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Intelligent Control for Video Broadcasting in Flying Ad Hoc Networks: A Simulation Study

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Abstract: This paper proposes an automated system for managing video stream transmission in Flying Ad hoc NETWORK (FANETs) specifically designed for search and rescue operations. The system utilizes a model-based approach to generate recommendations to support decision-making regarding the transmission or blocking of video streams, contributing to improved video broadcasting quality. Simulation experiments demonstrate that the automated system significantly increases the probability of making correct decisions compared to relying on the dispatcher's judgment alone, enhancing operational efficiency and effectiveness. Future work will focus on expanding the model's complexity, incorporating real-world constraints, and exploring the potential of machine learning for adaptive optimization.

Keywords: Unmanned aerial vehicle (UAV), Flying Ad hoc NETWORK(FANET), Video monitoring of territories, Decision support, Video broadcast.

Introduction

Unmanned Aerial Vehicles (UAVs) have become increasingly prevalent in various domains, including search and rescue operations, due to their relatively small overall dimensions (Alhafnawi et al.,2023; Boursianis et al., 2022). The ability to carry out work in conditions unsuitable for a human pilot, the relative cheapness of technical samples of aircraft, the ability to function in adverse weather conditions, cost-effectiveness, and ability to access remote or hazardous areas. UAVs can be equipped with different devices to perform a variety of missions. These tasks include Flying Ad hoc NETworks (FANETs), in precision agriculture, aerial photography for object detection, detection of cracks in building structures, solving transport problems, ensure communication, and functioning of the Internet of Things. The utilize of UAVs as communication nodes offer a promising solution for establishing temporary communication networks in challenging environments. Yet, the efficient transmission of high-quality video in dynamic FANETs, especially for critical search and rescue operations, continues to be a major challenge.

The movement of nodes and the anticipated variations in the topologies found with relevant channel conditions can lead to random fluctuations in video stream quality across the FANET. Any loss or degradation of video data may obstruct identification and rescuing victims in time, leading to possible adverse effects on search-and-rescue missions. Just as traditional approaches may not be able to handle properly the video streaming services in FANETs, existing solutions mostly are based on centralized control mechanisms or heuristic algorithms which neither ensure a high quality of service nor propose user adaptive ability. In order to challenge this issue, the paper introduces an Automated Technique for Handling Videos Stream Transmission (ATVST) in Search and Rescue with FANETs.

Literature Review

Chen et al. (2023) explores the development and applications of You Only Look Once (YOLO) based UAV technology (YBUT), which utilizes the YOLO algorithm for real-time multi-target detection and classification. YBUT has proven valuable in various fields, including engineering, transportation, agriculture, and automation. Paredes (2023) examines the role of LoRa, a low-power, long-range wireless technology for IoT, in the design of FANETs. Through a technical overview and systematic literature review, the paper analyzes communication, mobility, and energy aspects of FANET implementation and identifies open issues in protocol design, particularly in the context of LoRa-based FANET deployments. Polshchykov (2021) provides an algorithm of the optimization of data transmission in flying self-organizing networks, i.e. the geoecological monitoring. The algorithm optimizes the size of buffers and reserves channel performance, leading to higher data delivery speed and higher network capacity. The effectiveness of the algorithm is proven both in the studies and in the practice. Boursianis (2022) presents the possibility of transforming the agriculture sector by combining IoT and UAV technologies and uses precision farming methods to perform such activities as irrigation, fertilizing, and pest control. The latter Alhafnawi et al. (2023) also underscores the multi-purpose nature of the UAVs in indoor and outdoor settings in performing tasks such as target tracking, low maintenance cost, small size, and the ability to be compatible with other technologies. Li et al. (2023) addresses the problems of multi-target detection in aerial images obtained with UAVs and concerns the elimination of the problems of different target size and shape, the occurrence of occlusions, and the problem of varying light conditions. A novel detection model is proposed to enhance feature extraction, reduce model parameters, and optimize bounding box regression. Wang (2023) further addresses the specific challenge of detecting small objects in UAV imagery, introducing the UAV-YOLOv8 model optimized for aerial photography. Ding (2023) proposes a marker-free UAV system for accurate crack detection and quantification in concrete structures, employing a boundary refinement transformer (IBR-Former) for improved crack segmentation. Dai (2024) tackles the overload issue in vehicular edge computing by utilizing a UAV for task offloading, employing Lyapunov optimization and Markov approximation techniques. Zhao (2023), Jameel (2022) and Mu (2023) explores the application of integrated sensing and communications (ISAC) in UAV-aided communication, considering the impact of UAV movement and attitude on channel performance. Sarkar (2023) concludes that AI-based UAV networks are feasible and cost-effective, highlighting their potential for developing low-cost, energy-efficient autonomous networks, while also identifying open research areas for future exploration. Cheng et al. (2023) and Sharma (2023) examine the use of AI in UAV-assisted IoT networks, highlighting key technologies, applications, and research challenges. Liu (2023a) proposes two algorithms (PSO-based and better-response-based) for constructing FANETs in post-disaster scenarios to provide communication coverage and transmit disaster information. Noor (2020) discusses the emergence of FANETs using multiple small UAVs for civilian and commercial applications, highlighting their advantages and communication challenges (Srivastava, 2021).

Model Configuration

Figure 1 shows a possible FANET setup of video surveillance of a territory. The network is made of flying nodes (UAV), which have video recording and streaming capabilities to a control room. This control room is a focal point where all the video streams are received and broadcasted to be monitored, analyze situations and make decisions concerning rescue operations. Figure 1 has colored lines with arrows indicating the paths of the video streams to the control room.

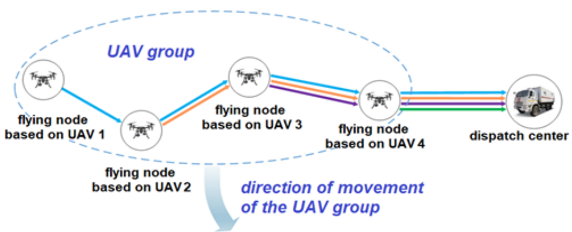

Figure 1. A modified FANET configuration for video monitoring of the territory.

FANET video communication is flawed by poor quality because of dynamic topology of the network and difficulties of transmission of wireless signals. This may result in a hindrance to timely detection of victims and those who need help as this is a big hindrance to effective rescue efforts. To be able to provide the video streaming of high quality, FANET deploys the system of video stream transmission control which is automated. This system gives advice to the supervisory dispatcher to assist him in making a decision. It is on these recommendations and based on their evaluation of the situation that the dispatcher makes the decision of whether to transmit or block new video streams, disable or leave existing video streams and the distance between transmitting and receiving network nodes.

The model has been created in MATLAB/Simulink as shown in Figure 2. The Streams- Transmission-Control subsystem is the virtual replica of the production and issue of recommendations of video stream transmission control. This subsystem employs three parameters which include Lamda, Tau and d. Lamda is the rate of video stream requests (in hour-1), Tau is the mean length of video streams (in hours), and d is the mean distance between the transmitting and receiving nodes of the channel of the wireless network which is the most utilized (in meters).

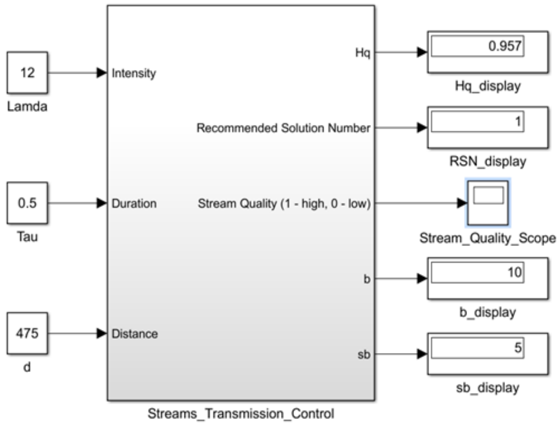

Figure 2. Model interface.

The video stream transmission parameters (Lamda, Tau and d) input values are utilized to compute the likelihood of high quality video broadcasting (Hq) in FANET. The calculation is carried out on the formulas in (Lehmer, 1944; Liu, 2023b; Mu, 2023). Through the virtual recorder Hq display, the calculated probability of having high quality video broadcasting (Hq) can be seen. The information is then employed in coming up with suggestions to control video stream transmission.

Take an example of a situation when a new stream of video captured by a UAV camera must be sent in the course of a FANET monitoring task. This extra load may end up compromising the quality of the already existing video streams. The automated system will help the dispatcher make informed decisions in such instances. In case the probability of the high-quality video broadcasting to be preserved ($Hq \geq 0.8$) is high, the Streams-Transmission-Control subsystem suggests that the transmission of the new video stream should be made possible. This suggestion is informed by the fact that the extra load will not have a significant effect on the general video broadcast (solution number 1).

When the computed probability suggests that there can be a risk ($Hq < 0.8$) of reduced video quality, and at least one video stream can be transmitting non-critical information (uninformative), the Streams-Transmission-Control subsystem would suggest the non-transmission of such a non-informative stream. The purpose of this is to decrease the total network traffic hence enhancing the quality of the video streams that are left (solution number 2).

In order to maximize the video stream transmission in case received streams are useful, the Streams-Transmission-Control system recommends solution number 3: reducing the distance between the transmitter node and the receiver node on the busiest channel. The purpose of this strategy is to enhance the signal strength and provide easier video broadcasting.

The desired number of the recommended solution is shown on the virtual interface which is labeled as; RSN-display. This model enables the simulation experiments to investigate the behavior of the automated system of video stream transmission in FANETs. An internal random number generator installed on the 'Streams-Transmission-Control' subsystem models the situations in which the video streams are transmitted with a high or a low quality, according to a given probability. The 'Stream-Quality-Scope' virtual oscilloscope shows the information of the quality of every separate video stream. Figure 3 shows the output of the waveform of this oscilloscope in the course of a sample simulation experiment.

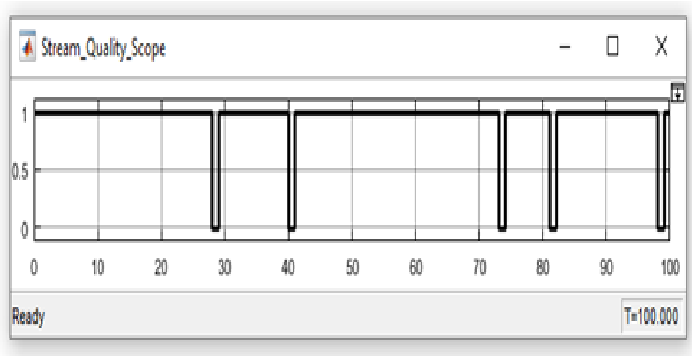

Figure 3. Oscillogram of the virtual oscilloscope Stream_Quality_Scope.

The transmission quality of 100 video streams was measured using the 'Stream-Quality-Scope' oscilloscope (as shown in Figure 3). The level of the waveform of 1 means quality transmission and 0 is low-quality transmission. As indicated by the experiment only 5 streams were passed across with low quality which made the value of [insert the actual value here] printed on the sb- display recorder.

The total number of low quality streams is usually the criteria by which a FANET video broadcast is deemed to be of high quality. This threshold was set on the so-called sb-display recorder and was set to [insert the actual value here]. In the experiment that is indicated in Figure 2, solution number 1 was suggested since the value of [insert the actual value here] was above the threshold of 0.95. This choice guaranteed video broadcasting of high quality by having the preferred limit of low-quality stream.

Figure 4 shows that a simulation was done with the distance between transmitting and receiving nodes changed to 490 meters, which changed the original circumstances of the experiment. Solution number 3 was suggested in this case. The essence of this solution was to achieve desired level of high quality video ($sb \le b$) broadcasting by making sure that [insert the actual value of the condition here] was achieved.

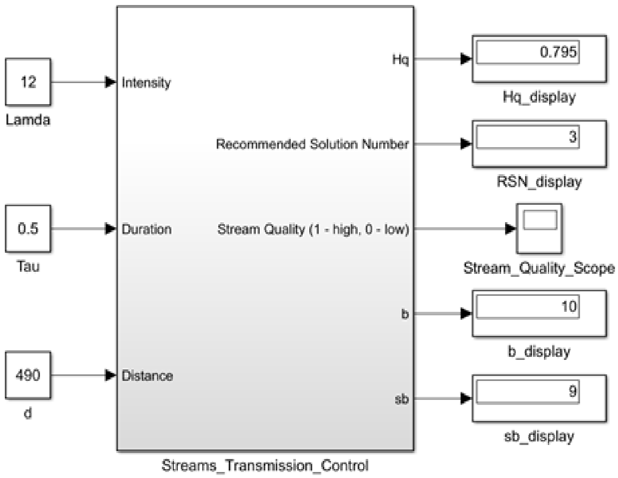

Figure 4. Interface of the model with changed source data.

Simulation Results

To evaluate the effectiveness of the proposed model in controlling video stream transmission within FANET, experiments were conducted to determine the probability of making the correct decision. This probability was calculated using the formula:

$$P_{corr} = \frac{E_{1.1} + E_{2.2}}{E_{1.1} + E_{1.2} + E_{2.1} + E_{2.2}} \quad (1)$$

Where: E11 - is the number of experiments that ended with a result of 1.1; E12 – the number of experiments that ended with a result of 1.2; E21 – the number of experiments that ended with a result of 2.1; E22 – the number of experiments that ended with a result of 2.2. Table 1 presents a detailed breakdown of the possible outcomes of the decision-making process, explaining each result in detail.

Table 1. Possible outcomes of decision-making.

Decisión	The right decision	
	Allow video streaming	Block the transmission of a video stream
Video stream transmission is allowed	Output 1.1: Correct decision made	Result 1.2: Type II error
Video stream transmission blocked	Output 2.1: Type 1 error	Output 2.2: Correct decision made

As explained in Table 1, the numerator of formula (1) represents the number of experiments where the correct decision was made, while the denominator represents the total number of experiments conducted [20]. To assess the probability of making the right decision using the automated system, 700 experiments were performed, each simulating the transmission of 100 video streams. These experiments were conducted with varying probabilities of transmitting a video stream with high quality (E11, E12, E21, E22).

Table 2. Obtained values of the number of experiments.

Results of decision-making	Probability of high-quality video stream transmission						
	0,86	0,88	0,90	0,92	0,94	0,96	0,98
$E_{1.1}$	5	27	46	77	95	100	100
$E_{1.2}$	95	73	54	23	5	0	0
$E_{2.1}$	0	0	0	0	0	0	0
$E_{2.2}$	95	73	54	0	0	0	0

A graph of the relationship between the probability of high-quality video stream transmission and the number of successful control decisions was drawn using the data in Table 2. This graph is shown in Figure 5.

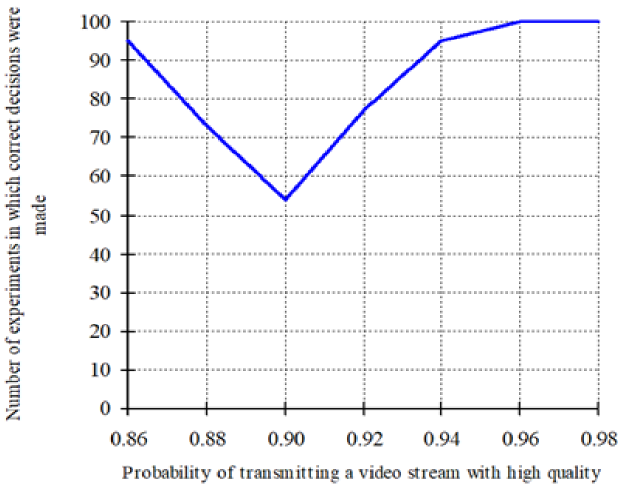

Figure 5. Relationship between the probability of transmitting a high-quality video stream and the number of experiments with correct control decisions using the automated system.

It was shown by experimental results that the proposed automated system has a significant likelihood of arriving at the correct decision in the control of the transmissions of video streams during FANET, with a considerable success rate of 0.849.To provide a comparison, a similar experimental study was conducted without using the proposed automated system. The results of this study, presented in Table 3, show the values of ($E_{1.1}, E_{1.2}, E_{2.1}, E_{2.2}$). Using this data, a graph was constructed to illustrate the relationship between the probability of transmitting a high-quality video stream and the number of experiments where correct control decisions were made. This graph is depicted in Figure 6.

Table 3. Obtained values of the number of experiments.

Results of decision-making	Probability of high-quality video stream transmission						
	0,86	0,88	0,90	0,92	0,94	0,96	0,98
$E_{1.1}$	5	27	46	77	95	100	100
$E_{1.2}$	95	73	54	23	5	0	0
$E_{2.1}$	0	0	0	0	0	0	0
$E_{2.2}$	0	0	0	0	0	0	0

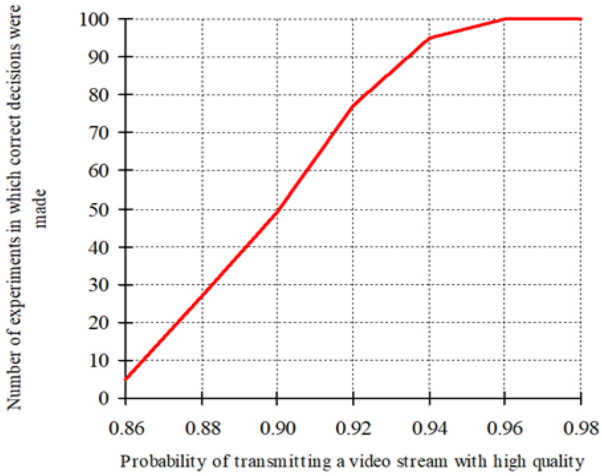

Figure 6. The correlation between the likelihood of delivering a high-quality video stream and the amount of experiments in which the automated system was correctly controlled.

Results and Discussion

In order to measure the efficiency of the suggested automated system, an automated system, 700 simulation experiments were carried out with a Matlab/Simulink model. Each experiment modeled the transmission of 100 video streams, and the probability of the transmission of high-quality (HQ) video stream transmission was changed between 0.86 and 0.98. The determination of the performance of the system was estimated by determining the chances of making the right decision to regulate the transmission of video streams through equation (2).

$$P = (N11 + N22)/(N11 + N12 + N21 + N22) \tag{2}$$

where:

N11- Number of experiments in which the system correctly allowed HQ video streaming, N12-Number of experiments in which the system incorrectly allowed low-quality (LQ) video streaming, N21- Number of experiments in which the system incorrectly blocked HQ video streaming, N22- Number of experiments in which the system correctly blocked LQ video streaming. The results of the simulation experiments are compiled in Table 4 that indicates the number of the experiments of each outcome in different probabilities of the HQ video transmission.

Table 4. Obtained values of the number of experiments.

Outcome	0.86	0.88	0.90	0.92	0.94	0.96	0.98
Correctly Allowed	95	73	0	0	0	0	0
Incorrectly Allowed	5	27	46	77	95	100	100
Incorrectly Blocked	0	0	0	23	5	0	0
Correctly Blocked	0	0	0	0	0	0	0

To compare, a similar research was done in which no automated system was used, the judgement of the dispatcher being the only guiding force. The outcome of these simulations is given in Table 5. The graph in figure 6 reveals that the dependence of the number of experiments with the correct decisions on the possibility of transmission of the video HQ without applying the automated system is a graph. This shows that there is lesser chance of making the right decision than with the automated system with a probability of 0.643 being the highest probability of all the situations. These simulation outcomes indicate that the proposed automated system would yield the potential of enhancing the quality of video broadcasting of FANETs utilized in search and rescue missions.

Table 5. Obtained values of the number of experiments without using the automated system.

Outcome	0.86	0.88	0.90	0.92	0.94	0.96	0.98
Correctly Allowed	5	27	46	77	95	100	100
Incorrectly Allowed	95	73	54	23	5	0	0
Incorrectly Blocked	0	0	0	0	0	0	0
Correctly Blocked	0	0	0	0	0	0	0

The automated system is very helpful in making correct decisions about transmitting video streams as the analysis of network parameters and recommendations to the dispatcher are provided by the system. This results in the more effective utilization of the bandwidth and enhances the quality of the video streaming as a whole, allowing to detect and react in emergency cases faster and more correctly. The fact that the probability of correct decision-making increased by 20.6 percent using the automated system in comparison with using the judgment of the dispatcher alone in the process of conducting real-time operations is an indication of the importance of the system in the assisting decision-making process. The fact that the system takes into consideration a number of factors in the network. Objective analysis and the provision of recommendations increase situational awareness and reduce the possibility of mistakes in the critical moments of decision-making.

Limitations

1) The existing model presupposes simplification of the FANET environment. It also lacks real world characteristics such as changing channel conditions, node failures, changing network topologies and interference.
2) The model is concentrated on video stream management only. It also leaves other important issues of FANET management out like routing, resource allocation, or security.
3) The assessment is based on simulations, and these might not reflect the realities and difficulties of the deployments in the real world.
4) The system is based on correct information on the network parameters such as distance between nodes, channel quality, and video stream quality. When it comes to real life situations, it may be hard to get and retain correct information.
5) Scalability to larger and more complicated FANETs consisting of large numbers of nodes and various traffic requirements is an additional subject of study in the model.

Conclusions

The study examines the effectiveness of an automated system that can be used to control video stream transmission at Flying Ad Hoc Networks (FANETs), in the case of search and rescue missions. The system uses a model approach to offer intelligent decisions of dispatchers to help improve the video broadcasting quality and efficiency. The simulation experiments indicate that the probability of making the right choice in controlling video stream transmission is significantly increased when the automated system is used in FANET. The increase in it, which is measured by 20.6 percent over manual control, indicates that the system can serve in improving the effectiveness of search and rescue operation by reducing the interruptions of the video streams and providing quality data streams capable of supporting timely decision-making.

Recommendations

While the current model demonstrates promising results, future research will focus on enhancing its capabilities and addressing its limitations. Key areas of focus include:

- Expanding the model to incorporate more realistic factors, such as channel fading, node mobility, interference, complex network topologies, and dynamic network scenarios.
- Expanded Management Capabilities: Developing the model to encompass other critical aspects of FANET management, including routing, resource allocation, and security.
- Real-World Validation: Conducting real-world experiments using real UAVs and FANET infrastructure to validate the model's effectiveness and identify potential issues in practical deployment.
- Developing algorithms that can handle uncertainties and variations in network conditions, enhancing the system's robustness and exploring adaptive mechanisms for adjusting system parameters based on dynamic network changes.
- Exploring the potential of machine learning techniques to further improve decision-making accuracy by leveraging real-time data and dynamically adapting to evolving network conditions.

Scientific Ethics Declaration

* The authors declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* No conflict of interest.

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