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OUTAGE PERFORMANCE OF COOPERATIVE RELAY PROTOCOL ON UAVS-BASED FLYING ADHOC NETWORK

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Abstract

Unmanned aerial vehicles (UAVs) are getting increased strength and count day by day in various civilian and military applications. The UAVs can form flying ad-hoc networks (FANET) to send data to a distant ground control station through multi-hop relaying. However, due to typical features of UAVs and limitations posed by areas of deployment, achieving efficient data dissemination with quality of service is a challenging task in such networks. Different algorithms have been reported in literature however, physical layer transmission issues need to be investigated more in such networks. In this work, we consider dual-hop cooperative communication using a single relay in a downlink communication scenario. A data dissemination scheme based on cooperative relaying is proposed to ensure reliability in operation. The performance of a non-buffer aided dual-hop relay network of UAVs considering the hardware impairments is analyzed. The end-to-end SNR analysis and derivation of the probability of outage expressions for both regenerative and non-regenerative modes of communication working in a half-duplexed fashion are presented. Monte Carlo Simulations verify the analytical results and depict that our proposed cooperative communication scheme improves the system performance compared to compulsory direct and compulsory indirect communication. The system achieves performance improvement at lower data rates using hardware without impairments working on Rayleigh fading channels in an urban environment. Results display that the fading distribution coefficients have a strong impact on system performance.

Keywords: Data Dissemination, Cooperative Relaying, UAV Deployment Scenarios, System Outage Probability, Monte Carlo Simulation

1.0 INTRODUCTION

The quadrotor unmanned aerial vehicles (UAVs) based flying ad-hoc networks (FANETs) find utilization in a range of applications like remote sensing, search and rescue, traffic monitoring, disaster management, wildlife surveillance, agriculture and communication network expansions, etc. [1]. UAVs can be installed with sensors, cameras, embedded systems, and transceivers. The acceptance of UAVs has resulted in wide availability of UAVs that can be utilized for these applications at lower costs [2]. An efficient way of improving the capability of these UAVs is to use cooperative relaying in FANETs [3]. This aerial relaying providing cooperative diversity is a cost-effective operation. The topology of relaying consumes less power due to a reduction in distance among communicating nodes compared to direct transmission [4]. The aerial relays can work in amplify-and-forward (AF) or decode-and-forward (DF) mode of wireless communication [5]. The relays with fixed or variable gain can be selected to meet the network requirements. A range of algorithms has been reported in literature that uses multiple relays in cooperative settings [6] improving the network range, capacity and performance. Naturally, the UAVs-based applications demand quality of service and reliability in operation [7] that can be provided by working across the layers [8]. The reliability of FANET needs to be improved by reducing the link outage [9].

The wireless ad-hoc networks suffer signal loss and interferences due to typical features of UAVs and limitations imposed by areas of deployment [10]. The buildings, trees and other obstacles make these networks intermittent and unreliable. The UAVs, if deployed in urban propagation environments to monitor the target areas, face fading and noise on their channels. The UAV channels suffer power fluctuations due to multipath propagation, Doppler spread, and air turbulences, which become even more severe at higher mobility of UAVs. The distortion noise of the low-cost UAVs affects the system performance as well. The issues with hardware equipment like impairments of the low-cost UAVs, and distance between communication nodes are additional causes of system unreliability [11]. Usually, these hardware impairments are due to nonlinear operation of the high power amplifiers, single input single output antenna systems, presence of phase noises and imbalances among the UAVs that lead to increased bit error rate, noise figure and mirror subcarriers. In low-cost hardware of UAVs, these impairments become even more prominent at higher data rates and should be considered in system design and evaluation.

The majority of the literature assumes ideal hardware and neglects some impairments due to which simulation results and practical experimental results of system performance show differences in parametric values [12]. Practically various hardware and software algorithms can be used to compensate for these impairments but residual impairments cannot be eliminated and contribute to the system outage. In addition, these solutions increase cost of the equipment. Researchers are finding ways to overcome these issues, improving the reliability of such networks and providing the capability to complete the tasks under various threats.

The UAVs-based network issues are reviewed by [3] studying gateway selection, hierarchy formation, and stability control deriving the closed-form expressions for asymptotic sum rate. Single-hop wireless communication is compared with dual-hop communication over FANET in [4] where authors envision for new solutions to overcome the typical limitations of the UAVs. The work presented in [13] studies hardware impairment aware data collection and energy usage minimizing algorithm using multi input multi output full-duplexed UAVs. The UAVs-based non-orthogonal multiple access multi relay network in AF mode is analyzed and the residual hardware impairments are considered while analyzing the system in [14]. The authors in [15] worked on three nodes based aerial network designing UAVs trajectory, and power allocation to enhance the system energy efficiency and considering the UAV's typical issues. They showed that if multiple relays are available between source and destination, they could support in signal cooperation. In addition, selection of one best among multiple available relays can reduce the required network resources.

The authors in [16] studied the probability of outage of a multi-hop communication system in Nakagami-m fading environment in presence of co-channel interferences with a relay working in a cooperative relaying fashion in AF and DF relaying protocols. They derived probability of outage expression for the N-hops in both cases and compared their performances in presence of independent and non-identical Nakagami-m fading interferers at the nodes. In this work, looking at the link quality on the direct path compared to that of the indirect path, the destination node selects the packet on the direct path or combines the packets from direct and indirect paths using the Maximal Ratio Combining (MRC) methods. The transmit and receive diversities were studied by authors in [17] using the maximum ratio transmission and MRC at the receiver. The authors in [18] studied performance of the dual-hop transmission system using a relay with fixed gain. The study carried out in [11] analyzes the impact of hardware impairments on imperfect channels of buffer-aided UAVs-based cooperative relaying networks.

Most of the reported work is focused on data dissemination algorithms in general packet radio network formations, however the physical layer outage performance in cooperative communication scenarios on UAVs-based cooperative networks needs to be investigated more. An in-depth analysis is required to find the impact of various network parameters, settings and scenarios on system performance. In this work, a cooperative communication algorithm on UAVs-based FANET is introduced that uses both direct and indirect paths while communicating with the ground control station (GCS). This work considers additive white Gaussian noise (AWGN) as a noise model while studying the performance of single input single output type UAVs in half-duplexed fashion and considering the hardware impairments. In this work, we focus on end-to-end system outage performance. The second section presents system model; the third section formulates the problem and derives expression for probability of outage for the system with Nakagami-m and Rayleigh fading links considering various scenarios; the fourth section provides the numerical result discussions, and the fifth section concludes the discussion.

2.0 SYSTEM MODEL

Consider a group of cooperative UAVs working with a GCS to observe a target area and passing the captured observation to the GCS directly or indirectly through an aerial relay being in close proximity as demonstrated in Figure 1. The relaying UAV forwards the gathered observation to the GCS in a non-buffer aided fashion. In downlink communication, we assume that the direct path can be obstructed between observing UAV and the GCS due to shadowing of the building environment of the urban area of deployment. Let d_2 is the geometric distance of relay UAV from GCS and d_{direct} is the distance of source UAV from the GCS such that $d_2 < d_{irect}$ while d_1 is the inter UAV distance. The UAVs are assumed to be deployed at same lower heights in urban propagation environments for observation purposes.

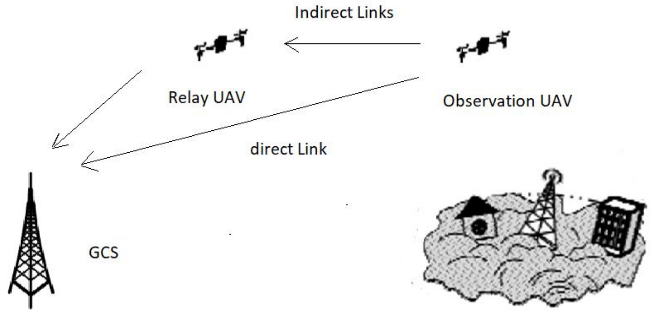

Figure 1 UAVs-based FANET with Single Relay

3.0 PROBLEM FORMULATION AND OUTAGE PROBABILITY ANALYSIS

Assume communication among nodes is on orthogonal channels where two independent signals reach the destination in the same time slot from source by using different frequencies or using two frequencies in two time slots. The path loss model for the UAV to UAV as air to air is given as Equation (1).

$$PL_1(d) = \pounds_1 10\ log_{10} d_1 + \text{ļ}_1 \tag{1}$$

in dBs and can be expressed as $\mathrm{pl}_1(\mathrm{d}) = 10^{0.1\mathrm{PL}_1(\mathrm{d})}$ in absolute values. The parameter $\pounds_1$ is the path loss exponent from UAV to UAV on air-to-air link and its value is approximately 2 for free space, and ranges from 2 to 6 in urban areas [19], d_1 is the distance between two UAVs while ļ_1 is the path loss at reference distance of 1 meter and is given by the expression $\text{ļ}_1 = 10\ log_{10}\left(\frac{4\pi f}{c}\right)$ which is function of carrier frequency. The air to ground path loss model for UAV to GCS is given as Equation (2).

$$PL_2(d) = \pounds_2 10\ log_{10} d_2 + \text{ļ}_2 \tag{2}$$

in dBs and can be expressed as $\mathrm{pl}_2(\mathrm{d}) = 10^{0.1\mathrm{PL}_2(\mathrm{d})}$ in absolute values. For direct possible air to ground link between source UAV and destination GCS, these expressions are as Equation (3).

$$PL_{direct}(d) = \pounds_3 10\ log_{10} d_{direct} + \text{ļ}_3 \tag{3}$$

and $\mathrm{pl}_{\mathrm{direct}}(\mathrm{d}) = 10^{0.1\mathrm{PL}_{\mathrm{direct}}(\mathrm{d})}$. The signal can reach destination directly or relay can contributed to the signal transmission as per cooperative relaying strategy. Assuming one relay contributes in signal transmission, the received signal can be expressed in general form as Equation (4).

$$y = h\sqrt{P_s} x_s + n \tag{4}$$

The parameters: h, x_s, and n are assumed independent of each other. $\sqrt{P_s} x_s$ is the transmitted source information, h is channel gain and $n \sim \mathbb{CN}(0, \sigma^2)$ is AWGN on channels of this multi-carrier system. Here x_s is the source transmitted data stream and P_s is maximum transmit power by the source. Here h, the channel magnitude that may follow Nakagmai-m with parameter m and average fading power Ω or Rayleigh fading distribution depending on deployment scenarios. The transmitter and receiver hardware impairments can cause distortion noise and disturb the received and transmitted signals and can introduce distortion in the received signal. The model introduced by [20], [21]describe these hardware impairments as expressed in Equation 5.

$$y = h\left(\sqrt{P_s} x_s + \eta_S\right) + \eta_D + n \tag{5}$$

Here distortion noise η, is the function of the hardware impairments of both source and destination nodes that are defined as $\eta_S \sim \mathbb{CN}(0, {I_S}^2 P)$ in source hardware as impairment distortion factor and $\eta_D \sim \mathbb{CN}(0, {I_D}^2 P|h|^2)$ in destination as hardware distortion factor [11]. Using the average signal power $P = \mathbb{E}\{|x_s|^2\}$, the instantaneous channel gain $|h|^2$ as seen at the receiver, and the impairments levels I_S and I_D in the source and destination, the aggregate distortion on the link can be expressed as Equation 6.

$$\mathbb{E}_{\eta_S, \eta_D}\{|h\eta_S + \eta_D|^2\} = P|h|^2({I_S}^2 + {I_D}^2) \tag{6}$$

Here $\mathbb{E}\{.\}$ is the expectation operator. In equation 6, $I_S, I_D \geq 0$ can be elaborated using error vector magnitudes that can be approximated at an aggregate level as $I = \sqrt{{I_S}^2 + {I_D}^2}$. Now without expressing the exact contribution of the source and destination and considering aggregate distortions I, the received signal can be approximated as Equation (7).

$$y = h\left(\sqrt{P_s} x_s + \eta\right) + n \tag{7}$$

here $\eta \sim \text{ÇÑ}(0, I^2 P)$ considers aggregate values. Selecting $I_S = 0$ and $I_D = 0$ in equation 4, refers to the hardware conditions without impairments. Considering indirect dual-hop communication link between source UAV and destination GCS through intermediate relaying UAV, the received signal of equation 7 can be generalized to Equation (8).

$$y_i = h_i\left(\sqrt{P_i} x_i + \eta_i\right) + n_i \tag{8}$$

where i represents the hop number of the relayed path. Both signals are assumed to have average signal powers of $\mathrm{P}_i = \mathbb{E}_{s_i}\{|\mathrm{x}_{si}|^2\}$ while signal to noise ratios (SNRs) of both hops of the indirect path can be expressed $\lambda_i = \frac{\mathrm{P}_i \mathbb{E}_{\rho_i}\{\rho_i\}}{\mathrm{N}_i pl_i(r)}$ which are position dependent and consider both fading and path losses. To conserve the system energy, we assume that the UAVs hover at predetermined locations, ignoring the UAVs acceleration and decelerations, we can use average SNR values of fading channels in analysis defined as $\lambda_i = \frac{\mathrm{P}_i \mathbb{E}_{\rho_i}\{\rho_i\}}{\mathrm{N}_i\, pl}$. In our considered scenario, the complex Gaussian receiver noise can be represented by $n_i \sim \mathbb{CN}(0, N_i)$, and the distortion noise can be represented by $\eta_i \sim \mathbb{CN}(0, I^2 P_i)$. The channel magnitudes h_i can be modelled using Nakagami-m or Rayleigh fading coefficients, which are independent, but non-identically gamma distributed. It leads to consider the channel gains $\rho_i = |\mathrm{h}_i|^2$ as $Gamma(\alpha_i, \beta_i)$ distributed random variables with $\alpha_i \geq 1$ and $\beta_i \geq 0$. Here α_i represents fading and shadowing severity rate factor and β_i represents fading and shadowing shape factor of both hops.

In this context, we introduce a data communication strategy from source UAV to destination GCS which is based on cooperative relaying (CR) where both direct and indirect communication through a relay paths contribute to the signal at the destination as described in Figure 1 and mathematically as Equation (9).

$$y_D = y_{direct} + y_{indirect} \tag{9}$$

Based on instantaneous strength of the overall path's end-to-end SNR the destination accepts the superimposed signal from source and relay if SNR is more than a threshold value ($\lambda_{th} = 2^{2r} - 1$) expressed as Equation (10).

$$\lambda_D = \lambda_{direct} + \lambda_{indirect} \geq \lambda_{th} \tag{10}$$

The maximum ratio combining technique using CSI is used here to combine direct and indirect signal.

For the non-regenerative AF mode of communication considering hardware distortions, as per [18], the end-to-end SNR of the dual hop indirect path is given as Equation (11)

$$\gamma_{AF} = \left[\prod_{i=1}^{2}\left(1 + \frac{1}{\gamma_i}\right) - 1\right]^{-1} \tag{11}$$

This expression shows that the power P2 at the relay node changes with change in first-hop channel gain. Here assume the signal transmitted by the relaying UAV is having gain G that is selected at the relay such that, the power constraint is satisfied and is defined as Equation (12).

$$G_{ni}^{AF} = \sqrt{\frac{P_2}{P_1\rho_1(1+I_1^2)+N_1}} \tag{12}$$

By performing mathematical manipulations on this expression, we obtain expression for the end-to-end SNR on dual hop indirect path as Equation (13).

$$\lambda_{ni}^{AF} = \frac{\rho_1\rho_2}{\rho_1\rho_2 u + \rho_2(1+I_2^2)\frac{N_1}{P_1} + \frac{N_2}{P_1(G_{ni}^{AF})^2}} \tag{13}$$

In this equation, parameter, $u = I_1^2 + I_2^2 + I_1^2 I_2^2$ is introduced assuming that the destination GCS knows statistical channel conditions with receiver and the distortion noises. For the case $I_1 = I_2 = 0$, the end-to-end SNR expression becomes as Equation (14).

$$\lambda_{id}^{AF} = \frac{\rho_1\rho_2}{\rho_2\frac{N_1}{P_1} + \frac{N_2}{P_1\left(G_{id}^{AF}\right)^2}} \tag{14}$$

and the gain expression is reduced to Equation (15).

$$G_{id}^{AF} = \sqrt{\frac{P_2}{P_1\mathbb{E}_{\rho_1}\{\rho_1\} + N_1}} \tag{15}$$

For regenerative DF mode of communication, expression for the end-to-end SNR for the indirect path is as Equation (16)

$$\lambda_{DF} = min(\lambda_1, \lambda_2) \tag{16}$$

Assuming that the relaying node has information about the channel magnitude h₁ and destination has the information about channel magnitude h₂ in addition to the distortion noises, the end-to-end SNR for DF mode, can be expressed as Equation (17).

$$\lambda_{ni}^{DF} = min\left(\frac{\rho_1 P_1}{P_1\rho_1 I_1^2 + N_1}, \frac{\rho_2 P_2}{P_2\rho_2 I_2^2 + N_2}\right) \tag{17}$$

This expression does not need channel knowledge at source since a fresh signal is to be generated in DF mode. Neglecting hardware impairments, equation 17 is left as Equation (18).

$$\lambda_{id}^{DF} = min\left(\frac{\rho_1 P_1}{N_1}, \frac{\rho_2 P_2}{N_2}\right) \tag{18}$$

Now considering the possibility of a direct link between observing UAV and the GCS, the channel status is expressed as Equation (19).

$$\lambda_{direct} = \frac{\rho_{direct}\,|h_{direct}|^2}{1+\rho_{direct}\,|h_{direct}|^2} \tag{19}$$

The case, the SNR is less than the threshold ($\lambda_D = \lambda_{direct} + \lambda_{indirect} < \lambda_{th}$), no communication happens and this situation is termed as outage. The probability of system outage can be derived using the cumulative distribution function (CDF) and probability density function (PDF) of the channel gain ρ_i which are defined by [22] as Equation (20) and (21).

$$F_{\rho_i}(x) = 1 - \sum_{j=0}^{\alpha_i - 1} \frac{e^{-\frac{x}{\beta_i}}}{j!}\left(\frac{x}{\beta_i}\right)^j, x \geq 0 \tag{20}$$

$$f_{\rho_i}(x) = \frac{x^{\alpha_i - 1} e^{-\frac{x}{\beta_i}}}{\mathrm{T}(\alpha_i)\beta_{i_i}^{\alpha_i}}, x \geq 0 \tag{21}$$

respectively. Here $\mathrm{T}(\alpha_i)$ is the gamma distribution for which the average fading power is $\mathbb{E}_{\rho_i}\{\rho_i\} = \alpha_i\beta_i$. The probability of outage is usually defined as the probability that the total SNR falls below a certain threshold value λ_{th} due to channel fading and is expressed [23] as Equation (22).

$$P_{out}(x) = \mathbb{P}\{\lambda_D < \lambda_{th}\} \tag{22}$$

For Nakagami-m fading, the outage probability of the system in AF mode can be generalized [18] as Equation (23).

$$P_{out}^{AF} = 1 - \prod_{i=1}^{2}\left(1 - \frac{\mathrm{T}(\alpha_i, \frac{\alpha_i\lambda_{th}}{\overline{\lambda_\iota}})}{\mathrm{T}(\alpha_i)}\right) \tag{23}$$

where $\overline{\lambda_\iota}$ is the average SNR of the i^th^ hop link and $\mathrm{T}(.)$ is the gamma function. The outage probability for the network hardware having impairments and working with Nakagami-m fading channels. The channel gain of the hop ρ_i is Gamma (α_i, β_i) distributed and $\alpha_i \geq 1, \beta_i > 0$. The Rayleigh fading is subject to the selection of parameters $\alpha_i = 1, \beta_i = \Omega_i$ [24]. For outage probability analysis of DF mode of communication in non-ideal case over Nakagami-m fading channel, let ρ_i is independent positive random variable as Equation (24).

$$\begin{aligned} P_{out}^{DF}(x) &= 1 - \mathbb{P}\{\lambda_1 > x\}\mathbb{P}\{\lambda_2 > x\} \\ &= 1 - (1 - F_{p_1}(x))(1 - F_{p_2}(x)) \end{aligned} \tag{24}$$

where $F_{p_1}(x), F_{p_2}(x)$ are the CDFs of both hops. For Rayleigh fading, the selection of parameters is $\alpha_i = 1, \beta_i = \Omega_i$. As per equation 10, the MRC signal determines quality in communication. To have asymptotic SNR analysis of P_{out} for both AF and DF modes of communication, we assume the, channel SNR grows large. In this case, the fading distribution of channel gains remain positive, due to which the relay gain converges. Numerical results can verify the combinations of system parameters for whom the proposed CR system can perform better in terms of outage probability. Next section discussed implementation results.

4.0 RESULTS DISCUSSION

The numerical results are validated through MATLAB simulations. Monte Carlo Simulations are run 10^5 times for different scenarios to validate the derived expressions. Figure 2 shows system outage probability, P_{out} as a function of the channel average SNR (γ) on a range from 0 to 40 dB for the base indirect transmission scheme through a relay working in AF mode. The SNR is increased either by increasing power level or by decreasing the internode distance of FANET, decreasing the path loss. The channel fading is assumed Nakagami-m distributed over dual-hop and source and relay are considered having hardware without impairments. The obtained graphs are results of various data rates of 0.5 to 5 b/s/Hz. Simulation results validate that the outage probability improves by decreasing the data rate on channels. Similar behavior is observed for the system using hardware having distortion impairments of $I_S = 0.1$ and $I_D = 0.1$ as demonstrated by Figure 3. Comparing the results, the hardware without impairments offers better system performance compared to hardware with impairment especially on channels with high data rates, which confirms the theory. For example for a data rate of 2, the hardware with impairments offers outage probability of 0.6 at SNR of 25 dB compared to 0.4 at same SNR and data rate for the hardware without impairments. At lower data rates, however, the performance is approximately same in two cases of hardware with and without impairments.

Figure 4 demonstrates the impact of proposed cooperative relaying using MRC at the destination. In scenario 1, Nakagami-m, fading channel behavior is demonstrated while scenario 2 discussed Rayleigh fading case. The data rate is considered 2 and the hardware is considered having no impairments for the analysis purposes while the relay is assumed to work in AF mode. The system outage probability improves considerably because MRC considers both signal components arriving indirectly from the relay and directly from the source that contribute to the signal strength at the destination. Even at lower SNR values, MRC enables data communication by improving the system outage. A similar behavior is observed for Rayleigh fading channels. Comparing the results, Rayleigh fading scenario performs better than the Nakagami-m scenario. For example, at 25dB, Rayleigh fading offers 0.1 Pout which is 0.2 for Nakagami-m.

Figure 5 demonstrates the system performance for the case, hardware has distortion noises and is having various symmetric and asymmetric impairments levels in source and relay for both AF and DF modes of communication. The data rate is fixed at 2 for analysis purposes. Results show that compared to AF, DF performs better. On increasing the impairment levels, the performance drops for both however, percentage of drop is high for AF compared to DF modes. In addition, results show that selecting asymmetric levels of impairments, and interchanging the impairment levels, there is minimum impact on system performance. Figure 6 shows system performance vs average link SNR at two data rates for the relay network with relay working in AF and DF modes. The symmetric hardware impairments are considered in source and relaying UAVs. The results demonstrate that the impact of these impairments is negligible at lower data rates compared to higher data rates. In addition, the performance of good hardware at higher data rates is better than the hardware with impairments. Results show that DF mode is less affected by change in data rate compared to AF mode of communication.

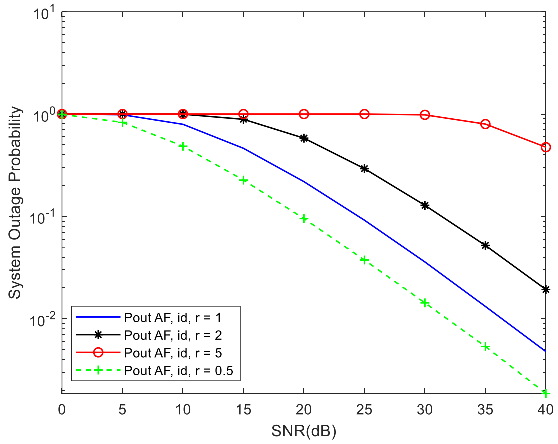

Figure 2 P_{out} for AF mode of relaying considering system equipment without impairments (ideal - id) at different data rates and threshold levels of SNR over Nakagami-m fading channels

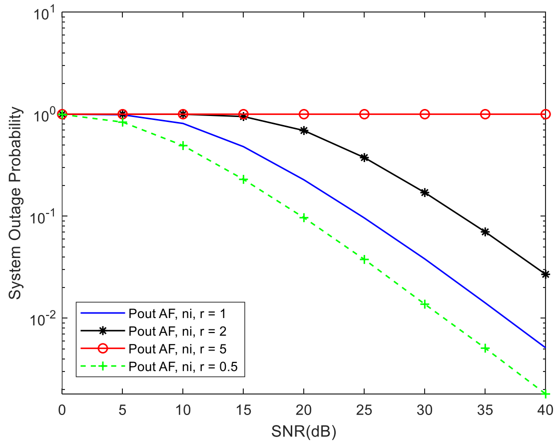

Figure 3 P_{out} for AF mode of relaying considering system equipment having impairments (non ideal - ni) at different data rates and threshold levels of SNR over Nakagami-m fading channels

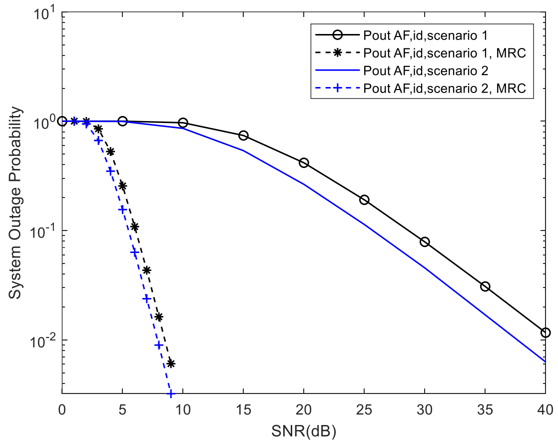

Figure 4 P_{out} comparison of proposed CR scheme with base indirect relay communication considering hardware without impairments (id) and relay in AF mode for both fading environments

Figure 7 elaborates the system performance at 2 b/s/Hz data rate comparing both channel fading scenarios for the relay considering the hardware impairments in AF and DF modes. For the analysis, hardware is considered with and without impairments. Results show that the hardware without impairments performs better than the hardware with impairments. The system outage probability is better for the relay working in DF mode compared to AF mode. Rayleigh fading channels (scenario 2) provide better system performance compared to Nakagami-m fading channels (scenario 1). The performance difference between two cases of hardware with and without impairments is close in case of DF mode compared to AF mode.

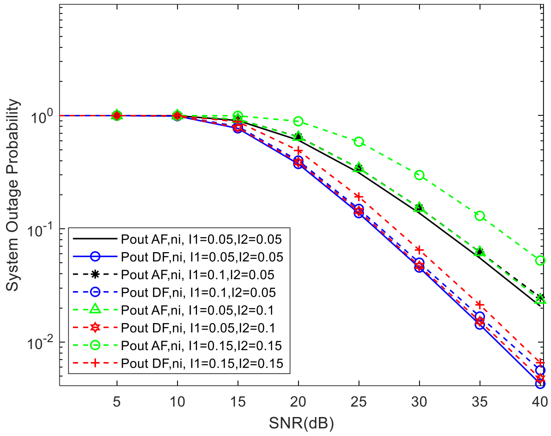

Figure 5 P_{out} for AF and DF mode of relaying in hardware with impairments (ni) case, at different levels of impairments in source and relay over Nakagami-m fading channels

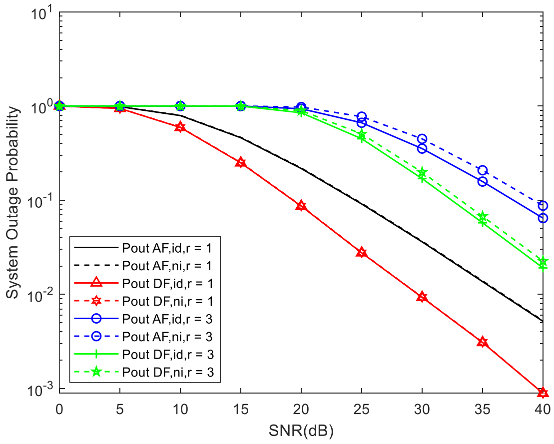

Figure 6 P_{out} for AF and DF mode of relaying with hardware without impairments (id) and with impairments (ni) hardware at different data rates and threshold levels of SNR over Nakagami-m fading channels

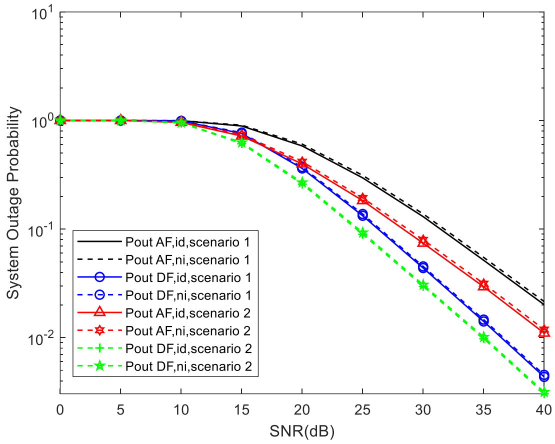

Figure 7 P_{out} for relay with and without impairments working in AF and DF mode for both scenarios of channel fading

The impact of propagation environment of deployment in terms of distribution of channel coefficients is demonstrated in Figures 8 to 11. Figures 8 and 9 outline the system behavior for various combinations of dual-hop fading distribution shape and rate parameters of AF mode of relaying while Figures 10 and 11 demonstrate DF mode of relaying in both fading scenarios. Hardware is assumed without impairments for analysis purposes. Simulation results show that the Rayleigh fading channels outperform for both AF and DF modes of operation. Overall DF provides better results compared to AF and outage probability drops to zero at higher SNR values much earlier compared to its counterpart. For both AF and DF modes, the best system performance is observed for system having $\alpha_1 = 1, \alpha_2 = 1, \beta_1 = 1, \beta_2 = 2$ in scenario 1 and $\alpha_1 = 1, \alpha_2 = 2, \beta_1 = 1, \beta_2 = 1$ in scenario 2.

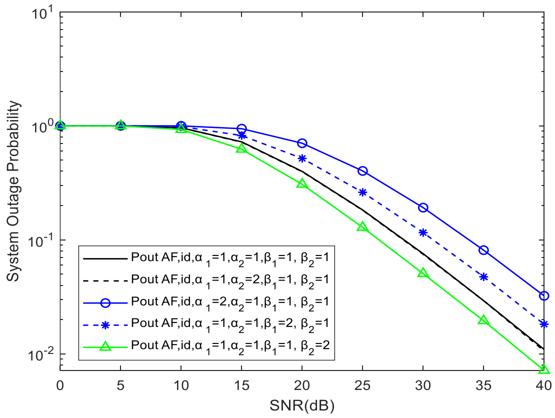

Figure 8 P_{out} for AF mode considering hardware is without impairments but different rate and shape parameters of fading distribution in scenario 1

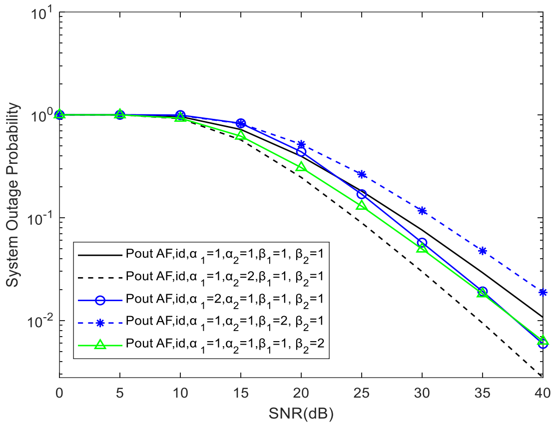

Figure 9 P_{out} for AF mode considering hardware is without impairments but different rate and shape parameters of fading distribution in scenario 2

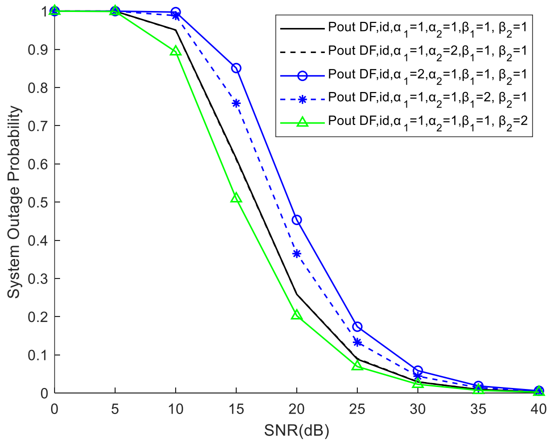

Figure 10 P_{out} for DF mode considering hardware is without impairments but different rate and shape parameters of fading distribution in scenario 1

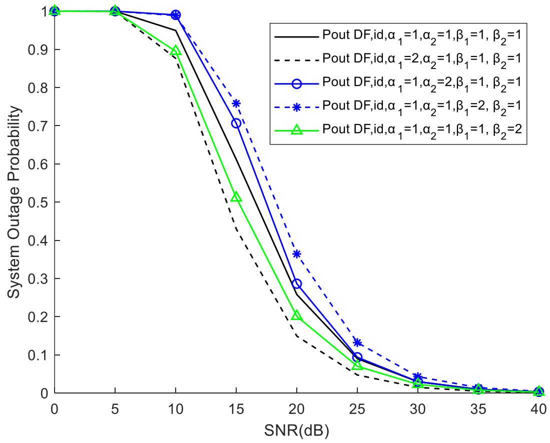

Figure 11 P_{out} for DF mode considering hardware is without impairments but different rate and shape parameters of fading distribution in scenario 2

5.0 CONCLUSION

This paper analyzes the performance of a non-buffer-aided, UAV-based FANET working in AF and DF relaying mode based transmission scheme. A cooperative relaying strategy is proposed where MRC combines the signals coming through indirect and the direct links at the destination. This signal combining improves the system performance considerably due to the availability of multiple paths showing success of proposed scheme. Simulation results demonstrate that the relay in the DF mode of operation performs better compared to the relay in the AF mode of operation which is due to regeneration of signal at relay. Similar trends are observed for various system configurations. The results demonstrate that the system outage probability is high at higher data rates. The equipment of the system without hardware impairments shows a better outage probability compared to equipment having hardware impairments. Further, the shape and rate parameters of the fading distribution affect the system performance and need proper selection. This scheme considered the relay in non-buffer aided fashion. In future, we will be investigating the system performance for the cooperative network of UAVs with buffer-aided communication to analyze the impact of a best relay selection on system performance.

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