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An algorithm for controlling the transmission of video streams in a flying ad hoc network

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ABSTRACT

This article discussing the enhancement of video surveillance in various territories through the implementation of a flying ad hoc network (FANET). The primary objective of the surveillance is for search and rescue operations. To optimize the quality of FANET video broadcasting, a decision-making algorithm for video stream management is introduced. This algorithm evaluates the likelihood of achieving high-quality video transmission. Depending on the assessed probabilities, the algorithm recommends one of the following actions: initiating a new video stream transmission, reducing the average length of wireless channels, or discontinuing the transmission of low-information video streams. Computational experiments demonstrate a significant improvement in the accuracy of decision-making regarding the management of video stream transmission to FANET when utilizing the proposed algorithm.

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1. INTRODUCTION

Flying ad hoc networks (FANETs) have emerged as a prominent research focus due to the increasing availability of unmanned aerial vehicles (UAVs) and the advancement of electronic components necessary for their control and connectivity, such as microcontrollers, single-board computers, and communication radios. UAVs are increasingly used across diverse applications [1]–[3], demonstrating particular efficacy in search and rescue operations for monitoring disaster-affected areas. Real-time video streams captured by UAV cameras play a crucial role in swiftly identifying victims and individuals requiring assistance, necessitating their broadcast to the rescue unit's dispatch center. When faced with the absence or failure of a traditional telecommunications infrastructure, the FANET technology proves adept at transmitting video information over substantial distances [4]–[6]. Nodes within this network, positioned on UAVs, perform retransmission and routing functions for transmitted data packets. This decentralized network enables the transmission of video information streams within a random topology, dynamically changing in three-dimensional space.

In the process of performing search and rescue operations and timely detection of victims, it is necessary to ensure high quality FANET video broadcasting. The problem of improving the quality of communication in wireless self-organizing networks is subject of publications by many researchers [7], [8]. However, insufficient attention has been paid to the issues of ensuring high-quality transmission of video streams in FANET.

Transmission of video streams in a FANET is characterized by heightened network topology dynamism and frequent changes in distances between moving nodes, potentially reaching significant values. These traits, coupled with limited network channel performance, result in video stream failures [9]–[11] and packet losses due to bit distortions from occasional decreases in received signal power [12]–[14]. These factors considerably compromise the quality of video broadcasting in FANET. Assuming nodes transmitting video streams operate at maximum permissible power levels, achieving high-quality video transmission becomes feasible through the control of various parameters. These parameters encompass the intensity of video stream requests, average video stream duration, and average length of wireless channels.

The control of these parameter values, critical for influencing video broadcast quality, revolves around decisions to transmit or refuse new video streams, disable or maintain transmitted video streams, and alter the distance between network nodes. Clearly, providers of video surveillance demand effective decision-making tools capable of offering informed recommendations to ensure high-quality video broadcasting. In light of this, research on the development of a decision-making support algorithm in the video surveillance process, leveraging FANET applications, emerges as a pertinent and valuable avenue of exploration.

The presented research is aimed at solving a pressing scientific and technical problem, which is to ensure high quality transmission of streaming data in wireless remote monitoring systems used by rescue services to provide timely assistance. The purpose of the article is to improve the process of video monitoring of territories. This is achieved through the development of an algorithm for controlling the transmission of video streams in a FANET.

2. LITERATURE REVIEW

An analysis of research has shown that a significant number of publications are devoted to the issues of data transmission in FANETs. In a flying peer-to-peer network designed to work in the event of various emergency situations, the multi-channel IEEE 802.11p MAC protocol has been proposed for use [6]. In order to provide guarantees for the timely exchange of information in conditions of a large number of nodes and intensive data traffic in FANET, it is proposed to use the MAC sublayer of the IEEE802.11p standard, which provides for the establishment of access priorities for different classes of information flows. Many works are devoted to analyzing the effectiveness of using routing procedures in self-organizing networks and developing network level algorithms adapted to the operating conditions of FANET. In order to improve the performance of FANET, it is proposed to take into account the presence of noise in wireless channels during the routing process [15], use learning cluster automata [16], and fuzzy logical inference systems [17]. To leverage the strengths of hybrid architectures that integrate long range (LoRa) with Wi-Fi to enhance communication capabilities in FANETs technologies for improved performance The authors conducted a theoretical analysis of the operating range of both LoRa and IEEE 802.11s, along with a simple experimental analysis of long range wide area network’s (LoRaWAN's) operating range for UAV-to-ground communications. These evaluations provide insights into the practical capabilities of LoRa in real-world scenarios [18]. To enhance the concurrent transmission of large-scale video streams within edge computing environments, a Q-learning data stream scheduling model is employed to facilitate dynamic load balancing across multiple network interface cards (NICs). This methodology entails the classification of data streams and the dynamic selection of the appropriate CPU transmission processing unit based on a reward function, thereby aiding in load balancing and the enhancement of overall system performance. The findings demonstrate that this approach can increase bandwidth by a factor of 3.6 in comparison to a benchmark scheme utilizing a single network port, while concurrently reducing the average CPU load ratio by 18% and decreasing system latency by 21%. Nevertheless, the study does not consider potential limitations, such as the scalability of the proposed method in exceptionally large data centers or the influence of fluctuating network conditions on the performance of the Q-learning algorithm, which may impact its efficacy in practical applications. which could affect its effectiveness in real-world applications [19]. In order to improve FANET routing, the use of neural network reinforcement learning has been proposed to select a utility indicator as a weighted sum of the indicator of successful delivery, delay and energy consumption [20].

Research has been carried out on the features of broadcasting video streams in FANET using the NS-3 simulation environment [21]. Research results have shown that with a small number of nodes in the network, significant packet losses are observed. This is due to the reduced level of transmitted signals at relatively large distances between network nodes. It has been established that the best indicators of the quality of transmission of video information streams are observed when operating in a network of 10 to 15 nodes. A further increase in the number of nodes leads to a deterioration in the quality of transmission of video streams, which is associated with an increase in the number of intermediate channels within the generated packet delivery routes. To reduce packet errors that occur in FANET due to network collisions or interference, a video streaming method based on automatic request for retransmissions at the application level has been proposed [22]. However, the above works do not examine the issues of achieving the required probability of ensuring high quality video broadcasting in FANET, estimating the recommended distance between transmitting and receiving nodes; little attention has been paid to the development of decision support tools in the FANET video monitoring process, taking into account the high probability of packet loss and the specific conditions for transmitting video information captured by UAV cameras.

Most works on FANET address the issue of routing and network architecture without any discussion of the characteristics of multiple channels. The routing strategy in the FANET has been studied by numerous researchers. Handling of network-level layers research work focuses on channel abstraction through multiple strategies including various channel conditions. Due to the dynamic topological changes of network-related studies, researchers such as with mobile nodes. They are capable of assembling network paths for wireless links [23], [24]. Thus, the research of many scientists and developers is devoted to improving the processes of information transmission in wireless remote monitoring systems [25]. However, the scientific and practical results they obtained require further development in terms of ensuring high quality video broadcasting in FANET.

3. PROPOSED ALGORITHM

Consider a scenario where video monitoring of territories is conducted using a FANET during a search and rescue operation. To identify victims, specific video streams captured by UAV-mounted cameras are transmitted to the rescue unit's dispatch center monitors. However, due to various reasons, some transmitted video streams may be intermittently discontinued, and the necessity to transmit new videos may arise. To ensure effective detection of individuals in need of rescue by dispatch center observers, it is imperative to guarantee high-quality FANET video transmission to the utilized monitors.

3.1. Rationale for recommended solutions

The performance of the FANET is both limited and unpredictable. To prevent an undesirable reduction in the quality of video broadcast when introducing new video streams in these challenging conditions, a set of recommended solutions is proposed and detailed in Table 1. The decision-making process primarily considers the value of Hq (probability of ensuring high video quality) when a new video stream is proposed. If the estimated value of Hq is equal to or greater than 0.95, the transmission of the new video stream is approved. Alternatively, if this value falls under 0.95, an additional factor is taken into account: the presence of a low-information video stream among the existing ones, which can be deactivated. If an ongoing transmission involves such a low-information video stream, it is advisable to disable it. In cases where no low-information video streams are identified, the recommended course of action is to reduce the average wireless channel length to the specified *rd* value.

Table 1. Recommended solutions

Value Hq	Transmitted/not transmitted low-information video stream	Recommended solutions
≥0.95	No importance	Transmitting a new video stream
<0.95	Not transmitted	Reduce the average channel length to rd meters
<0.95	Transmitted	Disconnecting the transmission of low-informational video stream

3.2. Estimating the probability of high quality broadcasting video streams

When assessing the probability of ensuring high quality video broadcasts over the network, one should take into account that in the most undesirable case, all video streams pass through the same busiest channel. Then the value of Hq is equal to the probability of high-quality broadcasting video streams over this channel and can be calculated using the (1).

$$Hq = \sum_{x=0}^{b} \frac{a!}{x!(a-x)!} [1-(p+g)]^{a-x} (p+g)^x \quad (1)$$

Here a is the number of received requests to transmit video streams; b is the value that should not exceed the sum of the number of failures in the transmission of video streams and the number of video streams transmitted with an unacceptable level of packet loss; p is the probability of failure in video stream transmission; g is the probability of transmitting a video stream with an unacceptable level of packet loss.

3.3. Probability of failure in video stream transmission

To compute the value p, consider a multi-channel system with a restricted queue length. The chance of failing to service a request is given in (2).

$$p=\frac{\frac{(\lambda\tau)^{(\frac{R}{r})}}{(\frac{R}{r})!}\left(\frac{\lambda\tau r}{R}\right)^{m}}{\frac{(\lambda\tau)^{(\frac{R}{r})}}{(\frac{R}{r})!}\sum_{u=1}^{m}\left(\frac{\lambda\tau r}{R}\right)^{u}+\sum_{x=0}^{(\frac{R}{r})}\frac{(\lambda\tau)^{x}}{x!}} \quad (2)$$

Here λ is the intensity of receipt of video stream requests on a channel; τ is the average duration of transmission of video streams on the channel; m is the buffer volume for the queue of video stream requests per channel; R is the bitrate of data transmission on the canal; r is channel performance used to transmit one video stream with a permissible level of package loss. In (2) is valid under following condition, as given in (3).

$$\frac{R}{r}>\lambda\tau \quad (3)$$

3.4. Probability of transmitting a video stream with an unacceptable level of packet loss

To calculate the probability of a video stream channel having an unacceptable amount of package loss use the (4).

$$g=1-\left[(1-v)^{w}+\sum_{z=1}^{PL}y_{w,z}(1-v)^{w-z}v^{z}\right] \quad (4)$$

Here w is the quantity of packets being transmitted in the video stream; v is the probability of a package being lost in the process of transmitting through the channel; PL is the permissible number of packages being lost during the transmission of the video feed. The value PL can be calculated by the (5).

$$PL=\left\lceil\frac{w-2\cdot CP}{CP+1}\right\rceil \quad (5)$$

Here CP is the number of packets that need to be obtained in a row before and after a lost package to compensate for its loss. Coefficients can be calculated with the (6).

$$y_{w,z}=\begin{cases}w-2CP, z=1;\\0, z>1, w\le 3CP+1;\\\sum_{i=2CP+1}^{w-z-1}y_{i,z-1}, z>1, w>3CP+1.\end{cases} \quad (6)$$

In (4) through (6) take into account the possibility of approximation processes being used at the receiving node to recover lost packets. But it's important to remember that at the receiving node, in order to effectively recover a lost packet, at least one packet before and one packet after it must be present in the sequence. The probability of packet loss during channel transmission can be computed using the (7).

$$v=1-\left[1-Q\left(\frac{2\left(P_{T}+10\,lg\frac{(\frac{c}{f})^{2}}{(4\pi d)^{2}L_{S}}\right)}{R\cdot k\cdot T_{R}\cdot N_{F}}\right)\right]^{s} \quad (7)$$

Here P_T is the signal transmission power; c is the signal spread speed; f is the signal frequency; d is the average distance between transmitting and receiving nodes; L_s are system losses; k is Boltzmann constant; T_R is the temperature; N_F is the noise coefficient; and s is the packet bit length.

To support decision-making in the process of conducting FANET video monitoring, the implementation of the algorithm presented in Algorithm 1 is proposed. The proposed algorithm was used in computational experiments performed using a simulation model of the decision-making process for managing the transmission of video streams to FANET.

Algorithm 1. Adaptive video stream transmission decision algorithm in FANET
Step 1: beginning of the algorithm.
Step 2: the starting data is entered T is the total number of intervals of time the algorithm performed; Λ=1 the number of video streams ST=0; the total duration of the transmission of the video's streams; the average time of transmission video stream on the channel τ=0; the intensity of the receipt of requests for transmission video streams λ=0.

Step 3: the number of time intervals t rises by one. Proceed to step 20 if the number for the current time interval is greater than the value. In the event when not, step 4 of the algorithm is executed.
Step 4: the i-video stream number increases by 1. If the video stream number exceeds Λ, move to step 7. Otherwise, the algorithm executes to step 5.
Step 5: if the transfer of the stream number *i* is completed earlier than the current time interval, move to step 6. Otherwise, the algorithm execution returns to step 4.
Step 6: the value of the total duration of transmission of *ST* video streams increases by one unit.
Step 7: the decision-maker is invited to answer question 1: "Is a new stream required?"
Step 8: if a new stream is required, move to step 9. Otherwise, the algorithm execution returns to step 3.
Step 9: a procedure is carried out to estimate the value of *pd* is the forecasted average length of the wireless channel.
Step 10: calculate the intensity of video stream requests per channel and the average video stream duration per channel according to (8) and (9).

$$\lambda = \frac{\Lambda+1}{t} \tag{8}$$

$$\tau = \frac{ST}{\Lambda} \tag{9}$$

The probability value of high-quality video transmission is calculated using (1) to (7).
Step 11: the following condition is verified: *Hq*>=0.95. If this condition is met, move to step 12. Otherwise, the algorithm executes to step 13.
Step 12: the decision-maker is given a message 1: "The transmission of the video stream will not significantly affect the video transmission quality. It is recommended to take decision 1 to transmit video stream". Running the algorithm goes to step 18.
Step 13: the decision-maker is invited to answer question 1: "Is there a low-information video stream amongst the video streams transmitted?"
Step 14: if the low-information stream is transmitted at the current time, the transition to step 17 is performed. Otherwise, the algorithm execution goes to step 15.
Step 15: the procedure is performed to estimate the *rd* value, the recommended average wireless channel length.
Step 16: the decision-maker receives a message 2: "Stream transmission may deteriorate the quality of the video transmission. It is recommended to take decision 2-to reduce the average length of the channel to *rd* meters". Running the algorithm goes to step 18.
Step 17: the decision-maker receives a message 2: "Stream transmission may deteriorate the quality of the video transmission. It is recommended that decision 3 be adopted-to disable the transmission of low-information flows".
Step 18: if decision 1 is adopted, the transition to step 19 takes place. Otherwise, the algorithm execution returns to step 3.
Step 19: the video stream number *Λ* increases by 1. Executing the algorithm returns to step 3.
Step 20: end of algorithm.

4. RESULTS AND DISCUSSION

As shown above, insufficient attention was paid to the issues of ensuring high-quality transmission of video streams in FANET in earlier studies. In this study, we proposed an original algorithm that estimates the probability of ensuring high quality video broadcasting. Depending on the values of this probability, one of the following solutions is recommended: transmit a new video stream, reduce the average length of wireless channels, or disable the transmission of a low-informative video stream. Using this algorithm, computational experiments were performed, the results of which are presented as follows.

4.1. Computational experiments

Using (1) to (6), a series of computational experiments was carried out. The results obtained are shown on the dependence graphs at *τ*=0.5 h (Figure 1). The graphs at *d*=480 m is presented in Figures 2 and 3. Analysis of the presented results of computational experiments showed that by controlling the values of parameters *λ*, *τ* and *d*, it is possible to increase the probability of providing high quality video transmission in the FANET. It is proposed to control the values of the above parameters by deciding on sending (or refusing to send) video streams, deleting (or not blocking) sent video streams and changing the distance between the sending and receiving network nodes. We will deem the decision to manage FANET video monitoring features as correct if its implementation guarantees a high quality of video transmission.

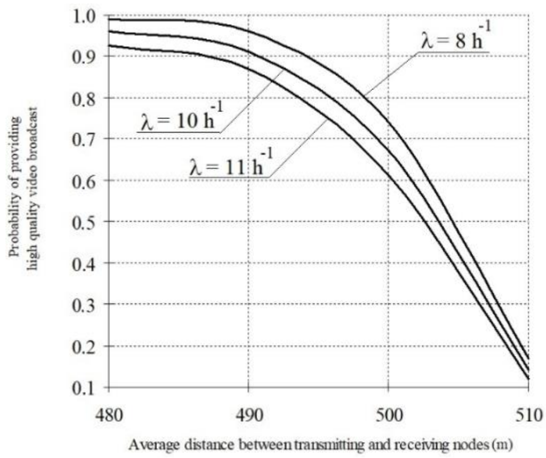

Figure 1. Hq(d) dependence graphs at τ=0.5 h

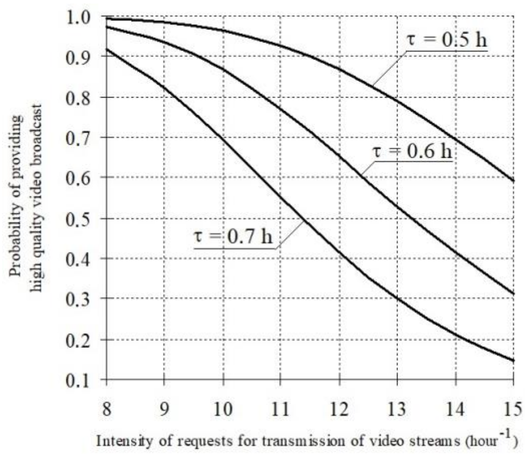

Figure 2. Hq(λ) dependence graphs at d=480 m

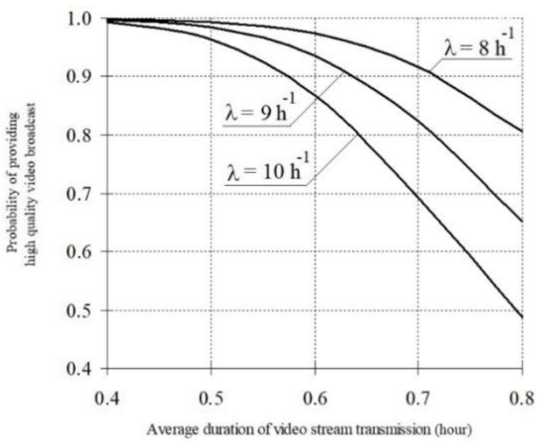

Figure 3. Hq(τ) dependence graphs at d=480 m

4.2. Comparative analysis

Let's introduce the variable *sb*, representing the sum of failures in video stream transmission and the number of video streams transmitted with an unacceptable level of packet loss. The high quality of video broadcasting will be ensured if the *sb* value does not exceed the value *b*, and where *a* is the number of video stream requests. The value of sb is expected not to exceed a percentage of the number of video stream requests received. The value can be calculated using the (10).

$$b = \left\lceil \frac{B \cdot a}{100\%} \right\rceil \tag{10}$$

In the process of computational experiments using a simulation model to assess the correctness of decision-making, the value of *sb* is calculated. At the end of each experiment this value is compared to the value *b*. If $sb \leq b$, then the experiment is considered to have provided high quality video broadcasting. The probability of making the right decision on managing the transmission of video streams in FANET is measured by the (11):

$$Pcorr = \frac{Ehq}{Etot} \tag{11}$$

Here *Ehq* is the number of experiments in which the high quality of video transmission is ensured; *Etot* is the total number of the experiments carried out.

In the research process, *Etot*=520 computational experiments were carried out to assess the correctness of decision-making for managing the transmission of video streams in FANET using the proposed algorithm. When performing experiments, calculations of values α and sb were carried out, values were calculated b according to the (9). At the end of each experiment, the sb value was compared to the value b. If, $sb \leq b$ then in this experiment it was recorded to provide high quality video broadcasting. Table 2 presents a fragment of the results obtained in the course of the computational experiments. The default value was 10%.

Analyzing the experimental data led to the computation of the value through (10). The results demonstrated that, with the application of the proposed algorithm, Table 3 shows a fragment of the results of these experiments. The probability of making accurate decisions regarding video stream transmission to FANET stands at 0.924. Comparable experiments were undertaken to assess decision-making accuracy in managing the transmission of video streams in FANET without employing the proposed algorithm, yielding a value *Pcorr*=0.761. Thus, the use of the proposed algorithm makes it possible to increase the probability of making the right decision on controlling the transmission of video streams in FANET by 16.3%.

Table 2. Results of computational experiments using the proposed algorithm

Experiment number	a	b	sb	$sb \leq b$
1	52	6	4	+
2	46	5	3	+
3	48	5	7	–
…	…	…	…	…
519	56	6	5	+
520	50	5	4	+

Table 3. Results of computational experiments without using the proposed algorithm

Experiment number	a	b	sb	$sb \leq b$
1	50	5	4	+
2	48	5	7	–
3	56	6	6	+
…	…	…	…	…
519	46	5	6	–
520	52	6	5	+

5. CONCLUSION

Our proposed algorithm serves as a valuable tool for supporting decision-making in the management of video streams within a flying FANET. This algorithm assesses the probability of achieving high-quality video transmission, offering recommended solutions based on these assessments: initiating a new video stream, reducing the average length of wireless channels, or discontinuing low-information video stream transmission. The outcomes of experimental studies unequivocally demonstrate the efficacy of our algorithm, showcasing a noteworthy 16.3% increase in the probability of making accurate decisions regarding the transmission management of video streams in FANET. Future endeavors will focus on developing dedicated software for the seamless implementation and integration of the proposed algorithm, paving the way for enhanced practical applications and widespread adoption within FANET systems.

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AUTHOR CONTRIBUTIONS STATEMENT

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Murtadha N. Rasol	✓		✓	✓			✓			✓	✓		✓	
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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