Improving Spatial Modulation performance in Distributed Antenna Systems

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***Abstract*— Having multiple-antennas distributed in a large area in Distributed Antennas Systems (DASs) results in performance improvement such as increased coverage and greater spatial diversity. Simulcasting, in which a message is transmitted over the same frequency band by all antennas simultaneously, is one of the main applications used in DAS. Orthogonal Space-Time Block Codes (OSTBCs) have been proposed for these systems. However, the rate decreases dramatically when there are more than two antennas in the system. Spatial Modulation (SM) is another method introduced for multiple-antenna systems to increase spectral efficiency. We analyze the performance of both STBC and SM in simulcasting DAS. Error probability relations are derived and verified for these schemes. We also propose a new STBC-SM code, a mixture of STBC and SM, to improve the performance of SM in DAS.**

Keywords-simulcast, spatial modulation, distributed antenna systems, space-time block codes.

I. INTRODUCTION

Distributed Antenna System (DAS) is a way of covering users in a cellular network in which antennas are distributed in each cell instead of being collocated in the center of the cell. The idea was first introduced for indoor applications [1]. Later, its capabilities in improving the overall performance of the system motivated cellular networks to use it as well [2]. The antennas distributed throughout the cell are connected to a base station using dedicated fibers and can be used in different ways such as blanket transmission and selective transmission. All these methods give spatial diversity along with power efficiency due to the decrease in average distance of users to the nearest available antenna.

In this paper we are going to focus on simulcasting in DASs, which is transmitting a single message on the same carrier frequency from all the antennas simultaneously [3]. If messages are transmitted using identical coding for all antennas, then users who receive comparable power from different antennas are prone to performance loss. This is, in fact, due to the reception of different copies of the same signal with different powers and with time shifts, which is a phenomenon similar to multipath fading. There are two main solutions suggested in the literature to address this issue: Orthogonal Space-Time Block Codes (OSTBC) and cyclic delays [4].

In the first method, which we discuss thoroughly in this paper, an OSTBC is used for transmission of the message from the antennas. The order of OSTBC is the number of antennas in the system. At the receiver, the detection of the messages received from each transmitting antenna are done independently due to the orthogonality of the code's matrix [5]. The problem, however, is the rate of OSTBCs which decreases as the number of antennas increases. To solve this, [3] suggested to divide the antennas into some groups and use OSTBC of the order equal to the number of groups, which is much less than the number of antennas.

Spatial Modulation (SM) is a method introduced more recently and discussed in [6] and [7] to use the resources more efficiently in a MIMO system. SM uses the index of the transmitting antenna, in a multiple antenna system, as an extra source of information and hence increases the spectral efficiency of MIMO systems logarithmically, e.g. the efficiency can be added by an amount of 2b/s/Hz if four antennas are available at the transmitter. In this paper we are going to evaluate the performance of SM compared to OSTBC for simulcasting, and suggest a new code to improve SM for DAS. We first derive theoretical results for different schemes in simulcasting DAS and then introduce a new STBC code mixed with SM which is able to improve the performance of SM noticeably in simulcasting DAS.

The remaining of this paper is organized as follows. In section II, we introduce the system model. Section III is dedicated to the derivation of theoretical relations for error probability in simulcasting DAS. We proposed our new code in section IV. The proposed code is evaluated against other methods for simulcasting DAS in section V. Finally, section VI concludes the paper.

II. SYSTEM MODEL

Consider a single-cell DAS in Down-Link mode as illustrated in Fig. 1[1]. The user is simultaneously receiving

[1] In order to have a clear figure, only one user is depicted

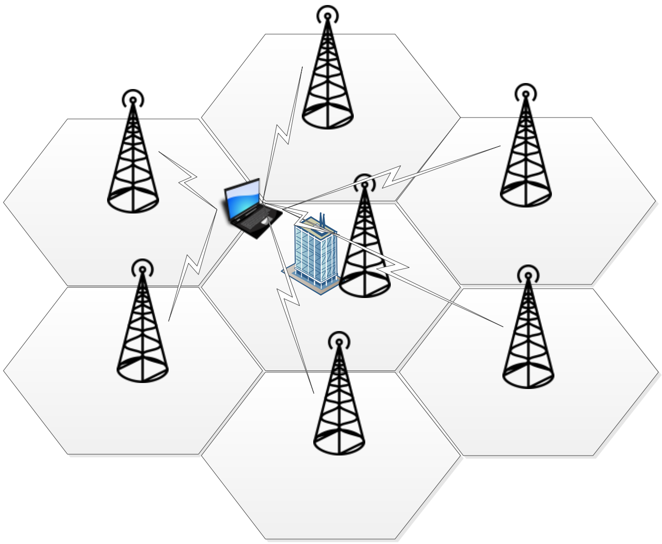

Figure 1. Illustration of a DAS with one cell covering a user using seven distributed antennas

signal from all the antennas located in the cell. We ignore the delay introduced by the transmission lines feeding the antennas as the differences are assumed to be compensated, so all the antennas transmit the same signal at exactly the same time. There will also be another difference in the signals' arrivals to user as their distances are different from the user. This is again ignored but the phase difference due to this time difference is considered. Channel is assumed to be quasi-stationary with a flat fading, so the coefficients could be modeled as a complex constant during each data frame. Putting all the assumptions together, the received discrete-time signal, at any point in the cell, will be

$$r[k]=\sum_{i=1}^{n_t} h_i x_i[k]+n[k], \tag{1}$$

where k is the discrete-time index, h_i is the i-th channel gain, between i-th antenna and the user, and includes both Rayleigh fading and path loss, x_i and n are the transmitted symbol by the i-th antenna, with energy E_s, and the Additive Gaussian Noise respectively.

$$h_i = h_i'\sqrt{P.L.}\ ,\ h_i' \sim CN(0,1). \tag{2}$$

$$\begin{aligned} &n \sim CN(0,2N_0) \\ &E_s = E\left\{\left|x_i[k]\right|^2\right\}, \end{aligned} \tag{3}$$

where h_i' are Rayleigh fading coefficients and assumed to be independent of each other. Path-loss is modeled using the formula $P.L.=\left(\frac{\lambda_w}{4\pi}\right)^2\left(\frac{1}{d}\right)^{\beta}$ from [8]. In this formula λ_w is the wavelength, β is the path loss exponent and d is the distance. Putting this into (2) and adding antennas' gains yields

$$h_i = h_i'\sqrt{G_t G_r\left(\frac{\lambda_w}{4\pi}\right)^2\left(\frac{1}{d_i}\right)^{\beta}}. \tag{4}$$

III. ERROR PROBABILITY

In this section we are going to derive error probability relations for different transmission schemes which include uncoded transmission, OSTBC transmission (ungrouped[1]), OSTBC transmission (grouped) and SM. In all these schemes we assume that symbols are drawn from an M-QAM constellation. Symbol error probability for a square M-QAM modulation in a receiver including n_r diversity branches using MRC will be [8]

$$\begin{aligned} P_E =& \frac{4}{\pi}q\int_0^{\pi/2}\prod_{l=1}^{n_r} I_l\left(\bar{\gamma}_l, g_{QAM}, \theta\right)d\theta \\ &-\frac{4}{\pi}q^2\int_0^{\pi/4}\prod_{l=1}^{n_r} I_l\left(\bar{\gamma}_l, g_{QAM}, \theta\right)d\theta, \end{aligned} \tag{5}$$

where,

$$I_l\left(\bar{\gamma}_l, g_{QAM}, \theta\right)=\int_0^{\infty}\exp\left(-\frac{g_{QAM}\gamma_l}{\sin^2\theta}\right)p_{\gamma_l}(\gamma)d\gamma. \tag{6}$$

$$\begin{aligned} q &= \left(1-\frac{1}{\sqrt{M}}\right) \\ g_{QAM} &= \frac{3}{2(M-1)}. \end{aligned} \tag{7}$$

As seen in (6) we need p_{γ_l} which is SNR probability distribution in the l-th branch of the receiver. Assuming all the receiver branches to have the same SNR distribution (5) is simplified into

$$P_E = \underbrace{\frac{4}{\pi}q\int_0^{\pi/2}\left[I_l\left(\bar{\gamma}_l, g_{QAM}, \theta\right)\right]^{n_r}d\theta}_{I_1} - \overbrace{\frac{4}{\pi}q^2\int_0^{\pi/4}\left[I_l\left(\bar{\gamma}_l, g_{QAM}, \theta\right)\right]^{n_r}d\theta}^{I_2}. \tag{8}$$

Using the notations I_1 and I_2, the error probability is the difference between the two. In the following subsections we will try to give (8) in its simplest form for different schemes.

A. Uncoded Transmission

All the antennas transmit the same symbol, hence in (1) we have $x_i[k]=x[k], \forall 1\le i\le n$ putting this into (1) yields

$$r_{un}[k]=\left(\sum_{i=1}^{n_t} h_i\right)x[k]+n[k]. \tag{9}$$

[1] OSTBC with an order of the number of antennas is used in ungrouped mode

$$SNR_{un}=\left|\sum_{i=1}^{n_t}h_i\right|^2\frac{E_s}{N_0}$$
$$=\left|\sum_{i=1}^{n_t}h_i'\frac{1}{d_i^{\beta/2}}\right|^2\underbrace{\frac{E_s}{N_0}G_tG_r\left(\frac{\lambda_w}{4\pi}\right)^2\frac{1}{n_t}}_{C}, \quad (10)$$

where the part denoted by C is deterministic and the rest is random.

$$h_i'\sim CN(0,1)\rightarrow h_i'\frac{1}{d_i^{\beta/2}}\sim CN(0,\frac{1}{d_i^{\beta}})$$
$$H_1=\sum_{i=1}^{n_t}h_i'\frac{1}{d_i^{\beta/2}}\sim CN(0,\sum_{i=1}^{n_t}\frac{1}{d_i^{\beta}}). \quad (11)$$

$$|H_1|^2=\left|\sum_{i=1}^{n_t}h_i'\frac{1}{d_i^{\beta/2}}\right|^2\sim EXP\left(\frac{1}{\sum_{i=1}^{n_t}\frac{1}{d_i^{\beta}}}\right). \quad (12)$$

$$SNR_{un}=C\,|H_1|^2\sim EXP\left(\frac{1}{C\sum_{i=1}^{n_t}\frac{1}{d_i^{\beta}}}\right). \quad (13)$$

$$f_{SNR_{un}}(\gamma)=\lambda' e^{-\lambda'\gamma}$$
$$\lambda'=\frac{1}{C\sum_{i=1}^{n_t}\frac{1}{d_i^{\beta}}}. \quad (14)$$

$$C=\frac{E_s}{N_0}G_tG_r\left(\frac{\lambda_w}{4\pi}\right)^2\frac{1}{n_t}. \quad (15)$$

Using (14), (6) will become

$$I_l\left(\overline{\gamma}_l,g_{QAM},\theta\right)=\int_0^{\infty}\exp\left(-\frac{g_{QAM}\gamma_l}{\sin^2\theta}\right)p_{\gamma_l}(\gamma)d\gamma$$
$$=\int_0^{\infty}e^{-\frac{g_{QAM}\gamma_l}{\sin^2\theta}}\lambda' e^{-\lambda'\gamma}d\gamma=\lambda'\int_0^{\infty}e^{-\frac{g_{QAM}\gamma_l}{\sin^2\theta}}e^{-\lambda'\gamma}d\gamma \quad (16)$$
$$=\frac{\lambda'}{\alpha+\lambda'},\alpha=\frac{g_{QAM}}{\sin^2\theta}.$$

Using (16), I_1 and I_2 in (8) will become

$$I_1=\frac{4q}{\pi}(\lambda')^{n_r}\int_0^{\pi/2}\left(\frac{1}{\alpha+\lambda'}\right)^{n_r}d\theta$$
$$I_2=\frac{4q^2}{\pi}(\lambda')^{n_r}\int_0^{\pi/4}\left(\frac{1}{\alpha+\lambda'}\right)^{n_r}d\theta \quad (17)$$
$$\lambda'=1\Big/\left(C\sum_{i=1}^{n_t}\frac{1}{d_i^{\beta}}\right),\alpha=\frac{g_{QAM}}{\sin^2\theta}.$$

B. *OSTBC-ungrouped*

To compute the SNR in OSTBC transmission mode, we will use a model introduced in [9], which models MIMO channel as a SISO. According to [9], SNR at the receiver of the equivalent model will be

$$SNR=\frac{\|H\|_F^2}{N_0/a}\frac{E_s}{a.R.n_t}=\frac{\|H\|_F^2\,E_s}{N_0.R.n_t}, \quad (18)$$

where $\|H\|_F$ denotes Frobenius norm of the channel matrix H, R is the code rate, n_t is the number of transmitter antennas and E_s and N_0 are the transmitted symbol energy and noise power spectral density respectively. Doing some calculations like that done in subsection A[1], I_1 and I_2, for one antenna at the receiver, are simplified into

$$I_1=\frac{4q}{\pi}\frac{1}{C_2}\left(\prod_{i=1}^{n_t}\lambda_i\right)\sum_{j=1}^{n_t}\frac{1}{\prod_{\substack{k=1\\k\neq j}}^{n}\left(\lambda_k-\lambda_j\right)}I_3\left(\pi/2;g_{QAM},\frac{\lambda_j}{C_2}\right)$$
$$I_2=\frac{4q^2}{\pi}\frac{1}{C_2}\left(\prod_{i=1}^{n_t}\lambda_i\right)\sum_{j=1}^{n_t}\frac{1}{\prod_{\substack{k=1\\k\neq j}}^{n}\left(\lambda_k-\lambda_j\right)}I_3\left(\pi/4;g_{QAM},\frac{\lambda_j}{C_2}\right), \quad (19)$$

where we have

$$\lambda_j=d_j^{\beta};1\le j\le n_t$$
$$C_2=\frac{1}{n_tR}\frac{E_s}{N_0}G_tG_r\left(\frac{\lambda_w}{4\pi}\right)^2, \quad (20)$$

and also,

$$I_3(x;a,b)=\int\frac{\sin^2(x)}{b\sin^2(x)+a}dx=\frac{x-\frac{\sqrt{a}tg^{-1}\left(\frac{\sqrt{a+b}tg(x)}{\sqrt{a}}\right)}{\sqrt{a+b}}}{b}. \quad (21)$$

For more than one antenna at the receiver the results will be

$$I_1=\frac{4}{\pi}q\prod_{i=1}^{n_t}\int_0^{\pi/2}\left(\frac{\lambda_i}{C_2\frac{g_{QAM}}{\sin^2\theta}+\lambda_i}\right)^{n_r}d\theta$$
$$I_2=\frac{4}{\pi}q^2\prod_{i=1}^{n_t}\int_0^{\pi/4}\left(\frac{\lambda_i}{C_2\frac{g_{QAM}}{\sin^2\theta}+\lambda_i}\right)^{n_r}d\theta. \quad (22)$$

[1] Due to limitations in the number of pages, the calculations are omitted.

As seen in (21), for more than one antenna at the receiver we need to do the integrations numerically, but for one antenna at the receiver, I_3 is given analytically in (20) [10].

C. OSTBC-grouped

One of the issues that OSTBCs face is their rates. They have the rate of one, at their best case which is achieved for two antennas in ALAMOUTI, and is then decreased for higher number of antennas. As mentioned in section I, grouping is a method suggested to use codes of lower orders than the number of antennas. In order to derive error probability for this case, we model it as a special case of subsection *B*. assume that we have *m* groups and each group has n_j antennas for $j=1,2,\ldots,m$. All the antennas in a group transmit the same STBC symbol, so we can model each group as a new single antenna and have an OSTBC code of order *m*. In each group, we use the model of subsection *A*, which gives us an equivalent channel coefficient for each group that is $h_{j,eq}=\frac{1}{\sqrt{n_j}}\sum_{k=1}^{n_j}h_{jk}$, where n_j is the number of antennas in group j and $\frac{1}{\sqrt{n_j}}$ is used to normalize transmission power. Fig. 2 illustrates this modelling well. Error probability for OSTBC with antenna grouping can then be found using (19), replacing n_t with m and h_j with $h_{j,eq}$.

D. SM

In this part, we will find a relation for the error probability of Spatial Modulation in the Simulcast scheme. In SM, in addition to the information symbols used in any other method for transmitting information, the index of the antenna in transmission is used to transmit information also. To make it clearer, suppose that we have at transmitter, a BPSK modulation with four antennas. If at any time only one of the antennas are used to transmit the BPSK symbols and we can say, with high confidence, in the receiver which antenna was used, we are able to increase the amount of information conveyed from one bit to three bits, two from the antennas' indices and one from the binary constellation. This is how SM works. In general we are able to convey $\tilde{m}$ bits of information

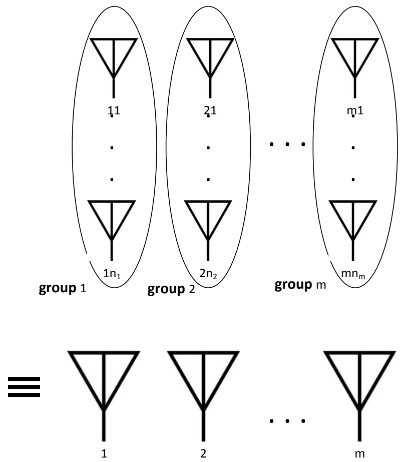

Figure 2. Each group in OSTBC-grouped can be modelled with a single antenna

which equals to $\tilde{m}=\log_2 n_t+m;\ m=\log_2 M$, where M is the constellation size. In order to detect a symbol correctly, we should both detect the information symbol and the index of the antenna which sent the signal. If we first detect the index and then the information symbol, provided that we detected the index correctly, the probability of error will be[1] $P_e=1-(1-P_a)(1-P_d)$, where P_a and P_d are the probability of error in antenna index detection and information symbol detection respectively. P_a is calculated in [6] and here we will calculate P_d. Suppose that the i-th antenna transmitted the signal. The SNR at the receiver will be

$$
\begin{aligned}
&SNR_{SM}\mid i=|h_i'|^2\left(\frac{1}{d_i}\right)^{\beta}\underbrace{G_tG_r\left(\frac{\lambda_w}{4\pi}\right)^2\frac{E_s}{N_0}}_{C_0}\\
&h_i'\sim CN(0,1)\rightarrow |h_i'|^2\sim EXP(1)\\
&\rightarrow SNR_{SM}\mid i\sim EXP(\lambda_i),\ \lambda_i=\frac{d_i^{\beta}}{C_0},1\le i\le n_t\\
&f_{SNR_{SM}|i}(\gamma)=\lambda_i e^{-\lambda_i\gamma},
\end{aligned}
\tag{23}
$$

where $SNR_{SM}\mid i$ denotes *SNR* provided the i-th antenna transmitted the signal. Assuming the input bit streams to SM transmitter are equally probable, the antennas are also selected with equal probability. Hence, we have

$$
f_{SNR_{SM}}(\gamma)=E_i\left(f_{SNR_{SM}|i}(\gamma)\right)=\frac{1}{n_t}\sum_{i=1}^{n_t}\lambda_i e^{-\lambda_i\gamma}. \tag{24}
$$

Putting (23) in (6) yields:

$$
\begin{aligned}
&I_l\left(\bar{\gamma}_l,g_{QAM},\theta\right)=\int_0^{\infty}e^{-\frac{g_{QAM}\gamma_l}{\sin^2\theta}}\left(\frac{1}{n_t}\sum_{i=1}^{n_t}\lambda_i e^{-\lambda_i\gamma_l}\right)d\gamma_l\\
&=\frac{1}{n_t}\sum_{i=1}^{n_t}\lambda_i\int_0^{\infty}\underbrace{e^{-\frac{g_{QAM}\gamma_l}{\sin^2\theta}}e^{-\lambda_i\gamma_l}}_{e^{-(\alpha+\lambda_i)\gamma_l}}d\gamma_l=\frac{1}{n_t}\sum_{i=1}^{n_t}\lambda_i\frac{1}{\alpha+\lambda_i},\alpha=\frac{g_{QAM}}{\sin^2\theta}.
\end{aligned}
\tag{25}
$$

So I_1 and I_2 will be:

$$
\begin{aligned}
I_1&=\frac{4q}{\pi}\frac{1}{n_t^{\,n_r}}\int_0^{\pi/2}\left(\sum_{i=1}^{n_t}\lambda_i\frac{1}{\alpha+\lambda_i}\right)^{n_r}d\theta\\
I_2&=\frac{4q^2}{\pi}\frac{1}{n_t^{\,n_r}}\int_0^{\pi/4}\left(\sum_{i=1}^{n_t}\lambda_i\frac{1}{\alpha+\lambda_i}\right)^{n_r}d\theta.
\end{aligned}
\tag{26}
$$

For $n_r=1$ the above integrals can be further simplified using I_3 introduced in (20).

IV. PROPOSED CODE

There are some issues with both OSTBC and SM in DAS, as will be seen in simulations also, the former has low bandwidth efficiency and the later has the lack of transmission

[1] This is the suboptimal detection of SM. It is used here to let us achieve a theoretical relation. It can be considered as an upper bound for an optimal detector [11], [12].

diversity. In this part we are going to propose an STBC-SM which is well-suited for DAS combining the advantages of both STBC and SM. STBC-SM is first introduced in [13] with the aim of achieving both transmission diversity and using antennas' indices to convey information. Suppose that we build an STBC-SM code based on ALAMOUTI with the following code words using four transmission antennas.

$$\aleph_1 = \{X_{11}, X_{12}\} = \left\{ \begin{pmatrix} x_1 & x_2 & 0 & 0 \\ -x_2^* & x_1^* & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 0 & x_1 & x_2 \\ 0 & 0 & -x_2^* & x_1^* \end{pmatrix} \right\}$$
$$\aleph_2 = \{X_{21}, X_{22}\} = \left\{ \begin{pmatrix} 0 & x_1 & x_2 & 0 \\ 0 & -x_2^* & x_1^* & 0 \end{pmatrix}, \begin{pmatrix} x_2 & 0 & 0 & x_1 \\ x_1^* & 0 & 0 & -x_2^* \end{pmatrix} \right\} e^{j\theta}. \quad (27)$$

This code will achieve a transmission diversity of order two, provided theta is chosen appropriately, but there is a problem in using it for DAS. The problem lies in the fact that antennas are distributed in DAS, so if two of the antennas are selected to which a user is far, that user experiences a poor SNR while a user in proximity of the two antennas will enjoy having a relatively high SNR. The problem is intrinsic in SM, so in order to solve it we should let any user receive from all of the antennas available and at the same time achieve order two diversity. We introduce the following code

$$X_1 = \begin{pmatrix} x_1 & 0 \\ 0 & x_1 \end{pmatrix}; X_2 = \begin{pmatrix} 0 & x_2 \\ x_2 & 0 \end{pmatrix} e^{j\theta}. \quad (28)$$

It is based on a repetition code so any user will receive signal from both antennas, or groups of antennas, at the end of the two symbol times. Theta should be set to satisfy the following criterion [1]

$$\delta_{\min} = \min_{x_1, x_2; x_1 \neq x_2} \det(X_1 - X_2)(X_1 - X_2)^H. \quad (29)$$

The optimum value of theta for BPSK and M-QAMs is given in table I.

In order to use this code for more than two antennas, we utilize the concept of grouping, previously discussed in section III-C. The proposed code adds one bit of extra information in two symbol times. In the next section we will evaluate the ability of this code to improve STBC-SM performance to be adapted to DAS.

V. Simulation Results

In this section we are going to evaluate the performance of the proposed code against that of other codes and also verify theoretical error probabilities obtained in section III. For our scenario, we assume a linear structure having 4 antennas separated by a distance that is 10 times that of their heights. Total transmission power is set to -25dBm and modulation sizes are chosen so as to achieve a spectral efficiency of 4bits/second/Hz in all transmission schemes. Antennas' placement is given in Fig. 3. Error probability in different parts of the line is plotted in Fig. 4. First observe that two of the schemes, uncoded and grouped OSTBC, perfectly match their theoretical relations and the two other schemes are very close

TABLE I. Optimum Rotation Angles for BPSK and M-QAM for the Proposed Code

modulation	BPSK	4QAM	8QAM	16QAM	32QAM	64QAM	128QAM
optimum rotation angle	1.57	0.77	0.8	0.8	0.8	0.54	0.54

to theory. Alamouti is illustrated only as a comparison since it uses two antennas while we have four antennas in our scenario. In grouped OSTBC there are two groups each including two antennas, first group includes first and third and second group include second and fourth antennas. But on the performance, we see that SM performs very poor but other schemes do much better and grouped OSTBC performs the best. Uncoded scheme is very similar to grouped OSTBC in the proximity of the antennas due to domination of that antenna's transmitted power to other antennas. SM performs very poor due to the possibility of selecting the antenna that is the farthest to the user and so the average probability of error is not satisfying.

As discussed in section IV, we proposed a repetition code which is able to achieve order two transmission diversity and at the same time utilizes the concept of SM. Fig. 5 and Fig. 6 show the performance of the proposed code- SM repetition and SM repetition grouped- against other schemes for two and four b/s/Hz spectral efficiency respectively. Antennas structure are the same as shown in Fig. 3. It is seen that the performance of STBC-SM has been improved much and very close to that of OSTBC and in some locations even better. The performance of the proposed code is much better in lower spectral efficiency. The reason can be found in the higher modulation order used for this code. The proposed code is based on repetition, so it needs twice the order of modulation used for other codes minus one-which is achieved through its SM nature- and that degrades the performance of the code.

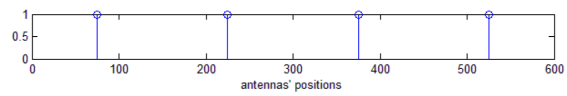

Figure 3. Antennas' placement in a linear structure

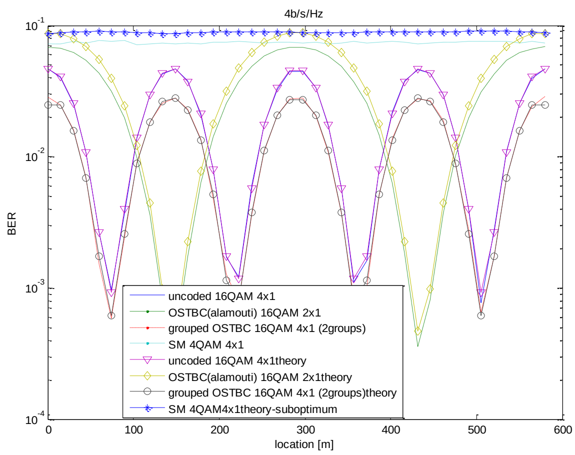

Figure 4. Error probability along the line with four antennas for different transmission schemes

[1] Known as "determinant criterion" in STBCs [14].

VI. CONCLUSION

In this paper we discussed simulcasting transmission in DASs. First, we derived some theoretical results for different schemes including uncoded transmission, STBC transmission, STBC with grouping antennas and SM transmission. Then we focused on SM as a new transmission method in DAS and tried to find its deficiencies and improve its performance. We proposed an STBC-SM scheme which uses multiple antennas in the transmitter to achieve transmission diversity and at the same time uses antennas' indices to convey information. This code significantly improved the performance of STBC-SM against other transmission schemes. We simulated and compared the performance of all the schemes discussed in the paper and verified the theoretical results at the end.

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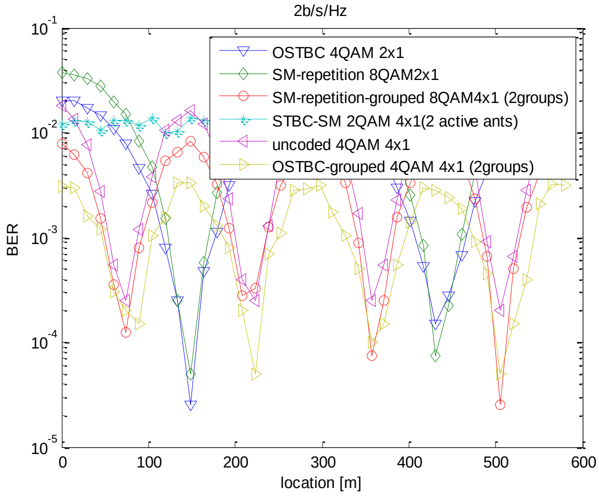

Figure 5. Error probability along the line for different transmission schemes against the proposed code (SM-repetition and SM-repetition-grouped) (spectral efficiency=2b/s/Hz)

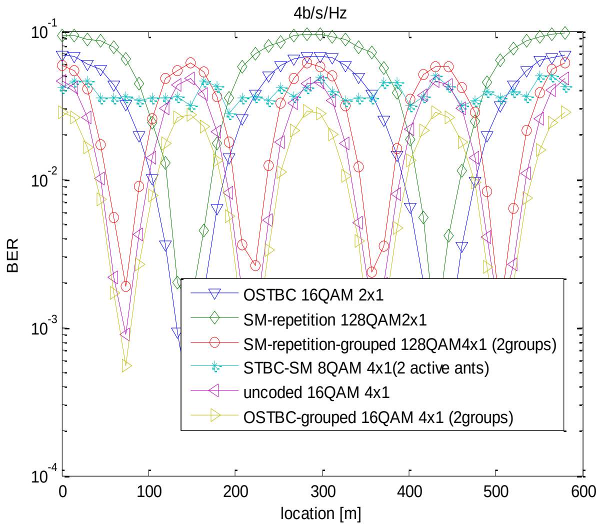

Figure 6. Error probability along the line for different transmission schemes against the proposed code (SM-repetition and SM-repetition-grouped) (spectral efficiency=4b/s/Hz)