Для побудови систем оптичної навігації необхідно проводити аналіз та оцінку ефективності потоків даних у бездротовій Ad Hoc мережі відеокамер. Запропонований метод активної координації відеокамер в оптичній навігації на основі мультиагентного підходу (MAC-on-MAA). В результаті дослідження покращені характеристики енергоспоживання мобільних агентів, підвищена захищеність каналів зв'язку, прискорений обмін таблицями маршрутизації реактивного протоколу AODV

Ключові слова: Ad Hoc, мультиагентна система, аналіз відеопотоку, стегоконтейнер, зменшення енергоспоживання беспілотних апаратів

Для построения систем оптической навигации необходимо проводить анализ и оценку эффективности потоков данных в беспроводой Ad Hoc сети видеокамер. Предложен метод активной координации видеокамер в оптической навигации на основе мультиагентного подхода (MAC-on-MAA). В результате исследования улучшены характеристики энергопотребления мобильных агентов, повышена защищённость каналов связи, ускорен обмен таблицами маршрутизации реактивного протокола AODV

Ключевые слова: Ad Hoc, мультиагентная система, анализ видеопотока, стегоконтейнер, снижение энергопотребления беспилотных аппаратов

UDC 004.75+004.627

DOI: 10.15587/1729-4061.2017.90863

DEVISING A METHOD FOR THE ACTIVE COORDINATION OF VIDEO CAMERAS IN OPTICAL NAVIGATION BASED ON THE MULTI-AGENT APPROACH

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1. Introduction

Modern networks of video cameras can use dynamic reconfiguration for fulfilling the tasks on video analysis of spatially-distributed objects. A characteristic problem is the limited hardware resources that have to be allocated in the course of operating a network of devices that provide for the transmission of video stream. The problem is the implementation of effective coordination of data obtained from cameras in real time. The networks of digital video cameras where the routing efficiency was assessed through the modification of standards metrics for wireless networks was examined for the first time in paper [1]. The use of network metrics allows for improvement in the algorithms of capturing the objects. But in the process of optical navigation, it is not enough to have video data from one source. Therefore, it is expedient to devise a method for coordinating the interaction of a network of video cameras in real time.

The relevance of present research is in the development of a progressive method for managing dynamic architecture of the network of devices that use network metadata for intelligent analysis of scenes during video surveillance.

2. Literature review and problem statement

Modern video surveillance has gained features of mobility. Networks can be organized taking into account the dynamics of video surveillance conditions. Such networks should possess substantiated benefits over wireless networks of traditional architecture. The most important advantages are less dependence of the distance of video data transmission on transmitter capacity, reliable provision of changes in the network infrastructure, the possibility of reconfiguration under critical conditions without losing video stream quality.

It is relevant to examine hardware-software implementations of video streams filters that enable the elimination of effects of noises on the quality of multimedia traffic [2, 3]. The aspects of solving the problem on the dependence of distance of transmission of these components of dynamic network and the power of signal level of the transmitter are explored by researchers in [4]. In the proposed solutions, the indicated problem is tackled by introducing intermediate transfer components and building the trajectories of data transmission. But this approach is not efficient enough during dynamic video monitoring.

Distributed network systems require efficient consumption of energy resources. Contemporary models reproduce the consumption of energy in multiprocessor systems depending on task scheduling algorithms [5]. But such models are not investigated under conditions of changing topology in Ad Hoc network.

Attention is paid to designing distributed systems using the principles of management automation. Such management is most effectively performed using the methods of parallel processing of network resources [6]. Applying the JADE technology (Java Agent Development Environment) allows the use of component architecture for mobile dynamic networks based on the component multi-agent autonomy. This approach, however, does not exclude potential occurrence of "bottlenecks" and competitive data modification (Concurrent Modification Exception) under specific conditions.

[7] explores hybrid models of managing data flows in wireless networks of sensors parameters monitoring. The problems of protocols hybridization remain solved only for a narrow class of tasks. The aspects of modeling dynamic sensory networks are examined based on object-oriented and agent-oriented approaches [8]. In this case, the topology, protocols, and data transmission routes schemes are taken into account. Implementations of systems of dynamic simulation are economically beneficial. But they still are quite abstract and require an increase in the level of reliability of consumption of hardware resources of network components.

Methods of reliability provision of dynamic networks are addressed in [9]. This paper also describes peculiarities in the application of evidence theory when assessing the probabilities of failure in the network nodes.

Architectures of mobile platforms of the components of wireless video networks are examined in [10, 11]. But they additionally have to take into account the mobility of nodes. A shortcoming of this approach is an additional increase in the dynamics of network topology with regard to the probability of displacement or the occurrence of obstacles. In addition, it is necessary to take into account limited supply of power sources for mobile components in a video surveillance network. Efficient power supply for mobile agents is needed both when designing hardware means and while organizing the interaction protocols.

Authors of Ad Hoc networks studies distinguish several classes of problems:

– increasing the efficiency of energy consumption by mobile agents [12, 13];

– provision of noise immunity and transmitted data safety when using a steganographic approach [14, 15];

– increasing a network through-put [16, 17];

– provision of effectiveness of the applied routing methods [17, 18].

The indicated classes of problems were examined in mobile Ad Hoc networks, in which reactive routing protocols have been improved based on situation modeling and computational intelligence systems [19, 20]. In papers [19, 20], however, protocols do not take into account short time of building a route and warranted packets delivery under conditions of video data transmission when the network topology changes.

Insufficient effectiveness of methods for the coordination of components of mobile Ad Hoc networks calls for the development of new methods. Such methods imply an analysis of coordinate metrics Field of View (FoV) and the Quality of Service (QoS) principle with a specified probability of data packets transmission [21]. In addition, it is necessary to promptly detect and recover breaks in the route, provide high scalability, high performance of network video stream transmission at various size of network.

3. The aim and tasks of the study

The studies conducted were aimed at devising a method for improving the efficiency of a network of cameras that is capable of being auto-configured.

To achieve the set aim, the following tasks were to be solved:

– to determine a sufficient level of normalization of illuminance of video frames based on the throughput of modules of multi-agent system when encoding video data transmission in the network;

– to reduce the time of video stream analysis through canceling the decoding of specified areas of graphic attributes in the obtained video frames of the network;

– to prolong the time of operation of mobile Ad Hoc network via saving limited power resources of mobile agent, due to decreasing the volume of computing actions over video stream;

– to increase protection of communication channel so that in case of information interception, the protection breaking time would exceed the period of relevance for the limited access information;

– to improve reliability of routing protocol based on the multi-agent model of parallel processing of service data from Ad Hoc network of video cameras.

4. Materials and methods of examining active coordination of video cameras with illuminance-correction feature, compression of data and the use of tag container in the data transfer channel

4. 1. Correlation of the illuminance level of video stream frames, the level of power consumption by mobile agent and the loading of video data transmission channel

In the highly dynamic heterogeneous networks, to which Ad Hoc networks may be attributed, an unmanned aerial vehicle (UAV) may serve as the data sender. To ensure stable wireless communication, data transmission in such a network to other UAV can be carried out directly or through transfer nodes (Fig. 1). Such nodes are required if either there is no direct electromagnetic visibility between the nodes of Ad Hoc network or permissible distance between them is exceeded [22].

In order to assess sufficient efficiency of a network of video cameras, we propose using the criterion of dynamic adaptability DA_C during the process of video surveillance over objects-targets:

$$DA_C = f(I_S, BW_C), \tag{1}$$

where I_S is the function of dependence of illuminance normalization of a frame from video stream, BW_C is the coefficient of data transmission rate to the throughput:

$$BW_C = BW_{MAS} \cdot \frac{1}{k} \cdot \sum_{k=1}^{v} \phi_L \cdot BW_k, \tag{2}$$

where k is the number of video camera and v is the quantity of video cameras in a multi-agent network with efficient throughput BW_{MAS}.

Frame size Fr_s is calculated by the known formula $Fr_s = n \cdot m \cdot Ch_r$, where m, n are the width and length of the frame in pixels (that is, resolution); Ch_r is the number of bits of the original illuminance of frame pixels [23]. The specified formula allows us to calculate the rate of video stream data transmission $BtR_k = (Fr_R)_k \cdot Fr_{PS}$.

Based on the fact that the maximum transmission rate $BW_k = \max(BtR_k)$ is the throughput, one can determine total coefficient of the load of transfer channel per unit of time:

$$\phi_L = \frac{1}{N_{FPS}} \cdot \sum_{t=1}^{N_{FPS}} \left[\frac{BtR_k}{BW_k} \right]_t , \qquad (3)$$

where t is the number of numerical value of ratio BtR_k and BW_k of metrics of k-th video camera; N_{FPS} is the possible quantity of video streams proportional to Fr_{PS}.

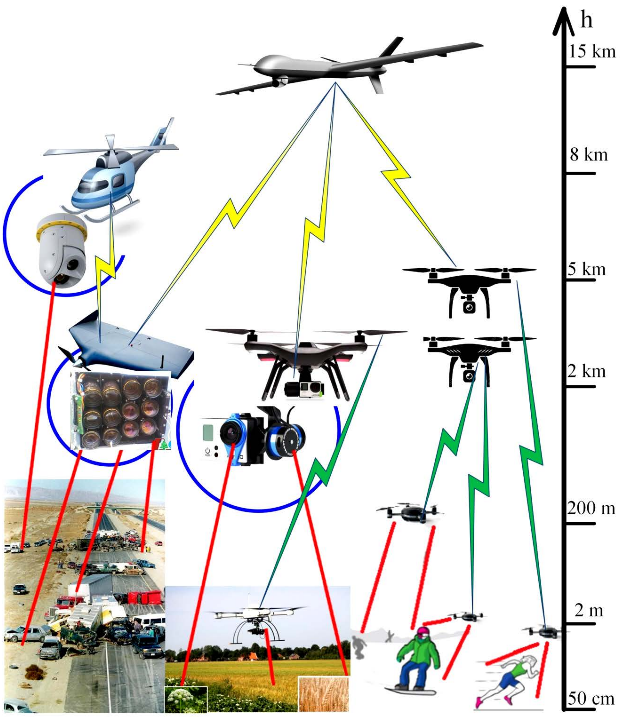

Fig. 1. Ad Hoc network of video cameras at different types of UAV design and height of flight ceiling h: red lines — formatio of direct video streams ("object-agent"); yellow lines — wireless channels of direct communication between agents; green lines —transfer of flows through transfer nodes; blue lines outline video equipment specifications

A significant factor that affects loading of the video stream transmission channel is the illuminance I_S of frames that form such flow. That is why we examined a known model of illuminance normalization [24]. It was found that this model does not take into account characteristics of the network transmission. Therefore, it is proposed to use factor γ in formula (4):

$$I_S = f(I_R, I_G, I_B), \; I_C = \frac{1 - \gamma \cdot \sum_{i,j=1}^{n,m} p_{i,j}^{\bar{C}}}{\sum_{i,j=1}^{n,m} p_{i,j}}, \qquad (4)$$

where $p_{i,j}$ is the sum of RGB values of a pixel; $p_{i,j}^{\bar{C}}$ is the sum of RGB pixel values in the absence of specified color; $\gamma = \frac{e^{BW_C}}{2}$ is the coefficient of filtration of color shades of the frame in a video stream, secured by coefficient BW_C.

We consider k-th intelligent video camera, which forms video stream for transmission to another node in Ad Hoc network. Then the adjustment of illuminance level is carried out by the results of calculations in accordance with formula (4). Thus, we obtain reduction in the current load of data transmission channel.

In addition, compression procedures should be applied to the video stream before sending it along communication channel. This will significantly reduce the volume of video stream. Along with a decrease in the required illuminance, this will significantly reduce the load on the mobile agent numerator. This approach is absolutely relevant in mobile Ad Hoc networks that use limited energy resources. The proposed approach allows fulfilling the set task of improving energy efficiency of using electric power systems of separate mobile agent. Reduction in power consumption prolongs the life cycle of such a network as a whole.

Quantitative characteristics of saving consumed electricity E can be estimated by modifying the technique, described in [13]:

$$E = E_{dyn} + E_{stat} = I_S k_1 V^2 L + k_2 (k_1 V^2 L) = \alpha V^2 L, \alpha = k_1 (I_S + k_2), \qquad (5)$$

where E_{dyn}, E_{stat} are the dynamic power (active mode of power consumption) and static power (idle mode), respectively; V is the level of power supply voltage; L is the duration of processing and transmitting a specified part of the video stream at coefficient k_1 of the numerator load; k_2=0.3 at normal (non-correlated) power consumption.

When filtering color shades of the frame, power consumption decreases. Then formula (5) should take into account illuminance I_s of frames based on filtration factor γ and takes into account the throughput metrics of a network of video cameras.

4.2. The use of compression algorithms for video stream

Components of the data transfer process (Fig. 2) in mobile Ad Hoc networks of video surveillance make use of compression. The basic compression algorithms are based on discrete cosine transform (DCT) [24].

Pixel data of video stream frames arrive to the Throughput Analyzer module of the multi-agent system (MAS). An evaluation is conducted of metadata from the network traffic nodes that participate in the video stream transfer. Based on this evaluation, the Luminance Modifier module calculates the level of frames illuminance. The sets of pixels of geometric areas of graphic attributes of objects-targets are formed. Such sets should be considered for recognition in the process of optical navigation. That is why they are not encoded in the frame of video stream. The domains of such graphic attributes enter to steganocontainers for further transmission.

Then a node of dynamic network of video surveillance receives a video frame. After that, this node necessarily in parallel decodes a steganocontainer and the compressed data transmitted by the network. In the next step, these data are transferred to the Pattern Recognition for Optical Navigation module. It performs the recognition of specific images of objects and determines the FoV of video cameras. The obtained values are used for the correction of other video cameras in the network. FoV parameters are entered into steganocontainers and passed on to the Camera angle adjustment module. Thus, a coordination of the video surveillance process by the entire network of video cameras is performed.

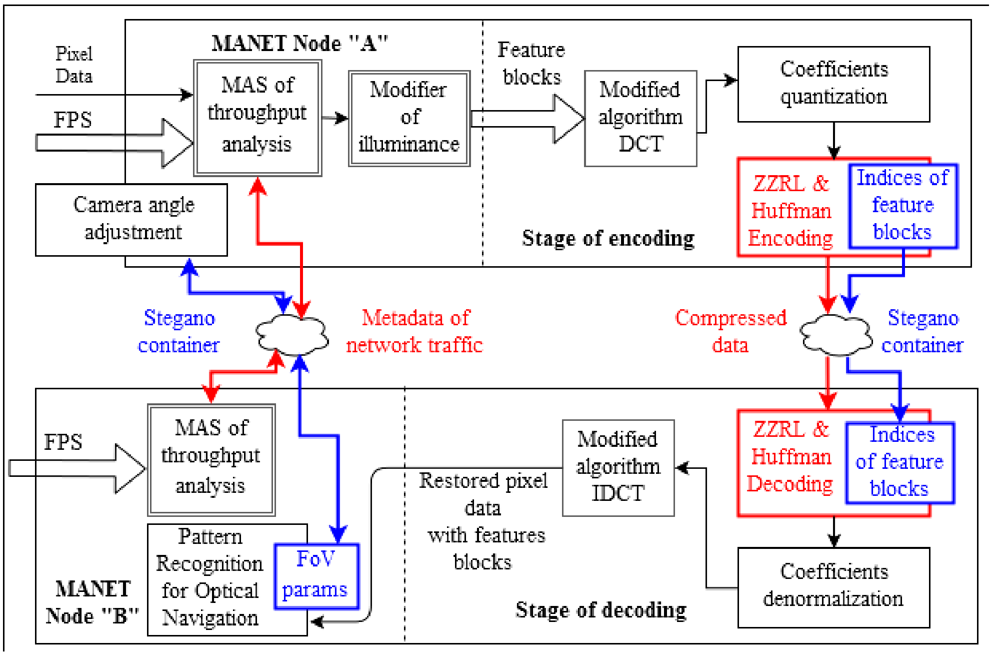

Fig. 2. Encoding and decoding of video stream transfer based on the DCT algorithm and network metadata

It is necessary to determine the part of the image, which will be subsequently used in the active phase of recognition of pattern attributes. If this part is to be encoded, it will lead to a loss of time for decoding. Most of the graphic attributes are characterised by irregular geometry. For them we proposed using the identification of a set of pixels of a graphic attribute instead of using geometric ranges of pixels of such a graphic attribute. This approach is efficinet if there is a set of pixels of graphic attributes of arbitrary geometric shapes $EX=\{p(x_1,y_1),...,p(x_K,y_K)\}$. Graphic attributes of objects-targets should be ignored when encoding. For the identification of blocks of such attributes at the image, we propose a modified formula of two-dimensional (2D) DCT algorithm [25]:

$$C(u,v)=\alpha(u,v)\sum_{x,y=0}^{N-1} f(x,y)\beta(x,u)\beta(y,v),\ \alpha(u,v)=$$

$$=\begin{cases}\dfrac{1}{\sqrt{N}},\ \text{if}(u,v\in EX)\vee(u,v)=0,\\ \sqrt{\dfrac{2}{N}},\ \text{if}(u,v\notin EX)\wedge(u,v)>0,\end{cases} \qquad (6)$$

$$\beta(p_1,p_2)=\cos\left[\frac{\pi(2p_1+1)p_2}{2N}\right]. \qquad (7)$$

Modification of algorithm (5, 6) affects the compression, namely, the Zig-Zag method of recording data in the image matrix. Fig. 3 shows frames of video stream where rectangles denote graphic attributes of objects that will not be compressed. This will accelerate image recognition by the Pattern Recognition for Optical Navigation module (Fig. 2).

During optical navigation, a module of pattern recognition determines the boundaries of the domain of graphic attribute of the object of video frame (Fig. 3, *a*). Parameters of pixels of the object's domain are introduced into set EX in formula (5). Another part of the image is compressed by the DCT algorithm. Its pixel data are recorded in the field of the video frame. This process is schematically shown in Fig. 3, *b*. Compressed video frame image with highlighted areas of graphic attributes of the objects is shown in Fig. 3, *c*. Such image will be transmitted by the network for the analysis by another node of Ad Hoc network.

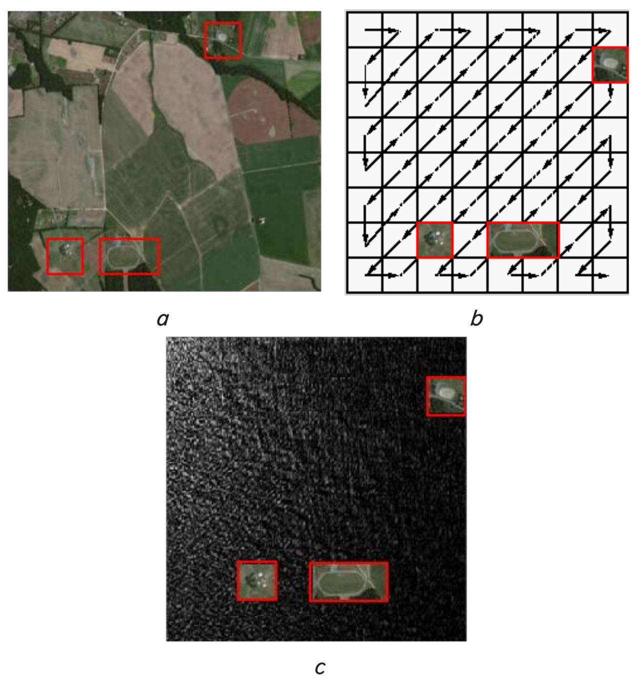

Fig. 3. Modified frame compression algorithm with specified domains of graphic attributes: *a* – in the process of recognition; *b* – in the process of compression; *c* – in the process of transfer over the network

4. 3. Formation of a steganocontainer for the transmission of indexes of non-compressed parts of video stream frames

A minimum configuration, rapid deployment and capability for self-organization allow the critical application of Ad Hoc network. These may include such emergencies as natural disasters, military conflicts, etc. We should not forget that the objects-targets defined in chapter 4.2 were ignored when encoding. In addition, they may be of interest not only for an Ad Hoc network owner but also, for example, for a competitive organization. Alternatively, open broadcast of intercepted video stream can cause havoc.

Such network can exist in different states: either an open data transmission/receiving or a closed transmission/receiving of limited access information. It is necessary to ensure such conditions so that in the event of data or control signals interception, the interceptor would not even guess that the network had passed into another state. This can be achieved using steganography.

That is why it makes sense for the indexes of pixels of graphic attributes of objects, whose selection for monitoring is expedient to hide (Indices of Feature Blocks in Fig. 2), to transmit with the main video stream (Compressed Data), but applying the steganographic method. Using a stegano-container allows hiding the fact of information transfer. Such approach, on the one hand, will ensure confidentiality of information about the objects-targets, on the other hand, will facilitate for a mobile agent-receiver of information to instantaneously highlight zones for further monitoring in the frame.

Steganography requires data with a component of randomness. Since the system processes video monitoring data, then over time these data change. And if one chooses very small intervals of time, then one may see that the values of RGB values of a pixel are different each time. Thus, a minor change in the value is accepted as something normal. This very principle will be applied for the formation of a stegano-container.

In order to represent floating-point numbers, the IEEE 754–2008 standard is used. According to it, a real number is recorded according to the structure shown in Fig. 4. This standard is utilized in both software realizations of arithmetic operations and in many hardware implementations, including mobile agents' numerators.

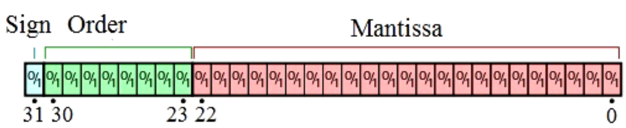

Fig. 4. Structure of a real number by the IEEE 754–2008 standard: "sign" is the positive or negative number; "order" is the degree of number; "mantissa" is the number itself

By examining a change in the number at the change in these parameters, it was found that younger 8 bits of the number can be used for steganography. This is due to the fact that the change in the indicated bits leads to a change in the number by 0.0000304 %. This very small magnitude practically does not affect the data integrity.

Usually, in the computing systems, RGB space is presented as a cube, with each of the coordinates representing one byte. All together, they carry 24 bits [15]. But in order to save the bit rate, usually in the cells for mobile agents they use a 16-bit color at most (with a range of shades 0–65535). Thus, in the RGB structure of pixel values, the last 8 bits can be "picked up" for steganography.

It should be noted that modern unmanned aerial vehicles use video cameras with a very high resolution of the matrix – from 9 to 50 megapixels [26]. In this study, the task was set about hidden transfer of objects' indexes, which are subject to monitoring by all Ad Hoc network agents. To solve it, we shall assume that 16 numbers × 8 bits=128 bits of steganographic data are sufficient.

This number of bits is sufficient, for example, for the transmission as GPS indices of the coordinates of objects-targets. These coordinates can be recorded in 4 real numbers, each of which contains 32 bits. Al in all, it is 4·32=128 bits of data.

An algorithm of steganography in this case takes the following form:

Step 1. Obtain (in accordance with chapter 4.2) GPS coordinates of objects at the frames of video stream, which will not be compressed.

Step 2. Map these coordinates in the form of bits sequence by using a function that interprets numbers as a sequence of bits.

Step 3. Represent rightmost 8 bits of each number of data on RGB values in the form of bits sequence.

Step 4. Obtain ith bit of the objects' GPS coordinates.

Step 5. Record this bit in ith bit of data on the pixel's RGB value.

Step 6. If there is the next bit, proceed to point 2 paragraph; otherwise, finalize the formation of data packet.

Step 7. Using the MAVLink (Micro Air Vehicle Link) protocol, forward the message to another Ad Hoc network agent (directly or through a transfer node, see Fig. 1).

Step 8. At the receiver, specified data are disclosed by the same sequence of numbers.

There is a probability that if Ad Hoc network of video cameras are discovered, the intruders would intercept hidden data to disclose them. The above described algorithm of steganography is very simple. Therefore, it will take less than half an hour for running a stego analysis of the hidden data if special forensics tools are applied [27]. In connection with this, we propose to introduce additional algorithm into the above described steganography algorithm. Using this algorithm, a sequence of bits should be wordshuffled randomly.

Steganography algorithm with the introduction of a random sequence will be complemented by the following steps:

Step 3a. Select the key by which a random sequence (seed) is built.

Step 3b. Construct a sequence from 1 to n (seq).

```
while(s<6){
        i = 0;
        t = seed+(6-s)*s;
        while(i<size){
                if(t&27){
                        tmp = seq[i];
                        i2 = i*s+t;
                        i2 %= size;
                        seq[i] = seq[i2];
                        seq[i2] = tmp;
                        t = roll_bits(t);
                }
                i++;
        }
        s++;
}
```

There are 128 data bits in total, and, using the formula of permutations when trying to run a stegoanalysis, an interceptor will need to look through 128! variants of the sequence of numbers. This would require conducting more than $3.856 \cdot 10^{215}$ permutations.

In addition to the use of steganography, protection of communication channels between UAV is enhanced through the transfer of information based on the MAVLink protocol.

This protocol can communicate in the network with a number of UAVs up to 255 units [28].

5. Results of research into data transfer in mobile Ad Hoc networks

A research into routing protocols characterizes sufficient performance of the dynamic routing protocol for mobile Ad Hoc networks – AODV (Ad Hoc On-Demand Distance Vector). However, a drawback of the AODV algorithm is a long time of processing the routing tables with neighboring nodes of mobile Ad Hoc network (Mobile Ad hoc Network, MANET) [29]. In the described method of active coordination of video cameras in optical navigation (MAC-on-MAA), we propose to use classes of the roles of agents specified in Fig. 5, for the parallelization of processing routing tables.

During reconfiguration, exchange of updated records in the routing tables between the MANET adjacent nodes of video cameras is performed periodically. With a large number of nodes, this process is critical in terms of multiflow access control to the routing tables. Asynchronous changes should be mapped along with updating adjacent nodes of the video surveillance network. SemaphoreAgent is needed when it is necessary to restrict the access to the routing table as a resource. The constructor of this class SemaphoreAgent (int permits) or SemaphoreAgent (int permits, boolean fair) necessarily receives the number of flows, to which SemaphoreAgent permits simultaneous use of this resource. A separate phase in the life of network or the stage of grouping requests from adjacent nodes on status update require corresponding changes in the routing table. Total change in records in the routing table is carried out in several flows. PhaserAgent allows the synchronization of these flows (Fig. 6).

CountDownLatchAgent should release the blocked flows when accessing the routing tables. The constructor CountDownLatchAgent necessarily receives the number of operations which must be performed prior to this. CyclicBarrierAgent is a point of synchronization, which determines the number of parallel flows that meet and are blocked. As soon as all incoming flows of update in the routing table were registered, a notification of MANET adjacent nodes about a possible update is announced.

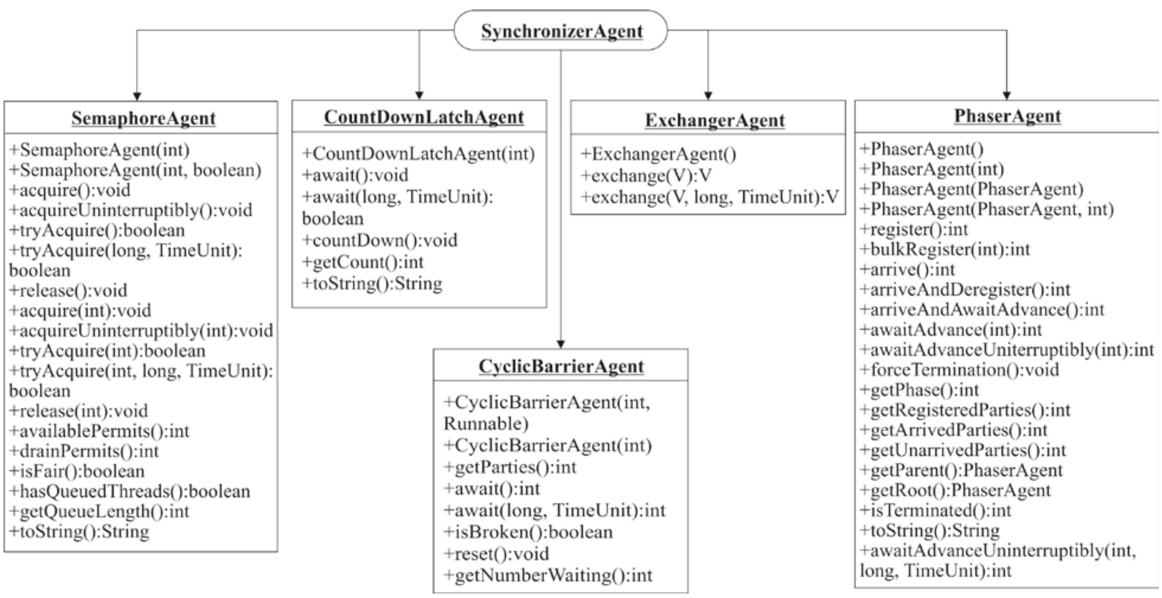

Fig. 5. Agents class diagram for the multiflow modification of AODV protocol routing tables

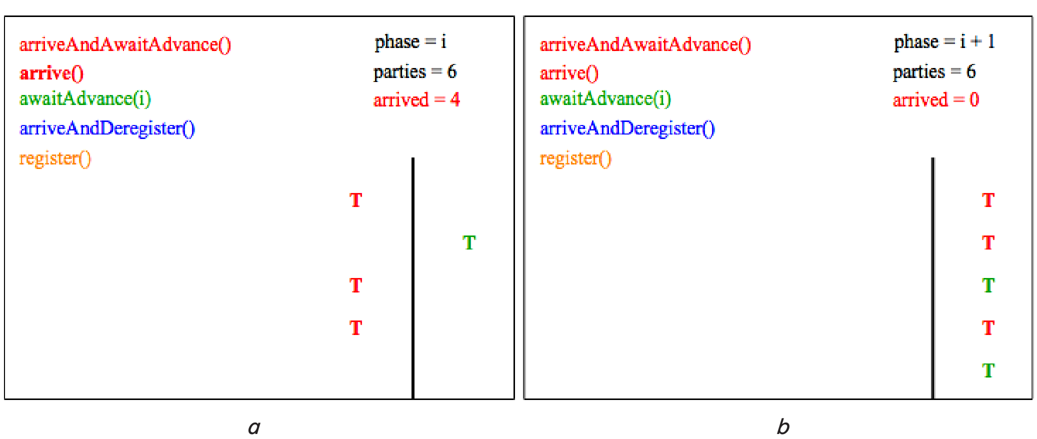

Fig. 6. Behavioral stages of PhaserAgent when updating routing tables of adjacent nodes: *a* – method of partial fulfillment of update; *b* – method of complete fulfillment of update transfer

Then the CyclicBarrierAgent is destroyed, and the flows are released. ExchangerAgent is a point of synchronization of flows pairs. The flow, which triggers the method exchange () in the ExchangerAgent, is blocked and awaits another flow. When another flow triggers the same method, the exchange of objects will be conducted. In this case, each ExchangerAgent of adjacent nodes will receive updated entries in the routing table as an argument of the method exchange().

Multi-agent approach to the process of updating routing tables of the AODV algorithm allows reducing the recovery time of the broken route at increasing the volume of service traffic by 8 %.

The implementation of the DA_C criteria provided for determining an adequate quality level of image reconstruction by the DCT algorithm during data transmission (Fig. 7). This approach ensures comprehensive adaptation of video stream metrics of the network of video cameras to the conditions of the video stream registration medium. Plane limit the domain of optimal ratio of maximal sufficient quality and maximum throughput. This reduces the time of video stream frames transfer and processing for further recognition of graphic attributes.

In the process of research, we measured indicators of energy efficiency of mobile agents without using the MAC-on-MAA method and after its introduction (Table 1).

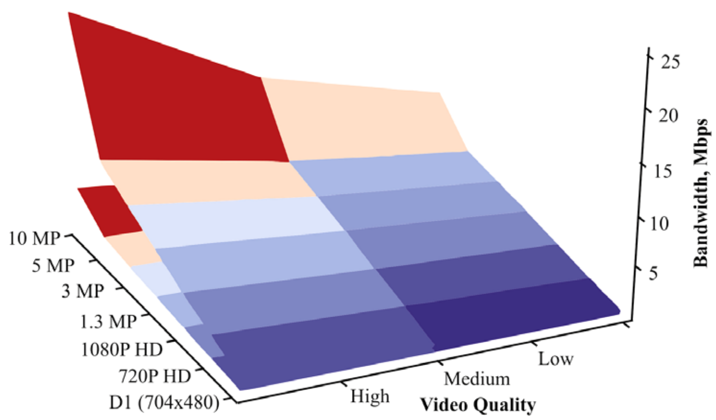

Fig. 7. Chart of dependence of the transmission channel throughput on the image quality that defines the boundary conditions of adaptation

Table 1

Results of measuring energy consumption of mobile agents

No.	Resolution for MJPEG (Medium), px	Bitrate, Mbps	Consumed current before the implementation of MAC-on-MAA, μA	Consumed current after the implementation of MAC-on-MAA, μA
1	D1, 720x480	1.2	10.4	9.8
2	720p_HD,1280x720	3.2	16.4	15.5
3	960p_HD, 1280x960	4.8	26.9	25.5
4	1080p_HD,1920x1080	6.8	31.4	27.4
5	1.3_MP,1280x1024	4.8	26.8	25.6
6	3_MP, 2048x1536	8.4	40.9	36.1
7	5_MP, 2592x1944	10.0	49.9	43.9

It was found as a result that reducing the time for analysis of graphic data by 6 %, the level of power consumption by mobile agents decreased by 8.2 %.

6. Discussion of results of implementing the method of active coordination of video cameras in the optical navigation

Automatically reconfigured networks of intelligent video cameras provide for the solution of task on the coordinated functioning of devices in distributed systems. This approach might be useful when constructing different large-scale environments and applications. In this case, the problems of adaptation to the changes in topology are solved successfully, as well as of coordination of the operation of various-type devices, hierarchical effective data processing, etc. Intelligent video cameras networks that are capable of maintaining active coordination are efficient for achieving the goals of optical navigation.

The proposed MAC-on-MAA method can extend the functionality of processing video stream by nodes of dynamic network of video cameras through the analysis of additional metadata. This is relevant in situations when the video informativeness should be enhanced by a comprehensive visualization of conventional video stream. Positive results can be obtained when it is necessary to recognize the objects in the infrared range. The method would be appropriate for filtering the stream when only the contours of objects should be displayed.

The most promising is to protect the data stream from unauthorized access by hiding the very fact of transfer of the coordinates of objects-targets by means of steganographic transformation of video stream.

The proposed multi-agent approach using Ad Hoc networks of video cameras allows remote inspection of technical condition of transportation infrastructure in the gas and oil pipelines, bridges and other technical facilities. It also contributes to the development of technologies for remote probing of natural resources and photogrammetry [26]. Research results may prove useful for agricultural enterprises with clear legally defined types of crops that have to be cultivated [30]. In this case, the MAC-on-MAA method is applicable for the optical navigation of UAV monitoring group, which are used to control the types, similarity and other characteristics of farmed crops.

7. Conclusions

In the course of the study we modified the conditions of encoding and decoding 2D DCT algorithm. The principle of exchanging the routing tables of AODV reactive protocol was modified. We examined the process of video transfer in the simulated distributed network. We proposed and described a method for active coordination of video cameras in optical navigation based on the multi-agent approach (MAC-on-MAA).

The most significant are the following results:

1. We ensured reduction in the time for analysis of video stream graphic data by 2.7 s at decreasing the network throughput in the range of 5–15 %. It should be noted that this increases the amount of service traffic by 8 %.

2. Analytic expressions for the assessment of quantitative characteristics of energy consumption

by mobile agents were obtained. It was determined that these characteristics improve by 8.2 % via reducing the time for analysis and volume of encoding of the video stream.

3. The mean value of constructing a route for data exchange at the coordination of a network of video cameras does not change. But the time for complete reconfiguration of the network, which was initiated by an arbitrary node, is reduced by 37 %.

4. The application of the proposed method of active coordination of video cameras in optical navigation based on the multi-agent approach decreases the total time for the video stream analysis by up to 6 % on average.

5. The introduction of the proposed algorithm to create a random sequence into the steganographic conversions and the application of MAVLink data transfer protocol enhance the protection of the communication channel. This is ensured by the need to perform more than $3.856 \cdot 10^{215}$ permutations to disclose of limited access information in the case of data interception and stegoanalysis.

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