INFORMATION FLOW MODELING IN WIRELESS SELF-ORGANIZING NETWORK

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Abstract. The technology of the wireless self-organizing network has good application prospects for information exchange provision to search and rescue operations and to perform the operations preventing natural and man-made emergency situations. The article presents the models of information flows transfer through the channels of a wireless self-organizing network. They are based on the representation of the simulated process current states with the help of package identifiers and confirmations related to the transmission of information flows through the channels of a given contour. Mathematical models are presented that take into account the dynamism of network topology and allow to estimate the efficiency of data delivery in the conditions of subscriber mobility and destructive influences..

Keywords: wireless self-organizing network, model, information flows, data packages, acknowledgments.

1 Introduction

A promising trend for telecommunication technology development is represented by wireless self-organizing networks (Mobile Ad-Hoc Networks, MANET) [1]. Due to its high survivability, a rapid deployment and the ability to deliver information in a dynamically changing topology, MANET technology can be used to build a wireless self-organizing network of special purpose, functioning with the aim of information exchange provision during specific task performance related to search and rescue operations and the operations preventing the emergency situations of natural and technogenic nature [2-15].

The change of MANET topology is caused not only by the mobility of subscribers, but also by random processes of node destruction (disconnection) due to the impact of destructive factors, as well as the addition of new nodes to certain sections of the area. In such conditions, the efficiency of information delivery to the network subscribers is reduced significantly [16-18]. In this regard, the modeling of information flows circulating in MANET appears to be an urgent scientific and technical task, the results of which are required to create new technologies that allow to increase the efficiency of the network under study.

The creation of adequate analytical models in the field of wireless self-organizing networks entails considerable difficulties due to the fact that the process of data transfer in ad-hoc networks is influenced by a large number of different factors that are random and weakly subjected to a strict mathematical analysis [19-26]. Therefore, a significant number of works is devoted to the simulation modeling of self-organizing networks, implemented on the basis of special (ns-2, ns-3, opnet) and universal software (GPSS, AnyLogic, MATLAB) use.

The analysis of scientific publications has shown that in the field of ad-hoc networks the researchers' efforts are focused mainly on the creation of routing models, and little attention is paid to the modeling of information flow transmission in selected routes. Besides, the existing models do not take into account the specifics of wireless information transfer in the context of accidental destructive effects, and therefore they can not provide fully an adequate estimate of data delivery efficiency in MANET.

2 Problem formulation

The information flows transmitted in MANET can be roughly divided into two main types: real-time traffic (speech, video) and data flows (control signals, text messages, topographic images, other graphic and tabular information). Each type of traffic is characterized by specific parameters and different transmission quality requirements [27-29].

Let the sending node transmit a data stream addressed to a destination node. This data flow is referred to as a controlled flow (CF) in [30]. To transmit the packages of the specified stream (CF-packages), a route is pre-selected - a sequence of channels leading from the sending node to the destination node. We will assume that this route includes the channels with numbers from 1 to (N-1). In order to send the confirmation of CF-package successful delivery, i.e. CF-confirmations, the route is defined, which is the sequence of the channels passing from the destination node to the sending node. This route includes the channels with numbers from N to (N + M). The combination of the two indicated (different in a general case) routes used for CF-packages transfer and CF-confirmations is a CF-circuit [2] (Figure 1).

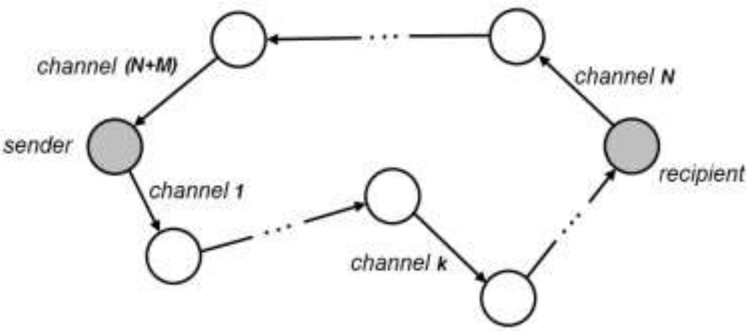
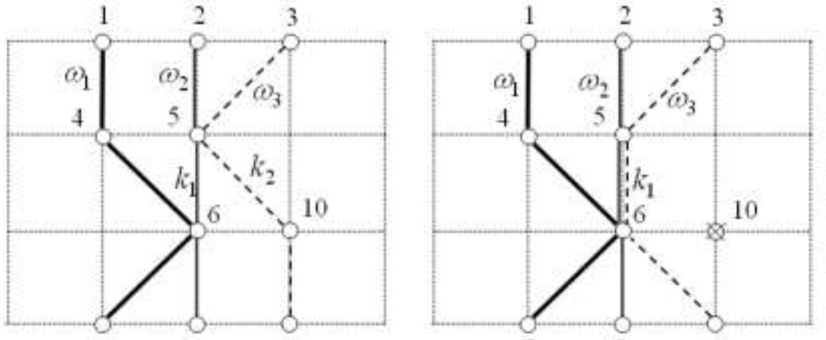


Fig. 1. CF-loop nodes and channels

In addition to the controlled flow transfer, the channels of the CF loop can be used to transmit other (competing) real-time flows and data streams. Data and real time streams, which would be transmitted through one or another channel of the CF-circuit, if the network had a fixed topology, will be called the main flows. Each primary real-time stream has the sequence number l ($l = 1, 2, \ldots, L$), and each main data stream has the sequence number g ($g = 1, 2, \ldots, G$). The following value is set $\overline{r}_{base}^{start}$ – the average time between the arrival of the main real-time stream packages for the transmission of the CF-loop via a channel, and the value $\overline{d}_{base}^{start}$ is known – the average time between the arrival of main data stream packages for the transmission via CF loop channel.

Due to the dynamism of the MANET topology, additional data streams and real time data can be transmitted via CF-loop channels, in addition to the main streams. Fig. 2 shows the example illustrating the transmission of the additional stream ω_3 via the channel k_1. On the figure above, the nodes of the network are indicated in the form of circles, each node is numbered. Information flows have the following designations: ω_1, ω_2 and ω_3. The flow transmission path ω_1 is indicated by a thick line, the flow ω_2 – by a thin line, and the flow ω_3 – by a dotted line. The analyzed channels are denoted as k_1 and k_2. In order to fix the topology change more conveniently, the terrain, on which the nodes are located, is conditionally divided into squares. The radius of the radio coverage zone of any node is limited by the length of the square diagonal. Fig. 2 considers the situation when the main stream ω_2 was transmitted along the channel k_1. At the same time, the node 10 was destroyed (or disabled) due to the impact of destructive factors. If this event did not occur, then the stream ω_3 would be transmitted over the channel k_2, which is less loaded than the channel k_1 (fig.2, a). But since the specified event occurred, an additional flow ω_3 was transmitted through the channel k_1 (fig. 2, б).



a) б)

Fig. 2. The example of an additional stream ω_3 transfer via the channel k_1 due to the reason of the node 10 destruction: a) the node 10 operates in the network; б) the node 10 is destroyed

The possibility of additional flows transfer through the channels of the CF loop in a fixed-topology environment would be ruled out. Each additional real-time stream has the sequence number j ($j = 1, 2, \ldots, J$), each additional data stream has the sequence number h ($h = 1, 2, \dots, H$). The value $\bar{r}_{add}^{start}$ is set – the average time between the starting periods of additional real-time stream package arrival for the transmission via the CF-loop channel, and the value $\bar{d}_{add}^{start}$ is also known – the average time between the times of additional data stream package arrival for the transmission over the CF-loop channel.

Besides, the following values are specified: $\bar{r}^{cont}$ – the average time of the real-time stream package arrival for the transmission via CF-loop channel; $\bar{d}^{cont}$ – the average duration of data stream package arrival for the transmission via CF-loop channel; $\tau^{CF}(t)$ – the current time interval between the moments of CF-packages development to send via channel 1 (inter-package interval); $\xi_i(t)$ – the current retransmission timeout, set during sending of CF package number i via channel 1; L_i – the bit length of the CF package number i; L^{β} – the average bit length of the data package (real-time package); c_k – the bandwidth of the channel k; p_k – the probability of bit error in the channel k; Q – the maximum number of packages that can be buffered to wait for transmission over a network channel; $\lambda_l^{r.base}$ – the intensity of the main real-time stream package arrival number l for the transmission via a network channel; $\lambda_j^{r.add}$ – the intensity of package arrival of an additional real-time stream number j for the transmission via a network channel; $\lambda_g^{d.base}$ – the intensity of the main data stream package arrival number g for the transmission via a network channel; $\lambda_h^{d.add}$ – the intensity of an additional data stream number h package arrival for the transmission via a network channel. It is known that real-time packages need to be transmitted with minimal delays, so these packages must be sent first through the channels of the CF loop.

Using the data presented above, it is required to develop a mathematical model for the transmission of information flows through CF loop channels, on the basis of which it would be possible to determine the values of the following indicators: $W(t)$ – the current waiting time of the CF receipt by the sender; Z – the number of redundant retransmission of CF packages; $I_k^{\nu}(t)$ – the number of CF packages and other data packages received for transmission via the channel k during the last ν tacts; $\rho_k^{\nu}(t)$ – the number of CF packages that claimed to be transmitted over the channel k and discarded during the last ν tacts; $\gamma_k(t)$ – the current delay of CF packages in k channel queue; $q_k(t)$ – the current number of CF packages and other data packages in the channel k queue; $E(t)$ – the current capacity of the CF loop available for CF stream transfer; T^{CF} – the duration of CF flow transmission.

3 Study methods

The complexity of the problem formulated above causes the need for its decomposition. The transmission of information flows through the channels of the CF loop includes the following processes: the development of CF packages in the sending node; the development of CF-confirmations in the recipient node; the arrival of real-time packages for transmission via CF-loop channels; the arrival of data packages for the transmission via CF loop channels; the receipt of CF-packages (CF-confirmations) for the transmission via CF-loop channels; the transfer of real-time packages, data packages and CF-packages (CF-confirmations) via CF-loop channels; the buffering of real-time packages received for the transmission via CF-loop channels; the buffering of data packages and CF-packages (CF-confirmations) received for the transmission via CF-loop channels; the removal of real-time packages, data packages, and CF packages (CF-confirmations) that claimed to be transmitted via CF-loop channels; the receiving of CF-packages by the destination node and CF-confirmations by the sending node. Therefore, the creation of a mathematical model for the transmission of information flows through the channels of the CF loop consists in the development of particular models for the processes listed above.

These models are based on the representation of the corresponding process current states with the help of package identifiers (confirmations) associated with the transmission of information flows through the channels of the CF-loop. Package identifiers can take the values i, β or 0. The numbers $i = 1, 2, \dots, I$ – the sequence numbers of these packages within the simulated CF stream are used as CF-package identifiers. The identifiers of CF-tickets coincide with the numbers of the corresponding CF-packages. The identifiers of other data and real time packages are assumed to be equal to the number $0 < \beta < 1$. This makes it possible to simulate the movements of each CF-package and each CF-receipt and distinguish them from other packages competing with them for the transmission via CF-loop channels. An identifier value of 0 indicates that there is no package in a current tact associated with the simulated state of the corresponding process.

4 Study results

The schemes of package identifiers (confirmations) associated with the transmission of information flows through the channels 1, k and N, are shown on Fig. 3-5. The above schemes used the following notations: F_1 – номера CF-пакетов, сформированных в узле-отправителе для передачи по каналу 1; F_N – the numbers of the CF packages generated in a sending node for the transmission via the channel N; S_k^{CF} – the numbers of CF-packages (CF-confirmations) received for the transmission via the channel k; S_k^d – the identifiers of data packages received for the transmission via the channel k; S_k^r – the identifiers of real-time packages received for the transmission via the channel k; θ_k – the identifiers of packages (confirmations) transmitted via the channel k; C_k^{rq} – the identifiers of real-time packages buffered in the cells q ($q = 1, 2, \ldots, Q$) for the transmission via the channel k; C_k^{dq} – the identifiers of data packages buffered in cells q for the transmission via the channel k; D_k^{CF} – the number of removed CF-packages (CF-confirmations) from the number of those which claimed for the transmission via the channel k; D_k^d – the identifiers of the removed data packages from the number of those which claimed for transmission via the channel k; D_k^r – the identifiers of discarded real-time packages from the number of those which claimed the transmission via the channel k; S_{rec}^{CF} – the numbers of CF packages received by the receiving node; S_{send}^{CF} – the numbers of CF confirmations received by the sending node.

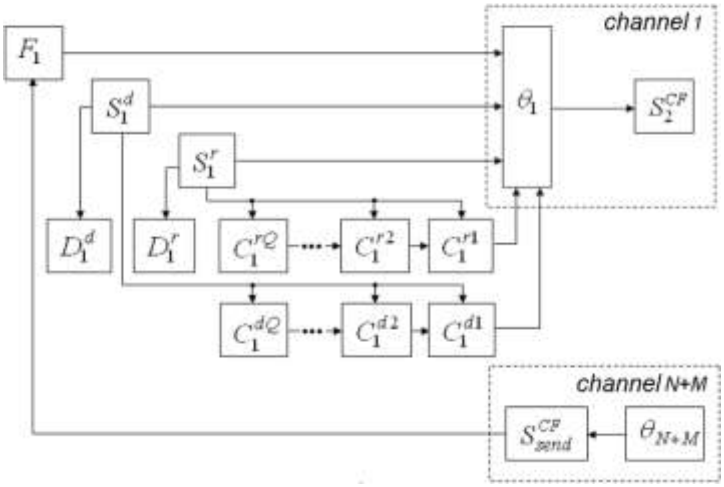


Fig. 3. Package identifier (confirmations) scheme associated with the transmission via the channel 1

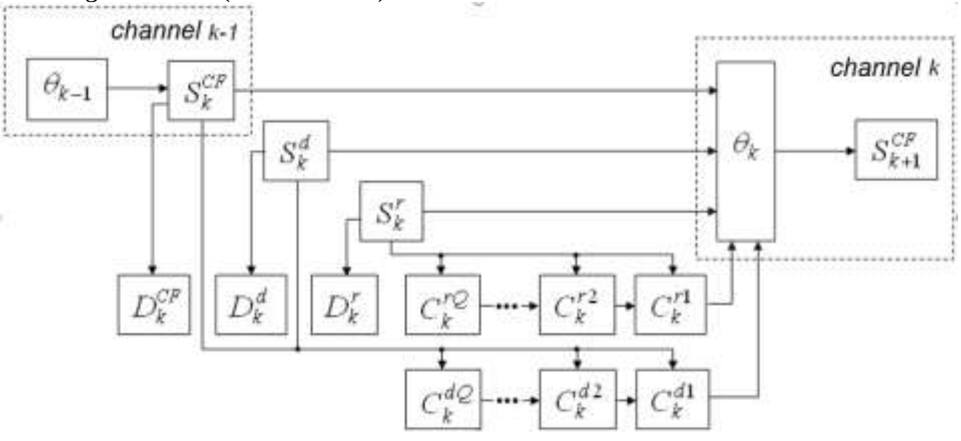


Fig. 4. Package identifier (confirmations) scheme associated with the transmission via the channel k

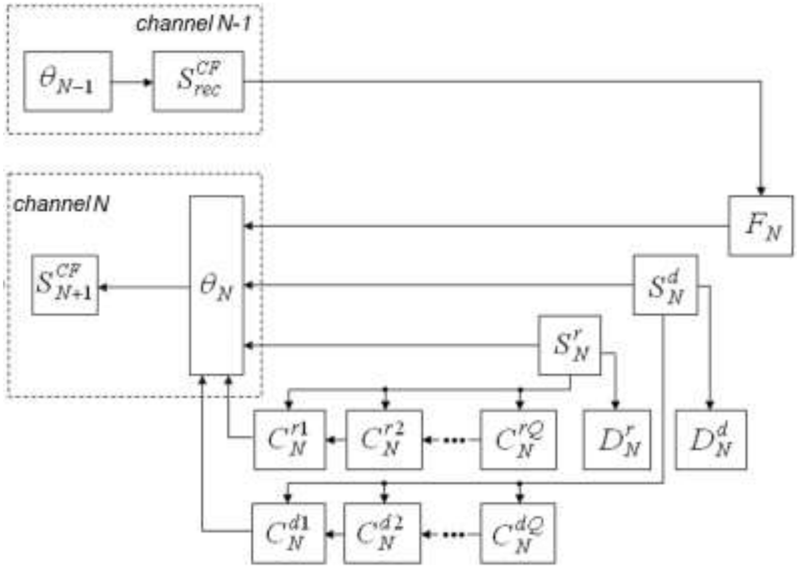


Fig. 5. Package identifier (confirmations) scheme associated with the transmission via the channel N

The arrows of Fig. 3-5 show the direct links between the values of some package identifiers (confirmations). For example, the arrows on Fig. 5, originating from the element S^d_N, indicate that the data package received for transmission via the channel N, can be transmitted via this channel, and secondly, may occupy a free cell in the waiting buffer, and, thirdly, it can be discarded in the next simulation tact, depending on a situation.

In order to determine the values of package identifiers (confirmations), appropriate expressions have been developed reflecting the logic of information flow transfer process through the channels of the CF loop. On the basis of these formulas, the analytical relations are obtained that allow one to calculate the values of the unknown indicators $W(t)$, Z, $I^{\nu}_k(t)$, $\rho^{\nu}_k(t)$, $\gamma_k(t)$, $q_k(t)$, $E(t)$ and T^{CF} at given initial data.

The proposed approach is universal in the sense that its application allows to model any algorithms implemented within the network and transport level protocols at the stages of information package transfer after the establishment of virtual connections and routing. At that, it is necessary to use the analytical dependencies connecting the values of the elements of the abovementioned schemes (Figures 3-5) in accordance with the logic of specific simulated algorithms (protocols). For example, when the repetitive sending of packages is simulated based on Jacobson algorithm within the TCP protocol, it is necessary to use the corresponding retransmission timeout $\xi_i(t)$ calculations in the formulas for determining F_1 values [31,32].

The approach illustrated by Fig. 3-5 schemes, can be used to model not only known, but also newly created package transfer algorithms. Thus, based on the proposed approach, they developed the models for the transmission of information flows in MANET with the implementation of two different algorithms to control the intensity of data sending by source nodes. The essence of these algorithms is reduced to the choice of such current values of the inter-package interval $\tau^{CF}(t)$, at which the duration of the controlled flow T^{CF} transfer and the number of retransmissions Z is reduced. The first algorithm in the process of selecting the value $\tau^{CF}(t)$ selection involves the use of a fuzzy neural network [6], and the second algorithm is based on the application of fuzzy inference classical system [27]. These models were implemented in the MatLab & Simulink software environment and are presented in [30,33].

5 Summary

They proposed new models for the transmission of information flows through MANET channels. They are based on the representation of the simulated process current states by the use of package identifiers and the confirmations related to the transmission of information flows through the set loop channels. The presented solutions differ from those known for the mathematical modeling of information flow transfer within the selected routes, taking into account not only the mobility of subscribers, but also destructive external influences. This is ensured by the use of indicators characterizing premature termination processes caused by the dynamic nature of the network topology concerning the transmission of information flows, the cancellation of transmission via certain channels of certain flows, and the addition of other transmitted streams. The application of the created models allows to estimate the effectiveness of various data transmission algorithm use in MANET implemented within the network and transport levels of network component interaction.

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