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13. ABSTRACT (Maximum 200 words)

In this paper, the problem of broadcast in ad hoc networks with smart antennas in a general propagation scenario is investigated. The conventional models proposed in the literature are surveyed and their limiting assumptions on the array at the receiver are identied. The connection between this point and the gain asymmetry for the broadcast of control packets is explored. As a first result, the impossibility to solve this problem in a conventional setting is proved. Then, a solution is mathematically deduced based on the consideration that a true MIMO (rather than MISO) system is required. The scheme can simultaneously send these packets farther, omnidirectionally and with very limited delay. Finally, a comparison with the Circular RTS scheme [1] is carried out with interesting results.

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On gain asymmetry and broadcast efficiency in MIMO ad hoc networks

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Abstract— **In this paper, the problem of broadcast in ad hoc networks with smart antennas in a general propagation scenario is investigated. The conventional models proposed in the literature are surveyed and their limiting assumptions on the array at the receiver are identified. The connection between this point and the gain asymmetry for the broadcast of control packets is explored. As a first result, the impossibility to solve this problem in a conventional setting is proved. Then, a solution is mathematically deduced based on the consideration that a true MIMO (rather than MISO) system is required. The scheme can simultaneously send these packets farther, omnidirectionally and with very limited delay. Finally, a comparison with the Circular RTS scheme [1] is carried out with interesting results.**

I. INTRODUCTION

The field of Mobile Ad hoc NETworks (MANETs) with smart antennas has enjoyed a good deal of attention in the recent past. The advantages due to the introduction of multiple antennas are unquestionable, though there is not yet general agreement on how to exploit them. A particularly effective technique is beamforming. Its ability to focus the signal energy towards a desired direction while suppressing co-channel interference is especially suited for point-to-point transmission. However, it may not be so effective for the transmission of packets meant for several nodes (e.g., control packets in networking protocols), since the presence of multiple intended receivers entails to spread the energy, thus reducing the maximum achievable range.

Most broadcast information (channel reservation, routing update, network discovery, etc.) significantly benefits from a wide distribution. For instance, increased network connectivity, shorter routes and improved resilience to mobility and link failure are prominent offsprings. The most natural way to broadcast[1] a packet is to use a single omnidirectional antenna. However, this falls short of providing a larger coverage. The dualism between an omnidirectional but short-range transmission and a beamforming long-range mode has been called the *gain asymmetry* problem [1], [2].

This problem is particularly important for (though by no means limited to) the RTS/CTS handshake in an IEEE 802.11-like MANET. A possible solution has been designed in [1], called the Circular RTS: the authors propose to achieve long-range omnidirectional communication by successively beamforming towards different directions, until the whole horizon is swept. This idea does increase the transmission range, due to the beamforming gain. In addition, it abates the extent of the hidden node problem thanks to the omnidirectional transmission. Moreover, it has no need for feedback from the receivers. These feedback signals would not be practically useful because it takes time to gather them and it is hard to satisfy all of them simultaneously. On the other hand, as proved in [3], the main drawback of the Circular RTS scheme is the latency due to several transmissions of the same packet (one per sector). This additional delay negatively impacts the overall performance of the protocol and should be avoided if possible.

The problem addressed in this paper is the design of a control packet exchange method that: 1) achieves the same performance as [1] in terms of transmission range and reliability, 2) provides a major reduction of the delay (possibly sending the packet only once), 3) is an open loop technique, 4) is not applicable to directional data transmission.

The last condition is explained as follows. If the technique found were applicable to both control and data packets, both types of transmissions would be equally boosted by the solution, and the asymmetry in gain would not be solved. For instance, conventional channel coding or TCM can be applied to both types, and thus are of no help here.

Another common problem of the proposed MAC protocols is the underlying assumption about the propagation environment. Most of the protocols are designed for Line Of Sight (LOS) conditions [1], [2], [4], [5], with a few exceptions focused on Rayleigh fading [6]. No existing scheme is equally valid in both cases. Instead, in this paper we establish a method which is proved to work in a generic Ricean fading environment, which includes LOS and Rayleigh fading as special cases. The main idea is to exploit a full rate Space Time Code at the transmitter, while the receiver performs Maximal Ratio Combining.

In the present literature, other papers have dealt with the problem of broadcast in MIMO MANETs, but the attention has focused on directional antennas [7], [8], [9]. These papers research algorithms that decrease the energy consumption and congestion by clever choices of the relaying nodes for network-wide broadcast, whereas the problem of the gain asymmetry is dealt with only marginally. Our study instead focuses on more effective physical layer techniques to improve networking performance.

The rest of the paper is organized as follows. Section II describes the system model and assumptions. Section III provides the main theoretical results and describes the proposed scheme based on the use of Space-Time Codes, and Section IV presents numerical results and comparisons with the Circular RTS scheme. Section V concludes the paper.

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[1] In this paper, by broadcast we mean the capability to reach all nodes within a circular area of a given radius, as opposed to network-wide dissemination of a message.

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II. MODELS AND ASSUMPTIONS

A. Antenna and channel models

In this paper, scalars are denoted by plain letters (i.e., x), vectors have an overline (i.e., $\overline{x}$), matrices are indicated by capital bold letters with an overline (i.e., $\overline{\mathbf{X}}$). The network model assumes that all nodes are equipped with N antennas.

The channel is regarded as flat fading, slowly time varying. The channel statistics is Ricean, but otherwise unspecified. The baseband (complex) channel gain from the i-th input to the j-th output is denoted by h_{ij}. We consider here a Space-Time Block Code (STBC) model [10], in which a block of K data symbols (arranged in the vector $\overline{x} = (x_1, x_2, \ldots, x_K)^T$) is transmitted in L symbol intervals (K/L is the code rate). In the ℓ-th symbol interval, the antennas send linear combinations of the K data symbols, computed according to a weighing $N \times K$ matrix $\overline{\mathbf{W}}_\ell$. More specifically, the signal transmitted by antenna i at time ℓ is obtained taking the inner product of the i-th row of $\overline{\mathbf{W}}_\ell$ and the symbol vector $\overline{x}$, and shaped by a suitable waveform, whose energy is equal to E_s. The output of the baseband equivalent of the N receiver antennas in the ℓ-th symbol interval (neglecting interference from other users and prior to any equalization) can be written as:

$$\overline{r}(t) = \overline{\mathbf{H}}\,\overline{\mathbf{W}}_\ell\,\overline{x} + \overline{n}(t) \qquad (1)$$

where $\overline{n}(t)$ is a zero-mean, spatially and temporally white Gaussian noise. A set of matrices $\overline{\mathbf{W}}_\ell, \ell = 1, \ldots, L$ defines a STBC. For instance, for the Alamouti code and BPSK modulation, two symbols are transmitted every two symbol intervals, so that $K = L = 2$ and $\overline{\mathbf{W}}_1 = [1\,0; 0\,1]$, $\overline{\mathbf{W}}_2 = [0\,1; -1\,0]$.

The receiver has perfect channel state information (CSI), while the transmitter has no channel knowledge. This asymmetry is due to the fact that in multicast the transmitter has many recipients, and the task of learning all the channels in a very brief time span would not be viable. (In fact, for the RTS packet in 802.11, the transmitter does not even know how many and which nodes it is trying to reach beyond its intended destination. And even if the channel and the nodes could be known, it is not clear how this knowledge could be used to beamform simultaneously towards all users, except in rather trivial situations.) Instead, the receiver, by training based estimation, can identify the channel. Therefore the receiver antenna gain can be greater than one. Instead, the majority of the proposed MAC protocols for MANET with smart antennas assume that an idle receiver can employ its antennas omnidirectionally but only with a unit gain (effectively using a single antenna) [1], [2], [3], [5]. Also, the studies of broadcast techniques with smart antennas follow this line [7], [8], [9]. Therefore, the pair transmitter-receiver is actually turned into a MISO (rather than MIMO) system. In such a case, the channel is a vector and is denoted as $\overline{h}$.

This is due to the erroneous belief that there is always a trade-off between beamforming gain and beamwidth. While this is certainly true at the *transmitter*, where sending on two beams simultaneously requires twice the power and is therefore impossible in the presence of a power constraint, at the *receiver* this is not the case, because starting from the baseband samples at the output of the antennas it is possible to form as many receiving beams as desired by just using signal processing (i.e., no additional power is needed to implement more beams, as long as the processing power consumption can be considered as negligible). This misinterpretation of the beamforming process at the receiver has led some authors to designing schemes that take into account a constraint that does not actually exist.

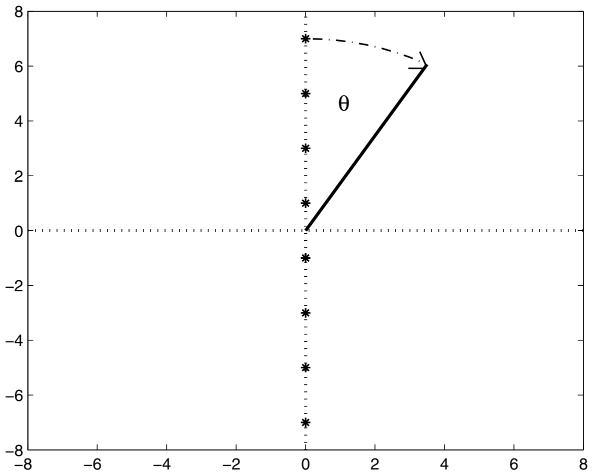

Fig. 1. Linear array configuration.

B. Circular RTS Delay

In [1], the Circular RTS scheme is proposed, in which omnidirectionality of the transmission is achieved by a sequence of directional transmissions, which leads to a latency that is proportional to the number of beams. While in [1] the number of beams was assumed to be equal to the number of antennas, in real systems it is important to consider the relationship between the two numbers, which depends on the beamforming technique and on the conventional definition of the beamwidth (we use 3-dB beamwidth in this paper).

As the reference case, consider a linear uniform phased array, typical of switched beam antennas. The maximum gain is N, because the antennas' currents are equal in magnitude. (However, note that with a 3-dB beamwidth the minimum guaranteed gain in the coverage area is only $N/2$). The array is assumed to be aligned along the vertical direction, and the bearing θ is measured starting from the positive half of the horizontal axis (see Fig. 1). In this situation, the array factor is equal to [11]:

$$AF = \left|\frac{\sin(N\psi/2)}{\sin(\psi/2)}\right|,\ \psi = kd\sin(\theta) + \beta \qquad (2)$$

where $k = 2\pi/\lambda$, λ is the wavelength, d is the spacing between two consecutive array elements and β is the difference in phase excitation between two adjacent antennas. The beams have a slightly different width according to the main lobe bearing, but it is quite good an approximation to pretend that they all have the same width except for the end-fire case (the direction along which the array is deployed), where the beam is actually significantly wider. The former 3-dB width can be evaluated by setting (2) equal to $1/\sqrt{2}$ and $\beta = 0$. (2) is rearranged as [11]:

$$AF = N\left|\frac{\sin(N\psi/2)/(N\psi/2)}{\sin(\psi/2)/(\psi/2)}\right| = N\left|\frac{\mathrm{sinc}(N\psi/2)}{\mathrm{sinc}(\psi/2)}\right| \qquad (3)$$

The conventional beamwidth is found by solving $\mathrm{sinc}(x) = 1/\sqrt{2}$, which leads to $x = 1.391$. The outcome is BW = $2 \cdot 1.391\lambda/(Nd\pi)$. Instead, the end-fire beam is assumed to have fixed width at $\pi/3$ rad. This is very close to the actual 3 dB beamwidth for a 4-antenna end fire array. For $N > 4$, the actual beamwidth is tighter, but the effect will be neglected. Therefore only $2\pi/3$ rad need to be covered by the other beams. The range of N considered is between 4 and 16, because these are the typical array sizes in many practical applications [11]. The ratio d/λ is fixed to 1/2, so as to avoid spatial grating and not cause excessive mutual coupling between antennas. In this case, the number of beams is equal to:

$$\begin{aligned} \eta &\simeq \left\lfloor 1+\frac{2\pi}{3\,BW}\right\rfloor = \left\lfloor 1+\frac{d\pi^2 N}{3\lambda\cdot 1.391}\right\rfloor \\ &\simeq \lfloor 1+1.18N\rfloor \end{aligned} \qquad (4)$$

where $\lfloor x \rfloor$ is the largest integer not greater than x. For $N = 4, 8, 12, 16$, we have $\eta = 5, 10, 15, 19$, respectively. (Note that the number of beams depends on the conventional beamwidth chosen.)

III. THEORETICAL RESULTS

In this section we provide some theoretical foundation for our proposed solution. This is given by two theorems. The former shows how in a MISO scheme (adopted for the RTS reception in the majority of MAC protocols as discussed) the gain asymmetry cannot be solved if the transmitter can send its packet only once. The latter considers instead a full MIMO system and shows (in a constructive fashion) how to solve the problem. The resulting scheme is one where we use a single transmission in all directions by means of a space-time code. The association of this scheme with maximal ratio combining reception provides the necessary gain to cover the same range as in directional transmission. Finally, Theorem 1 hinges also on the fact that a MISO system without CSI at the transmitter has reduced power gain. While the result is not itself new (see for instance [12] for an information theory based proof), the derivation presented here is different and addresses the asymmetry in gain problem more directly.

Theorem 1: A MISO system with N antennas, no CSI at the transmitter and iid channel coefficients cannot send a packet omnidirectionally with an average power gain of N with respect to a SISO system.

Proof: Let us call $\overline{h}_i$ the channel coefficients from the transmitter antennas to the i-th neighboring node and $\overline{w}$ a beamforming vector. The channel can be regarded as a linear map between $\mathbb{C}^N$ (domain) and $\mathbb{C}$. The pre-image has dimension 1, while the kernel $N-1$, because $dim(Im(\overline{h}_i)) + dim(ker(\overline{h}_i)) = N$. Let us pick the pre-image as the first vector for a basis in the domain. The noise free output can be written as $r = \overline{h}_i^T \overline{w} = (\overline{h}_i^*)^H \overline{w}$, that is the inner product between $\overline{h}_i^*$ and $\overline{w}$, where $*$ denotes conjugation and ^{H} conjugate transposed. Therefore, the pre-image is proportional to $\overline{h}_i^*$. This basis can be completed with $N-1$ more vectors drawn from the orthogonal complement of the pre-image (i.e., the kernel). With no loss in generality, we take this basis to be orthonormal, and call the vectors $\{\overline{v}_j\}$, $j \in \{1, ..., N\}$. Let α_j be the coefficient of the vector $\overline{w}$ with respect to $\overline{v}_j$, so that $\overline{w} = \sum_{j=1}^N \alpha_j \overline{v}_j$. As the basis is orthonormal, Parseval's theorem applies, and $\|\overline{w}\|^2 = \sum_{j=1}^N |\alpha_j|^2$. Since no CSI is available at the transmitter, the mutual orientation of $\overline{w}$ and $\overline{h}_i \propto \overline{v}_1^*$ is random. Therefore, there is no preferential position of $\overline{w}$ to any $\overline{v}_j$, so that $E\left[|\alpha_i|^2\right] = E\left[|\alpha_j|^2\right]$ and thus $E\left[|\alpha_1|^2\right] = \|\overline{w}\|^2/N$. Therefore (as a first fact) only $1/N$ of the input power is successfully delivered to the output. The receiver can (at best) perform coherent detection by compensating for the phase of the equivalent channel $\overline{h}_i^T \overline{w}$. In this case the Symbol Error Rate (SER) can be computed by conditioning the error probability on the channel coefficients and then by averaging over the channel statistic s [13]. The conditioned SER is equal to the complementary Gaussian distribution $Q(x)$ computed in $x = \sqrt{\beta\Lambda}$, where β is a constant depending on the modulation and Λ is the received SNR. For the iid hypothesis on the channel coefficients, Λ is on average $E[\|\overline{h}_i\|^2]\Lambda_0/N = E[|h|^2]\Lambda_0$, where Λ_0 is the SNR of an equivalent SISO system (same transmitted power) and $E[|h|^2]$ is the average square value of a single channel coefficient (i.e., any element of $\overline{h}_i$). The overall SNR Λ is divided by N because of the power loss due to the lack of CSI. Therefore, if no hypothesis is made on the channel statistics, SER = $E[Q(\sqrt{\beta\Lambda})] \geq Q(\sqrt{E[\beta\Lambda]}) = Q(\sqrt{\beta E[|h|^2]\Lambda_0})$. The inequality is due to the convexity of $Q(\sqrt{x})$ and the bound is met when there is no fading. This is the performance of a simple SISO system. It follows that no power gain is achievable and no range increase is possible unless packet retransmission is allowed. The last option would increase the subrange dimension (the received vector is made up by more received samples), and this in turn expands the pre-image dimension and therefore the power delivered to the output. On the other hand, packet retransmission raises the issue of increased latency and power consumption. ■

Thus, the introduction of multiple antennas only at the transmitter can improve the range, but only at the expense of increased delay. Instead, a MIMO system is not affected by this limitation, as shown by the second theorem. The rationale behind it is that if it is possible to provide a power gain equal to that of a MISO structure with perfect CSI at the transmitter without incurring any additional delay, the problem is solved.

Theorem 2: Consider an $N \times N$ MIMO system whose channel matrix has iid coefficients, and assume that perfect CSI is available only at the receiver. It is then possible to send a packet omnidirectionally with an average power gain of N with respect to a SISO system.

Proof: A MISO system with perfect CSI at the transmitter matches beamforming weights with channel coefficients ($\overline{w}_i = \overline{h}_i^*$). The decision statistics is proportional to $\beta\|\overline{h}_i\|E_s + n(t)$, which always yields a lower SER than a MISO system without CSI. A SIMO structure with CSI at the receiver yields the same performance, because the decision statistics would be $\beta\|\overline{h}_i\|^2 E_s + \|\overline{h}_i\| n(t) = \|\overline{h}_i\|(\beta\|\overline{h}_i\|E_s + n(t))$ (if the channel coefficients were identical). Indeed, the values of SER in the two cases are numerically equal (because the channels share the same statistics). Such a system attains the desired goal, because the average received SNR ($E[\|\overline{h}_i\|^2\Lambda_0] = NE[|h|^2]\Lambda_0$) does provide an array gain of N. ■

Another way to see why this result holds is that (if the channel is non-degenerate) the dimension of the kernel is 0, therefore all the input power is delivered to the output.

In a full MIMO channel, the transmitter antennas offer additional degrees of freedom. A careful examination of the statement of Theorem 2 suggests a suitable way to exploit them. The result in Theorem 2 holds on average, but no guarantees are made on the outage behavior of this broadcast system. Fading is the main source of outage in wireless systems, and a simple yet very effective way to reduce its influence is the introduction of diversity, for example by means of a space time block code (STBC) [10]. Since the introduced diversity can only improve the system performance (regardless of the channel statistics) and the packet is transmitted only once (if the STBC is full-rate), the goal is still attained.

Channel stabilization is desirable so as to achieve a performance in terms of SER which is independent of the channel conditions, and in particular as close as possible to a LOS environment. The STBC allows to achieve a coverage much less dependent on the channel variability. An example of full-rate and full-diversity STBC (developed in more detail in section IV) is the ABBA family [14] modified by constellation rotations [15].

Based on Theorem 2, we then propose to use a STBC with Maximal Ratio Combining to provide for the power gain of N, while retaining the omnidirectionality of transmission typical of space-time codes. In this fashion, our solution covers the same area as the Circular RTS protocol, but only needs one transmission, i.e., it achieves a factor of η delay reduction without any performance penalty.

Although the technique of STBC is not new, the proof that conventional protocols often employ inadequate antenna models is original. Finally, the statements do not depend on the channel statistics, making the proposed system applicable to general environments.

Moreover, the four conditions stated in the introduction are all met: point 2 (a major reduction of the delay) stems from the fact that a single packet transmission is needed; point 3 (no need for feedback) is satisfied because STBC is an open loop technique; the system complies with condition 4 (technique suitable only for omnidirectional communication) because a traditional STBC does not provide directionality, and thus would not be eligible for directional data packets. Point 1 is only partially proved by Theorem 1 (the Circular RTS employs a MIMO system), but this method compares well with it, as our simulations in the next section confirm.

The conclusion is that the gain asymmetry in broadcast scenarios for MANET with smart antennas has to be solved with truly MIMO systems (Th. 1), in contrast with the majority of the current MAC and broadcast protocols which basically regard an idle receiver as a single antenna node.

IV. NUMERICAL RESULTS

The proposed system is compared with the Circular RTS (C-RTS) [1] in terms of BER on a single link. The former employs a full-rate, full-diversity STBC, in conjunction with maximal ratio combining. C-RTS is simulated by a system with perfect CSI at the transmitter and selection diversity. This choice is due to the following two reasons: 1) in [1] the network is set in a LOS scenario, and therefore the transmitter can reasonably be assumed to compute good estimates of the channel coefficients towards every direction by geometrical arguments [11]; 2) the usage of selection diversity follows from [1]. In this case, the optimal BER can be attained if the transmitter beamforms towards the receiver antenna that provides the largest gain (i.e., it selects the column of $\overline{\mathbf{H}}$ with the highest energy). Therefore, broadcast is performed by sequentially sending the packet once towards each receiver with the suitable coefficients. It is also assumed that the time to acquire these coefficients is negligible. Of course, all these points are highly unrealistic for non LOS conditions (no elapsed time to acquire CSI from every neighbor and extremely efficient beamforming). Also, in the ideal antenna model of [1], the array gain is always N, while it actually oscillates between N and $N/2$. Therefore, the model we use here for the performance of the Circular RTS scheme is quite optimistic compared to the performance actually achievable by the protocol in [1]. In addition, we assume in this case that the lobes cover the whole circle corresponding to the maximum gain, whereas in some directions the corresponding gain may be reduced by as much as 3 dB. Therefore, the performance results shown for the Circular RTS scheme are to be seen as optimistic bounds rather than really achievable performance. Finally, selection diversity makes the C-RTS rely on a MIMO (rather than MISO) system, thus bringing the discussion out of the boundaries of theorem 1. It is nonetheless valuable to investigate if the usage of a full-rate, full-diversity STBC can achieve a comparable performance at a lower latency.

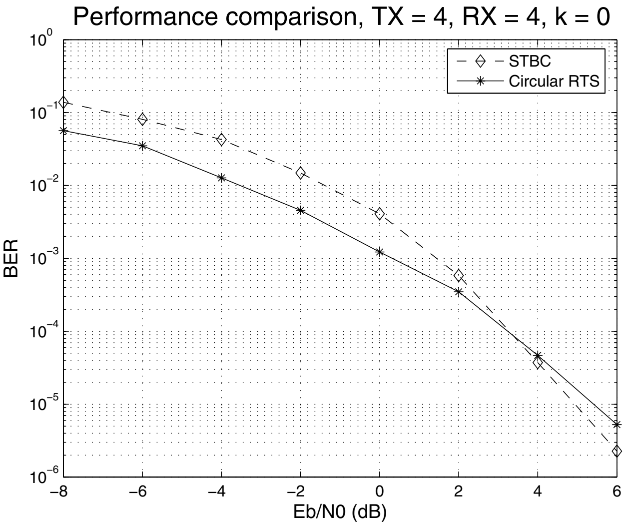

Fig. 2. Performance for nodes with four antennas in a Rayleigh fading environment.

The system has been tested for 4- and 8-antenna nodes. The STBC is the one designed in [14], improved by constellation rotations [15]. The symbols belong to QPSK modulation (as in [14]). The decoder is a twice iterated MMSE-DFE, which entails a limited computational complexity. In addition, even if this code is non-orthogonal, non-linear decoding can bring it very close to the performance of an ideal orthogonal STBC. For four antennas the results are shown in Figs. 2, 3, 4, which report the BER as a function of the Energy-per-bit-to-Noise Ratio (E_b/N_0). The Rice constant κ is 0, 8 and ∞, respectively. In the AWGN case, the small gap between the two schemes is due to the residual non-orthogonality of the ABBA STC. The remarkably low E_b/N_0 is due to the combination of array gain and diversity advantage. In each case the STBC does not provide the same performance as

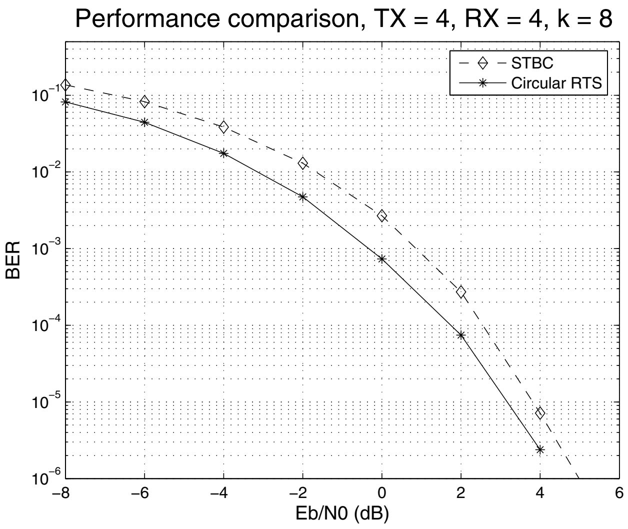

Fig. 3. Performance for nodes with four antennas in a Ricean fading environment, with κ constant equal to 8.

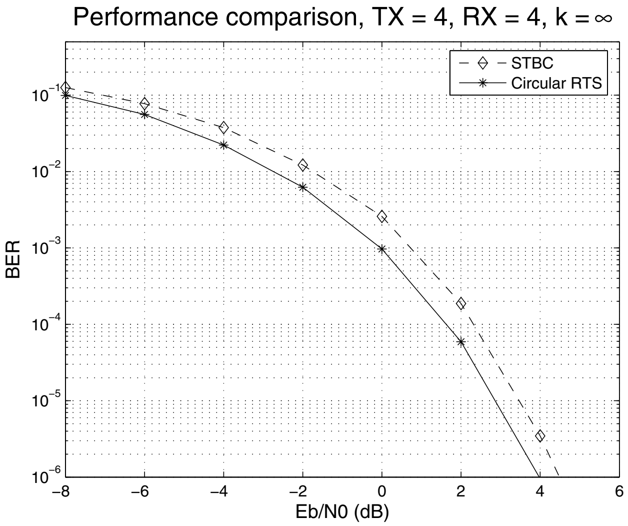

Fig. 4. Performance for nodes with four antennas in an AWGN channel.

the (ideal) Circular RTS. Nonetheless, the gap is small (up to 2 dB). If this loss can be tolerated, the major abatement of overhead can be fully exploited. Otherwise, with a reduced rate STBC, the proposed scheme can be brought to outperform the Circular RTS, although the delay is increased according to the reduced code rate.

For the 8-antenna case, the STBC is an 8×8 ABBA code [14]. The simulation results are reported in Figs. 5, 6 (κ = 0, ∞). As observed before, the STBC is not capable to fully cover the significant gain provided by selection diversity. Nonetheless the gap is only 3-dB wide for the worst case (Rayleigh fading), which can be bridged by doubling the symbol duration or by using a half rate (orthogonal) STBC [10]. The latter approach is preferable because an orthogonal STBC is more resilient to CSI estimation errors [16]. With respect to this half rate STBC for 8 antennas, the BER has been simulated, and Fig. 7 depicts the outcome for κ = 0. Although such a half rate scheme implies making the packet length twice as long, this system is still highly competitive: in comparison the Circular RTS needs a total of 10 transmissions and therefore our scheme still gives a delay which is five times smaller.

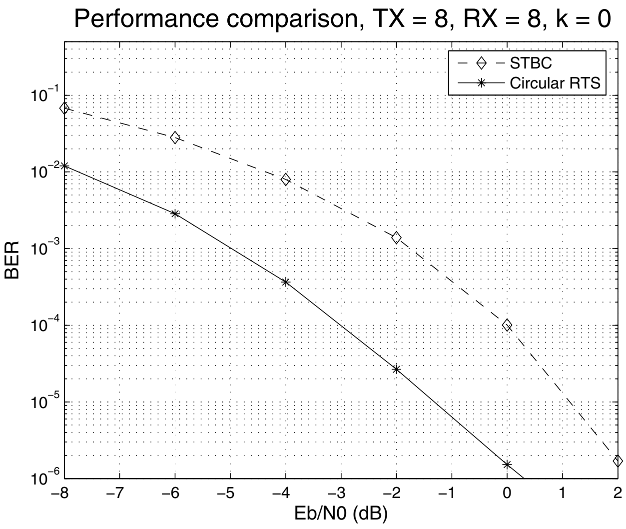

Fig. 5. Performance for nodes with eight antennas in a Rayleigh fading environment. The STBC is full rate

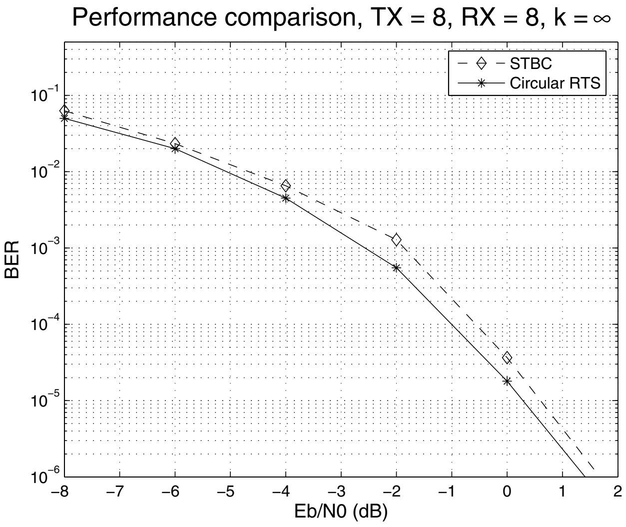

Fig. 6. Performance for nodes with eight antennas in an AWGN channel. The STBC is full rate

For more than 8 antennas, the ABBA scheme can be recursively expanded to encompass any number of antennas.

Therefore, we can conclude that our proposed solution based on the use of Space-Time Codes makes it possible to send a packet omnidirectionally with a power gain of N, minimum delay and no performance degradation when compared with Circular RTS (whose performance can actually be expected to be worse than shown due to the highly idealized assumptions under which these results have been obtained).

Finally, the important reduction of the handshake overhead is expected to make a complete data exchange (RTS/CTS/DATA/ACK) faster, thus improving the final throughput and delay. Our preliminary network simulations, shown in Fig. 8, confirm that this is the case, with a significant

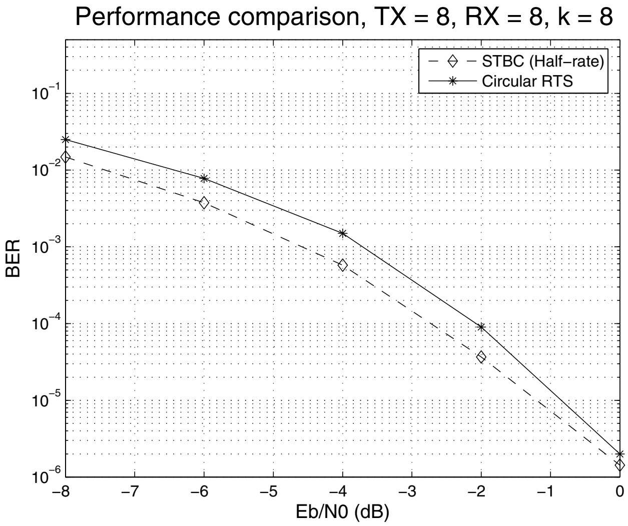

Fig. 7. Performance for nodes with eight antennas in a Ricean fading environment, with κ constant equal to 8. The STBC is half-rate

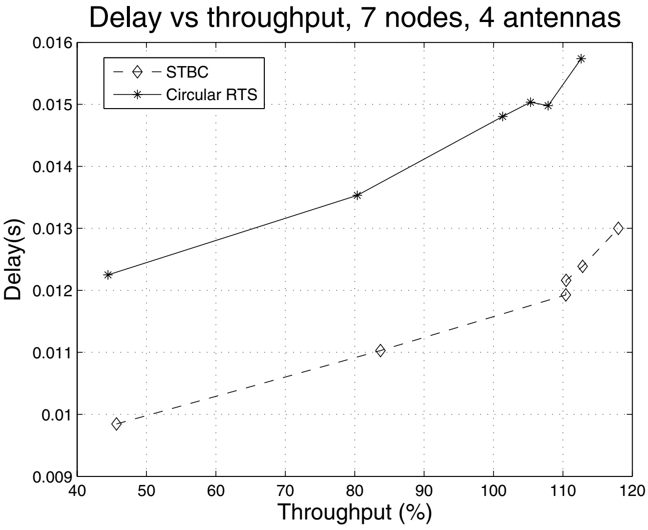

Fig. 8. Delay as a function of throughput for a 7-node network, 4 antennas per node and Rayleigh fading

gain in terms of packet delivery latency for a one-hop network, as well as an increase of the saturation throughput. A more extensive discussion can be found in [17].

V. CONCLUSIONS AND FUTURE WORK

In this paper, we have explored the potential (and limitations) of a MIMO system for the broadcast of control packets in a MANET with smart antennas. It has been proven that in order to overcome the asymmetry in gain, a MISO system (the most widespread model for this case in the literature) is not enough. By mathematical reasoning it is possible to infer that a STBC with N antennas at the transmitter and the receiver can transmit a packet omnidirectionally, with a power gain of N with respect to a SISO system and with little or no additional latency. This scheme has been compared to one of the finest known examples, showing a significant reduction of delay with no loss in performance. Moreover, the system is robust with respect to the channel statistics. While motivated by the need to provide efficient RTS/CTS exchange in an 802.11 MIMO MANET, the proposed technique naturally extends to the broadcast problem in general. Our future research will integrate this proposal in a complete MAC protocol and test it in a network simulation environment to check how the reduced delay translates into network level improvements (for instance throughput and energy saving).

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