Mathematical Model of Multimedia Information Exchange in Real Time Within A Mobile Ad Hoc Network

Kostiantyn O. Polshchykov, Sergej A. Lazarev and Elizaveta D. Kiseleva

Belgorod State National Research University, 85 Pobeda St, Belgorod, 308015, Russia

Summary
They developed a mathematical model to evaluate the efficiency of request servicing for the transfer of real time flows in a mobile ad hoc network. In order to ensure a high-quality transfer of audio and video streams, it is recommended to use the preliminary reservation of the required channel performance with the ability to buffer the incoming requests. The probability of request servicing for the transfer of real-time flows with a satisfactory quality is proposed as the indicator of multimedia information exchange efficiency evaluation. Based on the use of the main and additional real-time flow characteristics, the model takes into account the impact of dynamic network topology on its operation efficiency. The probability of an incoming request servicing for a real-time stream transfer is calculated for the most occupied network channel. The application of the model allows to justify the characteristics of the channels, which ensure an efficient exchange of real time flows in a wireless self-organizing network.
Key words:
mobile ad hoc network, mathematical model, real-time streams, requests service, channel productivity reservation.

1. Introduction

The Mobile Ad Hoc Network (MANET) has a decentralized mutable structure and it is capable to transfer information in the absence of base stations (fixed nodes) under the conditions of intense destructive effects and a high mobility of subscribers [Basagni et al., 2004; Polshchykov, 2013; Konstantinov et al., 2016; Konstantinov et al., 2017]. MANET networks are demanded for specific tasks related to search and rescue operations, the prevention and liquidation of emergencies, the works under the conditions of natural and man-made hazard impact, law enforcement and counter-terrorism operations, the protection of important and dangerous territorial objects [Cheong et al., 2011; Penders et al., 2011; Anjum et al., 2015; Verma, Chauhan, 2015; Kulla et al., 2015; Konstantinov et al., 2016; Polshchykov et al., 2016]. The solution of these tasks largely depends on the effectiveness of information exchange in the process of their implementation, in particular, on the quality of multimedia information transfer in the form of audio and video streams, i.e. real-time traffic.

A qualitative transfer of real-time traffic requires the minimization of packet delays and their variations (jitter). At the same time, a small volume of lost packets is allowed [Polshchykov, Zdorenko, 2014; Polschykov et al., 2010; Konstantinov et al., 2015; Polshchykov et al., 2015; Rvachova et al., 2015]. The provision of preset quality values is achieved via channel capacity reservation for incoming request servicing to transfer relevant audio and video streams [Awduche et al., 2001; Polschykov et al., 2013]. After the reservation and the provision of required channel performance for high-quality multimedia transfer, the allowed values of packet latency and jitter are provided automatically. Therefore, in order to evaluate the effectiveness of multimedia information exchange in MANET, it is advisable to use an indicator characterizing the quality of request servicing for the transfer of real-time flows, taking into account the possibility of necessary channel resource reservation.

Let's assume that the quality of request servicing for real-time stream transfer in a given period will be considered as satisfactory if during this period no more than a specified percentage from the number of received requests is not serviced. Then, in order to evaluate the efficiency of multimedia information exchange in MANET, one can propose that the indicator is the likelihood that the servicing of real-time stream transfer requests will be satisfied with a satisfactory quality.

The article is devoted to the development of a mathematical model that allows to calculate the indicator in order to obtain numerical values to estimate the effectiveness of multimedia information exchange in MANET. The development of the model should be carried out taking into account the influence of MANET features, in particular, the dynamism of the network topology, on the characteristics of the processes under study. Let's call a set of audio and video streams as the main real-time streams that would be transferred via a given channel if the network had a fixed topology in time. Due to the dynamic nature of the topology over the considered MANET channel, other (additional) real-time streams can be transferred, and some of the main streams may not be transferred. Besides, it should be borne in mind that, due to possible displacements, deletions, additions, node switching on and off, the transfer of certain primary and

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additional flows along a given channel can be started, but prematurely terminated.

2. Problem Formulation

Suppose that in order to ensure a high-quality transfer of real-time flows in MANET, the required channel performance is reserved. The following values are specified:

– the number of requests for the transfer of real-time streams received for servicing during a given period;

– channel capacity required for high-quality transfer of one real-time stream;

– the percentage of unserved requests from the number of requests received, beyond which the quality of request servicing for the transfer of real-time streams is considered unsatisfactory.

Assumptions:

1) the probability of incoming request for real time stream transfer corresponds to this indicator value calculated for the most loaded network channel with the following characteristics:

– channel bandwidth;

– the maximum length of request queue for which a channel capacity can be reserved required for high-quality real-time stream transfer;

2) incoming requests for the transfer of the main and additional real-time streams along a channel form a stationary Poisson stream with the following characteristics:

– the intensity of request receipt for the transfer of the main real-time streams along a network channel;

– the intensity of request receipt for the transfer of additional real-time streams over a network channel;

– the probability of request absence to transfer the main real-time streams through a channel due to the dynamic nature of the network topology;

3) the required duration of real-time stream transfer over a channel is distributed according to the exponential law with an average value ;

4) due to the dynamic nature of the network topology, the transfer of a particular real-time stream over a channel can be terminated prematurely with the probability .

It is required to obtain the analytical dependence of the quantity on the characteristics specified above.

3. Model Development

Based on the characteristics specified in the problem statement, it is possible to calculate the value β – the number of requests for the transfer of real-time streams, which make percent from the number α :

$$\beta = \frac{\alpha B}{100}. \quad (1)$$

In order to obtain the probability P_Q , it is necessary to take into account the probabilities of all possible combinations of events corresponding to servicing no less than $(\alpha - \beta)$ of requests for the transfer of real-time streams.

Let $\alpha = 5$, then $\beta = 2$ in accordance with the expression (1). The probabilistic graph of request servicing process for the transfer of real-time streams with the specified values α and β is shown on Fig. 1.

The following vertices correspond to the states of the simulated process:

«B» – the beginning of request servicing process;

"S" - an incoming request is served;

"F" - a request was denied due to the fullness of the queue for channel performance reservation;

"Q" - the servicing of requests for the transfer of real-time streams performed with a satisfactory quality.

The probability of transfer to any vertex "S" corresponds to the value p – the probability of an incoming request servicing for a real-time stream transfer. The probability of transition to any vertex "F" corresponds to the value q – the probability of denial from an incoming request servicing for a real-time stream transfer.

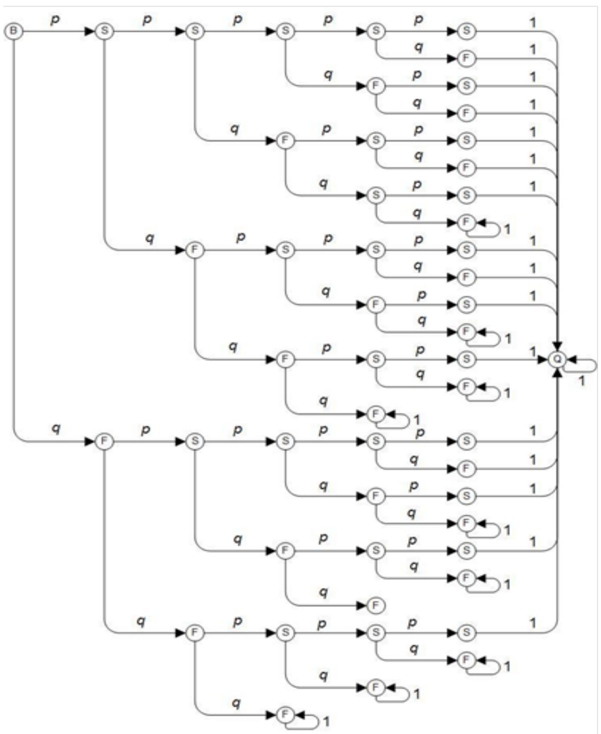

Fig. 1 Probabilistic graph of request servicing for the transfer of real-time flows

Based on the analysis of the graph, the expression is obtained to calculate the indicator P_Q at $\alpha = 5$ and $\beta = 2$:

$$P_Q = p^5 + 5p^4 q + 10p^3 q^2 \quad (2)$$

The result of request servicing simulation for the transfer of real-time streams, the expressions for the indicator P_Q calculation were obtained in a similar way at other values of α and β , presented in Table 1.

The analysis of the regularities contained in the expression (2) and table 1 allowed to obtain general formulas to calculate the probability of a request servicing with a satisfactory quality:

$$P_Q = p^\alpha \ , \ \beta = 0 ; \quad (3)$$

$$P_Q = p^\alpha + \alpha p^{\alpha-1} , \ \beta = 1 ;4) \quad (4)$$

$$P_Q = p^\alpha + \alpha\left[p^{\alpha-1} q + \sum_{x=2}^{\beta}\left[\frac{p^{\alpha-x} q^x}{x!} \prod_{y=1}^{x-1}(\alpha - y) \right]\right],$$

$$\beta = 2,3,4,\dots,\alpha \ . \quad (5)$$

Table 1: Expressions for the calculation of the indicator P_Q

α	β	P_Q
3	0	p^3
4	1	$p^4 + 4p^3 q$
6	3	$p^6 + 6p^5 q + 15p^4 q^2 + 20p^3 q^3$
10	4	$p^{10} + 10p^9 q + 45p^8 q^2 + 120p^7 q^3 + 210p^6 q^4$

On the basis of the assumptions indicated in the statement of the problem, it is possible to calculate the value p as the probability of servicing in a multichannel system with a limited request queue [Baccelli, Bremaud, 2003]:

$$p = 1 - \frac{\frac{(\lambda\tau)^n}{n!}\left(\frac{\lambda\tau}{n}\right)^m}{\sum_{k=0}^{n}\left[\frac{(\lambda\tau)^k}{k!}\right] + \frac{(\lambda\tau)^n}{n!}\sum_{u=1}^{m}\left(\frac{\lambda\tau}{n}\right)^u} \quad (6)$$

where n is the number of real time flows that can be simultaneously transferred over a channel with a required quality, $n > \lambda\tau$; λ – the intensity of request receipt for the transfer of real-time streams through a channel; τ – an average duration of the real-time stream transfer over a channel.

The value n can be found by the following formula:

$$n = \frac{C}{L} \quad (7)$$

In order to calculate the intensity of request receipt for the transfer of real-time streams over a channel, you can apply the following expression:

$$\lambda = (1 - q_{base})\lambda_{base} + \lambda_{add} \quad (8)$$

The value τ can be obtained by the following formula:

$$\tau = \tau_{req}(1 - p_{prem}) \quad (9)$$

The developed model can be used to evaluate the effectiveness of real-time multimedia information exchange in MANET, as well as to justify the values of this network characteristics.

4. Model application in computational experiments

Let's some search and rescue operation will be successfully carried out if a qualitative transfer of at least 90 real-time streams out of 100 incoming requests for its transfer is made via the network during the course of its conduct.

It is required to determine the bandwidth of network channels at which the service of requests for the transfer of real time flows will be performed with a satisfactory quality and with the probability of 0.98.

The initial data used to perform the computational experiments are presented in Table 2.

Table 2: Initial data

Indicators	Values	Measurement units
λ_{base}	90	Hour^{-1}
λ_{add}	15	hour^{-1}
q_{base}	0.115	
τ_{req}	8	Min
p_{prem}	0.25	
C	1,0 ... 1,5	Mbit/s
L	0.1	Mbit/s
m	2	-
α	100	-
B	10	%

On the basis of the abovementioned initial data, using the expressions (1) and (5 - 9), the values of the indicator P_Q are calculated for different values of C. The results of the calculations are presented in Table 3.

Table 3: Computational experiment results

Indicator C values, Mbit/s	1,0	1,1	1,2	1,3	1,4
Indicator P_Q values	0,26	0,77	0,98	0,99	1,00

The analysis of Table 3 data shows that it is recommended to use MANET channels with the bandwidth of 1.2 Mbit/s at least to service the requests for real-time stream transfer with satisfactory quality.

Summary

The multimedia information exchange in real time within a mobile ad hoc network is aimed to provide communication and solve various specific tasks in difficult conditions. At that, the qualitative transfer of audio or video streams in MANET can be guaranteed based on the reservation of the required channel performance. In this regard, it is advisable to use the probability of servicing no less than the specified number of requests for the transfer of real-time streams as the evaluation indicator for the effectiveness of multimedia information exchange in MANET. A mathematical model was developed based on the construction of probability graphs to calculate this indicator. The application of the model makes it possible to justify the channel characteristics that ensure an efficient exchange of real time streams in MANET.

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