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DF BASED COOPERATIVE UAVs COMMUNICATION with CO-CHANNEL INTERFERENCE

Asst. Prof. Dr. Muhammet Ali KARABULUT
Kafkas University
ORCID: 0000-0002-2080-5485

Asst. Prof. Dr. A. F. M. Shahen SHAH
Yildiz Technical University
ORCID: 0000-0002-3133-6557

1. Introduction

Unmanned aerial vehicles (UAVs) also known as drones offer many possibilities for wireless communication networks such as wide coverage, fast installation with low costs and flexible design. In addition, UAVs can increase the capacity of existing terrestrial networks by establishing a high probability direct view (line-of-sight, LoS) connection with terrestrial users. Although many existing UAV applications are based on a single UAV, better applications can be facilitated by using cooperative UAVs (Gupta, 2016). For example, multiple UAVs can improve the performance of military and civilian reconnaissance, surveillance, imaging, film, agricultural activity, electronic warfare, search and rescue, route determination, wayfinding, target detection and mine scanning, etc. applications (Wei, 2021). In the coming decade, cellular networks that go beyond 5G and 6G are anticipated to be crucial in supporting the broad and quickly growing use of UAVs in a variety of uses. The next iteration of cellular networks, which will eventually hit 6G, aims to offer customers constant, high-definition, smooth access. Connected devices and automation systems like autonomous vehicles and UAVs have high hopes for what 6G will offer in terms of dependability, data rate, delay, and energy economy (Shah, 2019; Shah 2022a).

The cooperative communication system has gained popularity in recent times because of its increased coverage, ease of installation, increased spectral efficiency and reliable delivery. In the cooperative diversity, the participating terminals bring a virtual antenna array. In a cooperative system, amplify-and-forward

(AF) and decode-and-forward (DF) approaches are the two transmission methods that are most frequently used. The AF method is founded on the idea that the relay terminal will amplify and send the signal that is sent from the source terminal. The biggest problem encountered in this technique is signal transmission as well as amplify of noise and interference components. The greatest advantage of the AF technique is the lower transmission delay and the lower application complexity. The relay receiver decodes the information in the DF method to retrieve the initial signal. The resolved signals are recoded and sent to the destination terminal. The greatest benefit of this approach is that it can degrade noise and interference components, but it is also seen as a disadvantage of reductions in the overall performance of the system due to mistakes it can make during decoding (Liu, 2009).

One of the most significant elements influencing cooperative system performance is co-channel interference. The interference caused by other terminals transmitting from the channels between the terminals limits the performance of the system. Generally, the additive white Gaussian noise (AWGN) is suppressed because the effect of the common channel interference on the system performance is higher than the AWGN.

In DF-based cooperative communication systems, various techniques have been proposed to combat the problem of error propagation due to detection errors in the relay terminal. These techniques include maximal ratio combining (MRC), cooperative maximal ratio combining (C-MRC), and virtual noise (VN) technique are the main techniques used.

Following is a list of the contributions this study provides.

- An analytical model is developed to investigate the effect of co-channel interference in a DF-based cooperative UAVs communication.
- Influencing parameters are considered and the average bit error rate (BER) is attained under Nakagami-m fading channels.
- In the instance of using C-MRC, MRC, and VN methods in the DF-based cooperative UAV communication system with co-channel disturbance in the relay terminal, Monte Carlo simulations of the system are obtained.

The remainder of the paper is structured as follows: Section 2 lists the relevant works. Section 3 presents the system model. Section 4 gives the various decision rule techniques. Section 5 provides the simulation results. Lastly, Section 6 provides the concluding comments.

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2. Related Work

UAV-based inspection has gained considerable attention in the last decade. UAVs' benefits of fast deployment, high mobility, and simplicity of use can be used to boost communication efficiency and broaden the scope of applications for wireless communication systems (Shah, 2022b; Shah 2022c; Karabulut, 2022).

Various techniques are used to reduce error propagation in cooperative communication systems. At the beginning of these techniques, MRC (Lee, 2021), C-MRC (Wang, 2007), and virtual noise technique (Kim, 2011).

A general system of co-channel initiatives has been developed by authors in (Win, 2009). The effect of the cooperative communication with co-channel disturbance was presented in (Pinto, 2010). In (Aslan, 2017), co-channel interference effects on DF based cooperative communication, which are the best relay selection using Rayleigh fading channels using C-MRC, LAR and MRC, are investigated.

Numerous studies have been carried out in the literature on initiatives in wireless networks (Shah, 2000; Zhang, 2005; Chayawan 2001; Ahn, 2009; Mohajer, 2011). Statistical models of the recipient terminal have been investigated using the largest and most widely used combinatorial technique used in these papers (Aslan, 2017; Shah, 2000; Zhang, 2005; Chayawan 2001). These mathematical models investigated for receiver systems with multiple antennas have shown that they can be applied to a cooperative system. After the mathematical modeling for the cooperative system, detailed studies have been investigated about the effect of the cooperative channel system (Ahn, 2009; Mohajer, 2011; Kim, 2011a; Ilhan, 2015).

In the literature, the channels between the terminals are usually modelled as Rayleigh and Nakagami-*m* distribution. All these conventional distributions, though, fall short when terminals are moving. Experimental investigations demonstrate that a novel model known as the multiplying channel model or cascaded channel model is used in this situation rather than these traditional models (Mohajer, 2011; Kim, 2011a; Ilhan, 2015).

3. System Model

A single source (*S*), multiple relays (*R*), the co-channel scenario with co-channel interference with relays, and destination (*D*) UAVs as shown in Figure 1 are considered. UAVs are half duplex in the system with single antenna. Channels between the terminals are treated as Nakagami-m. BPSK modulation is used in transmission. *S* terminal sends the data signals $x \in \{-1,1\}$ to *R* and *D* during the

first time slot. The *S* terminal transmits a noisy signal, which is received by the *R* terminal and the co-channel interference signal up to *L* and transmits it to the *D* terminal. In *D*, both the co-channel interference signal transmitted by *R* and the noisy signal transmitted by *S* are combined.

In Fig.1, h_{ij} and d_{ij} are the complex fading coefficient and the distance between node *i* and *j* respectively $\left(i \in \{S, R_1, ..., R_N\}, j \in \{R_1, ..., R_N, D\}, i \neq j\right)$. The magnitudes of all of the links follow Nakagami-m distribution. The probability density function (PDF) of Nakagami-m distribution is given by (Lee, 2009)

$$f_h(h) = \frac{2m^m h^{2m-1}}{\Gamma(m)\Omega^m} \exp\left(-\frac{mh^2}{\Omega}\right) \quad (1)$$

where Γ(.) is Gamma function, $\Omega = E\{h^2\}$ is variance of random variable *h*, $m = \Omega^2 / E\{h^2 - \Omega^2\} \geq 0.5$ is the Nakagami-m fading parameter and $E\{.\}$ is the statistical expectation operator.

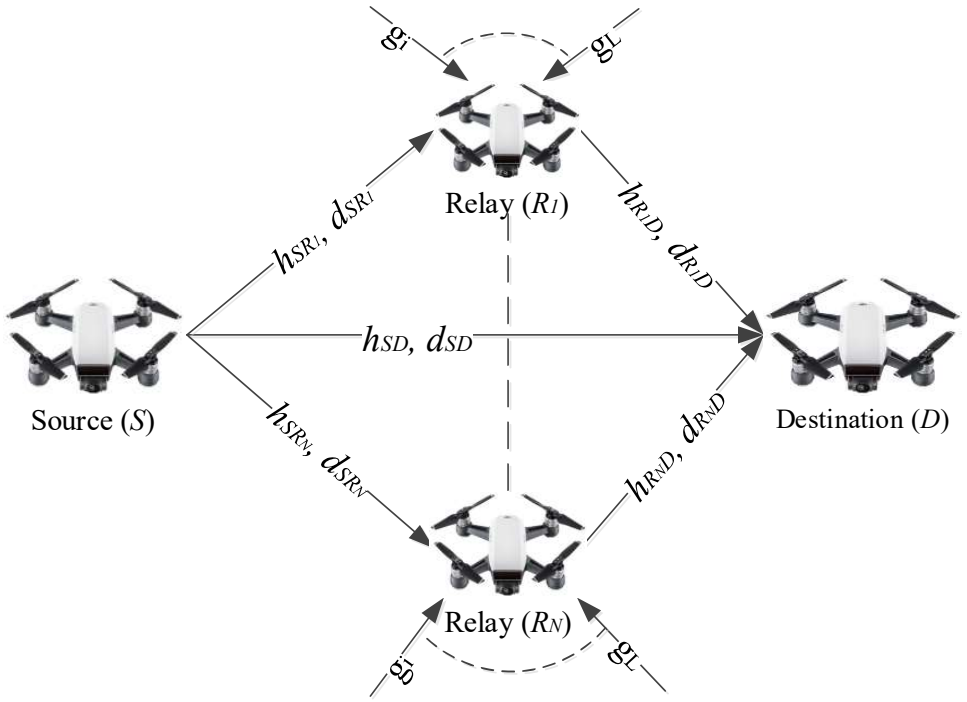


Figure 1. System model.

The received signals at the k_{th} relay terminal and the destination terminal during the first time slot for BPSK signaling can be written as

$$y_{SD} = h_{SD}\sqrt{E_S}x_S + z_{SD}, \quad (2)$$

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$$y_{SR_k} = h_{SR_k}\sqrt{E_S}x_S + \sum_{c=1}^{I}\sqrt{E_c}x_c g_c + z_{SR_k}. \quad (3)$$

Here, z_{SD} and z_{SRk} express the AWGN modeled as independent zero-mean complex Gaussian random variables with variance $N_o/2$ per dimension, x_s is the symbol of S, x_i is the symbol of co-channel interference and given by $x_S = -(-1)^{u_S}$ and $x_c = -(-1)^{u_c}$, respectively. Here, u_c is co-channel interferer's binary sequence. In (2) and (3), E_s denotes the transmitted symbol energy, E_c indicates the co-channel interference transmitted symbol energy, $\gamma_{ij} = E_S|h_{ij}|^2/N_0$ is the instantaneous value of the signal-to-noise ratio (SNR), g_c denotes the complex fading distribution whose magnitude represents the Nakagami distribution.

In the second time slot, the source terminal remains silent, the relay terminal anticipates the data signals, re-encodes and transmits them to the destination terminal. The predicted $\hat{x}_S$ sign can be expressed as:

$$\hat{x}_S = \arg_{x\in\{-1,1\}}\min\left|y_{SR} - \sqrt{E_S}x_S h_{SR}\right|^2. \quad (4)$$

The noisy signal transmitted from R terminal and received by D terminal can be expressed as:

$$y_{R_kD} = h_{R_kD}\sqrt{E_S}\hat{x}_S + z_{R_kD}. \quad (5)$$

4. Decision Rules

The following subsections provide an explanation of the decision criteria applied at the destination for MRC, C-MRC, and VN techniques.

A. Maximal Ratio Combining

Both the MRC weight weight vector and the outgoing signal are

$$\begin{aligned} w_x &= h_x \\ y_{SRD} &= w_x^H r \end{aligned} \quad (6)$$

where y denotes the combiner's result, and r is the signal that was received. Consequently, in ideal circumstances, the outgoing signal can be expressed as

$$y_{SRD} = w_{SD}^H y_{SD} + \sum_{k=1}^{N} w_{R_kD}^H y_{R_kD} \quad (7)$$

where w_{SD} and w_{RD} are optimal weight vector and depend on h_{SD} and h_{RD} respectively. Substituting $w_{SD}^H = h_{SD}^*$ and $w_{R_kD}^H = h_{R_kD}^*$ into (8), the output signal can be written as

$$y_{SRD} = \frac{h_{SD}^* y_{SD}}{N_0} + \sum_{k=1}^{N} \frac{h_{R_kD}^* y_{R_kD}}{N_0} \tag{8}$$

where the complex conjugate operator is indicated by (.)*. The MRC's decision rule can be expressed as

$$\hat{x}_s = \begin{cases} 1 \\ \square\{y_{SRD}\} \gtrless 0 \\ 0 \end{cases} \tag{9}$$

where $\square\{y_{SRD}\}$ denotes real part of $\{y_{SRD}\}$.

B. Cooperative Maximal Ratio Combining

In the C-MRC method, comparable SNR of the *S-R-D* link is used in finding the weight vectors as opposed to the MRC technique, which only considers the SNR of the *R-D* link. The weight vectors w_{SD} and w_{RD} for the C-MRC are provided as

$$\begin{aligned} w_{SD} &= h_{SD}^*, \\ w_{R_kD} &= \frac{\gamma_q}{\gamma_{R_kD}} h_{R_kD}^*, \end{aligned} \tag{10}$$

γ_q can given as [4]

$$\gamma_e = \left(Q^{-1}\left(P_e\left(\gamma_{SR_k}, \gamma_{R_kD}\right)\right)\right)^2 / \alpha, \tag{11}$$

where $Q(t) = \frac{1}{\sqrt{2\pi}} \int_t^{\infty} e^{\frac{-f^2}{2}} df$ and α is a constant that be contingent on the constellation (α=2 for BPSK). When the *S-R* transmission is properly received but the *R-D* transmission is incorrectly received, or the other way around, errors at the *D* occur. The bit error chance of *S-R-D* communication lines is denoted by P_e which can be expressed as

$$P_e\left(\gamma_{SR_k},\gamma_{R_kD}\right)=\left(1-P_{SR_k}\left(\gamma_{SR_k}\right)\right)P_{R_kD}\left(\gamma_{R_kD}\right)+\left(1-P_{R_kD}\left(\gamma_{R_kD}\right)\right)P_{SR_k}\left(\gamma_{SR_k}\right). \tag{12}$$

The following can be expressed as the C-MRC decision rule:

$$\hat{x}_S=\arg_{x\in A_x}\min\left|w_{SD}y_{SD}+w_{R_kD}y_{R_kD}+\left(w_{SD}y_{SD}+w_{R_kD}y_{R_kD}\right)x_s\right|^2. \tag{13}$$

C. Virtual Noise

The key concept of virtual noise based techniques is based on the strategy of modeling the prediction error occurring in the *R* terminal as a virtual noise component received from the *D* terminal. This method models estimation errors that happen at the *R* node as virtual noise. Therefore, the signal received by the *D* terminal and sent by the *R* terminal can be rewritten as (Kim, 2011b)

$$y_{R_kD}=h_{R_kD}\sqrt{E_S}\hat{x}_S+\sum_{c=1}^{L}\sqrt{E_c}x_c g_c+z_{R_kD}+z_{vr}, \tag{14}$$

where z_{vr} is the zero-averaged virtual noise component independent of the z_{RD} signal with added white Gaussian noise. The combined signal at the *D* terminal can be written as

$$y_{SRD}=w_{SD}y_{SD}+\sum_{k=1}^{N}w_{R_kD}y_{R_kD}. \tag{15}$$

The VN weight vectors w_{SD} and w_{RD} are given as

$$w_{SD}=h_{SD}^*/N_0,$$
$$w_{R_kD}=\frac{h_{R_kD}^*}{N_0\left(1+\left|h_{R_kD}\right|^2/\left|h_{SR_k}\right|^2\right)}. \tag{16}$$

The decision rule in the *D* terminal can be written as

$$\hat{x}_s=\begin{cases}1 & \{y_{SRD}\}>0\\ 0 & \{y_{SRD}\}<0\end{cases} \tag{17}$$

In this case, the average bit error rate in the *D* can be defined as follows (Kim, 2011b)

$$P_e = \left(1 - Q\left(\sqrt{2\gamma_{SR_k}}\right)\right) Q\left(\sqrt{\frac{2(\gamma_{SD}+\gamma_e)^2}{(\gamma_{SD}+\gamma_e')}}\right) + Q\left(\sqrt{2\gamma_{SR_k}}\right) Q\left(\sqrt{\frac{2(\gamma_{SD}+\gamma_e)^2}{(\gamma_{SD}+\gamma_e')}}\right). \quad (18)$$

In this case, γ_e and γ_e' can be written respectively as

$$\gamma_e = \frac{|h_{SR_k}|^2 \gamma_{R_kD}}{|h_{SR_k}|^2 + |h_{R_kD}|^2}, \quad (19)$$

$$\gamma_e' = \frac{|h_{SR_k}|^4 \gamma_{R_kD}}{\left(|h_{SR_k}|^2 + |h_{R_kD}|^2\right)^2}. \quad (20)$$

5. Simulation Results

In this section, simulation results are presented which are conducted in MATLAB. The simulation circumstances are similar to those in (Wang, 2007), and we presume that the source terminals are very near to one another, relays and destination nodes are situated where the path from the *S* to the k_{th} *R* $(d_{SR_k}, k=1, 2, \ldots, N)$, is in a straight line. The distances between *S* and *D* are used to normalize the distances from the k_{th} relay to the destination (d_{R_kD}), therefore, $d_{SR_k} + d_{R_kD} = 1, d_{SR_k} \approx d_{SR_k} \approx \ldots \approx d_{SR_k}$. The channel fading coefficient variance between nodes *i* and *j* is modeled as $\sigma_{ij}^2 = d_{ij}^{-v}$ where d_{ij} indicates the distance and the path loss coefficient is denoted by *v* which is selected to be 4 for the case of lossy environments and specular reflection from the earth surface (Wang, 2007). Signal-to-interference ratio (SIR) $\gamma_{g_c} = E_c / N_0$ is assumed to be 20 dB. The energy of co-channel interference is considered E_c=1. Comparisons of SNR are performed at a BER of 10^{-3}.

In Figure 2, in the absence of co-channel interference at *R* terminals, BER performance curves of the cooperative UAV system are obtained in the case of using C-MRC, MRC and VN techniques. As it is clear from the results, the performance of the cooperative UAV communication system using C-MRC technique is superior to MRC and VN techniques.

In Figure 3, we see the BER performance graphs of the cooperative UAV system under the conditions of co-channel interference 1 and 3 at the R nodes, when

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using the C-MRC, MRC, and VN methods, respectively. The number of relays N is taken as 3 in the system. As evidenced by the results, the performance of the cooperative UAV communication system using the C-MRC technique, where there is only one co-channel interference, is more successful than other techniques.

In Figure 4, BER performance curves under the Nakagami-m damped channel are given for the situation where the source is near to the relay (d_{RD}=0.75) as well as the situation where the relay is close to the destination (d_{RD}=0.25) in the systems examined for number of relays N=2 and co-channel interference L=2, respectively. The inclinations of the obtained curves show that complete diversification gain is always attained and that the relay performs best when it is placed near to the source node. The C-MRC method is superior to others.

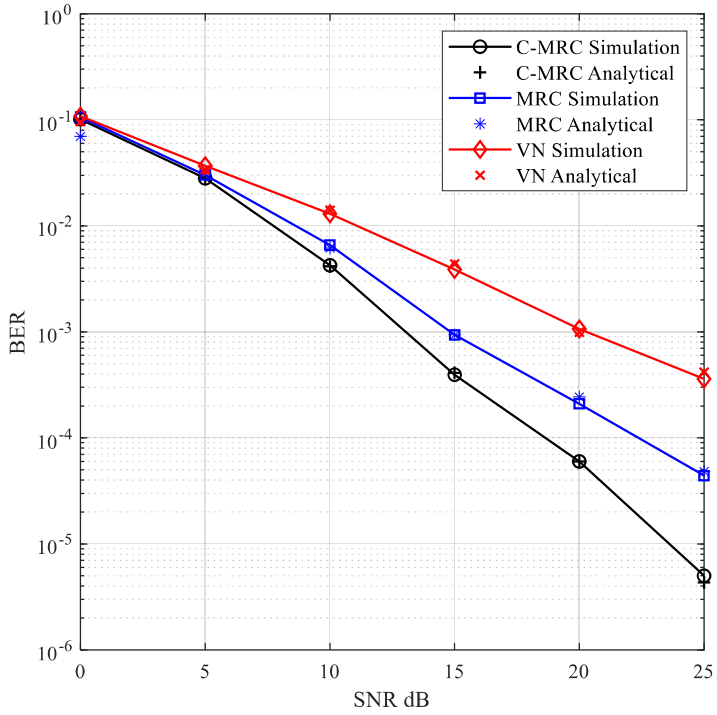


Figure 2. BER performance of cooperative UAV system with no co-channel interference at R (N=1).

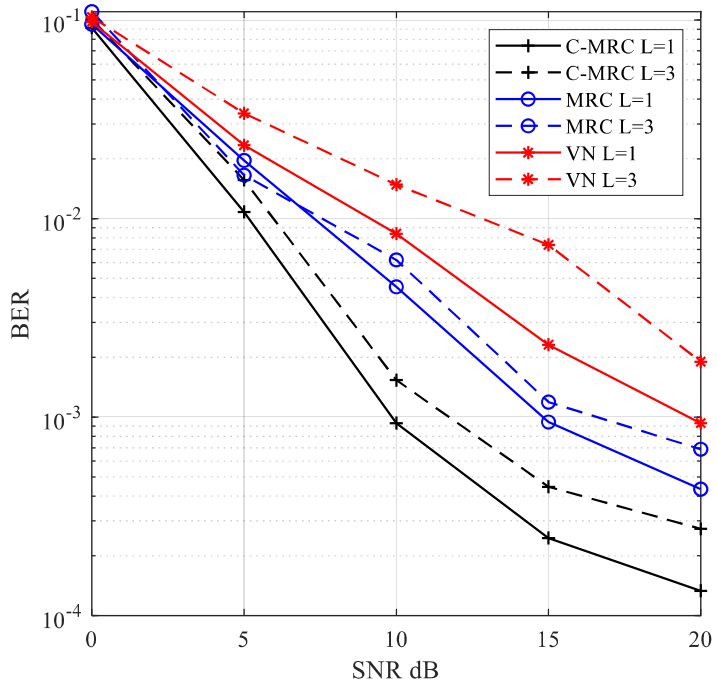


Figure 3. BER performance of cooperative UAV system with 1 and 3 co-channel interference at *R* (*N*=3).

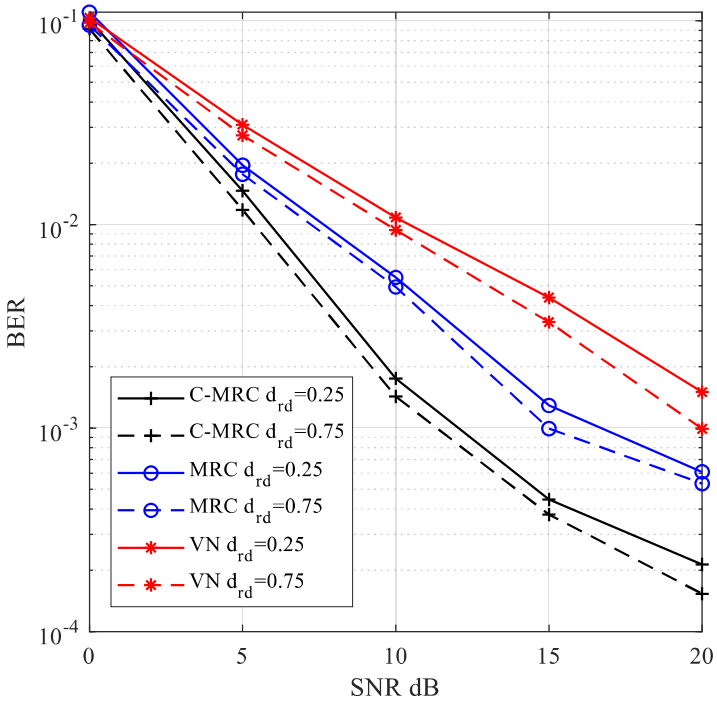


Figure 4. BER performance of cooperative UAV system with 2 co-channel interference at *R* (*N*=2).

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6. Conclusion

In this paper, an analytical model is developed to investigate the effect of co-channel interference in a DF-based cooperative UAVs communication. Under Nakagami-m fading channels, C-MRC, MRC, and VN methods are studied at the destination. The figures show that when there are numerous co-channel interferences at the relay end, the performance of the system under consideration notably degrades. Moreover, it is evident that the C-MRC method performs optimally when co-channel interference is present.

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