol.

the channel. A small random number of back-off mini-slots based on CSMA/CA are included at the beginning of each RTS slot to avoid collision of the RTS packets [1].

ii) Responding slot: After receiving the RTS packet, the receiver node waits for another RTS packet in the next slot. If it does not receive any more RTS packet, it generates a CTS-I packet (node B in Fig. 6(a)) to inform that it is ready for data transfer. If it receives another RTS packet for the other node while waiting, it generates a CTS-II packet (node B and D in Fig. 6(b)). If it receives another RTS packet for itself while waiting, it generates CTS-III packet (node B in Fig. 6(c)) to response both transmitters (node A and C in Fig. 6(c)). To alert other nodes of channel occupation, every node receiving a CTS packet starts network allocation vector (NAV) period. They stop generating RTS packets in NAV period otherwise it can collide the existing transfer.

iii) Training slot: The receiver uses the transmitted training sequence to estimate channel state information which is necessary for decoding computation.

iv) Data transfer slot: The transmitters that acquired the channel transmit their data in this slot. Unlike other slots, two data streams can be transferred simultaneously in one slot due to employing the MMSE interference canceller for data separation.

v) Acknowledgement slot: The receiver replies an ACK packet to confirm the data reception.

As shown in Fig. 6, slot timing and decoding vary in the transmission demands. Note that arrows on the left side shows the flow of data packets. To avoid the collision, the SDS-MAC protocol selects the proper decoding scheme corresponding to the number of RTS packets and the type of CTS packets as follows.

i) CTS-I: The CTS-I packet is used when only one RTS packet is transmitted in the contention slot. It means only one data stream is transmitted (DATA A to B). The destined node sends back a CTS-I to the transmitter for connection permission. This control packet stores the transmitter ID and reduced number of slots. The frame structure is reduced to a single stream transmission as shown in Fig. 6(a). Accordingly, the decoding scheme 1 is chosen since it does not need to suppress interferences.

ii) CTS-II: The CTS-II packet is used when two RTS packets are transmitted in the contention slot. Two terminals send their own data streams to different nodes at the same time (DATA A to B and DATA C to D). The CTS packets in the responding slot and the time line are shown in Fig. 6(b). The decoding scheme 2 is designed for this situation.

iii) CTS-III: In the case of DATA A to B and DATA C to B, the node B responses both terminals by the CTS-III packet. Transmitter IDs of both RTS packets are stored in the CTS-III packet. The frame structure is shown in Fig. 6(c) which one responding slot is excluded. The node B selects the decoding scheme 3 for data separation.

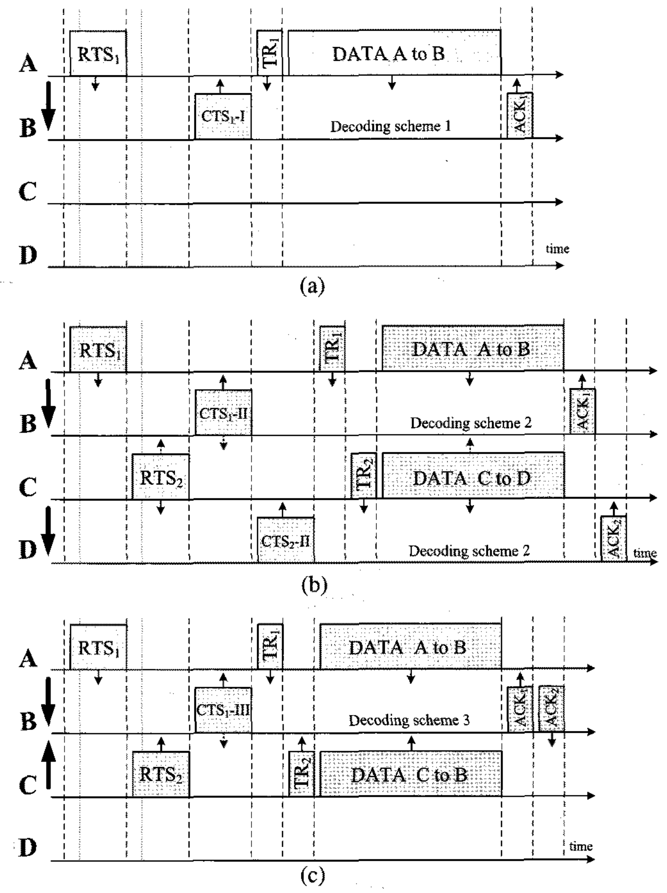

Fig. 6. Time line operations in the SDS-MAC protocol: (a) Scenario 1: A node receives only an RTS packet, (b) scenario 2: Two destined nodes receive its own RTS packet, and (c) scenario 3: A node receives two RTS packets for itself.

VI. CHANNEL CAPACITY

In Fig. 4, the received signal at any symbol period can be expressed as [14]

$$\mathbf{r} = \sqrt{\frac{E_s}{M_t}}\boldsymbol{\Phi}\mathbf{c} + \mathbf{n} \tag{15}$$

where E_s is the signal energy and M_t is the number of transmit antennas. In the proposed algorithm, $M_t = 2$ is assigned due to the Alamouti code. The received signal vector is $\mathbf{r} = [r_{1t} \ \ r_{2t}]^T$ where $r_{jt}, j = 1, 2$, is the received symbol at the jth receive antenna at symbol period t. $\boldsymbol{\Phi}$ is a 2×2 MIMO channel which each element Φ_{ij} is a fading coefficient between the ith transmit and jth receive antennas, and $\mathbf{n} = [n_{1t} \ \ n_{2t}]^T$ is a zero mean complex Gaussian noise vector with $E[\mathbf{n}\mathbf{n}^H] = N_0\mathbf{I}_2$. If $\boldsymbol{\Phi}$ has a full column rank, the channel capacity of links when we use the MMSE interference canceller is given by [14]

$$C_{\mathrm{SDS}} = r_c \sum_{k=1}^{M_t} \Bigg[\underbrace{\log_2(1+\eta_{1,k})}_{\text{Link 1}} + \underbrace{\log_2(1+\eta_{2,k})}_{\text{Link 2}} \Bigg] \tag{16}$$

where $r_c = 1$ for the Alamouti code. The kth data streams's post processing signal to noise ratio at the mth transmitter can be expressed as [14]

$$\eta_{m,k} = \frac{1}{\left[\left(\frac{2\rho}{M_t}\mathbf{\Phi}_m^H\mathbf{\Phi}_m + \mathbf{I}_{M_t}\right)^{-1}\right]_{k,k}} - 1 \tag{17}$$

where $\rho = E_s/N_0$. As shown in (16), the capacity increases proportionally to the number of transmit antennas, the number of links and transmitted powers.

To evaluate the SDS-MAC performance, the MIMA-MAC and PRP-MAC protocols are used for comparison. The differences of those protocols can be summarized as follows.

i) The SDS-MAC protocol allows the total transmit antennas (M_t) to be active whereas the MIMA-MAC protocol uses only half of its transmit antennas ($M_t/2$). Meanwhile, the PRP-MAC protocol has developed the MIMA-MAC protocol by using a half of total transmit antennas only for two pairs of data transmissions (not for single stream transmission).

ii) The SDS-MAC and the PRP-MAC protocols can have at most two simultaneous links in the network either to the same or to the different receivers. The MIMA-MAC system, however, is designed for at most two simultaneous transmission only for different receivers. This is to develop the mechanism of the 802.11 style MAC which there can be only one active transmitter at a time using all of M_t transmit antennas.

iii) The MMSE interference canceller mentioned in Section II is employed with the ML decoders in the SDS-MAC protocol. Meanwhile, ZF receiver [14] is employed as a spatial multiplexing and interference cancellation in the MIMA-MAC and the PRP-MAC protocols.

iv) Besides, the SDS-MAC protocol obtains transmit diversity provided by the Alamouti code.

For upper and lower bounds, the capacities of the conventional MIMO systems for one link without any interference cancellers are used for comparisons which is given by [2]

$$C = \log_2 \det\left[\mathbf{I}_{M_t} + (\rho/M_t)\mathbf{\Phi}^H\mathbf{\Phi}\right]. \tag{18}$$

The channel is assumed to be uncorrelated Rayleigh matrix and the quasi-static fading model. Each entry of the channel is a complex Gaussian random variable with zero mean and variance of one. For the upper bound, the number of transmit antennas and receive antenna are 4×4. For the lower bound, it is the single input and single output (SISO). Consider occurrence of one transmission, i.e. only DATA A to B. The results plotted in Fig. 7 show the capacities of the SDS-MAC system are more than that of the MIMA-MAC and the PRP-MAC systems. Due to the SDS-MAC system benefits, its capacities results are close to the 2×2 MIMO system. When the number of transmitters increases to two which includes the cases of (DATA A to B and DATA C to D) and (DATA A to B and DATA C to B), the channel capacities of the SDS-MAC protocol is still higher than those methods and close to the 4×4 MIMO system as shown in Fig. 8. For the case of two pairs of communications, the capacities of the SDS-MAC protocol is more than the 2×2 MIMO system since the 2×2 MIMO system has no ability to separate two data streams.

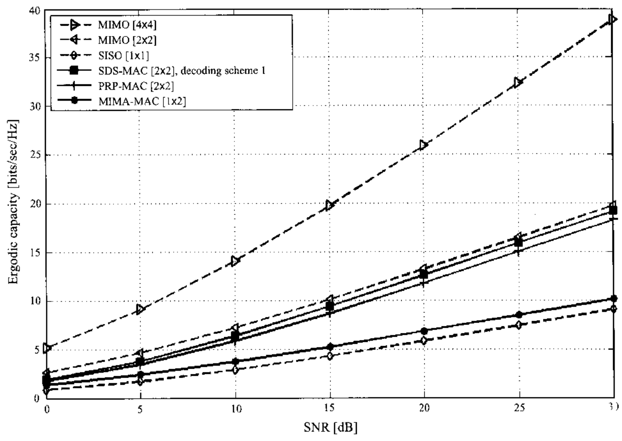

Fig. 7. Ergodic capacity comparisons in case of only one communication.

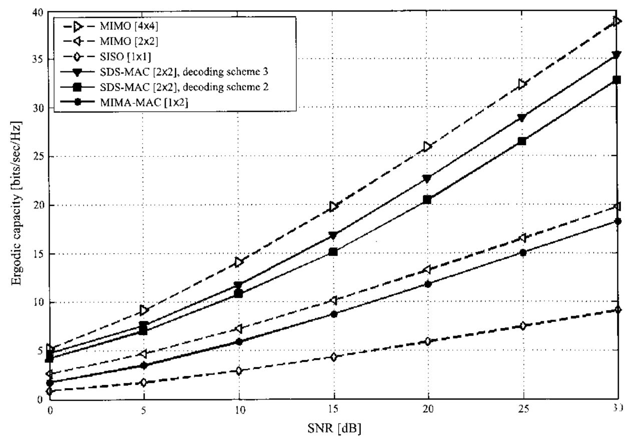

Fig. 8. Ergodic capacity comparisons in case of two pairs of communications.

VII. SIMULATION RESULTS

We evaluate the performance of the SDS-MAC protocol by simulating symbol error rates (SERs) and compare them to the MIMA-MAC and the PRP-MAC protocols. The channel state information $\mathbf{H}_1, \mathbf{H}_2$ and $\mathbf{G}_1, \mathbf{G}_2$ are assumed to be perfectly known at the receivers which can be estimated by using training sequences, in practice. In the case of one link (DATA A to B), Figs. 9 and 10 shows the SERs versus SNRs for binary phase shift keying (BPSK) and 8PSK modulations, respectively. In each modulation, the decoding scheme 1 has the SER results better than the decoding scheme 2 and the MIMA-MAC and the PRP-MAC protocols since the decoding scheme 1 is specifically designed for the scenario 1 and use the ML as a decoder which is optimal decoding, while the ZF receiver is sub-optimal. As expected, using 8PSK modulation results in decreasing SERs as compared Fig. 9 to Fig. 10.

In the cases of two links either (1) DATA A to B and DATA C to D or (2) DATA A to B and DATA C to B, the SER results are compared as illustrated in Fig. 11. We use the quadrature phase shift keying (QPSK) modulation. By using the SDS-MAC protocol, we improve the channel utilization that allows decod-

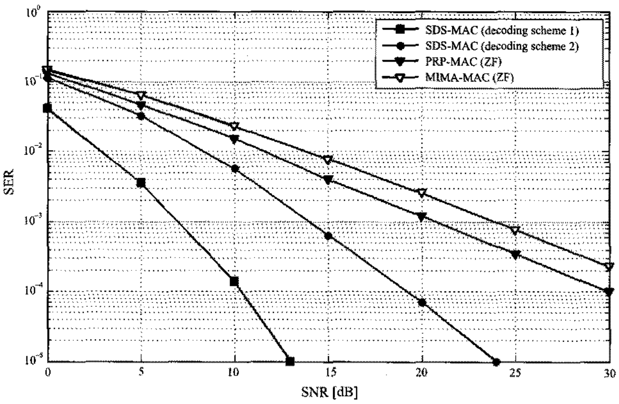

Fig. 9. SER comparisons in case of only one communication (BPSK).

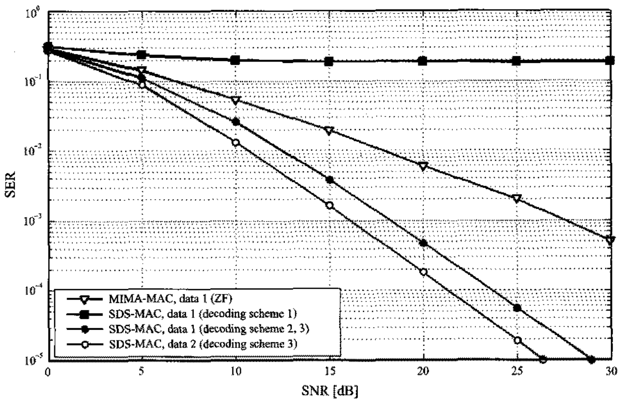

Fig. 11. SER comparisons in case of two pairs of communications (QPSK).

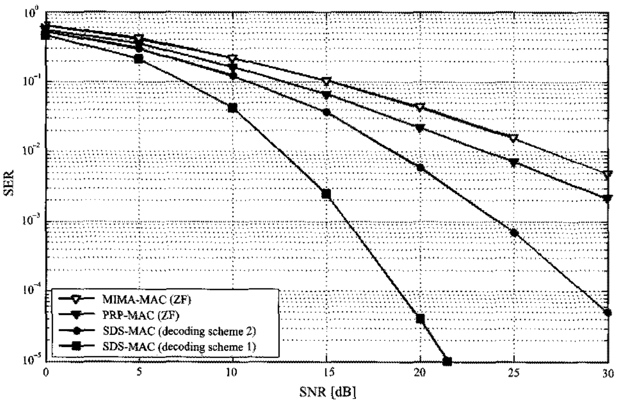

Fig. 10. SER comparisons in case of only one communication (8PSK).

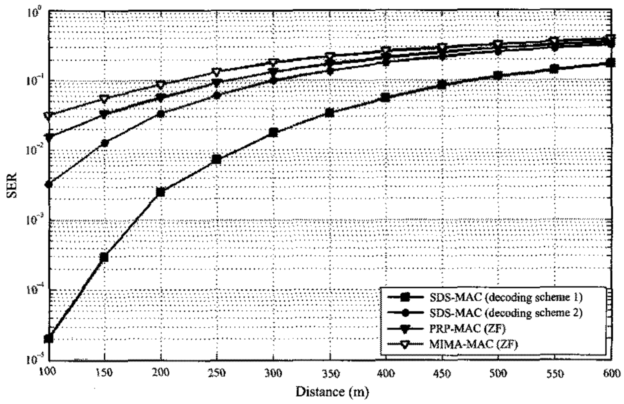

Fig. 12. SER comparisons in case of only one communication (QPSK).

ing two simultaneous data streams. In legend, data 1 refers to DATA A to B and Data 2 refers to DATA C to D or DATA C to B. With the presence of interferences, the decoding scheme 1 cannot decode data streams efficiently (SDS-MAC, data 1 (decoding scheme 1)). The MIMA-MAC system is worse as it is unable to decode data streams for the scenario 3 even though the ZF receiver can mitigate interferences (MIMA-MAC, data 1 (ZF)). By using our algorithm, the SERs of data 1 by decoding scheme 2 and 3 (SDS-MAC, data 1 (decoding schemes 2 and 3)) and data 2 by decoding scheme 3 (SDS-MAC, data 2 (decoding scheme 3)) are low. Note that the SER results of one link are better than that of two links since the diversity is four when there is only one user using the channel. In two links, the diversity reduces to two, because one of the receive antennas is effectively used for the interference suppression.

We apply the log-distance path loss model given by

$$\overline{PL}(\text{dB}) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) \tag{19}$$

where n is the path loss exponent, d_0 is the reference distance, and d is the transmitter-receiver separation distance. $\overline{PL}(d_0)$ is the reference path loss. Note that we use $\overline{PL}(\text{dB})$ to calculate the SNR of the received signal in (15). The distances, d, between the transceivers are varied from 100 to 500 meters. The path loss exponent is equal to 2. We use d_0= 100 meters for a reference distance to ensure the radio environment to be the far-field region. The SNR of each receive antennas equal to 16 dB at this reference point. The QPSK modulation is selected. Fig. 12 shows the SER results versus distances in the case of one link (DATA A to B). We can see that the decoding scheme 1 has the SER performance better than the decoding scheme 2, the MIMA-MAC protocol, and the PRP-MAC protocol which corresponds to the results shown in Figs. 9 and 10.

The SER results in the case of two links which might be either (1) DATA A to B and DATA C to D or (2) DATA A to B and DATA C to B are compared as illustrated in Fig. 13. The decoding scheme 3 which employ the MMSE interference cancellation can decode both data stream 1 and data stream 2 with lower SERs (SDS-MAC, data 1 (decoding schemes 2 and 3) and SDS-MAC, data 2 (decoding scheme 3)). Notice that the decoding scheme 2, which is decoding DATA A to B and DATA C to D, has the same performance as the decoding scheme 3 for data stream 1. It is similar to the results shown in Fig. 11.

VIII. CONCLUSION

A wireless MAC design with selective decoding schemes called the SDS-MAC protocol in MIMO ad hoc networks is presented. The MMSE interference canceller increases the channel utilization since it enables simultaneous data transmissions. The

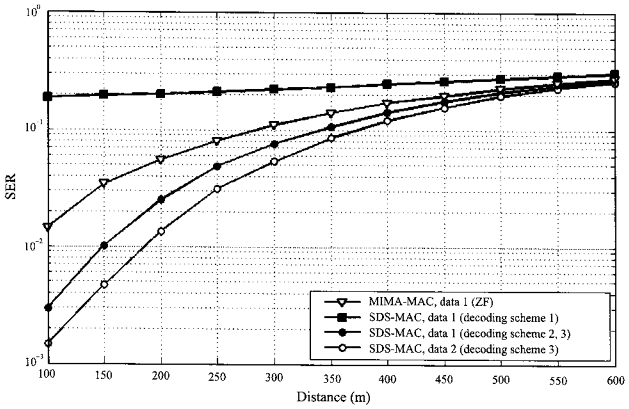

Fig. 13. SER comparisons in case of two pairs of communications (QPSK).

decoding schemes and frame time lines are properly selected depending on transmission demands of neighboring nodes. Consequently, two data streams can be simultaneously transferred by two terminals to the same or different destined nodes. The results assure the SDS-MAC protocol outperforms the MIMA-MAC and the PRP-MAC protocols.

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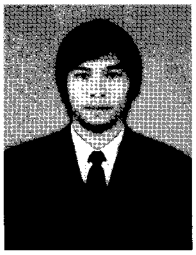

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