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Cooperative maximum-ratio transmission with multi-antenna relay nodes for tactical mobile ad-hoc networks

Chang Seok You, Jeong Seon Yeom, Bang Chul Jung*

Department of Electronics Engineering, Chungnam National University, South Korea

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Abstract

In this paper, we propose a cooperative maximum-ratio transmission (C-MRT) technique with multi-antenna relay nodes for tactical mobile ad-hoc networks (MANETs) where both the location and the number of antennas of relay nodes are arbitrary. Each relay node is assumed to know both the wireless channel coefficient from the source node to itself and the wireless channel from itself to the destination node, which is known as local channel state information (CSI) assumption. Maximum-ratio combining (MRC) and MRT techniques are used for beamforming the transmit and receive signals of the relay node, respectively. In addition, we mathematically analyze the overall outage probability of the proposed technique with moment generating function (MGF). It is shown that the mathematical analysis on the overall outage probability of the proposed C-MRT technique is matched well with the simulation results especially in high transmit power regimes. It is also observed that the proposed technique outperforms other schemes such as phase steering (PS) and optimal relay selection (ORS) in terms of outage probability.

Keywords: Tactical mobile ad-hoc networks; Cooperative relaying; Multiple antennas; Outage probability; Maximum ratio transmission

1. Introduction

Recently, tactical edge communications have become important due to explosively increasing data request in the battlefield for real-time battlefield videos or tracking and positioning information [1–3]. As shown in Fig. 1, individual or company units are distributed in the battlefield and information about missions and battlefield status needs to be communicated with each other. With advanced wireless communication technologies and devices, mobile ad-hoc networks (MANETs) have been considered as the significant networking architectures for such military applications due to reliability, flexibility, energy efficiency, and adaptability [4,5].

A cooperative communication is one of the most promising techniques to improve error performance of MANETs by utilizing multiple relay nodes. In the literature, many studies on cooperative relaying techniques have been investigated to achieve spatial diversity and improve the error performance of cooperative relaying networks [6–8]. In [6], the threshold-based adaptive relay selection techniques is proposed. The destination computes the optimal channel gain threshold and broadcasts it to all relays. And then, among the successful decoding relays, the relays whose channel gain toward the destination is above the threshold transmit a signal of source to the destination. In [7], a downlink cellular system is addressed for the effect of cooperative and selection relaying schemes, of which multiple relay stations are equipped with a single antenna. In [8], the phase steering scheme is analyzed in cooperative relay network, of which all relay are equipped with a single antenna. While, in case the relay nodes are equipped with multiple antennas, then the maximum-ratio combining/transmission (MRC/MRT) techniques can be used as receive and transmit beamforming techniques at the relays [9,10]. In [9], multiple relay nodes equipped with multiple *receive* antennas adopt the MRC beamforming for the signal reception from the source node at the first hop, while only some of the relay nodes that have successfully decoded the packet from the source node participate the second hop transmission with a *single* transmit antenna. At the second hop, a single-antenna destination node also adopts the MRC technique in combining signals from multiple relay nodes

* Corresponding author.
E-mail addresses: changseok.you@o.cnu.ac.kr (C.S. You), jsyeom@cnu.ac.kr (J.S. Yeom), bcjung@cnu.ac.kr (B.C. Jung).

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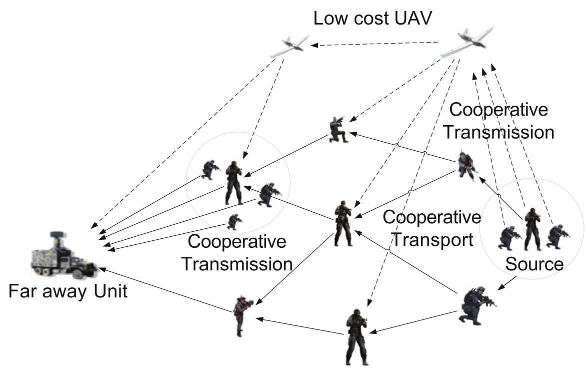

Fig. 1. Communication scenarios over tactical MANET in battlefield.

by assuming that multiple relay nodes send their signals over orthogonal radio resources such as orthogonal frequency bands or time slots, but it significantly sacrifices spectral efficiency. In [10], the transmit beamforming technique was proposed for both multi-antenna source node and a *single* multi-antenna relay node that operates with half-duplex DF strategy in the presence of the direct link between the source node and a *single-antenna* destination node. In the second hop, the multi-antenna relay node adapts MRT beamforming technique since it achieves the theoretically optimal performance [11]. However, as shown in Fig. 1, there exist multiple relays in practical battlefields.

Hence, we proposed a novel *cooperative* MRT (C-MRT) technique with multi-antenna relay nodes for tactical MANETs, where the relay nodes that have successfully decoded the packet from the source node simultaneously send the signal with MRT beamforming to the destination node over the same radio resource. In particular, the relay nodes are assumed to be located at arbitrary points and to have different number of antennas. In addition, we mathematically analyze the overall outage probability of the proposed C-MRT technique. A closed-form expression is derived using MGF approach.

The rest of this paper is organized as follows. In Section 2, we describe the system model we consider in this paper. In Section 3, we explain the proposed C-MRT technique in detail. In Section 4, its performance is analyzed in terms of the outage probability. The simulation results are shown in Section 5. Finally, conclusions are drawn in Section 6.

2. System model

We consider a two-hop cooperative relay network with multi-antenna half-duplex relay nodes as shown in Fig. 2, which consists of a single-antenna source node, a single-antenna destination node, and N relay nodes with multiple antennas. We assume that the number of antennas at relay nodes are not the same to each other and the number of antennas at the ith relay node is denoted by K_i ($i \in \{1, 2, \ldots, N\}$). The location of the ith relay node is assumed to be arbitrary and thus the distances from the source node and the destination node to the relay nodes is not identical to each other. The distances from the source node and the destination node to the ith relay node are denoted by $d_{\mathsf{s},i}$ and $d_{i,\mathsf{d}}$, respectively.

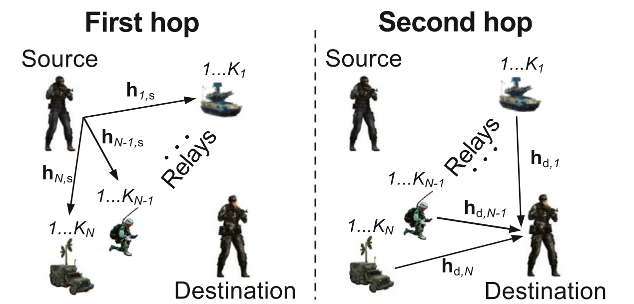

Fig. 2. Cooperative multi-relay with multiple antenna system in tactical network.

The small-scale fading channel coefficients between a certain transmit antenna and a certain receive antenna are assumed as Rayleigh fading and to follow identically and independently distributed (i.i.d.) complex Gaussian distribution with zero mean and unit variance. Thus, the wireless channel vector from the source node to the ith relay node is denoted by $\mathbf{h}_{\mathsf{s},i}$ $\left(\in \mathbb{C}^{K_i \times 1}\right)$ and the wireless channel vector from the ith relay node to the destination node is denoted as $\mathbf{h}_{i,\mathsf{d}}$ $\left(\in \mathbb{C}^{1 \times K_i}\right)$. The additive white Gaussian noise (AWGN) at all receive antennas follows the i.i.d. complex Gaussian distribution with zero mean and variance of N_0, i.e., $\mathcal{CN}(0, N_0)$. The noises at the i-the relay node and the destination node are denoted by $\mathbf{n}_i$ $\left(\in \mathbb{C}^{K_i \times 1}\right)$ and n_{d}, respectively. In addition, we assume that each relay node knows both the channel state information (CSI) from the source node to itself and the CSI from itself to the destination node, which is called *local CSI* assumption in the literature. Quasi-static frequency-flat fading is also assumed, which means that wireless channel coefficients are constant during two-hop transmission time and change independently for every two-hop transmission time.

3. Cooperative maximum ratio transmission

We describe the overall procedure of the proposed C-MRT technique in this section. At the first hop, the source node sends the packet to relay nodes, and then the received signal at the ith relay node is given by

$$\mathbf{y}_i = \mathbf{h}_{\mathsf{s},i}\sqrt{d_{\mathsf{s},i}^{-\alpha}}\, x_{\mathsf{s}} + \mathbf{n}_i, \tag{1}$$

where x_{s} denotes the transmit signal of the source node with the transmit power of the source node P, i.e., $\mathbb{E}\left[|x_{\mathsf{s}}|^2\right] = P$. The term α denotes the path-loss exponent. Each relay node adopts the optimal MRC technique to maximize the receive signal-to-noise ratio (SNR). After the MRC beamforming technique at the ith relay node, the received signal is given by

$$\bar{y}_i = \frac{\mathbf{h}_{\mathsf{s},i}^H}{\left\|\mathbf{h}_{\mathsf{s},i}\right\|}\mathbf{y}_i = \sqrt{\left\|\mathbf{h}_{\mathsf{s},i}\right\|^2 d_{\mathsf{s},i}^{-\alpha}}\, x_{\mathsf{s}} + \bar{n}_i, \tag{2}$$

where $\bar{n}_i \triangleq \frac{\mathbf{h}_{\mathsf{s},i}^H}{\|\mathbf{h}_{\mathsf{s},i}\|} \cdot \mathbf{n}_i$ and then $\bar{n}_i \sim \mathcal{CN}(0, N_0)$.

Each relay node tries to decode the received packet from the source node at the first hop and the packet decoding is assumed to be successful if the received SNR is larger than a certain threshold. Then, the index set of the relay nodes that succeed the packet decoding at the first hop, called decoding set $\mathcal{D}$, is defined as

$$\mathcal{D} = \{i \in \mathcal{R} \mid \gamma_{\mathsf{s},i} \triangleq d_{\mathsf{s},i}^{-\alpha} \|\mathbf{h}_{\mathsf{s},i}\|^2 \geq \gamma_{\mathsf{th}}\}, \tag{3}$$

where $\gamma_{\mathsf{th}} = (2^{2R}-1)/\rho_{\mathsf{T}}$, the transmit SNR of the source node at the first hop is defined as $\rho_{\mathsf{T}} \triangleq P/N_0$, and R indicates the data rate assuming the direct communication from the source node to the destination node. Note that we assume two-hop communication from the source node to the destination node and the required data rate for each hop is equal to $2R$. The set $\mathcal{R}$ is defined as $\{1, 2, \ldots, N\}$ and thus $\mathcal{D} \subset \mathcal{R}$.

At the second hop, each relay node with multiple antennas that belongs to decoding set $\mathcal{D}$ sends the packet to the destination node with the proposed C-MRT technique simultaneously. Assuming $i \in \mathcal{D}$, the transmit vector of the ith relay node is given by

$$\mathbf{s}_i = \frac{\sqrt{d_{i,\mathsf{d}}^{-\alpha}}\mathbf{h}_{i,\mathsf{d}}^H}{\sqrt{\gamma_{\mathsf{d}}}} x_{\mathsf{s}}, \tag{4}$$

where $\gamma_{\mathsf{d}} = \sum_{i\in\mathcal{D}} d_{i,\mathsf{d}}^{-\alpha} \left\|\mathbf{h}_{i,\mathsf{d}}\right\|^2$ and γ_{d} is assumed to be known to all relay nodes in this paper. After decoding the received packet at the first hop, all relay nodes feed ACK or NACK packet back to the source node over pre-assigned non-overlapping time-slots. When a certain relay node feeds ACK packet back to the source node, the relay node contains the wireless channel gain from itself to the destination in the ACK packet. For example, the ith relay node contains $d_{i,\mathsf{d}}^{-\alpha} \left\|\mathbf{h}_{i,\mathsf{d}}\right\|^2$ in its ACK packet if $i \in \mathcal{D}$, while the ith relay node contains 0 in its NACK packet if $i \notin \mathcal{D}$. All relay nodes in the decoding set can compute γ with a *distributed* manner by overhearing all ACK/NACK packets. In general, ACK or NACK packet is quite short compared with the data packet and we assume that time consumption for ACK or NACK packet is negligible in this paper as many studies including [12]. With the power normalization with γ_{d}, the sum of the transmit powers of the relay nodes that belong to $\mathcal{D}$ becomes P which is the same with the transmit power of the source node at the first hop.

The received signal at the destination node in the second hop is given by

$$\begin{aligned} y_{\mathsf{d}} &= \sum_{i\in\mathcal{D}} \sqrt{d_{i,\mathsf{d}}^{-\alpha}}\mathbf{h}_{i,\mathsf{d}}\mathbf{s}_i + n_{\mathsf{d}} \\ &= \sqrt{\sum_{i\in\mathcal{D}} d_{i,\mathsf{d}}^{-\alpha} \left\|\mathbf{h}_{i,\mathsf{d}}\right\|^2} x_{\mathsf{s}} + n_{\mathsf{d}}. \end{aligned} \tag{5}$$

Then, the received SNR at the destination node is given by

$$\rho_{\mathsf{d}} = \left(\sum_{i\in\mathcal{D}} d_{i,\mathsf{d}}^{-\alpha} \left\|\mathbf{h}_{i,\mathsf{d}}\right\|^2\right) \cdot \rho_{\mathsf{T}}. \tag{6}$$

4. Outage probability analysis

In this section, the proposed C-MRT technique is analyzed in terms of outage probability. The overall outage probability at the destination node is given by

$$\begin{aligned} P_{out} &= \Pr\{\mathsf{Outage}\} \\ &= \Pr\{\mathsf{Outage}|\mathcal{D} \neq \emptyset\} \Pr\{\mathcal{D} \neq \emptyset\} \\ &\quad + \Pr\{\mathsf{Outage}|\mathcal{D} = \emptyset\} \Pr\{\mathcal{D} = \emptyset\} \\ &= \Pr\{\mathsf{Outage}|\mathcal{D} \neq \emptyset\} \Pr\{\mathcal{D} \neq \emptyset\} + 1 \cdot \Pr\{\mathcal{D} = \emptyset\} \\ &= \sum_{\forall\mathcal{D}\subset\mathcal{R}\setminus\emptyset} \left[\prod_{i\notin\mathcal{D}} \Pr\{\gamma_{\mathsf{s},i} < \gamma_{\mathsf{th}}\} \prod_{j\in\mathcal{D}} \Pr\{\gamma_{\mathsf{s},j} \geq \gamma_{\mathsf{th}}\} \right. \\ &\quad \left. \times \Pr\{\gamma_{\mathsf{d}} < \gamma_{\mathsf{th}}|\mathcal{D}\}\right] + \prod_{r\in\mathcal{R}} \Pr\{\gamma_{\mathsf{s},r} < \gamma_{\mathsf{th}}\}. \end{aligned} \tag{7}$$

For outage probability analysis, first we obtain the cumulative distribution function (c.d.f.) of channel gain of each node at both first and second hop. Before that, for notational convenience, $\delta_{\mathsf{s},i} := d_{\mathsf{s},i}^{-\alpha}$ and $\delta_{i,\mathsf{d}} := d_{i,\mathsf{d}}^{-\alpha}$ and a random variable (RV) $Z_{\delta_{\mathsf{s},i}}^{K_i} \triangleq \delta_{\mathsf{s},i}\|\mathbf{h}_{\mathsf{s},i}\|^2$ and a RV $Z_{\delta_{i,\mathsf{d}}}^{K_i} \triangleq \delta_{i,\mathsf{d}}\|\mathbf{h}_{i,\mathsf{d}}\|^2$.

For the performance analysis of outage probability in cooperative multiple relay system, we first need to know the probability distributions of the effective channel gain of receiver at each hop. At first hop in this system, since ith relay node is equipped with K_i antennas and is located at d_i distance from the source node, its effective channel gain, $Z_{\delta_{\mathsf{s},i}^{K_i}}$, follows Erlang distribution with mean $K_i\delta_{\mathsf{s},i}$ and variance $K_i\delta_{\mathsf{s},i}^2$. Thus, the c.d.f. of Erlang distribution is given as

$$F_{Z_{\delta_{\mathsf{s},i}}^{K_i}}(z) = 1 - e^{-\frac{z}{\delta_{\mathsf{s},i}}} \sum_{k=0}^{K_i-1} \frac{1}{k!}\left(\frac{z}{\delta_{\mathsf{s},i}}\right)^k. \tag{8}$$

At second hop where receiver receives a C-MRT signal, the effective channel gain from (6) is given as $Z_{\mathsf{d}} \triangleq \sum_{i\in\mathcal{D}} Z_{\delta_{i,\mathsf{d}}}^{K_i}$. We derive its distribution in following subsection by using MGF approach.

4.1. Cumulative distribution function of effective channel gain for generalized C-MRT

Note that, at second hop of this system model, each relay node has an arbitrary number of antennas and is located at an arbitrary distance from the destination for the generalized C-MRT. As defined by the RV Z_{d}, we should need to know the c.d.f. of sum of $|\mathcal{D}|$ *nonidentical* and independent RVs following the Erlang distribution. Such like (8), the c.d.f. of $Z_{\delta_{i,\mathsf{d}}}^{K_i}$ is given as

$$F_{Z_{\delta_{i,\mathsf{d}}}^{K_i}}(z) = 1 - e^{-\frac{z}{\delta_{i,\mathsf{d}}}} \sum_{k=0}^{K_i-1} \frac{1}{k!}\left(\frac{z}{\delta_{i,\mathsf{d}}}\right)^k. \tag{9}$$

The CDF of Z_{d} can be derived from using the MGF approach [13]. The MGF of Z_{d} can be derived from the MGF of $Z_{\delta_{i,\mathsf{d}}}^{K_i}$. Using apply Taylor series expansion to (9), it can be expressed as

$$F_{Z_{\delta_{i,\mathsf{d}}}^{K_i}}(z) = \sum_{l=0}^{\infty} \sum_{k=0}^{K_i-1} \frac{(-1)^{k+1+l+K_i}}{k!\,(K_i+l-k)!}\left(\frac{z}{\delta_{i,\mathsf{d}}}\right)^{K_i+l}. \tag{10}$$

Let a function $\omega(l, K_i)$ be $\sum_{k=0}^{K_i-1} \frac{(-1)^{k+1+l+K_i}}{k!\,(K_i+l-k)!}$. Limiting to $L+1$ terms, (10) is approximated as

$$F_{Z_{\delta_{i,\mathsf{d}}}^{K_i}}(z) \approx \sum_{l=0}^{L} \omega(l, K_i)\left(\frac{z}{\delta_{i,\mathsf{d}}}\right)^{K_i+l}. \tag{11}$$

Using the inverse Laplace transform of the MGF of Z_{d}, we can obtain the c.d.f. of Z_{d}. Then, the MGF of $Z_{\delta_{i,\mathsf{d}}}^{K_i}$ can be obtained as

$$\begin{aligned}\mathcal{M}_{Z_{\delta_{i,\mathsf{d}}}^{K_i}}(s) &= s\int_0^{\infty} e^{-sz} F_{Z_{\delta_{i,\mathsf{d}}}^{K_i}}(z)dz \\ &\approx \sum_{l=0}^{L} \omega(l,K_i)\left(\frac{1}{\delta_{i,\mathsf{d}}}\right)^{K_i+l}\left[s\int_0^{\infty} e^{-sz} z^{K_i+l} dz\right] \\ &= \sum_{l=0}^{L} \omega(l,K_i)\left(\frac{1}{\delta_{i,\mathsf{d}}}\right)^{K_i+l}\frac{\Gamma(K_i+l+1)}{s^{K_i+l}}. \end{aligned} \tag{12}$$

As the all channels from all relays to the destination are assumed to be independent, the MGF of $Z_{\mathsf{d}} = \sum_{i\in\mathcal{D}} Z_{\delta_{i,\mathsf{d}}}^{K_i}$ can be obtained as

$$\begin{aligned}\mathcal{M}_{Z_{\mathsf{d}}}(s) &= \prod_{i\in\mathcal{D}}\left(\sum_{l=0}^{L}\omega(l,K_i)\left(\frac{1}{\delta_{i,\mathsf{d}}}\right)^{K_i+l}\frac{\Gamma(K_i+l+1)}{s^{K_i+l}}\right) \\ &= \sum_{l_{\mathcal{D}(1)}=0}^{L}\cdots\sum_{l_{\mathcal{D}(|\mathcal{D}|)}=0}^{L}\left[\prod_{i\in\mathcal{D}}\omega(l_i,K_i)\left(\frac{1}{\delta_{i,\mathsf{d}}}\right)^{K_i+l_i} \times \frac{\Gamma(K_i+l_i+1)}{s^{K_i+l_i}}\right],\end{aligned} \tag{13}$$

where a function $\mathcal{D}(x)$ has a output which is an xth smallest index in a set $\mathcal{D}$ for input x ($1 \le x \le |\mathcal{D}|$). Eq. (13) can be compactly expressed as

$$\mathcal{M}_{Z_{\mathsf{d}}}(s) = \sum_{l(\mathcal{D})}^{L}\left[\Omega(\mathcal{D})s^{-\Sigma(\mathcal{D})}\right], \tag{14}$$

where

$$\sum_{l(\mathcal{D})}^{L} := \sum_{l_{\mathcal{D}(1)}=0}^{L}\sum_{l_{\mathcal{D}(2)}=0}^{L}\cdots\sum_{l_{\mathcal{D}(|\mathcal{D}|)}=0}^{L}, \tag{15}$$

$$\Omega(\mathcal{D}) := \prod_{i\in\mathcal{D}}\omega(l,K_i)\left(\frac{1}{\delta_{i,\mathsf{d}}}\right)^{K_i+l_i}\Gamma(K_i+l_i+1), \tag{16}$$

$$\Sigma(\mathcal{D}) := \sum_{i\in\mathcal{D}}K_i + \sum_{i\in\mathcal{D}}l_i. \tag{17}$$

The same notations such as l_i for all i in (13), (15), (16), and (17) interact. Finally, the CDF of Z_{d} can be obtained by taking inverse Laplace transform of $\mathcal{M}_{Z_{\mathsf{d}}}/s$ as follows

$$F_{Z_{\mathsf{d}}}(z) = \sum_{l(\mathcal{D})}^{L}\frac{\Omega(\mathcal{D})}{\Gamma(\Sigma(\mathcal{D})+1)}z^{\Sigma(\mathcal{D})}. \tag{18}$$

4.2. Outage analysis

Finally, the overall outage probability is given by

$$\begin{aligned} P_{out} &= \sum_{\forall\mathcal{D}\subset\mathcal{R}\backslash\emptyset}\left[\prod_{i\in\mathcal{R}\backslash\mathcal{D}}\Pr\{\gamma_{\mathsf{s},i}<\gamma_{\mathsf{th}}\}\prod_{j\in\mathcal{D}}\Pr\{\gamma_{\mathsf{s},j}\ge\gamma_{\mathsf{th}}\} \times \Pr\{\gamma_{\mathsf{d}}<\gamma_{\mathsf{th}}|\mathcal{D}\}\right] + \prod_{r\in\mathcal{R}}\Pr\{\gamma_{\mathsf{s},r}<\gamma_{\mathsf{th}}\} \\ &= \sum_{\forall\mathcal{D}\subset\mathcal{R}\backslash\emptyset}\left[\left\{\prod_{i\in\mathcal{R}\backslash\mathcal{D}}F_{Z_{\delta_{\mathsf{s},i}}^{K_i}}(\gamma_{\mathsf{th}})\prod_{j\in\mathcal{D}}\bar{F}_{Z_{\delta_{j,\mathsf{d}}}^{K_j}}(\gamma_{\mathsf{th}})\right\}F_{Z_{\mathsf{d}}}(\gamma_{\mathsf{th}})\right] + \prod_{r\in\mathcal{R}}F_{Z_{\delta_{\mathsf{s},r}}^{K_r}}(\gamma_{\mathsf{th}}),\end{aligned} \tag{19}$$

where $\bar{F}_X(x)$ is the complementary cumulative distribution function for RV X, i.e., $\bar{F}_X(x) = 1 - F_X(x)$. Plugging (8) and (18) into (19),

$$\begin{aligned} P_{out} &= \sum_{\forall\mathcal{D}\subset\mathcal{R}\backslash\emptyset}\left[\left\{\prod_{i\in\mathcal{R}\backslash\mathcal{D}}\left(1-e^{-\frac{\gamma_{\mathsf{th}}}{\delta_{\mathsf{s},i}}}\sum_{k=0}^{K_i-1}\frac{1}{k!}\left(\frac{\gamma_{\mathsf{th}}}{\delta_{\mathsf{s},i}}\right)^k\right) \times \prod_{j\in\mathcal{D}}\left(e^{-\frac{\gamma_{\mathsf{th}}}{\delta_{\mathsf{s},j}}}\sum_{k=0}^{K_j-1}\frac{1}{k!}\left(\frac{\gamma_{\mathsf{th}}}{\delta_{\mathsf{s},j}}\right)^k\right)\right\} \times \sum_{l(\mathcal{D})}^{L}\frac{\Omega(\mathcal{D})}{\Gamma(\Sigma(\mathcal{D})+1)}(\gamma_{\mathsf{th}})^{\Sigma(\mathcal{D})}\right] \\ &\quad + \prod_{r\in\mathcal{R}}\left(1-e^{-\frac{\gamma_{\mathsf{th}}}{\delta_{\mathsf{s},r}}}\sum_{k=0}^{K_r-1}\frac{1}{k!}\left(\frac{\gamma_{\mathsf{th}}}{\delta_{\mathsf{s},r}}\right)^k\right).\end{aligned} \tag{20}$$

5. Simulation results

In this section, we show the performance of the proposed C-MRT technique in terms of outage probability through extensive computer simulations. Also, the proposed C-MRT technique is compared to other schemes such as PS scheme and ORS technique. For ORS, a destination node selects which link is best to communication with relay nodes as transmission relay. Only one relay with the best link transmit selectively [7]. PS scheme is to make each received signal from multiple relay nodes co-phased at the destination node by pre-adjusting the phase differences [8]. Simulation parameters are given as follows. The target rate is set to 1.5 bits/Hz/sec, i.e., $R = 1.5$ and the path-loss exponent is set to 3, i.e., $\alpha = 3$. The noise spectral density N_0 is set to -174 dBm/Hz and the system bandwidth (BW) is set to 10 MHz. Then, $\rho_{\mathsf{T}} = \left(10\log(P) - N_0 - 10\log 10^7\right)$ (dB). In the simulations, we assume a linear topology, which means $d_{\mathsf{s},i} + d_{i,\mathsf{d}} = 4$ km for all $i \in \{1,2,\ldots,N\}$. The parameter L related to analysis accuracy is 10.

Fig. 3 shows that the overall outage probability of the techniques of MANET for various $K \in \{1,2,3\}$ when $N = 3$. For the simplified simulation, K_i for all i is set as K. The proposed C-MRT as well as PS scheme and ORS technique have more improved performance as the number of antenna increase. Through the MGF approach for analysis, we analyze the tight upper bound performance of C-MRT. These theoretical results are matched well with simulation results in high SNR regime. The C-MRT technique outperforms the other techniques in MANET due to the higher diversity gain.

Fig. 4 shows that the overall outage probability of them for various number of relays $N \in \{1,2,3\}$ when $K_i = 3$ for all i. The tendency of simulation results is similar to that of

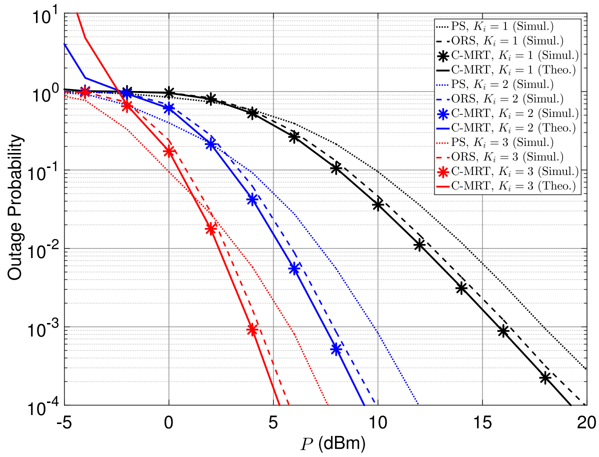

Fig. 3. Outage probability performance of MANET for various numbers of antennas, K_i, when $N = 3$ and $d_{\mathsf{s},i} = d_{i,\mathsf{d}} = 2$ for all $i \in \mathcal{R}$.

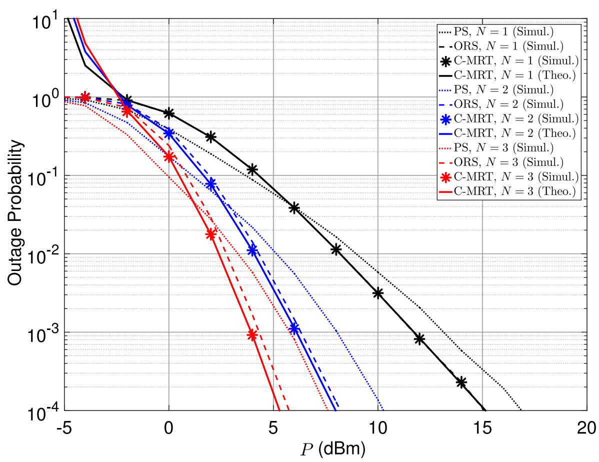

Fig. 4. Outage probability performance of MANET for various numbers of relays, N, when $K_i = 3$ and $d_{\mathsf{s},i} = d_{i,\mathsf{d}} = 2$ for all $i \in \mathcal{R}$.

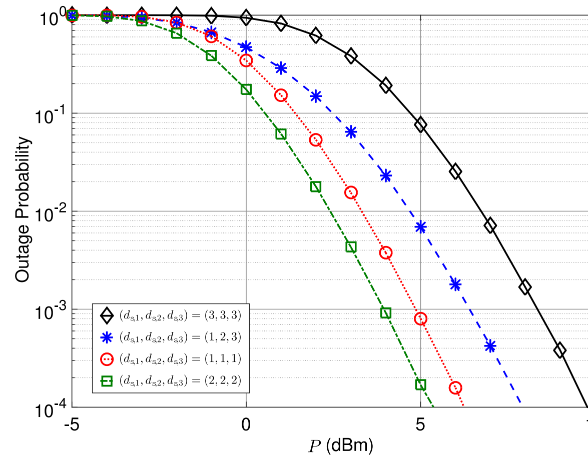

Fig. 5. Outage probability of the C-MRT technique for various locations of relays when $N = 3$ and $K_i = 3$ for all $i \in \mathcal{R}$.

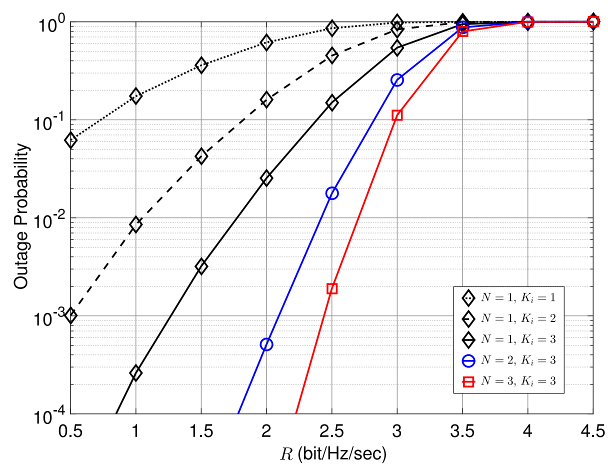

Fig. 6. Outage probability of the C-MRT technique for varying target rate R and various combination of $N \in \{1, 2, 3\}$ and $K_i \in \{1, 2, 3\}$ when $P = 10$ dBm.

results in Fig. 3 because the increase in number of relay has the same effect as the increase in number of antenna in terms of diversity gain.

Fig. 5 shows the outage probability of the C-MRT technique for various locations of relay nodes when $N = 3$ and $K_i = 3$ for all i. The distances between the source node and relay nodes are given as $(d_{\mathsf{s},1}, d_{\mathsf{s},2}, d_{\mathsf{s},3}) \in \{(3, 3, 3), (1, 2, 3), (1, 1, 1), (2, 2, 2)\}$, which is represented in kilometer unit. Note that, as noted before, the distance from the relay nodes to the destination node is set to $d_{i,\mathsf{d}} = 4 - d_{\mathsf{s},i}$ for all i. As expected, the outage performance with the relay nodes located in the center between the source node and the destination node outperforms other cases, while the outage performance varies according to the location of relay nodes.

Fig. 6 shows the outage probability of C-MRT for varying target rate R when the transmit power $P = 10$ dBm. As in the perspectives of Figs. 3 and 4, changes in the number of antennas and relays have a significant impact on the performance of the outage probability depending on the target rate.

6. Conclusions

In this paper, a novel cooperative maximum-ratio transmission technique (C-MRT) was proposed for a military mobile ad-hoc network (MANET) which consists of a single-antenna source node, a single-antenna destination node, and multiple relay nodes equipped with multiple antennas. It was assumed that each relay node is located in an arbitrary position and the arbitrary number of antennas at relay nodes. In this system, we mathematically analyzed the upper bounded overall outage probability by using the moment-generating function (MGF) approach. Through simulations, the performance of the proposed C-MRT technique in terms of outage probability was investigated with various system parameters and compared to other schemes such as phase steering scheme, optimal relay selection technique in MANET. Then, we verified that the proposed C-MRT technique outperforms the other techniques.

CRediT authorship contribution statement

Chang Seok You: Investigation, Formal analysis, Software, Investigation, Writing - original draft. **Jeong Seon Yeom:** Methodology, Software, Investigation, Validation, Formal analysis. **Bang Chul Jung:** Conceptualization, Supervision, Resources, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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