Video Streaming in Ad Hoc Networks

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***Abstract*—The paper is devoted to the search for the causes of packet loss in a video stream in a self-organizing wireless network. The search was carried out during an experiment that allowed for changing the structure of the video stream. We tested the main modes of operation of a wireless self-organizing network: ad hoc, mesh and broadcast. It was concluded that broadcast frames can only be used for route marking. While the transmission of the payload with broadcast packets and mesh packets leads to an unacceptable percentage of losses, at the same time, a variant of the stream with ad hoc frames was found, which avoids losses.**

***Keywords*—video quality in ad hoc networks, structure of video stream, open80211s, network quality in ad hoc networks**

1. Introduction

The problem of ensuring communication during emergencies will remain relevant for many years to come. Emergency situations can be caused by natural or man-made factors. However, often during disasters, the infrastructure for life support, including mobile and wireless communications, is completely destroyed. The engineering community has made numerous attempts to organize operational communications and emergency management [1].

In order to provide communication for every person in the emergency zone, it is necessary that there is an appropriate device with support for wireless technologies. Only a smartphone [2] can claim the role of such a device. Modern smartphones support several wireless technologies. As a rule, these are cellular networks of the fourth or fifth generation, networks of various IEEE 802.11 families known under the general Wi-Fi trademark, and networks of the IEEE 802.15 Bluetooth family of standards.

Some time ago it was proposed to combine such devices into a common network [3] without the participation of base stations. However, such networks must be built on completely new principles. It is difficult to both build and update complete routing tables for large clusters of unevenly distributed devices. Especially if the owners of these devices are actively moving around. Such networks are called self-organizing networks (ad hoc). Routing in self-organizing networks is based on local information from each node in the network, when only the nearest neighbors of a given node are known.

After numerous theoretical studies on the development of routing algorithms for self-organizing networks [4][5][6], attempts to create real communication protocols followed. A specialized protocol IEEE 802.11s [7][8] was developed. It allows organizing hierarchical wireless mesh networks with mobile and static nodes. After the draft version of the IEEE 802.11s protocol was published, the open80211s project was announced. The project was supposed to provide for free use of the Open Source implementation of the new standard. However, after the presentation of the first releases in 2011, the further development of the project slowed down. Since 2013, the project site has not been updated, although the main module is being modernized currently by Intel [9]. However, most efforts are made to support mesh technology for wireless access points, while drivers for endpoint adapters are not updated.

In recent years, there have been numerous attempts to develop software for self-organizing wireless networks that are capable of transmitting multimedia. However, all these attempts have failed. So, the developers of the self-organizing network cjdns abandoned their development back in 2017. They were unable to create a workable prototype for wireless networks and limited themselves to publishing their theoretical developments [10]. Their receivers from the netsukuku project and Yggdrasil fork have stepped back from developing self-organizing wireless networks and limited themselves to creating an overlay network over IP.

Currently, all existing solutions for wireless self-organizing networks (WSN, mesh, MANET) are capable of transmitting only text messages and small files attached to these messages. In order for new developments in the field of self-organizing wireless networks to be successful, it is necessary that their creators learn how to transmit multimedia information. Among the main types of media, it is necessary to focus on the transmission of voice information and video streams. It should be noted that starting from the second hop of the long route, numerous packet losses begin in the open80211s network, which makes it impossible to transmit video [11].

This study seeks to find out the reasons for the deterioration of the communication quality for long-distance channels, starting from the second route hop. To do this, we study the features of sending various types of Wi-Fi frames (ad hoc, mesh, broadcast) from the current node to its neighbors. There are more than 10 types of frames that transmit wireless data. These data are repeated for three different types of frames: management, control, and data. It is necessary to decide the question - what type of frame should be used for marking the route, and for the transmission of the payload. As for wireless networks, which are used as the basis for self-organizing networks, it is proposed to use modern varieties of Wi-Fi (IEEE 802.11) and Bluetooth (IEEE 802.15).

The prototype of a wireless self-organizing network with the ability to transmit voice and video will be in demand in many sectors of the economy. First of all, for the organization of communications and operational alerts in natural and man-made emergency situations.

The knowledge gained should be applied in the development of new communication protocols for self-organizing networks. However, the development of the protocol requires solving one more issue - this is the choice of the routing protocol and its refinement considering the new requirements. The new requirements include the use of a new packet structure for route marking and data transmission, and the selection of multiple sections of the route taking into account the bandwidth.

This study has a controversial nature, it discusses a lot of controversial points. It should be classified as work in progress. Nevertheless, the main idea of the research is formulated accurately. The paper will discuss attempts to control the quality of video streams by changing the structure of the video stream. This is primarily due to the use of alternative frame types for marking, control, and data transmission in an ideal wireless self-organizing network protocol.

2. Network Video Quality

The quality of the video transmitted over the network depends on many factors. The three main factors are listed below:

- quality of video digitizing
- quality of the network connection
- video stream structure

The quality of video digitization depends on the image processing methods. In this case, processing is performed on servers outside the network. On the transmitting side, the codecs convert the video sequence into a digital sequence. This sequence is split into individual packets using a dedicated streaming server and the packets are forwarded over the network. On the receiving side, digital data is again converted to video. Operations for converting a video series are performed using codecs.

The quality of a network connection is described by four variables [12]: packet transmission delay over the network, its variation (jitter), packet loss and available bandwidth. There are numerous models that investigated the quality of the received video depending on the quality of network connections [13][14]. It should be noted that the quality of the received video is most sensitive to packet loss and network jitter.

The structure of the video stream also affects the quality of the received video. There are several ways to improve video quality. For example, packet loss and distortion of different types has different impacts on video quality. The most distortions are caused by damage to keyframes [15]. Therefore, this part of the video stream packets can be duplicated. Video stream IP packets are encapsulated in wireless frames. A large number of frame types have been standardized for payload transfer. Among the main modes of network operation, we should mention ad hoc, mesh and broadcast. It is these modes that self-organizing wireless networking protocols use for route marking and load transfer.

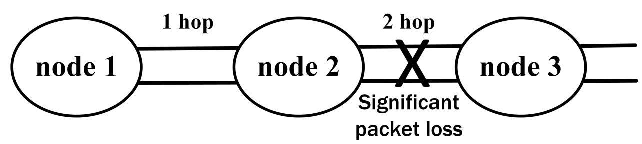

Figure 1. Illustration of Video Stream Packet Loss

The video quality also depends on the inter-packet intervals in the video stream. In this study, an attempt is made to control video quality by modernizing the structure of the video stream. Since the main network effect, leading to the impossibility of transmitting video in self-organizing wireless networks, is associated with significant packet losses on the second and subsequent route hops, we will not investigate the influence of codecs. Our task is to understand the causes of losses by analyzing the structure of the video stream by the type of frames used and the peculiarities of their transmission and reception.

3. An Experiment to Find the Causes of Packet Loss

This section of the paper describes our experiment to find the causes of packet loss in self-organizing wireless networks. Figure 1 shows how to set up such an experiment. Since packets are not lost on the first route hop between nodes 1 and 2, it is necessary to record and compare the traffic on the first and second hops. However, at the IP level, we can only identify out which packets are lost. The reasons for these losses can be understood only by studying frames at the link layer. By intercepting the relevant management, control and data frames related to the video stream, one can conclude the reasons for their losses.

However, recording all traffic on the link layer of the OSI model is not easy, and we will have to install additional wireless network adapters. Therefore, the following experimental scheme was proposed (Fig. 2).

Three nodes on which the wireless self-organizing network software is installed are located in series. Moreover, the extreme nodes cannot establish communications with

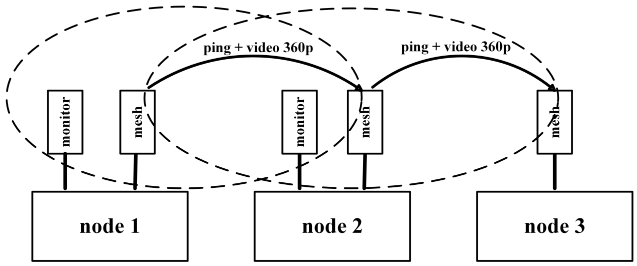

Figure 2. Scheme of the Traffic Analysis Experiment

each other. To organize a self-organizing network, we need to place an intermediate node in the middle.

In this case, the built-in network adapters of all three nodes will be used to organize communication. The first and second nodes from the diagram in Fig. 2 will be equipped with additional adapters. These adapters will be switched to RFMON (Radio Frequency MONitor) mode and will be used to collect all wireless frames at the link layer. From node 1, the video was broadcast to node 3 via the RTP / UDP protocol, while the Wi-Fi adapters were in mesh mode. For the broadcast, the videoland software package was used, which allows us to vary the settings of the video stream within wide limits.

In order to start a self-organizing network of the IEEE 802.11s standard, it is necessary to switch the network adapters to mesh mode. The Open Source package open80211s was used as software, which has been included in the Linux kernel since version 2.6.26. This package was installed on all three nodes and, after installing the package, the settings of the wireless self-organizing network were made.

Before the video stream was transmitted over the self-organizing network, the traffic was recorded at both the IP packet level and the LLC frame level. It should be noted that IP packets are encapsulated in MAC frames, so it is quite easy to track which frames were lost at the link layer.

Table 1 contains data on communication quality indicators for a self-organizing network built using the open80211s package. The network variables measured are network delay, jitter, and packet loss. The data was collected using the ping utility, that is, the two-way network latency (RTT) was measured. The results of measurements of delay, jitter and packet loss are shown in Table 1. The data were obtained when testing the network with packets of the smallest possible size (64 bytes).

TABLE 1. COMMUNICATION QUALITY INDICATORS FOR THE OPEN80211S NETWORK

Hops number	Minimal network delay, ms	Average network delay, ms	Network jitter, ms	Packet loss, %
1	1.7	5.5	3.6	0
2	3.0	7.0	5.8	4

The data in Table 1 suggests that the minimum delay is proportional to the number of route segments. The minimum time spent on the passage of one hop is 1.7 milliseconds for open80211s.

Another quantity that was estimated in the first experiment was the available bandwidth. To measure it, we used the iperf utility, which allows us to measure the maximum throughput for TCP connections and UDP streams. The available bandwidth is summarized in Table 2.

TABLE 2. THROUGHPUT DATA

Hops number	TCP throughput capacity	UDP stream speed
1	6.6 Mbps	1.6 Mbps
2	3.9 Mbps	unable to establish connection, loss >30%

Attention is drawn to the fact that the data transfer rate drops sharply in the second hop of the network.

4. New Self-Organizing Network Software Packages for Hypothesis Testing

The open80211s package is implemented as part of a Linux kernel module that interacts directly with other modules. Including those that implement the logic of working with Wi-Fi adapter chips and the network stack. It is exceedingly difficult to make changes to the program code of the mesh network since it works according to a well-defined standard and is connected with other modules. Therefore, the protocol [16] developed by us was used as a testing platform.

Our software can be divided into two logical parts. The first part implements the communication function, that is, the processing and forwarding of packets between neighboring nodes. The second part is responsible for routing. Since the neighborhood method is used to organize routing, the protocol received the same name (NH protocol). We tried to write the program code so that it is as versatile as possible and can encapsulate various types of network layer protocol packets.

Our protocol is implemented at the service level (OS low-level utility). It works with network sockets, which in all modern operating systems are made according to the uniform POSIX (Portable Operating System Interface) standards. It can run in the background and at high priority. The POSIX standard libraries describe creating, configuring, and binding sockets to a port, sending, and receiving packets, etc.

It should be noted that software at the service level is much more flexible than software at the kernel level. It is not tied to specific equipment. In addition, it is quite easy to add new modules to it that correct the identified deficiencies. In other words, such software is much easier to upgrade, and programmers can be less skilled than when programming kernel modules.

Analysis of the used frame types of the open80211s software package shows that broadcast frames are used for route marking and other service purposes. Payload transfer is done using mesh 0x0028 frames. It is these frames that are lost on the second hop of the route. However, changing the frame type or stream structure is not possible for the average administrator, nor the Linux kernel developer. At least these are undocumented features of this software package.

The difference between 802.11s frames is the presence of a mesh header at the beginning of the data field. This header is present in data packets if and only if they are transmitted from a mesh node to a mesh node over the connection established between them. It also attaches to one of the types of (Multihop Action) control packages. It is this feature of the frame that can explain the packet loss.

To test the structure of the video stream, we used our communication protocol, which runs over the AdHoc Wi-Fi mode. In our protocol, broadcast frames are used for route marking and other service purposes, but each node can relay such a packet only once, which eliminates a broadcast storm. We can change the order of the markup and use a different number of broadcast frames for it in one step of the algorithm. But to transfer the payload, our protocol uses unicast frames, a detailed description of the structure of which can be found in the paper [16]. These are standard MAC frames containing only the addresses of the two communicating nodes.

Testing has shown that with sequential transmission of broadcast frames, their loss begins after two successfully transmitted frames. Therefore, when drawing up a route marking algorithm, this fact must be considered. It is possible to use ad hoc frames to transfer the payload, since the NH protocol easily finds the next node among the neighbors of the current route node.

The structure of the NH protocol packet is shown in Fig. 3.

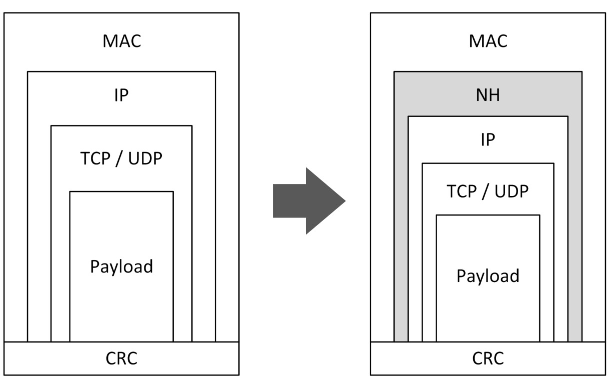

Figure 3. Payload Packet Structure for NH Protocol

MAC addresses of corresponding devices are used as host addresses. When transferring the payload with ad hoc frames, the current node of the route always knows the MAC address of the next node, so there is enough data to build a frame with the payload.

We have carried out testing for the NH protocol network. At the same time, the equipment and communication scheme remained the same as for the open80211s package (see Fig. 3.). However, on the network nodes, we changed the type of software used, replacing it with a utility from the software of the protocol we developed. The Wi-Fi mode of the mesh adapter was changed to AdHoc, and that part of our software that implements the NH protocol was used for routing.

For the exchange of any messages our utility uses Ethernet frames with the data type. In order to build a route, it is necessary to transmit the initial message to all neighboring points. For this, the destination MAC address is set to broadcast (ff: ff: ff: ff: ff: ff). Moreover, if there are a small number of such packets, then no packet loss is observed. If we start transmitting a video stream in this mode, then packets begin to be lost in an exceptionally large number. If, after marking the route, we send frames to a specific MAC address of the next node, then packet loss stops. This suggests that somewhere thresholds are set for the number of broadcast frames and / or the amount of information transmitted. Perhaps, there are additional restrictions on the broadcasting of individual link-layer protocols, since it was noticed that the transmission over the UDP protocol is accompanied by significantly higher losses than over the TCP protocol.

Ways to solve the problem with broadcast frame loss:

1) Mark the route with a broadcast packet and send the data to a specific MAC. After marking the route, we will know the MAC of the next hop. But if the route is long, then we may also encounter packet loss due to exceeding the threshold values.
2) Try to use Monitor instead of AdHoc mode. This hypothesis must be tested since it is not known whether frames can be sent in this mode and whether collision elimination will work.
3) Disable the broadcast packet filter somehow. Perhaps there is a Linux kernel option or module. It might just be possible to find this function in the source code of the corresponding module and comment it out.

Nevertheless, the experiment with sending the payload using frames in ad hoc mode along a marked sequence of nodes turned out to be successful, the loss of video stream packets stopped. Connection quality information is summarized in Tables 3 and 4.

TABLE 3. INDICATORS OF COMMUNICATION QUALITY FOR THE NH PROTOCOL NETWORK

Hops number	**Minimal network delay, ms**	**Average network delay, ms**	**Network jitter, ms**	**Packet loss, %**
1	3.8	5.6	1.8	0
2	7.6	9.6	3.6	13

Table 3 contains data on the indicators of communication quality for a self-organizing network built using the software we developed. The data in Table 3 suggest that the minimum delay value is again proportional to the number of route segments.

The available bandwidth is summarized in Table 4.

TABLE 4. DATA ON BANDWIDTH FOR THE NH PROTOCOL NETWORK

Hops number	TCP throughput capacity	UDP stream speed
1	780 Kbps	720 Kbps
2	720 Mbps	680 Kbps

The NH protocol provides less available bandwidth than the open80211s package. However, packet losses on the second hop of the route stopped, and available bandwidth is sufficient not only for voice transmission, but also for video of quite good quality.

5. Conclusion

The present research is devoted to finding ways of stable transmission of video streams over self-organizing wireless networks. Existing implementations for such networks face the loss of packets of video streams already on the second hop of the long route. This research examines the possibility of managing the quality of a network connection by changing the structure of the video stream. The study has not yet been completed as the work on only some hypotheses are expressed, but not all of them have been tested.

For experimental research, a special test site was created, on the network nodes of which software was installed that implements a self-organizing wireless network. Furthermore, these nodes are equipped with additional wireless adapters to collect traffic on the second layer of the OSI model. Comparing the traffic collected at the network and data link layers, as well as on the first and second hops of the route, we can conclude the reasons for packet loss.

The current conclusion is that broadcast frames should only be used for route marking. If such frames are used too often, then losses begin after the second consecutive broadcast request. Hypothesis testing was carried out using a specially developed communication protocol for wireless self-organizing networks. This protocol provides the ability to use different types of packets.

Load transmission using mesh frames does not stop the packet loss of the test video broadcast. However, broadcasting using ad hoc mode resulted in the end of packet loss.

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