End-to-End Antenna Selection Strategies for Multi-Hop Relay Channels

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Abstract— **Multi-hop relay channels use multiple relay stages, each with multiple relay nodes, to facilitate communication between a source and destination. Assuming a low-rate feedback link from the destination to each relay stage and the source, this paper proposes end-to-end antenna selection strategies to achieve maximum diversity gain in a multi-hop relay channel. For the full-duplex case, end-to-end antenna selection strategies are designed and proven to achieve maximum diversity gain by using a single antenna path (using single antenna of the source, each relay stage and the destination) with the maximum signal-to-noise ratio at the destination. For the half-duplex case, two paths with the two best signal-to-noise ratios in alternate time slots are used to overcome the rate loss with half-duplex nodes, with a small diversity gain penalty. To increase the multiplexing gain, a multiple stream end-to-end antenna selection strategy for full-duplex multi-hop relay channel is also proposed, where multiple data streams are transmitted simultaneously using multiple paths from the source to the destination.**

I. Introduction

Finding transmission strategies for wireless ad-hoc networks that perform well in terms of capacity, reliability, or delay is an ongoing challenge. A building block of wireless ad-hoc networks is the multihop relay channel, where communication between a single source and destination pair is considered, and the source uses multiple relay nodes to communicate with the destination. An important first step in finding good transmission strategies for wireless ad-hoc networks is to find near-optimal transmission strategies for the multihop relay channel.

Towards that end, there has been growing interest in designing maximum diversity gain achieving coding strategies for multi-hop relay channels [1]–[6], where a source uses $N-1$ relay stages to communicate with its destination and each relay stage is assumed to have one or more relay nodes. One class of coding strategies proposed to achieve the maximum diversity gain in a multi-hop relay channels are distributed space-time block codes (DSTBCs) [1]–[8]. In DSTBCs, coding is done in space, across antennas, and time by each relay node in a distributed manner.

Alternative coding strategies to DSTBCs, use antenna selection (AS) or relay selection (RS) to achieve the maximum diversity gain for a two-hop relay channel [1], [2], [9]–[12]. Relay selection strategies either choose a single relay node that has the maximum SNR at the destination [1], [2], [9], [10], [12], or the one that maximizes the mutual information at the destination [11] .The primary advantages of AS and RS strategies over DSTBCs are that they require a minimal number of active antennas and reduce the encoding and decoding complexity, however, they are only known for a two-hop relay channel. In this paper we propose an end-to-end antenna selection (EEAS) strategy for a multi-hop relay channel that is shown to achieve the maximum diversity gain. We also answer the question whether to code in space and time (use DSTBCs) or not in a multi-hop relay channel by comparing our proposed EEAS strategy with DSTBCs with respect to several important performance metrics.

For the full-duplex multi-hop relay channel we propose an EEAS strategy, that chooses a single antenna path over all other single antenna paths, that maximizes the SNR at the destination. We prove that this EEAS strategy achieves the maximum diversity gain in a full-duplex multi-hop relay channel by showing that in a multi-hop relay channel, the maximum number of single antenna paths that do not share any common edges is equal to the upper bound on the diversity gain of a multi-hop relay channel [5]. Therefore, by selecting the single antenna path that has the maximum SNR at the destination, maximum diversity gain can be achieved.

For the half-duplex multi-hop relay channel, we propose an EEAS strategy that alternatively uses two single antenna paths that have the two best SNRs at the destination, e.g. the single antenna path with the maximum SNR is used in odd time slots and the single antenna path with the next best SNR in the even time slots. We prove that by paying a small price in terms of diversity gain (in comparison to full-duplex case), this strategy can achieve full-duplex rates with half-duplex nodes.

Due to single data stream transmission in the full-duplex case, the multiplexing gain of the proposed EEAS strategies is limited to 1. To achieve higher multiplexing gains, we propose a multiple stream EEAS strategy, where to obtain a multiplexing gain r, $r+1$ single antenna paths are used simultaneously. The DM-tradeoff of the multiple stream EEAS is shown to achieve both the maximum diversity gain point and maximum multiplexing gain point of the optimal DM-tradeoff.

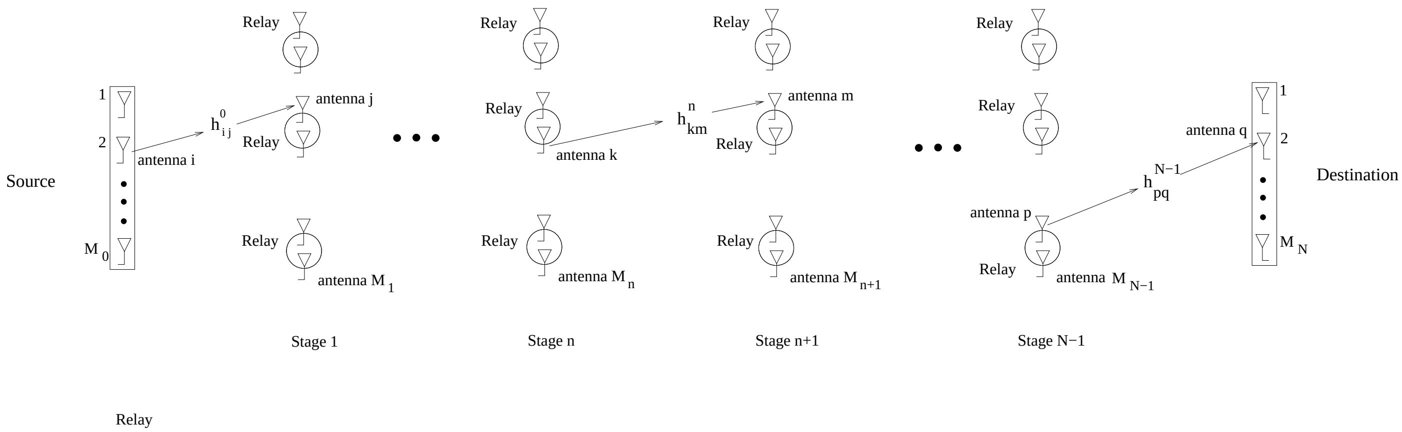

Fig. 1. System Block Diagram for Multi-Hop Relay Channel

II. System Model

We consider a multi-hop relay channel where a source terminal with M_0 antennas wants to communicate with a destination terminal with M_N antennas via $N-1$ stages of relays as shown in Fig. 1. The total number of antennas in the n^{th} relay stage is M_n. We assume that the relays do not generate their own data and each antenna of any relay node has an average power constraint of P. We assume that the CSI is only known at the destination and none of the relays have any CSI. We assume that there is no direct path between the source and the destination. This is a reasonable assumption for the case when relay stages are used for coverage improvement and the signal strength on the direct path is very weak. We also assume that there is no direct path between relay stage n and $n+2$. We consider both the full-duplex and half-duplex multi-hop relay channel.

As shown in Fig. 1, the channel coefficient between the i^{th} antenna of stage n and j^{th} antenna of stage $n+1$ is denoted by $h_{ij}^n,\ i=1,2,\ldots,M_n,\ j=1,2,\ldots,M_{n+1}\ n=0,1,\ldots,N-1$. The channel coefficient between the k^{th} antenna of stage n and the l^{th} antenna of stage n is denoted by $g_{kl}^n,\ k,l=1,2,\ldots,M_n, k\neq l,\ n=0,1,\ldots,N-1$. Stage 0 represents the source and stage N the destination.

For the full-duplex case we assume that only the destination knows $h_{ij}^n,\ \forall\ i,j,n$, while for the half-duplex case the destination is assumed to know both the $h_{ij}^n, g_{kl}^n\ \forall\ i,j,k,l,k\neq l$. For all the EEAS strategies discussed in this paper, we assume that the destination computes the end-to-end single antenna path for transmission depending on the relevant metric, and the index of the chosen path is fed back to the source and each relay stage using a low bit-rate feedback link from the destination. We assume that $h_{ij}^n, g_{kl}^n \in \mathbb{C}$ are independent and identically distributed (i.i.d.) $\mathcal{CN}(0,1)$ entries for all i,j,n to keep the analysis simple and tractable. We assume that all these channels are frequency flat, block fading channels, where the channel coefficients remain constant in a block of time duration $T_c \geq N$ and change independently from block to block.

A. Problem Formulation

The problem we consider in this paper is the design of EEAS strategies to achieve the DM-tradeoff of the multi-hop relay channel. Our main focus, however, will be on designing EEAS strategies to achieve the maximum diversity gain in a multi-hop relay channel with low decoding complexity. Achieving maximum diversity gain with low complexity is of importance due to practical considerations.

Recall that the DM-tradeoff [13] of a point-to-point MIMO channel with N_t transmit and N_r receive antennas is given by $d(r)=(N_t-r)(N_r-r)$. Next, we present an upper bound on the DM-tradeoff of the multi-hop relay channel obtained in [5].

Lemma 1: [5] The DM-tradeoff curve $(r, d(r))$ is upper bounded by the piecewise linear function connecting the points $(r^n, d^n(r)),\ r=0,1,\ldots,\min\{M_n, M_{n+1}\}$ where $d^n(r)=(M_n-r)(M_{n+1}-r)$, for each $n=0,1,2,\ldots,N-1$.

In the next three sections we propose EEAS strategies for the full-duplex and the half-duplex multi-hop relay channel. We compute their DM-tradeoffs and compare them with the DM-tradeoff upper bound (Lemma 1).

III. Full-Duplex Multi-Hop Relay Channel

Before introducing our EEAS strategy and analyzing its diversity gain, we need the following definitions and Lemma 4.

Definition 2: Let e_{ij}^n be the edge joining antenna i of stage n to antenna j of stage $n+1$ then a path in a multi-hop relay channel is defined as the sequence of edges $\left(e_{i_0i_1}^0, e_{i_1i_2}^1, \ldots, e_{i_{N-1}i_N}^{N-1}\right)\ i_n \in \{0,1,\ldots,M_n\},\ n\in\{0,1,\ldots,N\}$.

Definition 3: Two paths in a multi-hop relay channel are called independent if they share no common edge.

In the next lemma we compute the maximum number of independent paths in a multi-hop relay channel.

Lemma 4: The maximum number of independent paths in a multi-hop relay channel is $\alpha := \min\{M_nM_{n+1}\},\ n=0,1,\ldots,N-1$.

Proof: For lack of space we refer the reader to [14] for the proof. ∎

Now we are ready to describe our EEAS strategy for the full-duplex multi-hop relay channel. To transmit the signal from the source to the destination, a single path in a multi-hop relay channel is used for communication. How to choose that path is described in the following. Let the chosen path for the transmission be $\left(e^0_{i^*_0 i^*_1}, e^1_{i^*_1 i^*_2}, \ldots, e^{N-1}_{i^*_{N-1} i^*_N}\right)$, where the signal is transmitted from i_0^{*th} antenna of the source and is relayed through i_n^{*th} antenna of relay stage $n,\ n = 1, 2, \ldots N-1$ and decoded by the i_N^{*th} antenna of the destination. Each antenna on the chosen path uses an AF strategy to forward the signal to the next relay stage, i.e. each antenna on the chosen single antenna path transmits a scaled version of the received signal subject to its average power constraint P.

With this EEAS strategy the received signal at the i_N^{*th} antenna of the destination of a multi-hop relay channel is

$$\begin{aligned} r_{i^*_N} &= \prod_{n=0}^{N-1} \sqrt{\mu_n}\sqrt{P} h^n_{i^*_n i^*_{n+1}} x_t + \sum_{j=1}^{t-1} \sqrt{\gamma_j P} f_j x_{t-j} \\ &\quad \underbrace{+ \sum_{m=1}^{N-1} \prod_{k=m}^{N-1} \sqrt{\mu_k} q_k v_{i^*_k} + v_{i^*_N}}_{z_{t+N}} \end{aligned} \tag{1}$$

where f_j and q_k are functions of channel coefficients $h^n_{i^*_n i^*_{n+1}}$, γ_j is a function of μ_n's, $v_{i^*_n}, n = 1, 2, \ldots, N$ is the complex Gaussian noise with zero mean and unit variance added at stage n and $\mu_0 = 1$.

We propose to use successive decoding at the destination with the EEAS strategy. With successive decoding the destinations tries to decode only x_t at time $t+N,\ t = 1, 2, \ldots, T$ assuming that all the symbols $x_1, x_2, \ldots, x_{t-1}$ have been decoded correctly. Assuming that at time $t+N$ all the symbols $x_1, x_2, \ldots, x_{t-1}$ have been decoded correctly, the received signal can be written as

$$r^{eq}_{i^*_N t+N} = \sqrt{w^*} \prod_{n=0}^{N-1} \sqrt{\mu_n}\sqrt{P} h^n_{i^*_n i^*_{n+1}} x_t + z_{t+N}, \tag{2}$$

since the channel coefficients $h^n_{i^*_n i^*_{n+1}}$ are known at the destination. Let the probability of error in decoding x_t from (2) be P_t, then the probability of error P_e in decoding $x_1, x_2, \ldots, x_T$ from (1) with successive decoding P_e is $P_e \le 1 - \prod_{t=1}^T (1 - P_t) \,\dot{\le}\, P_t$ for any $t,\ t = 1, \ldots, T$.

Without loss of generality we compute an upper bound on P_1 to upper bound P_e. We first describe our EEAS strategy and then compute an upper bound on P_1 using that EEAS strategy. The EEAS strategy we propose chooses the path that maximizes the SNR at the destination. Recall that the channel coefficient on the edge $e^n_{i^*_q i^*_r}$ is $h^n_{i^*_q i^*_r},\ q = 1, 2, \ldots, M_n,\ r = 1, 2, \ldots, M_{n+1},\ n = 0, 1, \ldots, N-1$. Then, the EEAS strategy chooses path $(e^0_{i^*_0 i^*_1}, e^1_{i^*_1 i^*_2}, \ldots, e^{N-1}_{i^*_{N-1} i^*_N})$, if

$$P w^* \prod_{n=0}^{N-1} \mu_n |h^n_{i^*_n i^*_{n+1}}|^2 = \max_{i_n \in 0,1,\ldots,M_n,} P w \prod_{n=0}^{N-1} \mu_n |h^n_{i_n i_{n+1}}|^2.$$

Since we assumed that the destination of the multi-hop relay channel has CSI for all the channels in the receive mode, this optimization can be done at the destination and using a feedback link, the source and each relay stage can be informed about the index of antennas to use for transmission. Next, we evaluate the exponent of the outage probability of (2).

Theorem 5: The proposed EEAS strategy achieves the maximum diversity gain in a full-duplex multi-hop relay channel equal to $\alpha = \min_{n=0,1,\ldots,N-1}\{M_n M_{n+1}\}$.

Proof: From [13] we know that $P_1 \doteq P_{out}(r \log \mathsf{SNR})$, where $P_{out}(r \log \mathsf{SNR})$ is the outage probability of (2). Therefore it is sufficient to compute an upper bound on the outage probability of (2) to upper bound P_1. Let $\mathsf{SNR} := P \prod_{n=0}^{N-1} \mu_n$. With the proposed EEAS strategy, the outage probability of (2) can be written as

$$P_{out}(r \log \mathsf{SNR}) \doteq P\left(\max_{i_n \in 0,1,\ldots,M_n} w |h^n_{i_n i_{n+1}}|^2 \le \mathsf{SNR}^{-(1-r)}\right).$$

It can be shown that $w \doteq \mathsf{SNR}^0$, and $f(x) \doteq x^a$ if $\lim_{x\to\infty} \frac{\log(f(x))}{\log x} = a$.

Thus,

$$P_{out}(r \log \mathsf{SNR}) \;\; \le \;\; P\left(\max_{\mathbb{P}_N} \prod_{n=0}^{N-1} |h^n_{i_n i_{n+1}}|^2 \le \mathsf{SNR}^{-(1-r)}\right),$$

where $\mathbb{P}_N$ is the set containing maximum number of independent paths in a multi-hop relay channel. From Lemma 4, $|\mathbb{P}_N|$ is α and by definition of independent paths, channel coefficients on independent paths are independent. Thus,

$$P_{out}(r \log \mathsf{SNR}) \;\; = \;\; \prod_{j=1}^{\alpha} P\left(\prod_{n=0}^{N-1} |h^n_{i_n i_{n+1}}|^2 \le \mathsf{SNR}^{-(1-r)}\right).$$

From [5] $P\left(\prod_{n=0}^{N-1} |h^n_{i_n i_{n+1}}|^2 \le \mathsf{SNR}^{-(1-r)}\right) \doteq \mathsf{SNR}^{(1-r)},\ r \le 1$. Thus

$$P_{out}(r \log \mathsf{SNR}) \,\dot{\le}\, \mathsf{SNR}^{-\alpha(1-r)},\ r \le 1$$

and $d_{out}(r) = \alpha(1-r), r \le 1$. Hence for the EEAS strategy $P_e \,\dot{\le}\, P_1 \doteq \mathsf{SNR}^{-\alpha(1-r)}$ and the maximum diversity gain of EEAS strategy (obtained at $r = 0$) in a multi-hop relay channel is $\alpha = \min_{n=0,1,\ldots,N-1}\{M_n M_{n+1}\}$ which equals the upper bound on the diversity gain from Lemma 1. Hence we conclude that the proposed EEAS strategy achieves the maximum diversity gain in a multi-hop relay channel. ■

IV. Half-Duplex Multi-Hop Relay Channel

It is easy to see that by using the EEAS strategy proposed for the full-duplex case in a half-duplex multi-hop relay channel, the DM-Tradeoff curve is given by $d(r) = \alpha(1-2r)$, since half the time the source and the destination are silent. Thus, there is a spectral efficiency loss by a factor of $1/2$ by using the EEAS strategy proposed for the full-duplex case in a half-duplex multi-hop relay channel.

To improve the rate of transmission with half-duplex nodes, we propose an EEAS strategy that uses two paths that have the two best SNRs at the destination, in alternate time slots, e.g. the path with the maximum SNR is used in odd time slots and the path with the next best SNR in the even time slots. The two paths p_1 and p_2 for the half-duplex multi-hop relay channel are selected as follows. The path $p_1 = \left(e^{0}_{i_0^* i_1^*}, e^{1}_{i_1^* i_2^*}, \ldots, e^{N-1}_{i_{N-1}^* i_N^*}\right)$ is the first chosen path, if

$$Pw_i^* \prod_{n=0}^{N-1} \mu_n |h^n_{i_n^* i_{n+1}^*}|^2 = \max_{i_n \in 0,1,\ldots,M_n,} Pw_i \prod_{n=0}^{N-1} \mu_n |h^n_{i_n i_{n+1}}|^2$$

and the path $p_2 = \left(e^{0}_{j_0^* j_1^*}, e^{1}_{j_1^* j_2^*}, \ldots, e^{N-1}_{j_{N-1}^* j_N^*}\right)$ is the second chosen path if

$$Pw_j^* \prod_{n=0}^{N-1} \mu_n |h^n_{j_n^* j_{n+1}^*}|^2 = \max_{, \, j_n \in 0,1,\ldots,M_n,} Pw_j \prod_{n=0}^{N-1} \mu_n |h^n_{j_n j_{n+1}}|^2,$$

where $j_n \neq i_n^*$ Thus, p_1 has the best SNR among all paths in a multi-hop relay channel and p_2 has the best SNR among all paths excluding path p_1.

From Lemma 4, the number of independent paths in a multi-hop relay channel is α. Moreover, the number of independent paths from the source to the destination that does not include any antenna that lies on p_1 can be calculated by removing one antenna from each stage and applying Lemma 4 for a multi-hop relay channel with $M_n - 1$ antennas at each stage. Thus, the maximum number of independent paths in a multi-hop network that does not include any antenna that lies on p_1 is $\beta := \min\{(M_n - 1)(M_{n+1} - 1)\}, \ n = 0, 1, \ldots, N-1$. Then, clearly, path p_1 has better SNR than $\alpha - 1$ independent paths and path p_2 has better SNR than $\beta - 1$ independent paths.

Following a DM-tradeoff analysis similar to Section III, it can be shown that with successive decoding at the destination, the DM-tradeoff of the first path is $d(r) = \alpha(1-2r)$ and the he DM-tradeoff of the second path is $d(r) = \beta(1-2r)$. Thus, the resulting DM-tradeoff of this antenna selection strategy is $d(r) = \beta(1-r)$, since $\beta < \alpha$ and dominates the probability of error, and r is in place of $2r$ since the destination receives data in both the odd and the even time slots.

Therefore, the proposed EEAS strategy for the half-duplex multi-hop relay channel does not achieve the maximum diversity gain (Lemma 1), since $\beta < \alpha$, however, it removes the spectral efficiency loss due to the half-duplex assumption on the relay nodes. Thus, with a minimal penalty $\alpha - \beta$ in the diversity gain, the proposed EEAS strategy improves the spectral efficiency by a factor of 2.

V. Multiple Stream EEAS Strategy for Full-Duplex Multi-Hop Relay Channel

Recall that the DM-tradeoff of the EEAS strategy of Section III is $d(r) = \alpha(1-r)$. Therefore, the maximum multiplexing gain possible with the EEAS strategy is 1. To increase the multiplexing gain we propose the following modified EEAS strategy. To operate at multiplexing gain $r = r_0$, r_0+1 paths of the multi-hop relay channel are used simultaneously with AF at each intermediate antenna. Paths $p_1, \ldots, p_{r_0+1}$ are chosen in the decreasing order of SNR at the destination and on each path an independent data stream is transmitted. Thus, for $r = r_0$, paths $p_1, p_2, \ldots, p_{r_0+1}$ are used simultaneously, where path $p_l, \ l = 1, 2 \ldots, r_0+1$ is the single antenna path with the best SNR at the destination among all other paths excluding paths $p_1, p_2, \ldots, p_{l-1}$, and SNR is defined as the product of the norm of the channel coefficients of that path, similar to the last two sections. Similar to Section IV the destination employs successive decoding in time i.e. jointly decodes all the new $r_0 + 1$ symbols arriving at any time instant assuming that all the old symbols have been decoded correctly.

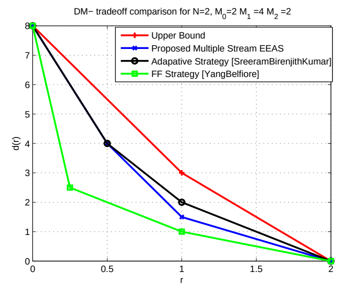

Fig. 2. DM-tradeoff comparison of DSTBCs and multiple stream EEAS for $N = 2, \ M_0 = 2, \ M_1 = 4, \ M_2 = 2$

Following the DM-tradeoff analysis of Section III, the DM-tradeoff of the modified EEAS strategy can be obtained as

$$d(r) = \min_{n=0,1,\ldots,N-1} (M_n - r_0)(M_{n+1} - r_0)\left(1 - \frac{r}{r_0+1}\right).$$

An intuitive explanation for this expression is as follows. Similar to Section IV, the diversity gain of the multiple stream EEAS strategy is dominated by the diversity gain of the worst of the $r_0 + 1$ paths. Clearly, path p_{r_0+1} is the worst among paths $p_1, p_2, \ldots, p_{r_0+1}$ and hence determines the diversity gain of the multiple stream EEAS strategy. Path p_{r_0+1} has the best SNR at the destination excluding paths $p_1, p_2, \ldots, p_{r_0}$. From Lemma 4, the number of independent paths in a multi-hop relay channel excluding the paths p_1 to p_{r_0} is $\min_{n=0,1,\ldots,N-1}(M_n - r_0)(M_{n+1} - r_0)$ and therefore the diversity gain of the multiple stream EEAS strategy is $\min_{n=0,1,\ldots,N-1}(M_n - r_0)(M_{n+1} - r_0)$. The term $\left(1 - \frac{r}{r_0+1}\right)$ results because of $r_0 + 1$ data streams being transmitted in parallel.

The DM-tradeoff of our EEAS strategy meets the upper bound (Lemma 1) at the maximum diversity gain point and the maximum multiplexing gain point by using $r_0 = 0$ and $r_0 = \min_{n=0,1,\ldots,N} M_n - 1$, respectively. For intermediate range of multiplexing gains, however, the lower bound does not meet the upper bound. Next, we compare our DM-tradeoff lower bound with other lower bounds obtained in [5], [6] and the DM-tradeoff upper bound for $N = 2, \ M_0 = 2, \ M_1 = 4, \ M_2 = 2$ in Fig. 2. From Fig. 2, we can see that our lower bound is better than the lower bound obtained in [5] using flip and forward strategy. In Fig. 2 our lower bound meets the lower bound of the adaptive strategy of [6] for some values of r and lies below if for other values of r.

VI. Simulation Results

In this section we provide some simulation results to demonstrate the uncoded bit error rates (BER) of the EEAS strategy and compare its performance with respect to the DSTBCs proposed in [3] and [8]. The specific cases of $N = 2$ and $N = 3$ are considered. In all the simulation plots we use

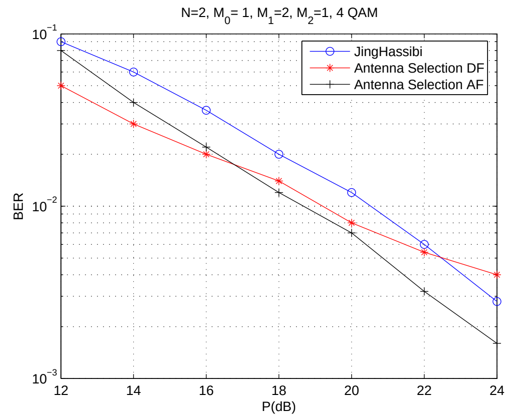

Fig. 3. BER comparison of EEAS strategy with JingHassibi code for $N = 2, M_0 = 1, M_1 = 2, M_2 = 1$.

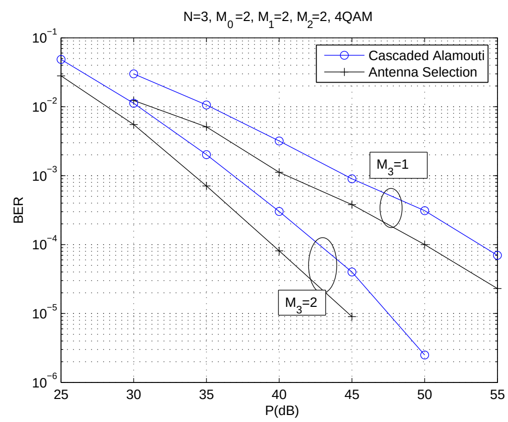

Fig. 4. BER comparison of EEAS strategy with cascaded Alamouti code for $N = 3, M_0 = M_1 = M_2 = 1, 2$.

4 QAM modulation. In Figs. 3 and 4 we plot the BER of the EEAS and the comparable DSTBC from [3] for $N = 2$, $M_0 = 1, M_1 = 2, M_2 = 1$, and $N = 3, M_0 = M_1 = M_2 = 2, M_3 = 1, 2$, respectively. It is easy to see that the EEAS with AF and the DSTBC [3] achieve the maximum diversity gain, while EEAS with AF, however, requires less power than the DSTBC to achieve the same BER because of less noise accumulation at the destination.

VII. Conclusions

The main conclusion we derived in this paper is that with EEAS strategies maximum diversity gain can be achieved in a multi-hop relay channel without any space-time coding (DSTBC). Next, we compare the performance of EEAS strategies and DSTBCs with respect to several important performance metrics. 1) **Overhead**: In the case of DSTBC's, CSI is required at each relay node and at the destination in the receive mode. With EEAS, CSI is only needed at the destination in the receive mode. In this case, however, a low bit-rate feedback is required from the destination to the source and each relay stage to communicate the source and the relay stage antenna indices to use. Thus EEAS reduces the training overhead compared to DSTBCs, but requires a low-rate feedback link. 2) **Noise Amplification**: With DSTBCs, each relay node [5], [6] is used to forward the signal to the designation using AF. Therefore, with DSTBCs, the noise received by all the relays in a relay stage is amplified and forwarded to the next relay stage. With a large number of relay stages, the contribution of the forwarded noise is significant in the received signal at the destination and severely limits the SNR. Using EEAS, only noise received by a single antenna of each relay stage is forwarded to the next relay stage and results in relatively less noise power at destination and provides with a substantial array gain. 3) **Decoding Complexity**: The decoding complexity of DSTBCs is significant, because of coding in space and time [5], [6]. With the proposed EEAS strategy rate of 1 complex symbol per channel use is guaranteed with minimum decoding complexity, since only one symbol is received by the destination at any given time instant. 4) **Latency**: With DSTBCs, the destination has to wait for the full coding length before it can start decoding. With multiple relay stages this delay can be significant. With the EEAS strategy, however, the destination can decode the signal after N time slots, which is minimum possible, since the destination cannot be reached from the source in less than N time slots.

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