Efficient Power Allocation for Outage Restricted Asymmetric Distributed MIMO Multi-hop Networks

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***Abstract*—Distributed MIMO multi-hop schemes can provide high data rates through spatially distributed relaying nodes. The relaying nodes allow the deployment of MIMO techniques to enhance the throughput by utilizing uncorrelated sub-channels. However, the spatial farness of geometrically separated relaying nodes results in different path losses from the nodes of one virtual antenna array (VAA) to the nodes of another VAA. In this paper we derive an approximative expression for the end-to-end (e2e) outage probability for such asymmetric networks, where orthogonal space-time block codes (OSTBC) are utilized for transmission. Based on this analytical expression a convex optimization problem that aims to reduce the total transmission power while meeting a given e2e outage level is formulated and an efficient near-optimal power allocation approach with low complexity is proposed. This near-optimum solution leads to the interesting result, that the same power is assigned to each node of one VAA. Thus, the power allocation turns out to be symmetric with respect to the nodes of one VAA also for networks with asymmetrically distributed nodes.**

I. Introduction

By the concept of virtual antenna array (VAA) spatially distributed relaying nodes are combined to create virtual MIMO systems [1]. This technology offers significant improvements for the data rate by utilizing distributed space-time block codes (STBC) in wireless multi-hop networks, where one source communicates with one destination via a number of relaying VAAs in multiple hops as illustrated in Fig. 1. Due to the spatial farness of the distributed relaying nodes, a common pathloss from the nodes of one VAA to the nodes of another VAA can not always be justified. Such network is termed asymmetric distributed MIMO multi-hop network.

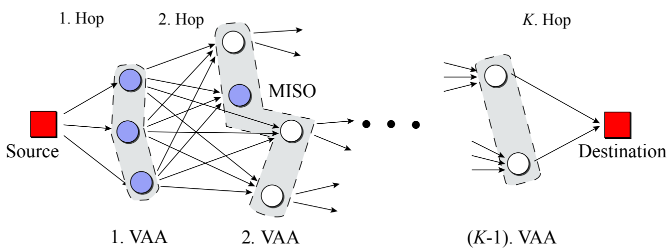

Fig. 1. An asymmetric distributed MIMO multi-hop system.

In an e2e communication Quality-of-Service (QoS) parameters like link reliability, data throughput, or outage probability depend on the transmission power per node. Due to the limited battery life the power consumption of wireless terminals may be one of the most limiting factors. Hence, it is important to determine the minimal power required to satisfy an e2e QoS constraint. Note that the majority of today's wireless applications happen over slow-fading channels, i.e., non-ergodic in the capacity sense, to which the concept of outage probability is applicable. Therefore, we will consider the e2e outage probability as the measurement for the QoS in this paper.

In order to achieve high ergodic channel capacity a resource allocation strategy for symmetric distributed MIMO multi-hop networks was introduced by Dohler et al. in [1], [2], where Decode-and-Forward (D&F) relaying protocol was applied . In [3], a power allocation solution to reduce the pairwise error probability (PEP) for a two-hop wireless network with Amplify-and-Forward (A&F) relaying protocol was developed. In both papers a fixed total power consumption $\mathcal{P}_{\text{total}}$ was assumed. However, for practical systems it is more interesting to determine the power allocation that aims to minimize the total power consumption while satisfying an given e2e QoS constraint. In [4], the authors introduced an efficient near-optimal power allocation strategy for symmetric distributed MIMO networks by solving a high-order equation in one variable. For the case of a large number of relaying nodes per VAA, a closed-form solution was proposed by approximating the high-order equation to a quadratic equation. Based on these results an efficient closed-form solution for an arbitrary number of nodes per VAA was recently presented in [5], [6].

In this paper we will extend these works to asymmetric networks. The optimal power allocation strategy is formulated as a convex optimization problem which can be solved by common optimization tools with considerable complexity. However, by using geometric mean and sum approximations for the e2e outage probability, a near-optimal power allocation solution for asymmetric networks with the complexity of solving a high-order equation is derived.

The remainder of the paper is organized as follows. In Section II the system model of the asymmetric distributed MIMO multi-hop scheme is introduced and an approximative expression for the e2e outage probability will be given in Section III. The optimization problem and the near-optimal solution are introduced in Section IV. Finally, some simulation results and conclusions are given in Section V and VI, respectively.

This work was supported in part by the Central Research Funding, University of Bremen under grant 01/129/07.

II. System Model of Asymmetric Networks

As depicted in Fig. 1, one source node communicates with one destination node via $K-1$ relaying VAAs in K hops. It is assumed that each relaying node has only one antenna element and a time-slotted transmission scheme is considered, i.e., time-diversion multiple-access (TDMA) between hops. One node can't transmit and receive signals simultaneously due to the half-duplex constraint. Moreover, the relaying protocol Decode-and-Forward (D&F) at each relaying node is utilized [7].

In the first time slot the source broadcasts the information to the first VAA over the entire frequency band W. Each node of the first VAA decodes the received information separately, i.e., they exchange no information during the decoding. Then they re-encode the decoded information "cooperatively" according to an orthogonal space-time block code (OSTBC). In the next time slot, the first VAA transmits the information to the second VAA over the entire frequency band W. Each node of the second VAA decodes the information separately, re-encodes, and retransmits it to the next VAA in the same manner as in the first time slot. The information is therefore "hopped" from one VAA to another VAA until it reaches the destination [1], [2]. Since the nodes within one VAA decode the information separately but re-encode the information with respect to the same space-time code word, the transmission within one hop can be modeled as several multiple-input single output (MISO) systems, as highlighted for the 2nd hop in Fig. 1.

We let k index the hop, K denote the number of hops, t_k, r_k be the number of transmit nodes and receive nodes at the kth hop, respectively. The pathloss between node i of the $(k-1)$th VAA and node j of the kth VAA is given by $1/d_{k,i,j}^{\epsilon}$, where $d_{k,i,j}$ denotes the distance between both nodes and ϵ is the pathloss exponent within range of 2 to 5 for most wireless channels. We define $\mathbf{S}_k \in \mathbb{C}^{t_k \times T_k}$ as the OSTBC encoded signal of length T_k transmitted from the t_k nodes at the kth hop. The received signal $\mathbf{y}_{k,j} \in \mathbb{C}^{1\times T_k}$ at the jth node is given by

$$\mathbf{y}_{k,j} = \mathbf{h}_{k,j} \cdot \mathbf{\Lambda}_k \cdot \mathbf{S}_k + \mathbf{n}_{k,j} \ , \tag{1}$$

with the diagonal matrix

$$\mathbf{\Lambda}_k = \mathrm{diag}\left\{ \sqrt{\frac{\mathcal{P}_{k,1}}{d_{k,1,j}^{\epsilon}}}, \cdots, \sqrt{\frac{\mathcal{P}_{k,t_k}}{d_{k,t_k,j}^{\epsilon}}} \right\} , \tag{2}$$

where $\mathbf{n}_{k,j} \sim \mathcal{N}_C(0, N_0) \in \mathbb{C}^{1\times T_k}$ denotes the Gaussian noise vector with power spectral density N_0 and $\mathcal{P}_{k,i}$ is the transmission power of the ith node at the kth hop. The channel from the t_k transmit nodes to the jth receive node at the kth hop is expressed as $\mathbf{h}_{k,j} \in \mathbb{C}^{1\times t_k}$. Its elements $h_{k,i,j}$ obey the same uncorrelated Rayleigh fading statistics, i.e., they are complex zero-mean circular symmetric Gaussian distributed with variance 1.

III. Outage Probability

A. Outage Probability of Asymmetric MISO

The instantaneous channel capacity of an asymmetric MISO system with OSTBC is given by

$$C_{k,j} = \rho_k W \log\left(1 + \frac{1}{\rho_k W N_0}\sum_{i=1}^{t_k} g_{k,i,j}|h_{k,i,j}|^2\right) \ , \tag{3}$$

where the weights $g_{k,i,j} = \mathcal{P}_{k,i}/d_{k,i,j}^{\epsilon}$ correspond to the squared diagonal elements of $\mathbf{\Lambda}_k$ defined in (2) [1]. The variable ρ_k denotes the rate loss introduced by the orthogonal STBC, e.g., $\rho_k = 1$ for Alamouti with $t_k = 2$ and $\rho_k = 3/4$ for OSTBC with $t_k = 3, 4$ [8]. The outage probability $P_{\text{out},k,j} = \Pr(R > C_{k,j})$ describes the probability, that the link from the t_k nodes of VAA $k-1$ to node j of VAA k can not support the data rate R. For asymmetric MISO systems the following closed-form expression was derived in [1, p. 65]

$$\begin{aligned} P_{\text{out},k,j} &= \Pr(R > C_{k,j}) \\ &= \Pr\left(\sum_{i=1}^{t_k} g_{k,i,j}|h_{k,i,j}|^2 < \left(2^{\frac{R}{\rho_k W}} - 1\right)\rho_k W N_0\right) \\ &= \sum_{i=1}^{t_k} \prod_{\substack{i'=1 \\ i'\neq i}}^{t_k} \frac{g_{k,i,j}}{g_{k,i,j} - g_{k,i',j}} \left(1 - e^{-g_{k,i,j}^{-1} Q_k}\right) \ , \end{aligned} \tag{4}$$

where the system parameters data rate, bandwidth, and rate loss are collected in the variable $Q_k = \left(2^{\frac{R}{\rho_k W}} - 1\right)\rho_k W N_0$. Due to the rather complex form (4), two approximations are subsequently introduced to simplify the further analysis.

B. Approximations for the Outage Probability

The random variable $\psi_{k,j} = \sum_{i=1}^{t_k} g_{k,i,j}|h_{k,i,j}|^2$ given in (4) describes a linear combination of t_k independent exponential distributed variables $|h_{k,i,j}|^2$ with different weights $g_{k,i,j}$. For low outage probabilities, $\psi_{k,j}$ can be accurately approximated by a gamma distributed variable with shape t_k and scale given by the geometric mean $\prod_{i=1}^{t_k} g_{k,i,j}^{1/t_k}$ of all weights $g_{k,i,j}$ [9], [10]

$$\psi_{k,j} \overset{\approx}{\sim} \text{Gamma}\left(t_k, \prod_{i=1}^{t_k} g_{k,i,j}^{1/t_k}\right) \ . \tag{5}$$

Herein $\overset{\approx}{\sim}$ means the random variable $\psi_{k,j}$ obeys the Gamma distribution approximately. By applying this geometric mean approximation, the asymmetric MISO system with different weights $g_{k,i,j}$ is transformed to a symmetric MISO system with common weight $\prod_{i=1}^{t_k} g_{k,i,j}^{1/t_k}$. Therefore, the outage probability $P_{\text{out},k,j}$ (4) can be approximated as

$$\begin{aligned} P_{\text{out,Geo},k,j} &= \Pr\left(\prod_{i=1}^{t_k} g_{k,i,j}^{1/t_k} \sum_{i=1}^{t_k} |h_{k,i,j}|^2 < Q_k\right) \\ &= \Pr\left(\sum_{i=1}^{t_k} |h_{k,i,j}|^2 < Q_k \prod_{i=1}^{t_k} g_{k,i,j}^{-1/t_k}\right) \\ &= \frac{\gamma(t_k, x_{k,j})}{\Gamma(t_k)} \ , \end{aligned} \tag{6}$$

where $\gamma(\cdot,\cdot)$ is the incomplete gamma function and $\Gamma(\cdot)$ denotes the gamma function. The introduced variable

$$x_{k,j} = Q_k \prod_{i=1}^{t_k} g_{k,i,j}^{-1/t_k} = Q_k \prod_{i=1}^{t_k} d_{k,i,j}^{\epsilon/t_k} \cdot \prod_{i=1}^{t_k} \mathcal{P}_{k,i}^{-1/t_k} \ . \tag{7}$$

describes the effective inverse SNR of the MISO system of investigation. With the abbreviation $D_{k,j} = Q_k \prod_{i=1}^{t_k} d_{k,i,j}^{\epsilon/t_k}$ this expression can be further simplified

$$x_{k,j} = D_{k,j} \cdot \prod_{i=1}^{t_k} \mathcal{P}_{k,i}^{-1/t_k} \ . \tag{8}$$

Note that the effective inverse SNR $x_{k,j}$ depends only on the geometric mean of the power $\mathcal{P}_{k,i}$ transmitted by the nodes of VAA $k-1$. As shown later, this property results in a symmetric assignment of the power to the nodes of one VAA.

Since the low outage probability region is concerned for practical systems, the incomplete gamma function in (6) can be approximated by $\gamma(t_k, x_{k,j}) \approx x_{k,j}^{t_k} t_k^{-1}$ [4], [11]. This leads to the simplified approximation for the outage probability (6)

$$\tilde{P}_{\text{out},k,j} = \frac{x_{k,j}^{t_k}}{\Gamma(t_k+1)} \ , \tag{9}$$

which fulfills the inequality $P_{\text{out},k,j} \leq P_{\text{out,Geo},k,j} \leq \tilde{P}_{\text{out},k,j}$.

C. Sum Approximation for E2E Outage Probability

Throughout the paper it is assumed that the e2e communication is in outage if any of the MISO systems can not correctly decode the information. Moreover, the signals are completely decoded at each VAA, so that the outage probabilities are mutually independent. Thus, the end-to-end outage probability is given by [1]

$$P_{\text{e2e}} = 1 - \prod_{k=1}^{K} \prod_{j=1}^{r_k} \left(1 - P_{\text{out},k,j}\right) \ . \tag{10}$$

This product representation can further be approximated by a sum expression yielding the following approximation for the e2e outage probability

$$\tilde{P}_{\text{e2e}} = \sum_{k=1}^{K} \sum_{j=1}^{r_k} \tilde{P}_{\text{out},k,j} = \sum_{k=1}^{K} \sum_{j=1}^{r_k} \frac{x_{k,j}^{t_k}}{\Gamma(t_k+1)} \ . \tag{11}$$

Similar to the proof in [12] it can be shown that $\tilde{P}_{\text{e2e}}$ is an upper bound of P_{e2e}, i.e., $P_{\text{e2e}} \leq \tilde{P}_{\text{e2e}}$.

IV. Near-Optimal Power Allocation

The optimization problem that minimizes the total transmit power $\mathcal{P}_{\text{total}}$ while satisfying the e2e outage probability requirement e is given by

$$\begin{aligned} &\text{minimize } \mathcal{P}_{\text{total}} = \sum_{k=1}^{K} \sum_{i=1}^{t_k} \mathcal{P}_{k,i} \\ &\text{subject to } P_{\text{e2e}} \leq e \ . \end{aligned} \tag{12}$$

Note that (12) can be shown to be convex for low e2e outage probability e by proving the Hessian matrix of $P_{\text{e2e}}(\mathcal{P}_{k,i}, \forall\, k)$ to be positive semi-definite [9]. Unfortunately, the optimization problem (12) doesn't have a closed-form solution in terms of the power per node. However, it can be solved by standard optimization tools leading to considerable complexity [13].

By replacing P_{e2e} in (12) with $\tilde{P}_{\text{e2e}}$ given in (11) the approximated optimization problem

$$\begin{aligned} &\text{minimize } \mathcal{P}_{\text{total}} = \sum_{k=1}^{K} \sum_{i=1}^{t_k} \mathcal{P}_{k,i} \\ &\text{subject to } \tilde{P}_{\text{e2e}} \leq e \end{aligned} \tag{13}$$

is achieved. The solution of this near-optimal power allocation problem leads to an increased total power consumption, but satisfies the original outage requirement $P_{\text{e2e}} \leq e$ as the more stringent constraint $\tilde{P}_{\text{e2e}} \geq P_{\text{e2e}}$ is considered. Furthermore, the near-optimal solution can be rapidly obtained by solving the constrained optimization problem (13) using Lagrange multipliers. To this end we define the Lagrangian as

$$L(\mathcal{P}_{k,i}) = \sum_{k=1}^{K} \sum_{i=1}^{t_k} \mathcal{P}_{k,i} + \lambda(\tilde{P}_{\text{e2e}} - e) \ . \tag{14}$$

According to the KKT conditions [13], the optimal power allocation is attained when $\tilde{P}_{\text{e2e}} = e$. Therefore, the near-optimal power $P_{k,i}^{*}$ satisfies the following two equations

$$\frac{\partial L(\mathcal{P}_{k,i})}{\partial \mathcal{P}_{k,i}} = 1 + \lambda \frac{\partial \tilde{P}_{\text{e2e}}}{\partial \mathcal{P}_{k,i}} = 0, \qquad \forall\, k, i \tag{15a}$$

$$\tilde{P}_{\text{e2e}}(\mathcal{P}_{k,i}^{*}) = \sum_{k=1}^{K} \sum_{j=1}^{r_k} \tilde{P}_{\text{out},k,j}(\mathcal{P}_{k,i}^{*}) = e \ , \tag{15b}$$

where the derivative in (15a) is given by

$$\begin{aligned} \frac{\partial \tilde{P}_{\text{e2e}}}{\partial \mathcal{P}_{k,i}} &= \sum_{j=1}^{r_k} \frac{\partial \tilde{P}_{\text{out},k,j}}{\partial \mathcal{P}_{k,i}} = \sum_{j=1}^{r_k} \frac{\partial}{\partial \mathcal{P}_{k,i}} \left(\frac{x_{k,j}^{t_k}}{\Gamma(t_k+1)} \right) \\ &= -\frac{1}{\Gamma(t_k+1)\mathcal{P}_{k,i}} \sum_{j=1}^{r_k} x_{k,j}^{t_k} \ . \end{aligned} \tag{16}$$

As indicated by (15a), the first derivative of $\tilde{P}_{\text{e2e}}$ with respect to each $\mathcal{P}_{k,i}$ has to be equal. Let A denote this constant value

$$A = -\frac{\partial \tilde{P}_{\text{e2e}}}{\partial \mathcal{P}_{k,i}} = \Gamma(t_k+1)^{-1} \mathcal{P}_{k,i}^{-1} \sum_{j=1}^{r_k} x_{k,j}^{t_k} \tag{17}$$

then $\mathcal{P}_{k,i}$ can be described by A as follows

$$\mathcal{P}_{k,i} = \Gamma(t_k+1)^{-1} A^{-1} \sum_{j=1}^{r_k} x_{k,j}^{t_k} \ . \tag{18}$$

Thus, the interesting result $\mathcal{P}_{k,1} = \cdots = \mathcal{P}_{k,t_k}$ can be observed, i.e., also for asymmetric networks the nodes of one VAA transmit with the same power independent of their location. This result bases on the geometric mean approximation and was already mentioned in the discussion of (8).

In order to determine the near-optimal power allocation, the optimization parameter A has to be calculated so that (15b) is fulfilled. To derive this analytical solution, the expression of the power per node $\mathcal{P}_{k,i}$ (18) is inserted in (8) leading to the implicit equation

$$x_{k,j} = D_{k,j}\mathcal{P}_{k,i}^{-1} = D_{k,j} \cdot \Gamma(t_k+1)A\left(\sum_{j=1}^{r_k} x_{k,j}^{t_k}\right)^{-1} . \quad (19)$$

With this result the sum of $x_{k,j}^{t_k}$ over r_k is given by

$$\sum_{j=1}^{r_k} x_{k,j}^{t_k} = \sum_{j=1}^{r_k} D_{k,j}^{t_k} \cdot (\Gamma(t_k+1)A)^{t_k}\left(\sum_{j'=1}^{r_k} x_{k,j'}^{t_k}\right)^{-t_k} \quad (20)$$

and by rewriting this equation the relation

$$\sum_{j=1}^{r_k} x_{k,j}^{t_k} = \left(\sum_{j=1}^{r_k} D_{k,j}^{t_k}\right)^{\frac{1}{t_k+1}} \cdot (\Gamma(t_k+1)A)^{\frac{t_k}{t_k+1}} \quad (21)$$

is achieved. Inserting this into the implicit equation (19) yields

$$x_{k,j} = D_{k,j} \cdot (\Gamma(t_k+1)A)^{\frac{1}{t_k+1}}\left(\sum_{j=1}^{r_k} D_{k,j}^{t_k}\right)^{\frac{-1}{t_k+1}} , \quad (22)$$

and the outage probability $\tilde{P}_{\text{out},k,j}$ can be determined by using (22) in (9). Thus, the constraint equation (15b) corresponds to a high-order equation in the variable A

$$\tilde{P}_{\text{e2e}} = \sum_{k=1}^{K}\sum_{j=1}^{r_k} \tilde{P}_{\text{out},k,j} = \sum_{k=1}^{K}\sum_{j=1}^{r_k} a_{k,j} A^{\frac{t_k}{t_k+1}} = e , \quad (23)$$

with coefficients

$$a_{k,j} = \Gamma(t_k+1)^{\frac{-1}{t_k+1}} D_{k,j}^{t_k}\left(\sum_{j=1}^{r_k} D_{k,j}^{t_k}\right)^{\frac{-t_k}{t_k+1}} . \quad (24)$$

The parameter A that fulfills (23) with equality can be determined by common root-finding algorithms. Thus, the power allocation task corresponds to finding the non-negative real root of a high-order polynomial.

Theorem 1 (Near-optimal power allocation (NOPA)): In an asymmetric distributed MIMO multi-hop system with an arbitrary number of nodes t_k per VAA and a given e2e outage probability requirement e, the near-optimal power allocation $\mathcal{P}_{k,i}^*$ is given by

$$\mathcal{P}_{k,i}^* = \left(\sum_{j=1}^{r_k} D_{k,j}^{t_k}\right)^{\frac{1}{t_k+1}} \cdot (\Gamma(t_k+1)A)^{\frac{-1}{t_k+1}} , \quad (25)$$

where A is the real-valued positive root of the high-order equation (23). Note that efficient methods of root searching like Newton can be used to determine A. Under the assumption of large t_k the approximation $\frac{t_k}{t_k+1} \approx 1$ holds and (23) simplifies to a quadratic equation, which can be even solved in closed-form [4]. An extension of this solution for arbitrary t_k was derived in [5] and analytical investigations have been presented in [6]. These efficient approaches for solving the power allocation problem of symmetric systems can also be extended for asymmetric networks as considered in this paper.

Theorem 2 (Equal power allocation within one VAA): As can be observed from (18), the near-optimal power allocation assigns the same power $\mathcal{P}_{k,i}^*$ to the nodes $1 \le i \le t_k$ of one VAA also for asymmetric networks, i.e.,

$$\mathcal{P}_{k,1}^* = \cdots = \mathcal{P}_{k,t_k}^* . \quad (26)$$

V. Performance

We consider the asymmetric distributed MIMO multi-hop network depicted in Fig. 2 with $K = 4$ hops and the same number of relaying nodes $t_k = 4$ per VAA (connected by solid lines in the figure). It is assumed that the e2e communication should meet an e2e outage probability constraint $e = 1\%$ over $W = 5$ MHz. The distance between the source and destination is 4 km and the pathloss exponent $\epsilon = 3$. The relaying nodes are randomly positioned in the area between source and destination. Furthermore, we assume $N_0 = -174$ dBm according to the UMTS standards.

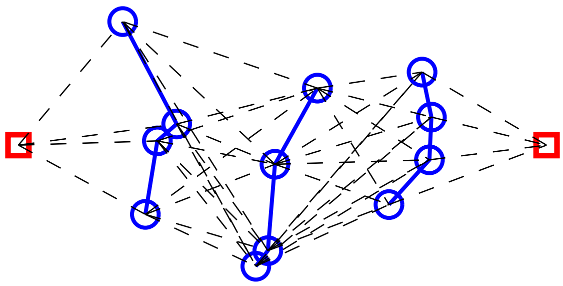

Fig. 2. Illustration of a randomly generated asymmetric network with 4 hops and $t_k = 4$ nodes in each VAA.

Fig. 3 depicts the total power consumption versus the data rate R in Mbps obtained by numerical iterations of the problem (12) with respect to exact outage probability (4). In addition, the optimum solution considering the geometric mean approximation (6) as well as the simplified NOPA approach requiring the solution of a high-order equation are depicted.

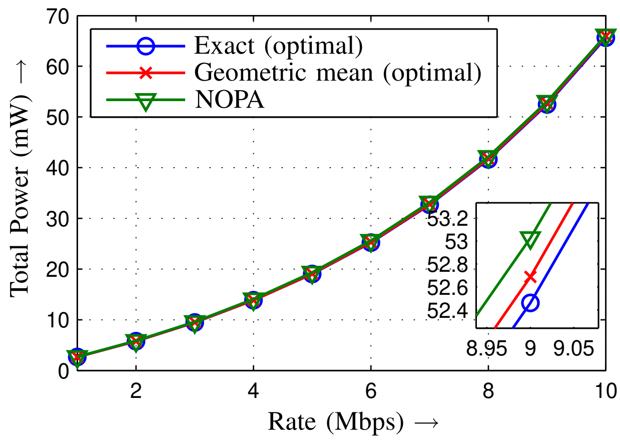

Fig. 3. Total power consumption for optimal power allocation and NOPA for the asymmetric network shown in Fig. 2 with $K = 4$, $t_k = 4$ and $e = 1\%$.

It can be observed, that the geometric mean approximation for the outage probability is meaningful as the power allocation differs only slightly form the optimal solution with exact form. We can conclude that the geometric mean approximation does provide a relatively good accuracy at low outage probability. In addition, the NOPA solution developed in this paper achieves almost the same performance as the optimal solution. It leads only to a slightly higher power usage. The reason for this is that we use the more stringent $\tilde{P}_{\text{e2e}}$ instead of the exact e2e outage probability P_{e2e} of the system, which causes higher power consumption. Fig. 4 shows the achieved e2e outage probabilities and indicates that NOPA solution exceeds the outage requirement.

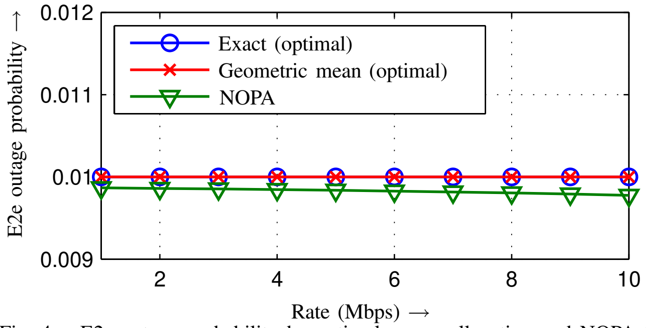

Fig. 4. E2e outage probability by optimal power allocation and NOPA for an asymmetric network with $K = 4$, $t_k = 4$ and $e = 1\%$.

In order to further evaluate the accuracy of the geometric mean approximation, a 2-hop system with two relays in the VAA is considered. We fix the position of the first relay which is $d_{1,1,1} = 400$ m away from the source. The second relay moves on the line from the source to the destination corresponding to the distance $d_{1,1,2}$ to the source. Other parameters remain unchanged. Fig. 5 shows the normalized optimal power ratio $\mathcal{P}_{k,i}/\mathcal{P}_{\text{total}}$ per node versus the distance between the source and the second relay $d_{1,1,2}$ according to the exact form and geometric mean approximation, respectively. The solution by using geometric mean approximation achieves almost the same power consumption as the exact form for each node and leads only to a slight difference when the second relay is very near to the destination which can be viewed as an extremely asymmetric case. However, the optimal solution by the exact form behaves still in a near symmetric manner, i.e., both relay nodes transmit with almost common power. The difference between the exact form and the geometric mean approximation is negligible. Hence, it is reasonable to apply the geometric mean approximation to reduce the effort of finding a near-optimal power allocation for asymmetric networks.

VI. Conclusion

In this paper, we studied power allocation strategies for e2e outage probability restricted asymmetric distributed MIMO multi-hop networks. In order to derive a simple power allocation solution with lower complexity, some more stringent approximations for the e2e outage probability were used,

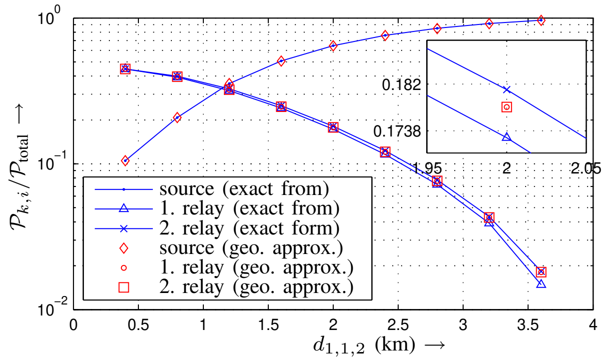

Fig. 5. Normalized power ratio which shows the accuracy of geometric mean approximation for different distance $d_{1,1,2}$ between the source and the second relay in a 2-hop network. The first relay is assumed to be fixed.

including geometric mean approximation and sum approximation. Thanks to the applied geometric mean approximation, the asymmetric network can be transformed to a similar symmetric network. This leads to an interesting result that for an outage restricted asymmetric network the nodes within one VAA transmit the signals at the same power level correspongding to a symmetric system. The proposed power allocation strategy has been shown to be efficient and achieve near-optimal performance at low computational effort.

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