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THE ASSESS THE FAULT-TOLERANCE, EFFICIENCY AND PERFORMANCE OF MILITARY FIELD LOCAL NETWORK TOPOLOGY

Abstract. Depending on the location of communication nodes of the control points and points of relay in the field, especially in mountainous areas, finding line of sight (LOS) and establishing a good radio relay connection can be challenging. In addition, depending on the requirements for bandwidth and communication stability, in the field, a situation often arises where it is possible to build a network only based on certain types of topologies. To assess the security of military field telecommunication networks, it is important to determine such important parameters as network stability or fault-tolerance, efficiency, transmission capacity and delay time. It is known that the greatest values of these parameters are achieved in the type of "fully connected" network topology. However, low efficiency, high power consumption, difficulties in safely and hidden placement of a large number of vehicles in the battle area and the complexity of maintenance, as well as the fact that radio relay hardware vehicles consist mainly of 2 sets of radio relay devices make this type of topology unsuitable for field networks. Therefore, it is important to define a network topology with high stability, using the minimum amount of radio relay vehicles. For the above reason, the article proposes mathematical methods for calculating the fault tolerance and efficiency of the selected network topology, as well as fault tolerance, bandwidth and latency for each network node.

Keywords: control points; throughput; channel stability and delay time of communication channels; network topology; fault tolerance and efficiency of network topology; radio relay equipment.

Introduction

As you know, in a modern military field telecommunications network, communication between nodes is organized using radio relay stations and satellite communications based on Ethernet technologies, as well as optical cables. Sources of information are located in specially equipped server rooms away from hazardous areas. Information confidentiality is provided mainly by cryptographic tools based on complex algorithms. In terms of strength and performance, all of the above tools in most cases fully comply with modern requirements. However, the ever-changing conditions of the battlefield require a special approach to the resilience and performance of the network topology, as well as the efficient use of redundant communications.

In order to determine the most stable and efficient topology for providing users with access to information resources at nodes within certain specified limits, in advance, before creating a field telecommunication network, the article developed and presented a methodology for assessing the corresponding topology parameters.

Assess the fault-tolerant of the node

The node fault tolerance (T_N) characterizes the ability of a network to perform its functions with the specified quality, despite the failure of any element during a given period of operation [1]. The stability of the host depends on the stability of the hardware, devices and other elements used here and the method of interconnection, as well as the availability of reserves and replacement period (t_{rp} - replacement period) for fault devises (to simplify the procedure, the time required to replace the elements here is assumed to be greater than the time allowed for the host to pause):

$$T_N = T_{CD\Sigma} \cdot T_{ap\Sigma}, \quad (1)$$

where $T_{CD\Sigma}$ - is the final stability of n_{CD} series-connected elements commonly used for all radio relay apparatuses in the control point (index: CD -commonly used device):

$$T_{CD\Sigma} = \prod_{k=1}^{n_{CD}} P_{CD k}, \quad (2)$$

$T_{ap\Sigma}$ - is the final stability of n_{ap} radio relay apparatus applied in parallel:

$$T_{ap\Sigma} = 1 - \prod_{i=1}^{n_{ap}} (1 - P_{ap i}), \quad (3)$$

$P_{ap i}$ - the probability of uninterrupted operation of the elements common to all radio relay sets in the i radio relay apparatus; $T_{RR\Sigma}$ - is the total stability of a set of n_{RR} radio relays applied in parallel:

$$T_{RR\Sigma} = 1 - \prod_{j=1}^{n_{RR}} (1 - P_{RR j}), \quad (4)$$

$P_{RR j}$ - the probability of continuous operation of the j radio relay set.

In practice, each of the radio relay apparatus can operate autonomously, and the element common to all of them is mainly a single power source of the control centre. Since each radio relay apparatus is equipped with its own electric generator and uninterruptible power supply period (T_{UPS}), i.e. the availability of backup and $t_{rp} < T_{UPS}$ allows us to assume $T_{CD\Sigma} = 1$. The topology sustainability report does not take into account the fact that there is a single number of workstations serving users and their reliability.

The uninterrupted operation of common elements in the radio relay apparatus is very critical for radio relay sets, in practice their failure (excluding the power supply) completely restricts access to the network, regardless of the number of sets in the apparatus, and adversely affects the stability of the network. Therefore, it is very important to ensure a high $T_{ap\Sigma}$ parameter in the hardware (Fig. 1).

The graph shows that if the number of radio relay sets is $n \geq 2$ and belong to different radio relay apparatus, i.e. $m \geq 2$, the stability of the host can be considered maximum, i.e. $T_N \approx 1$. However, at some nodes, the use of more than one apparatus is not only inefficient and difficult to provide electricity in the field, but also in terms of privacy and security. The radio relay sets can be connected to each other in such a way that the radio relay

hardware continues to function as a transit in the network, despite the failure of general-purpose devices. Under such conditions, it is possible to accept $T_{ap\Sigma} = 1$ without taking into account the influence of these devices on the stability of the topology, and the connection of each node to the network from two directions ($n = 2$) can be considered satisfactory from the point of view of the stability of the topology, i.e. $T_N \approx 1$.

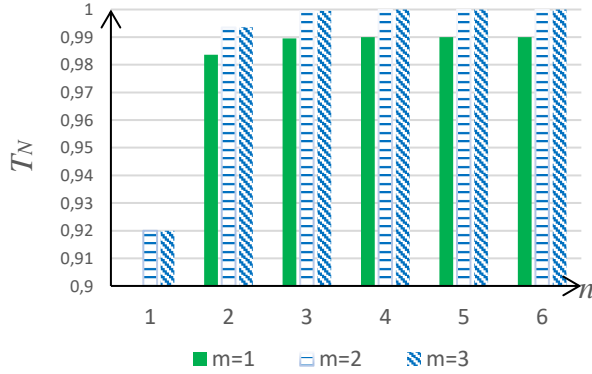


Fig. 1. Graph of the dependence of the host stability on the number of radio relay sets for $m=1, m=2$ and $m=3$ cases of the number of apparatuses

The expression for the probability of node failure can be written as follows: $Q_N = 1 - T_N$.

Depending on whether the devices are connected in series or in parallel in any group of elements at the control point, the total probability of continuous operation of that group is calculated as follows:

The total probability of continuous operation of n devices connected in series and also without backup (or the time required to replace the spare device exceeds the allowable break time):

$$P_{sd} = \prod_{k=1}^n P_k.$$

The total probability of continuous operation of m devices with "hot" reserve (2 connected in parallel):

$$P_{pd} = \prod_{l=1}^m (1 - (1 - P_1)(1 - P_2))_t.$$

The continuity of services for users at control points also depends on the number of channels the node connects to the network and the stability of the rest of the network.

Assess the fault-tolerant of the topology

The field telecommunications network must provide users at control points with safe, timely and with a given quality access to information resources, as well as the continuity of the services provided, regardless of internal and external destabilizing influences.

The stability of a telecommunications network is its ability to ensure uninterrupted access of hosts to information resources, regardless of the exit of one of its nodes or the loss of one of its channels.

The probability of uninterrupted operation of the network depends on the reliability of each nodes of networks, reliability of communication between them and reliability of implemented topology, as well as server redundancy and channel loading [2].

Considering that the probability of simultaneous failure of two or more network nodes or two or more channels is very small, sustainability of topology can be determined taking into account such parameters like the number of nodes connected in one direction (n_{deg1}) and their stability (T_{Ndeg1}); the number of critical links (n_{CL}) and nodes (n_{CN}), where their failure can be the reason for the loss of access to the servers of other nodes in the network, probabilities of failure of them (Q_{CL} and Q_{CN}); as well as the number of nodes (n_{DCN}) that are disconnected from the servers due to their failure and coefficients indicating levels of importance of them ($K_{I\Sigma DNC}$). Mathematically it can be written like this

$$T_T = T_{CN\Sigma} \cdot T_{CL\Sigma} \cdot T_{deg1} \tag{5}$$

$$\text{or } T_T = \prod_{m=0}^{n_{CN}} T_{CNm}^{\frac{K_{I\Sigma DNC}}{K_{I\Sigma N}}} \cdot \prod_{k=0}^{n_{CL}} T_{CLk}^{\frac{K_{I\Sigma DNC}}{K_{I\Sigma N}}} \times \left(1 - \frac{K_{I\Sigma deg1}}{K_{I\Sigma N}} \left(1 - \prod_{l=0}^{n_{deg1}} T_{Ndeg1_l} T_{Adeg1_l} T_{Ldeg1_l} \right) \right).$$

The expressions take into account the following critical factors that affect the stability of the network:

$T_{CN\Sigma}$ - is a multiplier that determines the influence of the probability of failure of critical nodes on the stability of the network, in the absence of a critical link, we take $T_{CN\Sigma} = 1$:

$$T_{CN\Sigma} = \prod_{m=0}^{n_{CN}} T_{CNm}^{\frac{K_{I\Sigma DNC}}{K_{I\Sigma N}}}, \tag{6}$$

where $K_{I\Sigma DNC} = \sum_{i=0}^{n_{DCN}} K_{Ii}$ - is the sum of the coefficients indicating the importance of all nodes that lost accessibility with the server due to the failure of the critical node (link); $K_{I\Sigma N} = \sum_{j=0}^{n_N} K_{Ij}$ - is the sum of the coefficients indicating the importance of all nodes in the network. $T_{CL\Sigma}$ - fault tolerance of critical links, this multiplier determines the influence of the probability of failure of critical connections on the stability of the network, and in the absence of a critical link, we take $T_{CL\Sigma} = 1$:

$$T_{CL\Sigma} = \prod_{k=0}^{n_{CL}} T_{CLk}^{\frac{K_{I\Sigma DNC}}{K_{I\Sigma N}}}.$$

Fig. 2 shows the number of critical nodes $n_{CN} = 1, n_{CN} = 2, n_{CN} = 3, n_{CN} = 4 \forall n_{CN} = 5$ (number of critical links $n_{CL} = 1, n_{CL} = 2, n_{CL} = 3, n_{CL} = 4 \forall n_{CL} = 5$), as well as the dependence of the $T_{CN\Sigma}$ and $T_{CL\Sigma}$ values on the ratio $K_{I\Sigma DNC}/K_{I\Sigma N}$ for network topologies with stability of all support points $T_{CN} = 0.9$. As can be seen from the graph, the higher the number of critical nodes and the number of nodes that lose accessibility to the servers in the event of their failure, the lower the value of $T_{CN\Sigma}$ bit.

If each network has a single critical link ($n_{CN} = 1$) and its failure causes all other support points to lose contact with the server, i.e. $K_{I\Sigma DNC}/K_{I\Sigma N} = 1$, then the stability of the topology is affected, the value $T_{CN\Sigma}$ ($T_{CL\Sigma}$) will be determined by the stability of this critical node (link), in our example $T_{CN\Sigma} = 0.9$. If the number of such critical nodes (links) increases, the value of the multiplier decreases even more.

T_{deg1} - is a multiplier that determines the influence of the probability of no-failure operation of nodes with one-way communication on the stability of the network, where is taking into account the fault tolerance of these

nodes (T_{Ndeg1}), fault tolerance adjacent nodes with them (T_{Adeg1}) and fault tolerance of the link between them (T_{Ldeg1}), as well as the ratio $K_{I\Sigma deg1}/K_{I\Sigma N}$:

$$T_{deg1} = \left(1 - \frac{K_{I\Sigma deg1}}{K_{I\Sigma N}} \left(1 - \prod_{l=0}^{n_{deg1}} T_{Ndeg1_l} T_{Adeg1_l} T_{Ldeg1_l} \right) \right), \quad (9)$$

where $K_{I\Sigma DNC} = \sum_{i=0}^{n_{deg1}} K_{I deg1 i}$ – is the sum of the coefficients indicating the importance of the nodes that communicate in one direction

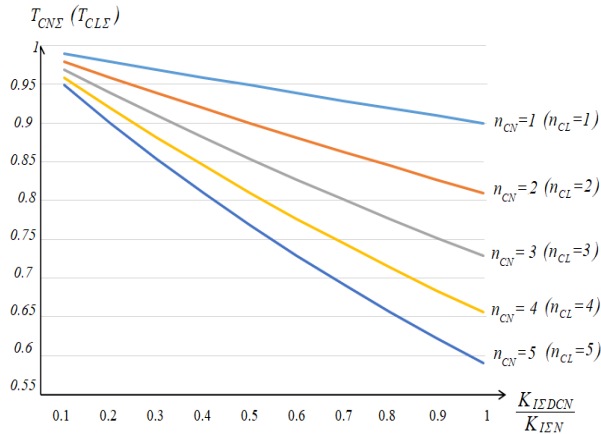


Fig. 2. Dependence of the final $T_{CN\Sigma}$ and $T_{CL\Sigma}$ values on the ratio $K_{I\Sigma DNC}/K_{I\Sigma N}$, which affects the fault tolerance of the network topology

Loss of communication links due to external influences can be caused by electromagnetic jamming or physical damage by the enemy any of the radio relay stations (h_i or h_j) that make it up, as well as due to unfavourable weather conditions. Therefore, for the stability or the probability of failure of links, we can write the following expression:

$$T_L = T_{EJ i} \cdot T_{EJ j} \cdot T_{PD i} \cdot T_{PD j} \cdot T_{UWC} \quad (9)$$

and

$$Q_L = 1 - T_{CL}$$

where T_{EJ} - is the resilience of the i and j radio relay stations forming the link to electromagnetic jamming; T_{PD} - is the resilience of the i and j radio relay stations forming the link to physical destruction by the enemy; T_{UWC} - is the resilience of the link against the effects of adverse weather conditions.

The resilience of the radio relay stations forming the link depends on technical parameters such as the antenna directivity, the maximal output power of radio relay stations and applying automatic control mode for it, the immunity to interference of the used type of modulation and its automatic adjustment, applying anti-jamming technology (OFDM, MIMO), selected frequencies and channel width, applying frequency hopping mode, frequency hopping speed and hopping algorithm complexity, the signal-to-interference ratio required for the normal operation of the radio relay station, as well as on factors such as the maximal output power of electronic warfare station, the distance between the radio relay and electronic warfare stations, the angle between the link and the direction to the electronic warfare station and topography. To evaluate T_{EJ} parameter, there are

appropriate methodologies that take into account the above factors and can be calculated [3].

The likelihood of physical disabling of a radio relay station depends on the proximity of its location in the enemy's engagement zone, the intensity of fire and the presence of the enemy with high-precision weapons, as well as the possibility of penetration of reconnaissance and sabotage groups. The choice of safe places for stations and their antenna feeder devices, the organization of the security of the communication centre, the installation of equipment on armoured vehicles, the effective use of the protective and masking capabilities of the terrain reduces this possibility. In addition, the presence of a reserve in a safe area in short distance, the availability of safe road infrastructure, weather conditions, cross-country ability of vehicles and staff training level are important factors for recovery of a failed station in a short time. The evaluation of T_{PD} can be done experimentally, taking into account the above factors. In order to identify critical links (CL) and critical nodes (CN), as well as other suitable parameters a new algorithm is proposed, based on the Dijkstra algorithm from Graph theory. Algorithm sequence:

1. The initial parameters of the topology are determined from the database in the following sequence:

1.1. Number of nodes in the network, n_N ;

1.2. The coefficients indicating the importance of all nodes in the network, K_I ;

1.3. Minimum bandwidth of links, F_{Lmin} ;

1.4. The fault-tolerance of nodes due to internal reasons, T_N ;

1.5. The fault-tolerance of nodes to electromagnetic attenuation, T_{EJ} ;

1.6. The fault-tolerance of nodes to physical destruction, T_{PD} ;

1.7. Nodes connected to a local stationary network (servers), n_{ST} ;

2. **Bandwidth table** showing the adjacent nodes for each node and their throughput is compiled. The columns of the **bandwidth table** are:

2.1. List of adjacent nodes (stationary node inclusive if there is a connection to it);

2.2. Bandwidth with each adjacent node (bandwidth with stationary node can be take $1Qbits$);

2.3. The degree of nodes, $degN$;

3. Using Dijkstra's algorithm in graph theory, a subroutine is developed to check if there is a path between each node;

4. Critical nodes are defined and the value $T_{CN\Sigma}$ is calculated, for which:

4.1. The nodes in the network where $degN \geq 2$ are cancelled one by one (for this it is enough to select their throughput in the **matrix** equal to 0) and move on to point 3;

4.2. If there is a node that loses contact with the static local network (server), the cancelled nodes are considered critical and are defined as follows:

4.2.1. The number of cancelled nodes is added to the list "CN - Critical Nodes" and the number (n_{CN}) is determined;

4.2.2. Lists of nodes that lose contact with the stationary network (server) due to failure of each critical node are compiled, as well as the number (n_{DCN}) and degrees of importance of them ($K_{I\Sigma DNC}$) are calculated;

4.3. The value $T_{CN\Sigma}$ is calculated based on the (6);

5. Critical links are identified and the value $T_{CL\Sigma}$ is calculated, for which:

5.1. The links in the network are cancelled one by one (for this it is enough to select the corresponding capacity of the nodes forming that link in the matrix equal to 0) and move on to point 3;

5.2. If there is a node that loses contact with the static network (server), the cancelled links are considered critical and the following are defined:

5.2.1. The number of cancelled nodes is added to the list "CL - Critical Links" and the number (n_{CL}) is determined;

5.2.2. Lists of nodes that lose contact with the stationary network (server) due to failure of each critical link are compiled, as well as the number (n_{DCN}) and degrees of importance of them ($K_{I\Sigma DNC}$) are calculated;

5.3. The value $T_{CL\Sigma}$ is calculated based on the expression (7)

6. The T_T fault-tolerance of the topology is calculated based on the expression (5)

Assess the efficiency of the topology

Topology efficiency is the ability of a network to perform specified functions in accordance with specified requirements using a minimum number of tools. This parameter is proposed to be determined by the ratio of the minimum number of radio relay stations (obviously this is n_N , when $n_N \geq 3$ and there are usually 2 radio relay sets in each radio relay stations) required to connect nodes from at least two directions to the number of radio relay devices used:

$$E_T = \frac{n_N}{n_{ap}} = \frac{n_N}{\sum_i^{n_N} (|degN/2| + n_{ex})_i}, \quad (10)$$

where $[degN/2]$ - is the minimum number of radio relay stations (taking into account that it contains 2 sets of radio relays) required at the i node; n_{ex} - is the number of RR apparatus supplied to the support i node in addition to the required.

Evaluating Network Topology Performance

In field control points, it is required to provide users within the established limits with access to information resources located in stationary centres. In modern times, the requirement to organize a live video conference for management staff between control points, as well as the sending of video images from various surveillance cameras for users requires high performance of the information and telecommunications system. Therefore, it is important to assess the ability to transfer information from a stationary network to a local area network established in the field, and to identify a more productive topology. It is also necessary to know the time parameters such as packet latency and response time in order to provide access to information resources located in stationary centres for users at the nodes [4].

Depending on the value of the $degN$ of nodes of the field telecommunication network and the information transmission capacity of adjected nodes, it is recommended to select the most suitable node for integration of the desert telecommunication network into the stationary network as follows:

1. The minimum information transfer rates required for node and for the entire network are defined:

$$F_{N\ OUT} = \sum_{RN=1}^k n_{RN} \cdot F_{RN}; \quad (11)$$

and

$$F_{\Sigma\ OUT} = \sum_{n=1}^{n_N} F_{N\ OUT}.$$

where $n_{RN} \cdot F_{RN}$ is the final transfer rate required at the node for each communication type (n_{RN} is the number of users in that communication type and F_{RN} is the minimum transmission speed required for one channel in this type of communication), n_N is the number of reference points.

2. For each node, the maximum speed that a stationary network can be send to the field telecommunication network using that it is determined here:

$$F_{IN} = \sum_{j=1}^{degN} F_{Aj}, \quad (12)$$

where F_{Aj} is the capacity of the connection with the adjacent node, $degN$ - the number of connections of the support point with neighbouring nodes.

3. If any node (source) is connected to a stationary network, the transmission speeds to be provided at each other node (target) are determined. The Ford-Fulkerson algorithm can be used for this purpose.

4. The final flow rate to the network is calculated.

5. Nodes that affect the speed of receiving information in each node from central data sources are identified.

Conclusion

1. To maximize the stability of nodes in a field computer network, it is sufficient to install them on two radio relay apparatuses, each with two sets of radio relays.

2. In order to ensure reliable access to information resources in the field computer network, each node is required to be connected to the network from at least two directions.

3. It is required to have spare parts for devices with a high probability of failure in the radio relay apparatus and to make the necessary preparations for their replacement in a short time, as well as to arrange supply bases in a convenient place to ensure that spare parts and devices are delivered to the fault point in a short time.

4. The fault tolerance of the topology plays a more critical role in the field computer network based on radio relays in terms of network security.

5. Assessing the fault-tolerant of a topology based on the following critical factors can provide a more accurate result:

a. The fault tolerance of critical nodes, as well as the number of nodes that lose contact with the servers in the event of their failure, the degree of importance of them and the ratio of the number of total nodes;

b. The fault tolerance of critical links, the importance and number of support points that lose contact with servers in the event of their failure, and the ratio of this number to the total number of support points.

c. The number of nodes with just a single connection and the ratio of this number to the total number of all nodes of network, the degree of importance and the fault tolerance of each, as well as the fault tolerance of adjected node with it, the fault tolerance of the link between them.

6. The Dijkstra algorithm in Graph theory can be used to identify critical links and points, for which the appropriate algorithm is presented above.

7. Depending on the node to which the servers are connected, the speed of data transmission to and from the field computer network is different and depends on the bandwidth of links of the nodes with neighbours.

8. The maximum velocities of information flow, which can be transmitted individually and simultaneously to each reference point, are determined by the Dijkstra algorithm in Graph theory.

9. The delay in the flow of information from servers to support points varies depending on the chosen route.

10. Depending on the speed and latency requirements of the information type, suitable routes should be calculated in advance, and for these routes in the network devices, appropriate adjustments should be made.

11. On servers and workstations in communication centres, appropriate adjustment work should be carried out taking into account the speed and delay of data transmission.

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Оцінка надійності, ефективності і продуктивності топології військово-польової локальної мережі

А. Р. Настакалов

Анотація. Залежно від розташування вузлів зв'язку в пунктах управління і точок ретрансляції в польових умовах, особливо в гірських районах, знаходження точок з прямою видимістю і встановлення хорошого радіорелейного з'єднання з сусідніми вузлами може бути складним завданням. Крім того, в залежності від вимог до пропускної здатності і стабільності зв'язку в польових умовах часто виникає ситуація, коли можна побудувати мережу тільки на основі певних типів топологій. Для оцінки безпеки телекомунікаційних мереж військового призначення важливо визначити такі важливі параметри, як відмовостійкість і ефективність мережі, пропускна здатність і час затримки каналів зв'язку. Відомо, що найбільші значення цих параметрів досягаються в топології мережі типу «повнозв'язна». Однак низька ефективність, високе енергоспоживання, складності з безпечним і прихованим розміщенням великої кількості техніки в зоні бойових дій і складність обслуговування, а також той факт, що радіорелейний апаратура складається в основному з 2 комплектів радіорелейних пристроїв, роблять цей тип топології непридатним для польових мереж. Отже, важливо визначити топологію мережі з високою стабільністю, використовуючи мінімальну кількість радіорелейних транспортних засобів. За вищевказаній причині в статті пропонуються математичні методи розрахунку відмовостійкості і ефективності обраної топології мережі, а також відмовостійкості, пропускної спроможності і затримки для кожного мережевого вузла.

Ключові слова: пункти управління; пропускна здатність; стабільність каналу та час задержки каналів зв'язку; топологія мереж; відказостійкість та ефективність топології мереж; радіорелейна апаратура.

Оценка надежности, эффективности и производительности топологии военно-полевой локальной сети

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Аннотация. В зависимости от расположения узлов связи в пунктах управления и точек ретрансляции в полевых условиях, особенно в горных районах, нахождения точек с прямой видимостью (LOS) и установление хорошего радиорелейного соединения с соседними узлами может быть сложной задачей. Кроме того, в зависимости от требований к пропускной способности и стабильности связи в полевых условиях часто возникает ситуация, когда можно построить сеть только на основе определенных типов топологий. Для оценки безопасности телекоммуникационных сетей военного назначения важно определить такие важные параметры, как отказоустойчивость и эффективность сети, пропускная способность и время задержки каналов связи. Известно, что наибольшие значения этих параметров достигаются в топологии сети типа «полносвязная». Однако низкая эффективность, высокое энергопотребление, сложности с безопасным и скрытым размещением большого количества техники в зоне боевых действий и сложность обслуживания, а также тот факт, что радиорелейная аппаратура состоит в основном из 2 комплектов радиорелейных устройств, делают этот тип топологии непригодным для полевых сетей. Следовательно, важно определить топологию сети с высокой стабильностью, используя минимальное количество радиорелейных транспортных средств. По вышеуказанной причине в статье предлагаются математические методы расчета отказоустойчивости и эффективности выбранной топологии сети, а также отказоустойчивости, пропускной способности и задержки для каждого сетевого узла.

Ключевые слова: пункты управления; пропускная способность; стабильность канала и время задержки каналов связи; топология сети; отказоустойчивость и эффективность топологии сети; радиорелейная аппаратура.