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RESILIENT HYBRID RADIO COMMUNICATION NETWORK USING RADIO RELAY LINKS AND TROPOSCATTER LINKS WITH FAILOVER MECHANISMS

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Abstract: The paper presents the design and simulation of a hybrid microwave radio communication network based on the integration of radio relay and troposcatter links, aimed at ensuring communication continuity under various propagation conditions. Radio relay systems provide high capacity and low latency but require line-of-sight (LoS), while troposcatter links enable long-distance communication without LoS, at the cost of lower capacity. A hybrid architecture was adopted, where radio relay links serve as primary paths and troposcatter links act as backup. The link simulations were carried out using HTZ Warfare software. A redundant network was implemented using OSPF dynamic routing, configured to prioritize primary links and enable automatic failover. The results confirm the effectiveness of the proposed solution in ensuring reliable and robust communications for military applications.
Key words: microwave communications, troposcatter systems, dynamic routing, OSPF, network redundancy, failover.

1. INTRODUCTION

The continuous provision of communications is essential for the operation of critical infrastructures, especially in military or emergency scenarios, where the loss of a communication link can disrupt information flow and coordination between network nodes. For this reason, modern communication systems incorporate redundancy mechanisms and link protection solutions to ensure service continuity even in the presence of disturbances [1].

In medium- and long-distance radio communications, radio relay systems are widely used due to their high capacity and rapid deployment. However, they rely on line-of-sight (LOS) conditions, which may not always be achievable. In such cases, tropospheric communications can be used as a backup solution, enabling long-distance transmission without direct visibility by exploiting wave scattering in the troposphere [2].

This paper analyses a hybrid communication architecture in which radio relay links serve as the primary transmission medium, while tropospheric links act as backup. Traffic switching between the two is performed automatically using the OSPF dynamic routing protocol, implemented in a virtualized environment. The radio links were modelled using the HTZ Warfare platform, and the routing infrastructure was deployed in EVE-NG, allowing the evaluation of network behaviour under both normal and failure conditions [3].

2. METHODS AND MATERIALS

2.1 HTZ Warfare Simulation Environment

HTZ Warfare is specialized software used for the planning and analysis of radio links in several types of operational scenarios, developed by the company ALTDI. The application allows the simulation of the propagation of electromagnetic waves, considering the technical parameters of the radio equipment, the characteristics of the terrain and the propagation conditions. With digital terrain models and geographic databases, the platform offers the possibility of calculating the radio link budget and evaluating its performance according to the parameters and characteristics of the equipment used, as well as the geographical environment, based on the propagation patterns of the radio channel [4].

2.2 Network Emulation Environment – EVE-NG

EVE-NG (Emulated Virtual Environment – Next Generation) is a network emulation platform used to simulate and test communication infrastructures in a virtual environment. The application allows the integration and interconnection of different types of

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virtual network equipment, providing the possibility of replicating complex topologies without the use of physical equipment. Through this platform, routing protocols, redundancy mechanisms and various operating scenarios of IP networks can be configured and tested, making it a useful tool for analysis, testing and research in the field of data communications [5].

2.3 Radio relay link modelling

The radio relay link was modelled in HTZ Warfare by defining the geographical position of the network nodes and configuring the technical parameters of the radio equipment used. During the simulation, the locations for the transmitting and receiving stations were selected, along with the main characteristics of the radio system, to reproduce the signal propagation conditions in the analysed geographical environment.

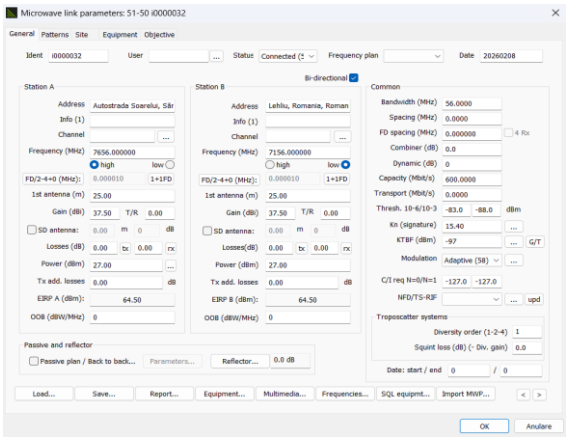
The topology of the radio relay link was created using digital terrain models and geographic databases available within the simulation platform, allowing the analysis of the radio path and the evaluation of propagation conditions between communication nodes. In the analyzed scenario, several locations in Romania were selected, including Bucharest, Buzău, Focșani, Bacău, Iași and Galați, which represent the main nodes of the network.



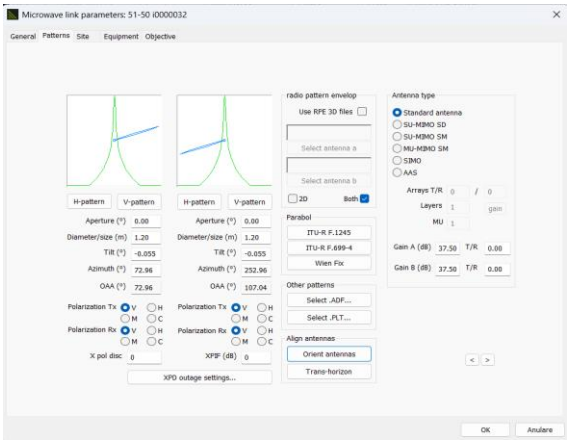
Figure 1 Topology of the radio relay network used in the simulation scenario

The main parameters of the radio relay system used in the simulation, such as operating frequency, transmitting power and radio system characteristics, were defined according to the specifications of the equipment used, namely the IP-20G. The operating frequency was automatically selected by the simulation platform in the range 7.1–8.5 GHz, corresponding to the band used for radio relay communications (Figure 2(a)).

During the simulation, the characteristics of the antenna used, type Am-4-7_8-CIRC-CR1, were also defined, which influenced the performance of the radio link and the calculation of the link budget. The antenna used is a directional antenna, with a diameter of 1.2 m, having the general characteristics specific to parabolic antennas used in radio relay systems (Figure 2(b)).



(a) Radio relay system parameters



(b) Characteristics of the antenna used

Figure 2 Parameters of the radio relay system and characteristics of the antenna used

2.4 Tropospheric link modelling

To increase the resilience of the communication system, a tropospheric link was added to the created scenario, used as a backup link in case of unavailability of the radio relay link. The topology of this link was created in HTZ Warfare by defining nodes between the cities of Bucharest, Focșani, Galați and Iași, these being considered strategic locations hosting important military units (Figure 3).

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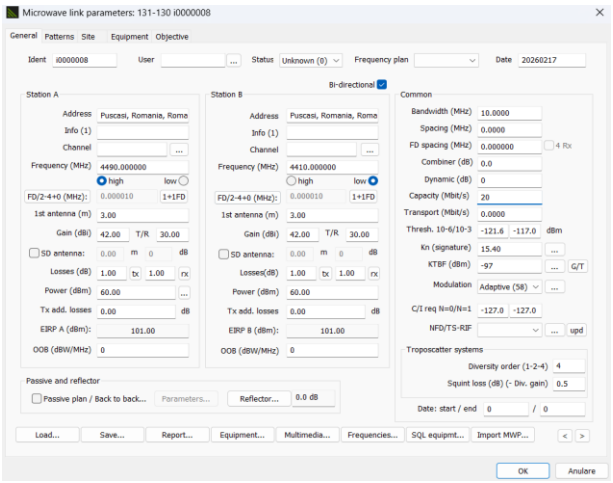
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Figure 3 Tropospheric network topology used in the simulation scenario

Tropospheric communications are based on the phenomenon of scattering of electromagnetic waves in the lower layer of the atmosphere (troposphere), which allows communications to be carried out over long distances even in the absence of direct visibility between stations. With this method, a small part of the energy of the transmitted signal is scattered in the troposphere and can be received by the remote station.

The main parameters of the tropospheric link used in the simulation were defined according to the characteristics of the equipment used, namely the tropospheric modem Datum M7 (Figure 4(a)). The operating frequency was automatically selected by the simulation platform in the 4.4–5 GHz range, specific to ground-level communication systems. The Tropoline 240 antenna was used to make the link, which is common in tropospheric communication systems due to its high gain and directive characteristics. The antenna used has general characteristics specific to this type of antenna, being used to ensure the performance of the tropospheric link (Figure 4(b)).



(a) Parameters of the tropospheric system



(b) Features of the Tropoline 240 antenna

Figure 4 Parameters of the tropospheric system and characteristics of the antenna used

2.5 Configuring the Routing Protocol and Failover Mechanism

To achieve the redundancy mechanism at the IP network level, the OSPF (Open Shortest Path First) dynamic routing protocol was used, configured in the EVE-NG emulation environment using MikroTik virtual routers. The routers were interconnected according to the network topology, allowing the exchange of routing information between the system nodes and the automatic determination of the optimal route for the transport of data traffic.

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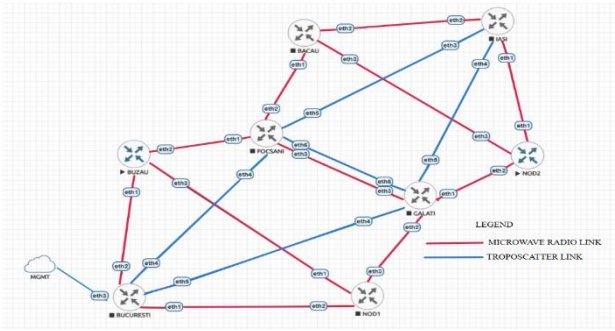


Figure 5 Hybrid Microwave–Troposcatter Network Topology

The configuration of the routers within the simulated network was carried out using the MikroTik RouterOS operating system. The complete configuration details for one of the routers are available online in a public repository at the following address, providing full access to the implemented parameters, routing mechanisms, and failover configurations used within the network: https://github.com/CiofirdelCristian/hybrid-radio-network-config.

The configuration includes the IP addressing setup and the initialization of the OSPF protocol, including the assignment of IP addresses to each interface, the configuration of a loopback address used as the router ID, and the inclusion of interfaces in the backbone area.

Additionally, the configuration defines the implementation of troposcatter links and the assignment of OSPF costs, where these links are configured with higher cost values to serve as backup routes, while microwave radio relay links are used as primary paths.

Furthermore, OSPF optimization and failover mechanisms are implemented through the adjustment of hello and dead intervals, as well as the use of the Netwatch tool for link monitoring. In the event of primary link degradation, the OSPF cost is dynamically modified, enabling traffic rerouting over backup links and controlled restoration to the primary path once the connection stabilizes.

3. RESULTS AND DISCUSSION

3.1 Results of the radio link simulation

In the simulation, the parameters of the radio relay links were configured so that their transmission capacity is between 400 and 600 Mbps. Under these conditions, the maximum distance between two stations is approximately 20 km, a value determined according to the propagation conditions, the characteristics of the radio equipment used and the performance requirements of the system. To ensure reliable and stable operation in the simulation, a minimum link availability of 99.95% was imposed and the fading margin was set to approximately 20 dB.

The profile of a radio relay link obtained from the simulation is shown in Figure 6. The analysis of the terrain profile allows the evaluation of the propagation conditions between the two communication stations and the verification of the existence of direct visibility (LOS – Line of Sight) between them. From the analysis of the profile, the line of sight between the nodes is maintained over the entire distance of the connection, and the First Fresnel zone is not significantly obstructed by relief.

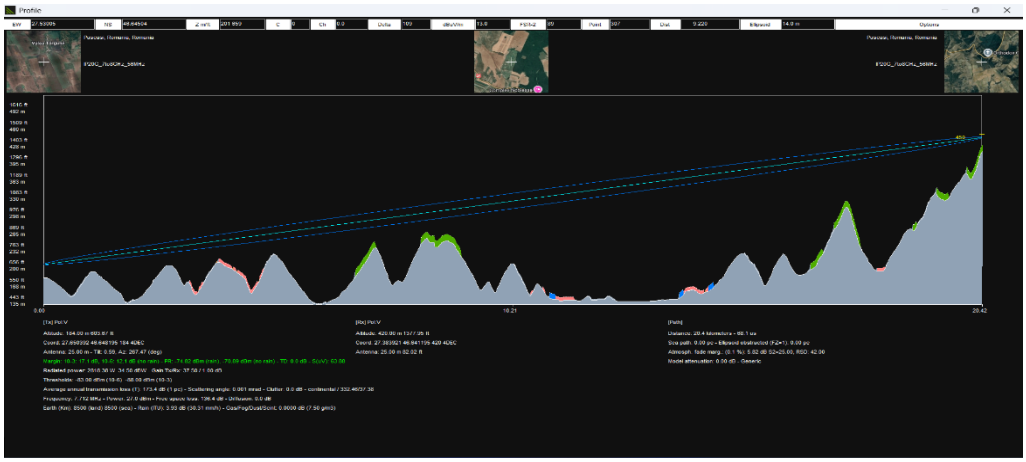


Figure 6 Profile of the radio relay link and analysis of visibility conditions

During the simulation, situations were also identified in which the first Fresnel zone is partially obstructed by relief (Figure 7). However, the degree of obstruction does not exceed 60% of the Fresnel zone, a value that allows the link to be maintained without significant degradation in performance. Therefore, the radio relay link can be considered feasible and reliable under the existing conditions.

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Figure 7 Example of a radio relay link profile in which the first Fresnel zone is partially obstructed by relief.

3.2 Results of the tropospheric link simulation

To evaluate the performance of the tropospheric link, the main parameters of the communication system were analysed. The simulation aimed to determine a reliable communication distance, as well as the link performance under configured system conditions. Also, for the evaluation of the reliability of the system, a minimum availability of 99.95% was imposed. Under these conditions, the transmission capacity was configured in the range of 5–25 Mbps, varying depending on the propagation conditions.

An example of the tropospheric link profile obtained in the simulation is shown in Figure 8. The analysis of the results indicates that the distance between the two tropospheric stations is approximately 144 km, significantly greater than in the case of radio relay links. Under the conditions of the parameters configured in the simulation, the link has a fading margin of approximately 18 dB, which allows the stable operation of the system to be maintained. For these operating conditions, the estimated transmission capacity of the link is approximately 20 Mbps, which is sufficient to ensure the operation of the backup link within the proposed communication architecture.



Figure 8 Tropospheric Link Profile and Propagation Analysis

3.3 Network behaviour and failover mechanism

To evaluate the behaviour of the network in normal operation scenarios and in failure situations, it was analysed how the OSPF routing protocol handles the routes available in the network. Under normal operating conditions, the traffic between the nodes of the network is routed through the radio relay links, which are configured with a lower OSPF cost.

To verify the redundancy mechanism implemented in the network, the traceroute command from the router located in the Bucharest node to the destination address in Iași was used. Under normal operating conditions, traffic is directed through radio relay links, the route of the packets being Bucharest – Nod1 – Galați – Nod2 – Iași. After deactivating the interfaces corresponding to the radio relay links in Bucharest, the OSPF protocol automatically recalculated the routing table, and the traffic was redirected through the tropospheric link to the Galați node, after which it continues through the existing radio relay infrastructure to the destination. In this situation, the route becomes Bucharest – Galați – Nod2 – Iași. This change of route confirms the correct operation of the failover mechanism and the ability of the network

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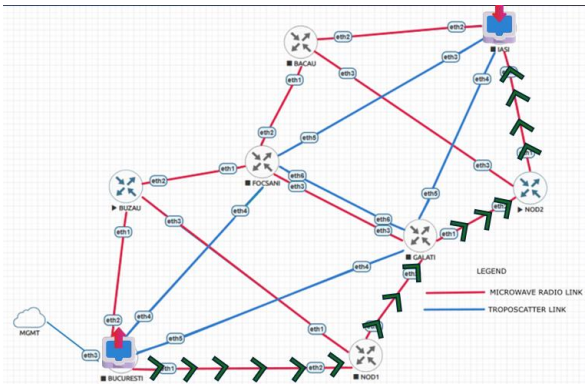
to maintain continuity of communications in the event of the unavailability of the main link (Figure 9).

```
[admin@BUCURESTI] > /tool traceroute 10.255.0.5
ADDRESS                          LOSS SENT    LAST     AVG    BEST   WORST STD-DEV STATUS
10.0.0.6                           0%   61     1ms     1.7     0.7    19.8     2.4
10.0.0.41                          0%   61   1.9ms     2.9     1.3    36.6     4.4
10.0.0.37                          0%   61   2.9ms     6.4     2.2   180.2    22.5
10.255.0.5                         0%   61   4.3ms     6.5     3.2   125.3    15.4

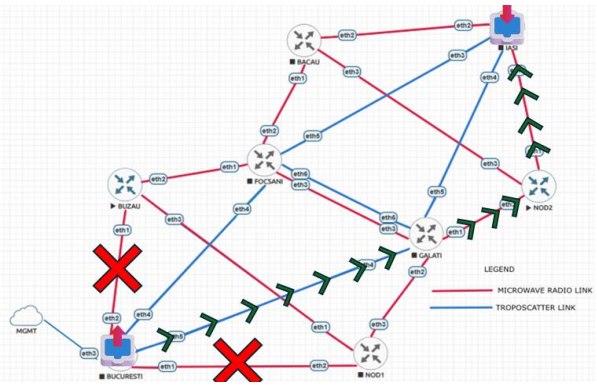
[admin@BUCURESTI] > /interface disable ether1
[admin@BUCURESTI] > /interface disable ether2
[admin@BUCURESTI] >
[admin@BUCURESTI] > /tool traceroute 10.255.0.5
ADDRESS                          LOSS SENT    LAST     AVG    BEST   WORST STD-DEV STATUS
10.0.100.6                         1%   97   1.1ms     1.7     0.8     4.2     0.5
10.0.0.37                          0%   97   2.1ms     2.8     1.6     5.5     0.7
10.255.0.5                         0%   97   3.3ms     3.3     1.7     8.3     0.8
```

Figure 9 The route of network traffic under normal conditions and after the failover mechanism is activated.

The visual representation in Figure 10 supports the previously described behaviour of the routing process. Under normal operating conditions, the traceroute output confirms that traffic is transmitted through the primary radio relay links. After the intentional deactivation of these links, the routing path is automatically modified by the OSPF protocol, redirecting the traffic through the troposcatter link [6-9]. This visual evidence clearly illustrates the dynamic rerouting capability of the network and validates the correct operation of the implemented failover mechanism.



(a) Traffic routing under normal conditions through the primary radio relay links.



(b) Traffic rerouting after failover, using the troposcatter link as a backup path.

Figure 10 Visual representation of network traffic routing under normal operating conditions and after the activation of the failover mechanism.

4. CONCLUSIONS

The paper presented the creation and analysis of a hybrid communications architecture in the microwave range, using radio relay links as the main infrastructure and tropospheric links as a backup solution. The modelling and evaluation of the performance of the radio links were carried out using the HTZ Warfare simulation platform, and the behaviour of the IP network was analysed in an EVE-NG emulation environment.

The results of the simulations showed that radio relay links for capacities of 400-600 Mbps can provide transmission over distances of about 20 km between stations, while tropospheric links allow communications over significantly longer distances of more than 100 km, but with a lower transmission capacity, located in the range of 5–25 Mbps. These characteristics make tropospheric links suitable for use as a backup solution in critical communication networks.

The integration of the two types of links in a network infrastructure based on the OSPF routing protocol allows the implementation of an automatic failover mechanism, whereby traffic is redirected to the tropospheric link in case of unavailability of the main radio link. The results obtained show how this approach works and highlight the potential of using a hybrid architecture to increase the resilience of communication systems.

5. CREdit authors statement

Conceptualization: C.C., S.A.; Data curation: C.C.; Formal analysis: C.C.; Funding acquisition: not applicable; Investigation: C.C.; Methodology: C.C., S.A.; Project administration: S.A.; Resources: C.C.; Software: C.C.; Supervision: S.A.; Validation: C.C., S.A.; Visualization: C.C.; Writing – original draft: C.C.; Writing – review & editing: C.C., S.A..

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