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A Systematic Review of Performance Determinants in UAV-Assisted Cooperative Communication Systems

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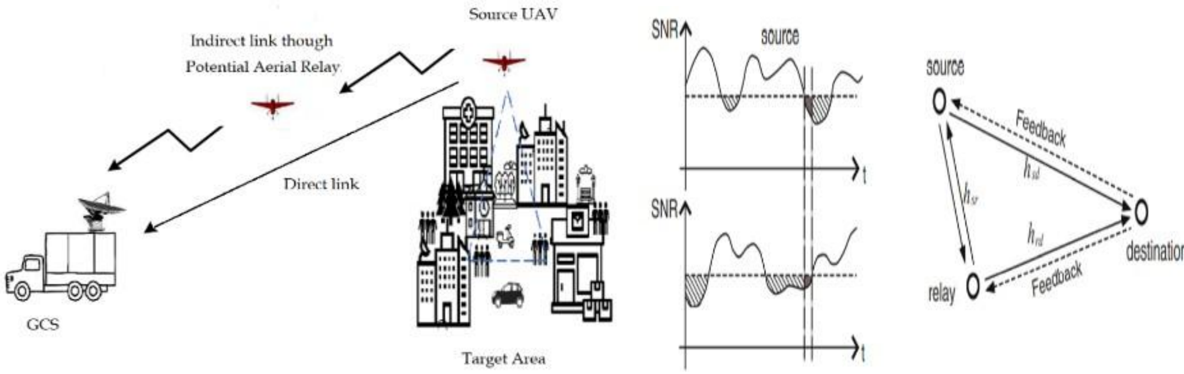
Abstract

Unmanned aerial vehicles (UAVs)-assisted communication systems present a cost-effective solution for ad-hoc network operations. In mission-critical applications like surveillance, UAVs can function as aerial relays, particularly when multiple UAVs collaborate. This collaborative approach proves to be more efficient and economical in accomplishing assigned tasks compared to the use of a single UAV. Achieving reliable operation, however, requires addressing significant issues associated with deploying UAVs in mission areas. This article explores the opportunities offered by a cooperative relaying topology in a multi-UAV system, shedding light on specific challenges related to its implementation and providing communication reliability. Additionally, the article delves into the system evaluation metrics essential for measuring the performance of such network and discusses simulation tools suitable for this purpose.

Keywords*:* ad-hoc network; aerial relays; multiple UAVs; cooperative relaying; communication reliability; system evaluation; simulation tool

1. Introduction

Due to the special qualities and benefits, unmanned aerial vehicle (UAV), often known as drone, is getting employment in a variety of communication applications. It is anticipated that UAVs count will rise over the next 20 years. UAV offers unique abilities including agility and altitude control. UAV has demonstrated value in improving the capacity, coverage, and quality of service (QoS) of existing terrestrial communication networks. Similar deployments can be advantageous for applications like mapping, localization, and border surveillance where UAV is flown in target area to collect the observation and passing on to the ground control station (GCS). Ad-hoc communication can also be established between isolated, disaster affected and remote locations using UAV. Direct communication on single hop link between transmitter and receiver is always limited in performance. This limitation can be overcome by introducing another relaying UAV between observing UAV and destination GCS. A group of UAVs can support the network to cover larger areas and can simulate the reconfigurable antenna arrays. The data can reach to the destination GCS using direct path and on redundant path through relaying UAV as illustrated in figure 1a and 1b.

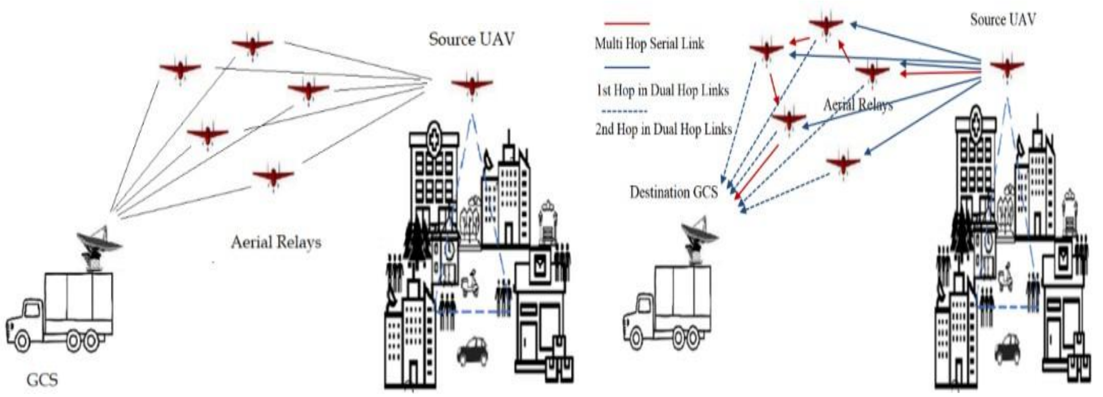


(a) (b)

Figure 1: UAV Assisted Cooperative Communication System

UAV relaying data in cooperative relaying (CR) manner provides cooperative diversity (CD), system diversity gain (DG) and supports data transmission reliability (Bashir & Yusof, 2021). CD schemes using multiple relays between end terminals support the system in passing-on the data from source to the destination. In Figure 1a, the destination GCS can select data coming from source UAV either through direct path only if it is up to the mark or from indirect path only or from both paths and then combining them. Out of these, selecting data on a particular link is termed as incremental selective relaying (ISCR) (Bashir, et al., 2022). The concept of resource optimization is usually based on ISCR which is a two phased operation. In first phase relay receives the data from source and sends to destination while second phase compares and selects direct or indirect link for signal reception. The signal combining techniques at the destination play a pivotal role in communication quality. The maximal ratio combining (MRC) method employed by GCS, combines signals from multiple links. Figure 1b indicates two way communications both for the signal and feedback control messages and links are defined by h_{sr}, h_{sd} and h_{rd} respectively. The signal strengths on direct and indirect links are also illustrated in terms of signal to noise ratios (SNRs). The signal quality can be improved by using multiple aerial relays between source and destination. Figures 2a illustrates a situation where multiple relaying UAVs are used to provide CD to the source UAV in passing on its observation of the target area to the destination GCS. The network planning may deploy UAVs that establish either multiple dual-hop parallel links or a multi-hop serial link or combination as illustrated in Figure 2b.

Various diversity schemes have been discussed in literature to provide reliability in communication (Barnard, 2008) (Bashir, et al., 2022). CD using CR in UAVs based systems help in overcoming the challenges posed by traditional limitations of UAVs. CD is an important area of research for developing efficient and effective UAV communication systems. The UAVs as relays can be configured working in amplify-and-forward (AF) or decode-and-forward (DF) modes or hybrid of both while relaying data from source UAV to destination GCS (Yusof & Iqbal, 2022). Additionally, relays can have fixed or variable gain capabilities, both offer certain advantages and disadvantages. The relay options can be working in all-active configuration where all available relays contribute in relaying data, or selective configuration where one or more selected relay(s), selected based on some objective function contribute to relaying and this mode is termed as selective combining (SC). In presence of multiple relays, the optimal relay choice is determined by GCS for the one offering the best reception and transmission quality between source and destination nodes. In the realm of communication systems for multi-UAVs, relay-based strategies may employ either transparent or non-transparent relays as well as regular or fixed relays.



(a) (b)

Figure 2: Arrangement of UAVs in CR

When working together, UAVs offer significant advantages, but it is important to coordinate their operations effectively. Although UAVs have a broad range of applications; nevertheless, their capabilities are limited by their operational level, their limited coverage, and their operating environment (Alzidaneen, et al., 2020) (Lee, et al., 2018). The typical features of UAVs and their deployment requirements can affect the performance of such communication systems. Effective internal communication, system robustness, and efficiency are increasingly important factors to consider when constructing multi UAV-based systems. The problems of cross zone interference, capacity and power control, however needs optimization. Optimal management of resources is imperative for achieving the best outcomes from communication networks. The ISCR is a fashion of CR where a signal is sent through a relay only if the direct transmission link fails or is of poor quality. The signal quality is given importance in ISCR, as that relay is selected and used in relaying which provides best quality of signal. Power allocation and priority policies for communication links exert a strong influence on communication quality, requiring careful optimization. When utilizing UAVs as relays, hardware (HW) imperfections influence the signal communication quality. The system's performance is contingent on optimizing UAV positioning, deployment schemes, path selection, routing, and collision avoidance on the relay plane. Transmission scheduling in CR, based on relay buffer occupancy status (RBOS), can involve fixed or non-fixed transmission modes (Yusof & Iqbal, 2022). The wireless channel model, encompassing error probability and various impairments affecting wireless signal transmission quality, is crucial. Accurate modeling of UAVs' wireless channels is essential for system quality evaluation. The UAVs links experience fading and interferences due to various reasons which can be managed by using proper CD scheme.

Based on the issues posed by the UAVs and deployment environment, the system reliability of UAVs-assisted wireless networks is still under-researched. Only a few literature has considered the UAVs' issues and deployment requirements as a combined operation in problem formulation. In using ISCR as a two-phased transmission scheme, the signal reaching from the source UAV to the destination GCS may have different power allocation factors due to the UAV antennas and the multipath profile of the area of deployment. These power allocation factors can be adjusted for the direct and indirect paths; this aspect can be captured in system modelling evaluating their impact in system performance formulation. Based on the deployment area characteristics, the modeling of the linkages between nodes can either Rayleigh fading or Nakagami-m fading, Rician fading or mixed fading that may be evaluated. When defining the challenges, two scenarios of UAV deployment as a fixed-gain relay and as a relay that can vary its gain which may operate in a non-buffered configuration may be taken into consideration (Yusof & Iqbal, 2022).

Only a few works in the literature have considered the UAVs' variable gain capability, HW impairments, buffer management, and their constellation creating a serial link or multiple parallel links, and deployment requirements as a combined operation in problem formulation using ISCR as a two-phased transmission scheme. This demands for the development and testing of a network paradigm that offers DG providing system reliability as a function of buffer size, relay count, and other unique UAV variables (Barnard, 2008). Using the channel state information (CSI) and RBOS based relay, packet and channel selection, along with taking care of the full or empty buffer problem, are the areas to be worked on for UAVs based communication systems. For a single relay option between the source UAV and the destination GCS, the mathematical analysis for direct link transmission, cooperative indirect link transmission with and without a direct link can be performed, taking into account the CSI in terms of SNR and UAV's HW impairments (Nguyen, et al., 2021). The analysis can be extended to a situation if multiple relays are available in the deployment environment, and all relays can contribute to the CR. In addition, selecting the optimal relay to contribute to CR by making the system resource-efficient and less complex can be studied. A combined hop, channel and packet selection algorithm needs to be formulated on relaying UAV buffers. In the event that the buffer fills up completely, queuing latency issues may arise. These can be resolved by allocating channel weights in a way that gives priority to the relay to destination connection over the source to relay link while keeping the buffer queue size unchanged.

Investigating the system DG is possible if the UAV's memory buffer is asymmetrical and has random access capabilities, and takes into account the CSI, relay count, buffer size, and RBOS. For such UAVs assisted communication networks, issues that arise due to requirements for data rate, noise, and interference, SNRs, path losses, HW impairments, channel coding, relaying modes, buffer conditions, and signal processing need to be studied. Based on the constraints of UAVs, the performance of a cooperative relay-based packet transmission support system in various settings in a fading environment can be studied. The performance improvement by selecting optimal relay and optimal packet when compared to the case where all relays contribute to cooperative relaying and finding which selection scheme offers better results needs investigation. Furthermore, a relaying UAV's AF and DF mode adaptation method can be devised and a hop priority policy for dual-hop links can be proposed, analyzing its impact on system performance. In this research work, an intensive literature review has facilitated the identification of the associated challenges on deploying CD using CR in multi- UAVs system and the evaluation matrices.

Contribution of this article is the identification of the research gap in the CR network of UAVs. The relevant literature review on CR networks of UAVs is presented in following sections in order to better understand what factors do affect the performance of such networks in what way and how to maximize their features and increase the system performance and resilience. Following Section 2 discusses the factors that affect the performance of a multi-UAV system, Section 3 discusses the system performance evaluation metrics, and Section 4 outlines the possible simulation platforms while Section 5 concludes the discussion.

2. Factors Affecting The UAVs Assisted Cr System Performance& Methods

The system parameters that impact the UAVs assisted CR system performance are briefly summarized in the following sub-sections:

2.1. Multi-UAV System Configurations

Group of UAVs can coordinate with their neighbors by reconfiguring and rescaling their network geometry. CR at physical layer can solves couple of issues of traditional communication systems. CR can use UAVs as wireless air-borne relays to improve the energy and spectrum efficiency of the system. Generally, a low-complexity relay network is preferred (Nomikos, et al., 2018). The reliability of the system increases with the number of relaying UAVs in a multiple relay scenario with numerous dual hop links, but at the expense of more complexity and resource requirements. A serial multi-hop link of UAVs can increase the communication range where optimal number of relays guarantee resource efficiency however an increase in the number of relays results in computational complexity (Tang, et al., 2018). The limited range of UAVs restricts their utilization in range extension applications (Alzidaneen, et al., 2020). A chain of UAVs can be set up to increase the range in order to solve this issue; however, as per (Lee, et al., 2018), a thorough analysis is necessary in order to evaluate the effects on P_{out}, system resource efficiency, and complexity (Nomikos, et al., 2018). On increasing the nodes in serial configuration, the P_{out} increases in serial topology, throughput decreases and end-to-end delay requirements increase. In addition, multiple aerial nodes, they occupy multiple channels, lead to spectrum inefficiency. An optimal relay count needs to be identified while designing such networks. Optimized relay count selection ensures spectrum and resource efficiency. A range of relay selection techniques are reported in (Tang, et al., 2018). Few relay selection techniques are based on second Hop CSI (Ruby, et al., 2021) (Phan, et al., 2015), few are based on the number of packets in waiting (Poulimeneas, et al., 2018), few are based on relay stored energy or throughput (Gautam, et al., 2019), few are RBOS based considering links with max CSI (Manoj, et al., 2018) while few use random link selection. Furthermore, if multiple relaying options are present, what is the role of using all relays on system performance in comparison to selecting an optimal relay to take part in cooperative communication, needs investigation. Similarly, in the case of multiple relays, identifying which technique of relay selection offers the optimum results, needs investigation. The approach published in (Phan, et al., 2015) addresses the relay selection and resource allocation problem for multi-source, multi-relay dual-hop wireless networks in a buffer-assisted fashion. In addition, the outcomes for relay and packet choices in buffered and non-buffering deployments need to be assessed.

In such configurations, buffered schemes are usually more complex than non-buffered schemes. The UAVs can have Omni-directional antennas, directional antennas, or a combination of both. While directional antennas perform better than Omni-directional ones, misalignment and beam control are challenges for UAVs. Furthermore, single input single output (SISO), multi-input single output (MISO), and multi-input multi-output (MIMO) architectures of UAV antennas have been reported in (Bashir & Yusof, 2021) (Tang, et al., 2018). The transmission of data can follow half-duplex mode in AF or DF or adaptive AF and DF style of communication. The network link among nodes can be selected to participate in communication (Phan, et al., 2015) (Poulimeneas, et al., 2018), while packets from the relay buffer can be selected (Ruby, et al., 2021) too. Most of the state-of-the-art research considers that the relaying UAVs have ideal HW and neglects few important impairments. Due to this, the practical experimental results and simulation implementation results show differences in parametric values of system performance (Zhou, et al., 2021). Although several HW and software algorithms can be employed to compensate for the distortion and noises that cause defects in UAV's HW in practice, residual impairments cannot be entirely eradicated, which adds to the P_{out}. Furthermore, such corrective measures, increase the equipment costs. Similarly, UAV trajectory should be optimized for the energy consumption, throughput, delay, reliability, and energy efficiency etc. Other physical concerns like on-board power restrictions and fluctuating channel conditions due to 3D fluid mobility of UAVs, as well as effective navigation and trajectory control, must all be investigated.

2.2. UAVs Channel Conditions

The main requirements of UAVs based communication system are to transmit the captured data to the GCS, receive and respond to control commands, plan and coordinate the network, and complete assigned tasks efficiently. However, the internode communication is subject to various constraints, such as UAV deployment environment, speed, energy, storage, and elevation angle. The channel SNR index indicates the link quality and probability of error and is useful for determining suitable transmit power or receive levels based on the deployment conditions. Similarly, the target information rate needs to be tested to determine the quality of communication. For UAVs, on-board energy resources and storages are limited, and affect the data forwarding efficiency and data rate. Therefore, a multi-UAV deployment framework with efficient channel models, handover mechanisms, and scheduling algorithms can achieve QoS. The system's throughput, scheduling, end-to-end delay, and energy efficiency must all be evaluated. An in-depth investigation of the implementation utilizing high-performance simulation tools is necessary to evaluate the performance of the communication network paradigm with multiple UAVs.

To communicate with the GCS, a relay network of UAVs must be characterized in terms of coverage probability, capacity and spectral efficiency. The environment and the application requirements determine the link characteristics and may result in an unreliable network design. Communication algorithms should be able to handle frequent topology changes, and consider data characteristics, user requirements, channel circumstances, on-board powers, on-board processing capabilities, node failure probability, and buffer conditions to deliver information with acceptable quality. The system topology is volatile and frequently changes due to varying internode distances and link quality fluctuations. Moreover, heterogeneity, mobility, and geographical and temporal correlations should all be captured in system modelling and be evaluated. Therefore, the fading characteristics and types in the deployment area, as well as the rate, scale, and shape parameters indicating the probability distribution function of the signal strength at different points, should be tested under various conditions.

Compared to the multi-hop communication using DF relaying protocol and network coding for FD channels, system performance with multiple dual-hop links should be compared with that selects optimal relay. There is a need to evaluate system reliability along with a comparison with relaying options with and without buffer aids. The reliability of UAV-based communication networks using UAVs and satellites is studied in (Nguyen, et al., 2021). However, using a satellite as part of the network introduces complexity, severe path loss, and high power amplification needs, which reduces reliability. In contrast, SISO-type UAV nodes can be deployed in this considered application situation, and instead of increasing the transmit antenna count, alternate communication diversity can be sought and tested (Bashir & Yusof, 2021). Furthermore, if UAVs fly at lower altitudes to monitor metropolitan areas, the fading channels are better modelled by Nakagami-m and Rayleigh fading distributions must be examined. (Poulimeneas, et al., 2018) provides a model for modeling the delay that data in a buffer-aided relay network experiences. In this work, the transmission time is minimized by employing buffer size as a decision metric by proposing delay-sensitive relay selection policies to reduce delays and maintain diversity. In this work, Markov Chains are used to assess the policies and to derive expressions for P_{out}, throughput, and latency. The asymptotic and simulation studies show an improvement in the performance of the presented system. However, basic CSI and RBOS in relay selection are not taken into account. Furthermore, packet selection must be based on channel characteristics, which need to be studied.

2.3. Resource Management and Resource Efficiency

The literature review on channel or link selection approaches in multi-hop CR communication indicates that a well-managed CR network can ensure network performance. However, if the buffer is constantly accessible and is full it may lead to packet overflow while packet shortages may occur at some relays since selection criteria is link CSI. The available and occupied buffer status can be used as selection criteria instead of link quality as a metric of relay selection. This strategy, however, does not appear to address the issues of poor link quality. Since the channel model is determined by the application deployment scenarios, when developing such networks, the CSI, buffer size, priority, and link weights should all be taken into account and tested. Depending on the criteria characteristics, the destination can mix signals from the relay node and the source at the destination, or it can select a signal on a direct link without the need for a relay. An examination of a combined packet and relay selection method is needed for a costeffective paradigm in a multi-hop air-interfaced communication scenario. This system is based on a random access relay buffer with DG as a function of relays and buffer state.

Analyzing performance metrics like P_{out} is crucial when it comes to the RBOS as well. Given that P_{out} is inversely correlated with the amount of links and relays that are available, it is best to avoid having a buffer that is either fully full or fully empty. The relay's destination link has to be prioritized and assigned a higher weight in order to lower queuing delay. The selection probability of the relay's destination link should be changed to support the incoming packet and shorten queuing time if a packet arrives at the relay and the buffer is nearly full. Keeping more packets in the buffer leads to a higher weight on the relay's destination link, but this can result in queuing delay, which can be avoided by compromising on the buffer queue size and weights on relay destination connections.

The (Gautam, et al., 2019) proposes the performance of buffer-aided wireless power and data transfer on cooperative systems between two nodes via multiple relays with energy harvesting capability. Energy harvesting is believed to extend the relay's life. This research work investigates the impact of buffer storage on system performance by formulating the throughput and energy storage problems and introducing a relay selection criteria based on throughput and energy stored at the relay. However, when disseminating data, normal issues of buffer management, HW flaws, power allocation, path loss, and channel fading are not considered. A network model, in general, describes a set of tasks that are used to formulate the channel selection problem for the relaying UAV between the source and the destination. When using the AF or DF relaying strategy in a fading environment, a diversity approach based on average channel effects should be investigated instead of immediate fading due to multipath propagation, even though the primary goal is to provide adequate coordination between network elements to increase performance. The parameters that impact the multi-UAV systems' performance and discussed above are listed in Table 1.

Table 1: Factors affecting System Performance

System Parameters Affecting System Performance	Typical System Parameters and Related Literature
System configuration	ISCR (Bashir, et al., 2022) Power Allocation Factors (a_i) (Alnwaimi & Boujemaa, 2020) Hop Priority Weights (w_i) (Manoj, et al., 2018) Signal Combining Method as MRC and SC (Bashir, et al., 2022) Relay count (K) as Single Relay (Yusof & Iqbal, 2022) (Nguyen, et al., 2021) (Ruby, et al., 2021) (Poulimeneas, et al., 2018) and Multiple Relays (Tang, et al., 2018) (Manoj, et al., 2018) Multiple Hops Serial Link or Multiple Dual Hop Parallel Links (Alnwaimi & Boujemaa, 2020)
Relay Type and Relay Mode	AF (Yusof & Iqbal, 2022) DF (Gautam, et al., 2019) (Manoj, et al., 2018) (Alnwaimi & Boujemaa, 2020) Hybrid AF and DF communication (Bashir, et al., 2023) Buffer aided Relaying (Tang, et al., 2018) (Nomikos, et al., 2018) (Ruby, et al., 2021) (Phan, et al., 2015) (Poulimeneas, et al., 2018) (Gautam, et al., 2019) (Bashir, et al., 2023) (Manoj, et al., 2018) Relay Buffer size (B_i) (Ruby, et al., 2021) Non-Buffered Relaying (Manoj, et al., 2018) Relay with fixed gain (Yusof & Iqbal, 2022)

	Relay with variable gain (Fidan & Kucur, 2020) Relay without HW impairments and Relay with HW impairments (Nguyen, et al., 2021) (Zhou, et al., 2021) Relay with SISO type antenna (Nguyen, et al., 2021) All active Relaying (Alnwaimi & Boujemaa, 2020) (Fidan & Kucur, 2020) Selective Relaying (Fidan & Kucur, 2020)
Channel Conditions	Channel hop SNR (λ_i) (Yusof & Iqbal, 2022) (Nguyen, et al., 2021) (Phan, et al., 2015) (Manoj, et al., 2018) Target Information Rate (r) (Alzidaneen, et al., 2020) (Nomikos, et al., 2018) (Ruby, et al., 2021) (Phan, et al., 2015) (Poulimeneas, et al., 2018) (Gautam, et al., 2019) Noise variances ($\mathbb{N}_i$) of both hops of indirect link (Poulimeneas, et al., 2018) (Gautam, et al., 2019) (Bashir, et al., 2023) (Manoj, et al., 2018) Channel fading scenario as Nakagami-m (Yusof & Iqbal, 2022) (Tang, et al., 2018) (Poulimeneas, et al., 2018) (Gautam, et al., 2019) (Bashir, et al., 2023) (Manoj, et al., 2018) and Rayleigh (Yusof & Iqbal, 2022) (Tang, et al., 2018) (Poulimeneas, et al., 2018) (Gautam, et al., 2019) (Bashir, et al., 2023) (Manoj, et al., 2018) with Shape and Rate Parameters (α_i and β_i)
Resource Efficiency	Hop, channel and packet selection (Tang, et al., 2018) (Phan, et al., 2015) (Poulimeneas, et al., 2018) (Gautam, et al., 2019) (Bashir, et al., 2023) (Manoj, et al., 2018)

3. System Performance Evaluation Metrics

The literature provides information on various performance metrics used to study the behavior of relaying based systems. Along with using the bit error rate (BER) and throughput to analyze system performance, there is a need to analyze the transmission scheme, end-to-end SNR, and system outage probability of the considered system based on the application scenarios. The algorithms developed for CR schemes are to be tested, compared, and benchmarked with direct-only and indirect-only transmissions, while the impact of hop weights is to be evaluated through simulations. The following sub-sections discuss the metrics that can evaluate the designed algorithms of ISCR on a multi-UAV system:

3.1. End-to-End Delay Analysis

The transmission delay is the length of time from the beginning to the end of message transmission in seconds and depends on the medium, network configuration, and packet size. The amount of time a packet takes for a data packet to travel from a source device to the destination device through the wireless medium determines the packet delay. This delay is caused by various factors such as the time taken for the packet to traverse the wireless channel, the processing time at the intermediate network nodes, and the queuing delay at the routers. In a wireless network, the packet delay can also be affected by factors such as the signal strength, interference from other wireless devices, the number of nodes in the network, and the available bandwidth. The network performance is affected by the packet delay, particularly for real-time applications handling voice and video streaming, etc. To minimize packet delay in a wireless network, various techniques such as packet prioritization, congestion control, and QoS mechanisms are used. These techniques ensure that high-priority packets are given preferential treatment, and the network resources are efficiently utilized to minimize packet delay and ensure smooth communication between the devices in the network. Measuring the transmission time helps to understand the quality of the network and its delay. The delays need to be calculated and optimized. Since a packet is selected from the buffer for transmission based on a single SNR criterion, buffer delay may occur if that packet arrives at the destination node out of order. Another issue may be the spread in the spectrum which need to be estimated in such networks (Ruby, et al., 2021) (Phan, et al., 2015).

3.2. Channel Hop CSI, End-to-End CSI and Asymptotic Analysis

The end-to-end CSI expressed in terms of SNR or SNIR can be chosen as a performance metric. It is an optimal criterion derived using the system outage probability and ergodic capacity. System quality can be assessed with the use of end-to-end SNR estimation. In this system, the connection quality measured in terms of instantaneous SNR or CSI is typically used as the packet and relay selection criterion. The inverse Laplace transform can compute the PDF and CDF of the end-to-end SNR, statistically analyzing the system performance. Comparably, system behavior in the high SNR regime is provided by asymptotic SNR analysis (Tang, et al., 2018). P_{out} appears if there is no relay available or selected based on channel distances and SNRs in comparison with the threshold SNR value. P_{out} may also appear if the selected relay has a related hop SNR less than the threshold SNR. For non-fixed transmission regulations, this approach should be investigated.

3.3. Outage Probability Analysis

System reliability can be defined as the ability to execute required tasks under defined constraints within a given time (Barnard, 2008). The probability that the end-to-end SNR drops below a given predetermined threshold value is known as the system outage probability. The cause may be channel fading, which raises the link's BER. As a result, when the P_{out} exceeds a certain threshold, BER can be used to quantify it. In addition, if relays are available but cannot be selected due to shortcomings in selection algorithms or other reasons, the system experiences an outage. Similarly, if a relay is available but its buffer is empty, the algorithm cannot select the packet for transmission, or the relay cannot receive because its buffer is already full, this also leads to system outage. The probability of outage, as a reliability metric for fading channels, can be mathematically expressed by equation $P_{out}(x) = Pr(\lambda_{DF} < \lambda_{th})$. Here, λ_{DF} is the SNR for the end to end link in DF case while λ_{th} is the threshold SNR depending on the target information rate. P_{out} can be calculated mathematically by obtaining the CDF and PDF of the statistically distributed channel gains, which can be modeled by Nakagami-m or Rayleigh-distributed random variables (Nomikos, et al., 2018) (Fidan & Kucur, 2020).

3.4. Diversity Gain Analysis

DG metric characterizes the rate of performance improvement with increasing channel SNR on independent communication links and can be defined as the count of independently faded replicas of a transmitted symbol reaching the destination. It can be expressed as a function of the communication channel SNR. While MIMO systems can provide cooperative and spatial diversity, their large size and cost may be impractical in some cases (Bashir & Yusof, 2021). CR can support network DG and overcome issues arising from multipath fading and shadowing at a lower cost, which is an important advantage in various settings of the system (Nguyen, et al., 2021) (Nomikos, et al., 2018). As P_{out} indicates system outage for a given channel SNR $\bar{\lambda_h}$ with respect to a threshold SNR, DG can be used to perform asymptotic analysis of the system.

3.5. Ergodic Channel Capacity Analysis

The capacity ceiling of the wireless relay based network is estimated using the ergodic capacity. The ergodic channel capacity refers to the maximum data transmission rate that can be achieved on an average over a long period of time, taking into account the random fluctuations in the channel caused by fading and interference. System sum rate is usually defined as average message count successfully transmitted per unit time. Calculation of sum rate is dependent on the vulnerable time duration where packets are susceptible to collisions. Usually high sum rate is required by the applications by devising a suitable communication protocol (Alzidaneen, et al., 2020). In non-buffered scenario considered in this article, the transmission time over multi hops of the link determine the system delay and ergodic capacity. In case of buffered scenarios, the probability of storage time in buffer plays important role in determining the transmission time and hence the delay.

Ergodic channel capacity reflects the average achievable data rate over a long period, rather than the instantaneous rate at a particular moment in time. The calculation of ergodic channel capacity in wireless relay networks involves taking into account factors such as the channel gain, the interference from other wireless devices, the transmit power of the source and relays, and the modulation and coding scheme used for data transmission. The channel capacity is an important performance metric for evaluating the efficiency of wireless relay networks in terms of the average data transmission rate that can be achieved over time, while taking into account the random fluctuations and interference present in the wireless channel. Following Table 2 provides the list of the system performance evaluation metrics for the considered multi-UAV system in this article using reviewed literature.

Table 2: Performance Evaluation Metrics for CR based Multi-UAV Systems

System Performance Parameter	Description	Related Literature

Đ	End-to-End Delay	(Nomikos, et al., 2018) (Ruby, et al., 2021) (Phan, et al., 2015) (Poulimeneas, et al., 2018)
λ	Hop SNR / End-to-End SNR / Asymptotic SNR	(Yusof & Iqbal, 2022) (Nguyen, et al., 2021) (Tang, et al., 2018) (Nomikos, et al., 2018) (Phan, et al., 2015) (Manoj, et al., 2018) (Fidan & Kucur, 2020)
Pout	System Outage Probability	(Yusof & Iqbal, 2022) (Barnard, 2008) (Nguyen, et al., 2021) (Nomikos, et al., 2018) (Ruby, et al., 2021) (Poulimeneas, et al., 2018) (Bashir, et al., 2023) (Manoj, et al., 2018) (Fidan & Kucur, 2020)
DG	Diversity Gain	(Bashir & Yusof, 2021) (Nguyen, et al., 2021) (Tang, et al., 2018) (Nomikos, et al., 2018) (Gautam, et al., 2019) (Bashir, et al., 2023)
C	Channel Capacity	(Alzidaneen, et al., 2020) (Nomikos, et al., 2018) (Ruby, et al., 2021) (Phan, et al., 2015) (Poulimeneas, et al., 2018) (Gautam, et al., 2019)

4. System Evaluation Tools

Methods based on greedy computations and linear programming can be applied in wireless communication systems, and simulations are required to validate the proposed approach. Simulation modelling is a powerful tool that can help in optimizing the performance of communication networks and improving their reliability and efficiency (Barnard, 2008) (Bashir, et al., 2022). Simulation can provide insights into the behavior of the system in different scenarios and help in making informed decisions about the design and deployment of the network. Simulators such as ns-2, ns-3, OPNET, OMNET++, GloMoSiM, QualNet, JiST/SWANS, and general purpose ones like GPSS and AnyLogic are commonly used for network design and analysis (Phan, et al., 2015) (Liu, et al., 2020). However, traditional network simulators may not fully capture the unique constraints posed by UAVs. MATLAB provides an alternate tool for implementing and studying the networks and can capture multiple physical factors simultaneously and explore the effects on the physical layer. For computer graphic visualization, modeling, programming, simulation, and numerical data analysis, this software package has shown to be incredibly reliable and efficient. Additionally, MATLAB is well suited for conducting Monte Carlo simulations to validate the proposed solutions and improve the network's overall performance. It is important to ensure that the simulation models accurately reflect the real-world conditions and take into account the relevant parameters and variables. In addition, the results obtained from simulations should be validated with experimental measurements and field trials to ensure their accuracy and reliability.

Conclusion

This article has presented a literature review highlighting key technological foundations for the efficient design of a multi-UAV system with CD. The literature emphasizes the importance of investigating resource efficiency and communication reliability in UAV-assisted networks, taking into account UAV constraints and deployment environments. The critical parameter in this context is the CSI, specifically in terms of SNR of communication links among nodes, along with on-board RBOS. An additional approach involves assigning weights to the hops in the indirect path to explore channel selection. When multiple relays are available, selecting the optimal relay becomes crucial to maximize overall system resource efficiency. The system configuration, relay type and its mode of operation, channel conditions, and resource management, significantly influence the system quality. The UAVs assisted network model analysis should encompass various factors such as system path loss, delay, channel conditions, buffer status, relay count, CSI, end-to-end SNR, asymptotic SNR, diversity gain, and probability of system outage to understand the system performance. Additionally, evaluating performance metrics like end-to-end delay, hop and end-to-end SNR, asymptotic SNR, system outage probability, channel capacity, and diversity gain using a suitable simulation tool can provide insights into the overall system performance. Next phase of this work will be working on problem formulation, and devising the methodology to solve the indicated problems.

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