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An algorithm determining the optimal length of the queue of requests for data transmission over the channels of a wireless ad-hoc network

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Abstract

The article presents the results of the development and research of an algorithm determining the optimal queue length of requests for transmitting information flows over wireless channels of the geoecological monitoring system for agricultural facilities. The proposed model allows to assess the use of wireless channels in the transmission of measurement information, which allows us to extend the queue of requests for communication sessions in a wireless ad-hoc network. A presented model estimates the waiting time for the start of transmission of information flows, on its basis the developed algorithm is executed. It is shown that the algorithm allows to support decision-making to increase the use of channels and ensure the permissible delay of the requested communication sessions.

Keywords: wireless ad-hoc network, transmission of information flows, communication sessions, request queue length, wireless channels, geoecological monitoring.

Introduction

When organizing systems for geoecological monitoring of geographically distributed objects of the agro-industrial complex (AIC), it is importante to manage information exchange. Its effectiveness largely depends on the quality of transmission of measurement information flows [1,2]. At the same time, the implementation of the above tasks is often carried out in conditions of partially working (damaged) or missing telecommunications infrastructure and possible destructive external influences. In such situations, it is preferable to deploy a wireless mobile ad-hoc network (MANET), which is based on packet transmission of information, has an arbitrary decentralized topology and is able to function without base stations [3-10].

The analysis of the scientific and technical literature and the patent base showed that the known transmission management methods in data transmission networks are not adapted to the operating conditions of an overloaded MANET, which requires new developments in this subject area and determines the relevance of the article [11-14]. Well-known approaches and methods focused on solving these problems reduce the level of network congestion, minimize the loss and delay of transmitted packets, and reduce packet jitter. The classical methods of ensuring the quality of service (QoS) of requests for the transmission of streaming information are based on the reservation of network resources and have found application in the technologies of Integrated Services (IntServ) and Differentiated Services (DiffServ). IntServ technology is designed to provide guaranteed quality of transmission of individual streams [15]. It provides for reserving the necessary resources on each network router along the path from the sender to the recipient. The RSVP (Resource Reservation Protocol) is used to implement the reservation [16, 17]. It checks whether the network has the resources required for high-quality information delivery. Then the decision is made to make a reservation and then transfer the stream. The need to transmit a huge number of different streams in large networks has led to great difficulties in implementing IntServ technology on main sections. As a result, the concept of DiffServ was proposed, which combines individual threads into a few classes [18]. According to DiffServ, whether a stream belongs to a particular class determines the quality of its transmission.

In technologies based on network resource redundancy, to avoid congestion and maintain the required level of QoS, means of smoothing packet flows are used in accordance with the specified profile of a specific quality-of-service class. For example, the "Leaky Bucket" algorithm is a means of limiting the maximum traffic intensity, and the "Token Bucket" algorithm can be used to get traffic with a limited average intensity and an acceptable level of jitter [19]. By reserving resources, packets are delivered with low latency and jitter values.

A number of routing protocols have been created to transmit streaming information to MANET [20-25], but their use does not allow reducing channel congestion to the required level. The solution to this problem is based on the proposed mechanism of traffic generation for real-time applications based on the transfer of markers in the process of packet routing in MANET transit nodes [26], a hybrid scheme for controlling the frequency of route information updates during video streaming in MANET [27]. In order to improve the quality of received streams in MANET, an approach is proposed that focuses on optimizing the distribution of channel performance for several competing sources [28]. However, all of the above approaches and algorithms do not significantly reduce packet loss and latency and, therefore, do not guarantee the achievement of a given level of quality of voice streams in MANET.

The receipt of requests from MANET subscribers for information exchange sessions varies randomly. At times of urgent need for rapid solution of numerous critical management tasks, the activity of MANET users sharply increases, which causes temporary shortage of channel resources, i.e. the occurrence of network congestion. At such moments, the quality of information transmission significantly deteriorates. The uneven flow of requests to the network leads to inefficient use of channels and a decrease in the quality of transmission. In order to avoid such situations, before transmitting a specific information stream when a corresponding request is received in MANET, it is advisable to ensure that the necessary channel performance is reserved in advance.

Reserving the channel performance will ensure the required quality of information flow transmission, but not always the available channel resources will be sufficient to service all incoming requests. In the conditions of high activity of network users and a lack of channel performance, at some points in time, some of the received requests for the transmission of information flows will be denied of service. This could be avoided if the requests that arrived at the time when all channels are fully occupied are queued (buffered) and served a little later, when the necessary channel performance resources are released. This approach will not only increase the number of information flows transmitted with the required quality (served requests), but also rationally spend channel performance, increasing the use of network channels.

When implementing request buffering, the more such requests are in the queue, the longer their delay to start serving, so correctly limiting the length of this queue is an important task.

The purpose of the article is to develop and study an algorithm obtaining the recommended requests queue length for transmitting information flows through MANET channels. This algorithm should make it possible, when setting up the parameters of a wireless ad-hoc network, to increase channel utilization while ensuring an acceptable delay in the start of communication sessions for geocological monitoring of the agro-industrial complex.

The problem of constructing an optimization algorithm

The dynamic nature of the network topology should be taken into account when supporting decisions to increase the use of channels and ensure acceptable delay in the start of communication sessions in MANET. To this end, we introduce the concepts of basic and additional information flows in relation to a specific communication channel. The main information flows will include many streams of measurement and service information that would be transmitted over the considered channel if the network topology did not change over time. Due to changes in the network topology, additional information flows can be transmitted over this channel, in addition to the main ones. In addition, in a network with a dynamic topology, some of the main information flows on the channel under consideration may not be transmitted, and the transmission of certain main and additional information flows may prematurely stop. The structure explaining the work of the communication channel with the main and additional information flows is shown in Figure 1.

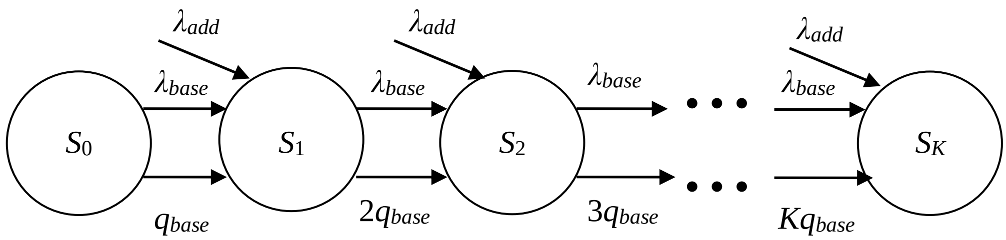

Figure 1 – Organization of the communication channel with the main and additional information flows

In Figure 1 and further down the text, the following notation is used:

Si - states of the system in which i channels are occupied (i=0, 1, 2 ...., K)

T_{req} – the allowed average delay before the start of the communication session;

K - the maximum number of wireless channels that can be used to transmit the information flow during a communication session;

λ_{base} - the intensity of requests for the transmission of the main information flows over the wireless channel;

λ_{add} - the intensity of requests for the transmission of additional information streams over the wireless channel;

q_{base} - the probability of no requests for the transmission of the main information flows over the wireless channel due to changes in the network topology;

p_{prem} - the probability of premature termination of the communication session due to a change in the network topology;

τ_{req} – the average required duration of a communication session in a wireless ad-hoc network;

R – the performance of the wireless communication channel;

n - the maximum number of information streams that can be simultaneously transmitted over a wireless channel with the required quality;

Q – the maximum number that limits the requests queue length for transmitting information streams over the wireless channel.

At the same time, it is necessary to develop an algorithm obtaining a value $m \in [1, 2, \ldots, Q]$ – a number that should limit the requests queue length for transmitting information flows over the channels of a wireless ad-hoc network, so that the maximum utilization of these channels C_{ut} increases, but the delays to start communication sessions in the network do not exceed the permissible value T_{req}.

Models of information exchange of geoecological monitoring

In accordance with the classical theory of teletraffic, incoming requests for connections form stationary Poisson flows with intensity λ, and the service duration of these requests is distributed according to an exponential law with mean value τ [29, 30].

Taking into account the dynamism of the topology of a wireless ad-hoc network, to calculate the intensity of requests for transmitting information flows over a wireless channel, we can use the expression:

$$\lambda = (1 - q_{base})\lambda_{base} + \lambda_{add}, \tag{1}$$

and the average duration of audio sessions in MANET can be obtained by the formula:

$$\tau = \tau_{req}(1 - p_{prem}). \tag{2}$$

An average used performance of the wireless channel can be calculated using the formula:

$$C_{ut} = R\bar{n}\,, \tag{3}$$

where $\bar{n}$ is the average number of voice streams simultaneously transmitted over the wireless channel.

In the case when MANET does not provide buffering of incoming requests for transmitting information streams over a wireless channel, the value of $\bar{n}$ can be obtained as the average number of busy service devices in the system *M/M/n* / 0 [31-33]:

$$\bar{n} = \frac{\sum_{k=0}^{n} \frac{k(\lambda\tau)^k}{k!}}{\sum_{k=0}^{n} \frac{(\lambda\tau)^k}{k!}}\,. \tag{4}$$

If the incoming requests for the transmission of voice streams over a wireless channel can form a queue, the length of which is limited to a number *m*, then we can find $\bar{n}$ as the average number of busy service devices in the system *M/M/n/m* [34]:

$$\bar{n} = n - p_0 \sum_{k=0}^{n} \frac{(n-k)(\lambda\tau)^k}{k!}\,, \tag{5}$$

where p_0 is the probability that no voice stream is transmitted over the MANET channel, i.e. all service devices in the system *M/M/n/m* are free.

The value of p_0 can be calculated using the expression [34]:

$$p_0 = \frac{1}{\sum_{k=0}^{n} \frac{(\lambda\tau)^k}{k!} + \frac{(\lambda\tau)^n}{n!} \sum_{u=1}^{m} \left(\frac{\lambda\tau}{n}\right)^u}\,. \tag{6}$$

To study the dependence of the average used performance of the wireless channel on the m value, we used the initial data (see Table 1) corresponding to the real functioning conditions of a wireless ad-hoc network. The value of *R* is chosen taking into account the standard bit rate of the main digital channel, which allows for high-quality transmission of measurement information streams [35]. The dependence graph $C_{ut} = f(m)$ obtained as a result of calculations via formulas (1) – (6) is shown in Figure 2.

Table 1 – Initial data

Designations	Values	Measurement units
n	15	–
K	10	–
T_{req}	0.01	our
λ_{base}	450	our^{-1}
λ_{add}	88	our^{-1}
q_{base}	0.12	–
p_{prem}	0.08	–
τ_{req}	0.025	our
R	64	kbit/s
m	1, 2, …8	–

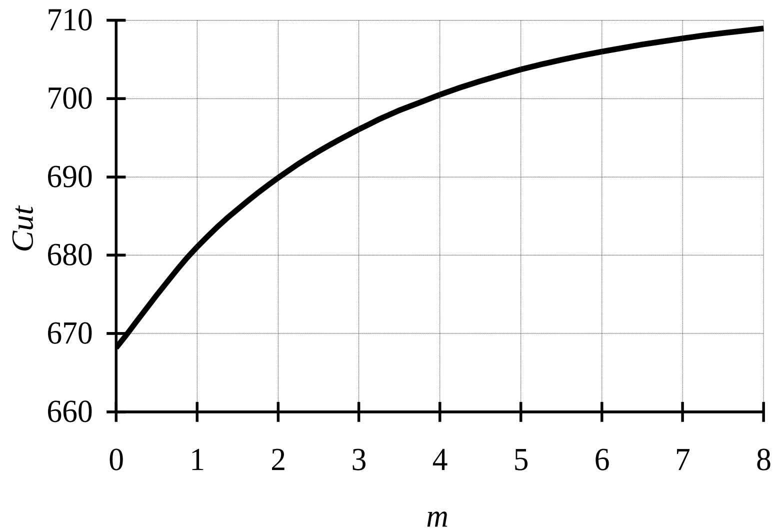

Figure 2 – Graph of the dependence $C_{ut} = f(m)$

The analysis of the data shown in Figure 2 reveales that to increase the use of wireless channels, it is necessary to expand the requests queue for transmitting information flows. On the other hand, it should be taken into account that the more requests for the transmission of information flows are in the channel queues, the longer the delay for the release of channel resources to start communication sessions.

To confirm the correctness of the above statement, we obtain expressions for the average delay T_{del} to start communication sessions in MANET, which occurs due to the presence of queues of requests for the transmission of information flows over wireless network channels. For this purpose, we can use the model to calculate the average waiting time for the start of query service in the *M/M/n/m* system [34]. Taking into account the possible delay before transmission of the information flow in all *K* channels that can be used to establish a wireless connection, we obtain the formula for T_{del}:

$$T_{del} = \frac{K\pi}{\frac{n}{\tau} - \lambda}, \tag{7}$$

where π is the probability that n information streams are simultaneously transmitted over the MANET channel, i.e. all the service devices in the *M/M/n/m* system are busy.

The value of π can be calculated using the expression [34]:

$$\pi = p_0 \frac{(\lambda\tau)^n}{n!} \sum_{k=n}^{n+m} \left(\frac{\lambda\tau}{n}\right)^{k-n}. \tag{8}$$

Figure 3 shows the graph of the dependence $T_{del}(m)$ obtained via formulas (1), (2), (7) and (8). The initial data from the Table 1 were used.

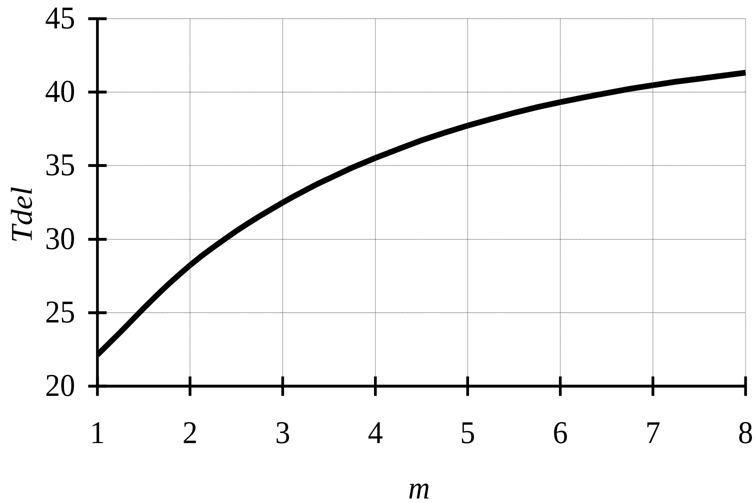

Figure 3 – Graph of the dependence $T_{del}(m)$

The analysis of the obtained results allows us to make sure that with extention of the requests queue, the average delay in the start of communication sessions in MANET also increases. An increase of the value T_{del} is undesirable, since a significant delay in the time of information exchange reduces its relevance and increases the risks of non-fulfillment of certain specific tasks of the monitoring system. In this regard, it is advisable to limit delay to some acceptable value that minimizes the above risks.

In order to obtain such a value of m that C_{ut} is maximized, but the average delay before the start of communication sessions does not exceed the required permissible threshold T_{req}, the corresponding algorithm is developed.

Algorithm determining the optimal length of the request queue

The flow diagram of the algorithm obtaining the recommended value of m is shown in Figure 4.

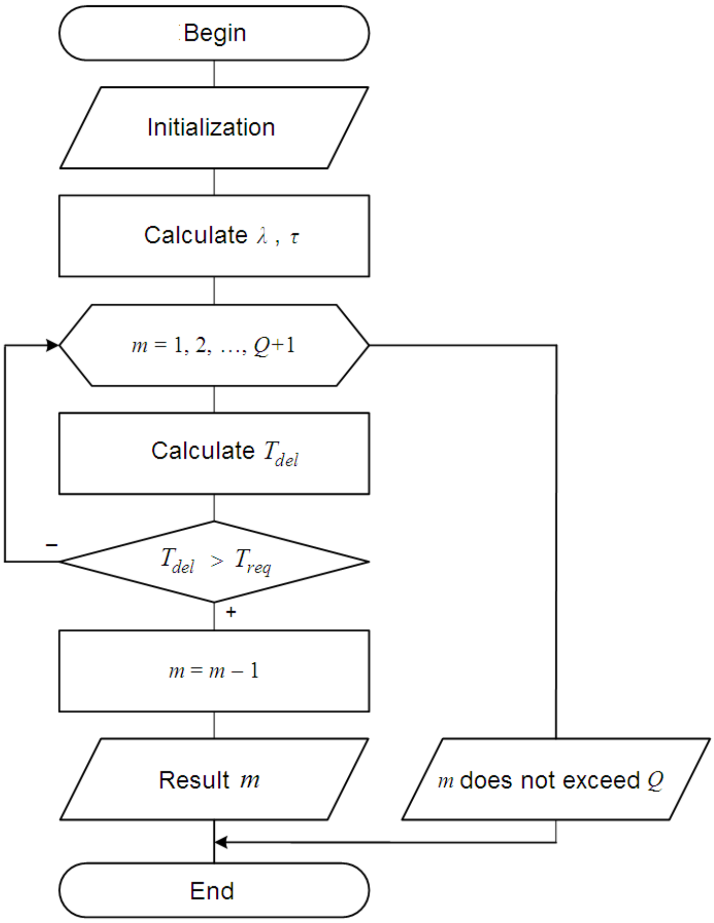

Figure 4 – Flowchart of the algorithm

The algorithm prescribes the following 10 steps.

Step 1. Initialization is performed (input of the initial data): the values n, K,

T_{req}, λ_{base}, λ_{add}, q_{base}, p_{prem}, τ_{req}, R, Q, T_{del} .

Step 2. The values of λ and τ are calculated via formulas (1) and (2), respectively.

Step 3. At the first execution of step 3, the value $m = 1$ is set. At each iteration of step 3, m increases by 1. If $m > Q + 1$ then the transition to step 8 is performed.

Step 4. The value of T_{del} is calculated using formulas (7) and (8).

Step 5 .The following condition is verified:

$$T_{del} > T_{req} . \tag{9}$$

If the last condition is met, go to step 6, otherwise go to step 3.

Step 6. The current value of m is reduced by 1.

Step 7. Output of the result that the requests queue length for transmitting information flows through MANET channels should not exceed m. End of the algorithm.

Step 8. Output of the result that the requests queue length for transmitting information flows through MANET channels should not exceed Q. End of the algorithm.

Thus, as a result of the algorithm, the limit requests queue length for the transmission of information flows is obtained. The result can be applied for wireless channels of the ad-hoc network of geoecological monitoring of agricultural facilities.

Computational experiments

In accordance with the algorithm presented above, computational experiments were conducted to obtain the recommended value of *m*. As an example, Table 2 shows the results of one of these experiments, which used the initial data presented in Table 1.

Table 2 – Results of the computational experiment

Designations	Values	Measurement units
λ	484	our^{-1}
τ	0.023	our
m	4	–

Experimental studies show that as a result of the proposed algorithm with the given initial parameters, the data are obtained that there should be no more than 4 requests in the queue for transmitting information flows through MANET channels. Calculations performed via formulas (1) – (6) and the above source data indicate that at m=4, the utilization of network channels increases by 4.84% compared to the option when MANET does not provide buffering of incoming requests for the transmission of information flows.

The implementation of the developed algorithm with other initial data corresponding to the real conditions of a wireless ad-hoc network showed that the recommended values of m are in the range from 2 to 6. At the same time, it was found that the channel utilization can be increased to 12.56 %. Thus, the conducted studies confirm the correctness of the algorithm. They indicate feasibility of its application for configuring the channels of a wireless ad-hoc network in the system of data collection and management of geoecological monitoring of agricultural facilities.

CONCLUSION

The research described in the article provided the following results:

1. A new model has been developed for assessing the use of wireless channels in the transmission of information flows. Unlike the known ones, the model reflects the average channel performance taking into account the dynamism of the network topology of the geoecological monitoring system. The model allows to expand the requests queue and increase the use of channels of a wireless ad-hoc network.
2. A model has been developed for estimating the initial delay before the start of data transmission over network channels. Unlike the known ones, the model reflects the dependence of the average delay on the intensity of requests taking into account the dynamism of the network topology.
3. A proposed algorithm obtains the recommended requests queue length for the transmission of information flows over network channels. During configuration of a wireless ad-hoc network, the algorithm allows to increase the use of channels and ensure an acceptable delay before the start of communication sessions.

The direction of further research will be the development of software for the practical implementation of the proposed algorithm.

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