Proposal for Implementation of Novel Routing Protocols for IP Radio Networks above 70 GHz in MPLS

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Abstract — **In this paper, a proposal for implementation of novel routing protocols for IP radio networks at frequencies above 70 GHz is described. The protocols are designed to improve a network performance in the presence of the rain that has an intensity that causes a link down state and/or capacity reduction of some links in the network, but a network graph remains connected. New protocols, named OSPF-BPI and OSPF-BNI, are modifications of standard OSPF routing protocol which imply traffic sharing between the main shortest path route and specially defined backup routes. It is shown that the majority of novel routing protocols' features can be achieved just with a proper configuration of routers with standardized multi protocol label switching (MPLS) traffic engineering (TE) capabilities. For both types of backup routes attention is paid to avoid an additional unavailability due to equipment failure. The same MTTR time is kept for the same IP network when no protection mechanism are applied.**

Keywords — **Backup routes, Millimeter wave network, Rain attenuation, Traffic protection**

I. Introduction

MILLIMETER wave links above 70 GHz enable high speed communication with throughput up to 10 GBit/s [1], and they are becoming popular worldwide for applications in 4G and ISP backhaul urban scenarios. The main limitation of this band usage is rain attenuation [2] which limits hop length to about 10 km. Using two-dimensional rain models described in [3], [4], the performances of classical routing protocols like Routing Information Protocol (RIP), Enhanced Interior Gateway Routing Protocol (EIGRP) and Open Shortest Path First (OSPF) are investigated in [5]. It was shown that the finite duration of network routing process convergence could not track rain cell movement and thus a significant traffic loss occurs. In order to overcome this problem, a cross layer adaptation of OSPF protocol, as well as a novel proactive routing protocol that uses radar image of rain storm, are proposed in the literature [6].

In our previous paper [7], we presented another traffic protection method based on backup routes calculated using PHY and NOPHY algorithms. That method improves a network performance in the case when rain causes unavailability and/or link capacity reduction for a number of links in the network, but a network graph still remains connected. The main advantage of novel protection method is that traffic sharing coefficients between the main and backup route could be adjusted instantly and hence does not provoke network convergence instability problems. It was shown that, according to a proportional fairness criterion [8], the novel protection method had considerably better results than default OSPF which reacts by shortest path rerouting 40s after a link state change with link costs reversely proportional to its nominal bandwidth [9], [10].

In [11] different load balancing schemes between the main and backup route are explored. It was concluded that the combinations of OSPF-E, OSPF-BPI, OSPF-BNI and OSPF-CI should be used. OSPF-E is a default OSPF routing protocol which performs even load balancing in the case of equal-cost multiple paths. Depending on which algorithm is used for backup route precalculation, PHY or NOPHY, novel routing protocols that perform iterative load balancing are denoted as OSPF-BPI and OSPF-BNI, respectively. An ideal routing protocol with iterative load balancing is denoted as OSPF-CI. It is proved that the combination of traffic distribution between the main and backup route in combination with OSPF-like rerouting 40s after a link state change can reach the performance of ideal routing protocol. It instantly reacts to each link capacity change by rerouting according to the shortest path algorithm with a link cost reversely proportional to links current bandwidth. However, due to network instability problems caused by the finite duration of network convergence after rerouting, OSPF-CI is not realizable.

A further performance analysis of novel routing protocols OSPF-BPI and OSPF-BNI is presented in [11]. It was shown that, according to a congestion criterion and a maximum achievable throughput criterion, OSPF-BPI and OSPF-BNI also have a better performance than OSPF-E, and, in many scenarios, a performance close to ideal OSPF-CI. Depending on a particular network topology, link fading margins and the rain cell characteristics of OSPF-BPI or OSPF-BNI has a better performance.

The straightforward implementation of OSPF-BPI and OSPF-BNI requires the implementation of a communication protocol between a radio-relay link and router equipment to share information about current link

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capacities. It also requires a modification of router firmware, which results in considerable development costs. To overcome this problem we have investigated possibilities to implement simplified versions OSPF-BPI and OSPF-BNI on existing platforms with a proper choice of configuration parameters.

The main feature, that technology for practical implementation of new protocols should have, is the possibility of complete paths definition (from one to another end of the network, and type of traffic distribution between them).

One such technology is MPLS (*Multiprotocol Label Switching*) [12], with additional functionalities for traffic engineering MPLS-TE [13] - [18], which was developed aiming to fasten packet forwarding in one network segment.

In this paper, a procedure of MPLS-TE adjustment for implementation of PHY and NOPHY protection methods is explained. Examples are given on the same network topology as in [7], [11]. The network consists of 12 nodes, which are interconnected by 32 unidirectional links (16 bidirectional links) and covers a geographical area of approximately 7 x 7 km. Taking into consideration [19], we assume a transmitter power of 15dBm, antenna gains of 46dBi, and a receiver thresholds of -59dBm, -72dBm and -88dBm for bit rates 1Gbit/s, 100Mbit/s and 10Mbit/s, respectively. Furthermore, we assume a central frequency of 80 GHz, and vertical polarization for which a fading margin is calculated according to [2].

II. Definition of Backup Routes PHY and NOPHY

In a standard OSPF routing protocol [9], a route is calculated using the Dijkstra shortest path algorithm (SPF) in which link costs are inversely proportional to a link capacity [10].

In Fig. 1. an example is shown for selection of the main route between nodes 12 and 1.

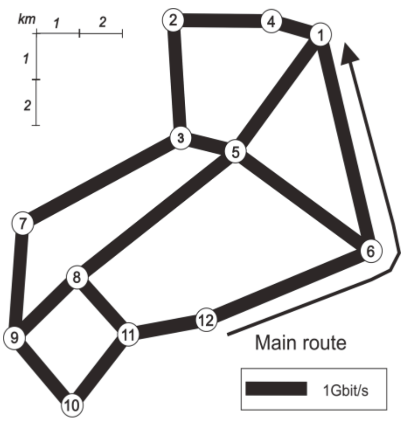

Fig. 1. Selection of main route with SFP algorithm.

For PHY backup route calculation, rain attenuation is taken into account. The basic model for calculation of specific attenuation due to rain is described in the Appendix. As all network links are within a small geographical area, with the same climatic parameters, longer links have a greater outage possibility [2]. Rain doesn't fall uniformly over the entire area, instead of that rain cells are formed [3,21]. In the rain cell center, rain has a maximum intensity which decreases towards a periphery. The rain cell of maximum capacity which doesn't disconnect a network graph is called a critical rain cell. For the calculation of backup routes with PHY algorithm, a critical rain cell has to be determined [22]. Such a rain cell has a maximum rain intensity in the center, but a network graph remains connected. Its parameters are: a maximum intensity in the center of critical rain cell $R_{\max}^{\mathrm{CRC}}$ and a corresponding critical rain cell diameter ρ^{CRC}. A rain cell model with a Gaussian distribution, that is moving by wind at a speed of 10 m/s, is used. According to [3] an inverse proportion exists between a maximum intensity in the rain cell center $R_{\max}$ and rain cell diameter ρ, as shown in Table 1. Values that are not given in the table are obtained using a piecewise linear approximation for $R_{\max}$ and ρ.

Table 1. Inverse proportion of Rmax and ρ.

$R_{\max}$(mm/h)	< 20	20	30	40	50	60	>60
ρ (km)	5	5	3.5	2.5	1.8	1.2	1.2

Values for $R_{\max}^{\mathrm{CRC}}$ and ρ^{CRC} can be calculated acording to the following algorithm that employs Monte-Carlo simulation, as illustrated in Fig. 2.

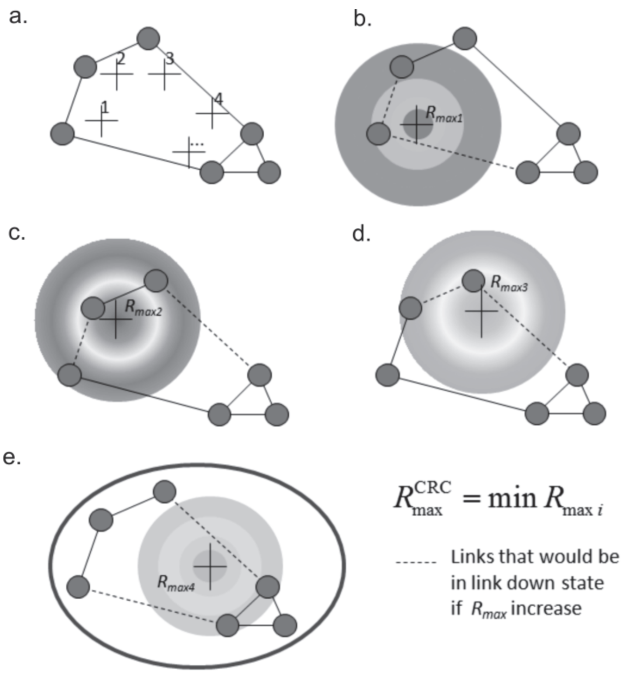

Fig. 2. Illustration of described method for critical cell parameters determination.

Inside the smallest convex polygone that contains all network nodes, N_p possible critical rain cell position are randomly selected (Fig. 2. a). For each position, a maximum rain intensity in the center of the rain cell is increased, with a corresponding change of ρ, until a graph becomes unconnected. The values of such R_{max} are denoted as R_{max1}, R_{max2},...R_{maxNp}., as illustrated in Fig. 2, b., c., d. and e. For every rain cell center position, the results of link capacity reduction due to rain attenuation are graphically represented. The smallest value of them is $R_{\max}^{\mathrm{CRC}}$, with a corresponding diameter ρ^{CRC}. In the example shown in Fig 2, $R_{\max}^{\mathrm{CRC}}$ is equal to R_{max2}. Precision needed for the determination of $R_{\max}^{\mathrm{CRC}}$ value is ±1 mm/h..

For every link in the network, a minimum capacity $c^{\mathrm{CRC}}(e)$, in the presence of a critical rain cell, is determined.. The worst case happens when a critical rain cell center is positioned at the middle of this link. Note that the worst CRC positions are different for each link. Attenuation due to rain is also calculated and a corresponding received signal level and link capacity are obtained $c^{\mathrm{CRC}}(e)$, e=1,...,E.

For every link, its cost is found according to the link capacity $c^{\mathrm{CRC}}(e)$. Formula for link cost calculation is the same as in OSPF protocol: K/ $c^{\mathrm{CRC}}(e)$, e=1,...,E, K=*const.* Calculation with the Dijkstra shortest path algorithm gives PHY backup paths as results.

Fig. 3.a. illustrates the algorithm for the calculation of PHY backup route. A critical rain cell for this network has a maximum rain intensity of 40mm/h, which corresponds to a rain cell diameter of 2.5km. Under its influence, three links (1-6, 6-12 and 5-8), have a capacity of 10Mbit/s (1-5, 5-6 and 7-3), three links have a capacity of 100Mbit/s (7-9, 2-3 and 2-4), while other seven links have kept a nominal capacity of 1Gbit/s.

NOPHY algorithm for the selection of backup route doesn't take into account propagation characteristics in the frequency range above 70GHz, but only the fact that some links can become unavailable due to rain. Therefore, a backup route consists of links in the shortest path between two network nodes, when all links from the main route are down (Fig. 3.b.).

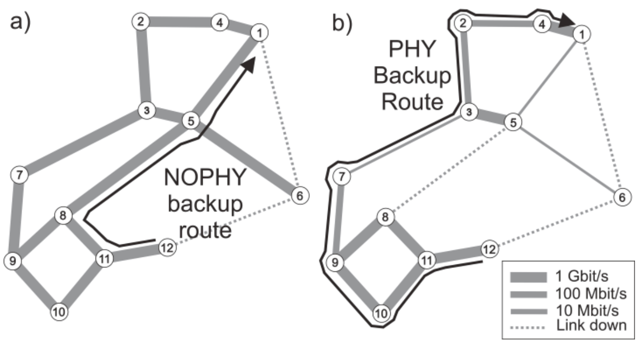

Fig. 3. Selection of backup routes: a) PHY b) NOPHY.

Traffic between the main and backup path is distributed using an iterative algorithm with the aim to minimize congestion possibilities, which are described by a link load parameter L [11,23]. The parameter L is defined as the number of flows served by one link divided with a link capacity. A link in the network which has a maximal value of L, denoted as L_{max}, has the highest probability to be congested. As the overall network performance indicator, the average value of L, denoted as L_{ave} could be investigated. For a comparison of two routing schemes in a network, a lower value of L_{ave} means a smaller possibility to have congested links. Figs 4a and 4b show the cumulative distribution function of distribution for L_{max} and L_{ave} in the presence of a heavy rain cell whose R_{max} is equal to 40mm/h and ρ equal to 2.5km, for novel routing protocols OSPF-BPI and OSPF-BNI, compared with reference cases OSPF-E and OSPF-CI.

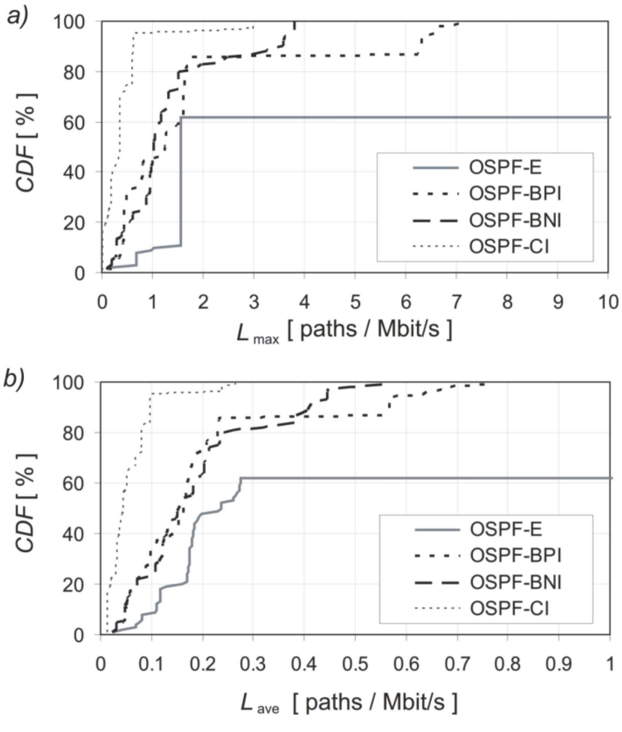

Fig. 4. CDF's of congestion parameter link load L maximum and average values in case of heavy rain (a) L_{max}, (b) L_{ave}.

Analysis has shown that, due to a finite reaction time, a standard OSPF-E routing protocol can't serve 38% traffic demands, while other routing protocols can serve all traffic demands. Due to traffic distribution between the main and backup routes, novel routing protocols OSPF-BPI and OSPF-BNI can serve all the traffic and balance link loads in the networks. However, load balancing and decreasing congestion possibilities are 2-3 times worse than in the ideal OSPF-CI routing protocol.

Advantages that OSPF-BPI and OSPF-BNI have over a standard OSPF approve their practical implementation. It is expected that the performance of ideal protocol is superior, but it is impossible to realize because of instant reaction assumption.

III. MPLS Technology

MPLS is called Layer 2-and-a-half technology [14], between network layer (OSI communication model third layer) and data link layer (OSI communication model second layer). Instead of using global IP addresses for packet forwarding in routers, MPLS technology uses local labels valid only for a specific MPLS network segment. A route in MPLS network segment is called a LSP (*Label Switched Path*). From the viewpoint of global IP network, the entire LSP in a MPLS network segment is treated as one hop.

Relatively to LSP, every router in MPLS network can be an ingress router, a transit router or an egress router. Ingress and egress routers are start and end points for LSP and they are called ELR (*Edge Label Routers*), whilst transit routers are called LSR (*Label Switch Router*). For every LSP, route labels define all ELR and LSR that take part in its realization. MPLS protocol enables LSP realization while the list of LSRs participating in its realization is obtained by network layer routing protocols, e.g. OSPF or IS-IS or they can be defined as static routes. MPLS protocol functioning is explained in detail in [14].

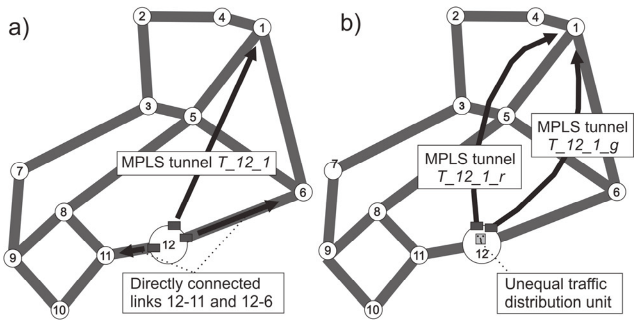

Fig. 5. Connectivity of router in node 12 with other routers via direct links and one defined MPLS tunnel (a) and two MPLS-TE with unequal traffic distribution between them (b).

In a test IP network above 70 GHz in Fig. 5a, a router in node 12 has a direct connection to nodes 6 and 11. Using a standard OSPF routing protocol, the IP packet that arrived to node 12, with a destination node 1, would be forwarded towards node 6. After arrival in node 6, this packet would be forwarded to a final destination node 1. Eventually, route 12-6-1 would be realized. Using the MPLS technology a tunnel would be formed between nodes 1 and 12 (marked as *T-1-12*), therefore the packet arrived in node 12 with a destination node 1 wouldn't be forwarded to node 6, but directly to tunnel *T-1-12*. Furthermore, MPLS as a lower layer communication protocol, by label switching ensures that the packet reaches a final destination node 1. For the IP routing protocol as a higher layer protocol, an exact MPLS route isn't important.

An additional functionality in MPLS technology is achieved using traffic engineering MPLS-TE, which allows the definition of several tunnels between two nodes and traffic distribution between them. In the case of traffic protection with PHY and NOPHY algorithms, for communication between node 12 and 1, two tunnels are defined: main *T_12_1_g* and backup *T_12_1_r* (Fig 5b.). A router settled in node 12 performs load balancing between these two tunnels.

IV. Definition of PHY and NOPHY Backup Routes in MPLS-TE Technology

A. Routes definition in MPLS-TE

In MPLS-TE technology a realization path for a tunnel can be defined in two ways: explicitly and dynamically [14]. An explicit path definition is a simple definition of links and routers that path will use. A dynamically defined path is based on shortest path selection technique with given constraints CSPF (*Constrained Shortest Path Routing*). Besides network topology and individual link costs, input for this algorithm are constraints addressing bandwidth reservation or exclusion of specific links from the path. Differently from the Dijkstra algorithm, that determines the shortest paths from one router to all others, CSPF determines just one path between two routers. In case when there is more than one shortest path, the one with the highest value of available bandwidth is selected. If more than one such route still exists, the one with the lowest number of hops is selected. If the selection still doesn't end, a random path is picked between the available paths. Therefore, MPLS-TE guarantees that one tunnel uses only one path in the network.

In the case of backup routes that are defined using PHY algorithm, the choice of main route doesn't affect the choice of backup route, so tunnel *T_12_1_g* can be defined as a dynamic path without limitations, whilst backup for tunnel *T_12_1_r* is defined as an explicit path (exactly 12-11-10-9-1-3-2-4-1), as illustrated in Fig. 6. Therefore, when a link state change occurs, the main path is rerouted to the backup route as it is assumed in the routing protocol using PHY algorithm OSPF-BP [11]. A difference in performance is expected considering that MPLS dynamic paths take packet rerouting information from upper layer routing protocols (e.g. OSPF), so the resulting reaction time will be longer than the supposed 40 s.

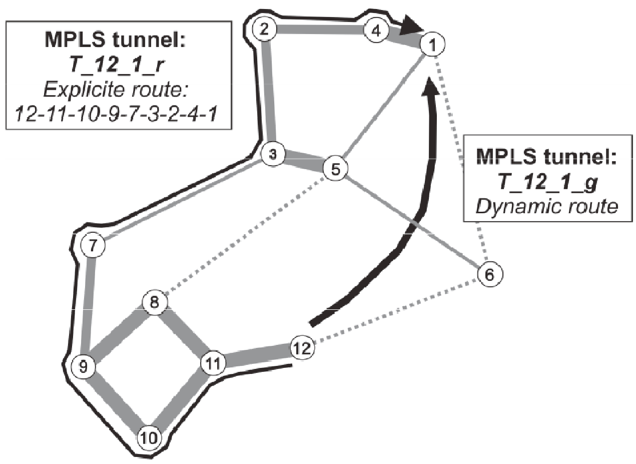

Fig. 6. Implementation of new routing protocol OSPF-BP in MPLS-TE technology.

In the case of backup routes that are defined using NOPHY algorithm, the choice of backup route depends on the choice of main route, that aggravates a direct implementation in accordance with the definition of NOPHY backup route. However, considering that network topology is known a priori, using the shortest path method one of the shortest paths can be calculated (Fig 7, path 12-6-1) for which NOPHY backup route is calculated (Fig 7, path 12-11-8-5-1). After that, NOPHY path for tunnel *T_12_1_r* is defined as explicit, as illustrated in Fig. 7. The advantage of CSPF algorithm is the capability of constraint definition, in which links that should be excluded can be specified [14], [15].

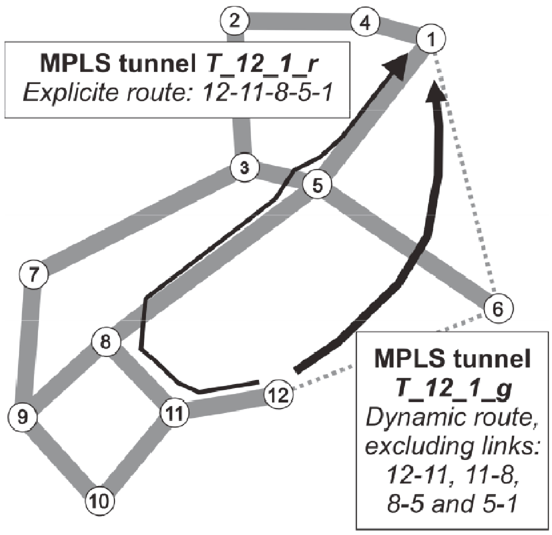

Fig. 7. Implementation of new routing protocol OSPF-BN in MPLS-TE technology.

Accordingly, for tunnel *T_12_1_g* a path is defined as dynamic, with the constraint of not including links belonging to backup NOPHY route 12-11-8-5-1. Therefore, the CSPF algorithm using MPLS-TE will choose the expected route 12-6-1 as a route that fulfils a given criterion. Similarly, as in the case of PHY routes, when a link state changes, a main route is rerouted to a backup route and this implementation method simulates OSPF-BN routing protocol, with the mentioned degradation in reaction time in case of link state change.

B. Load balancing

The basic idea of MPLS-TE is the capability of capacity reservation for LSP tunnels and control of traffic direction by an ingress router. In [13], it is described in detail how traffic load can be distributed between several paths (equally and unequally). For unequal load balancing coefficients are configured for paths directly or indirectly using link path metrics (e.g. link capacity).

Considering that changing a tunnel capacity reservation requires manual intervention and a router configuration change, when traffic demands intensity changes frequently, special tools have to be used for tracking and preparing new capacity reservations in accordance with actual traffic demands intensities.

Also, in the case of IP radio networks realized above 70 GHz, frequent capacity reservation changes would be needed because of a capacity reduction that appears due to rain attenuation. For this reason, router configuration software would need corrections to include communication with radio-relay equipment hardware.

Alternatively, an existing mechanism called *Auto-bandwidth* [14], [16] can be used. Periodically, an ingress router measures the capacity used for traffic transmission and changes tunnel configuration for better adjustment to capacity requirements. *Auto-bandwidth* uses statistical values to determine a maximum average throughput *MaxAvgBW*, after each sample interval [16]. At the end of each adjustment interval, actual value *MaxAvgBW* is compared to the capacity reserved for LSP tunnel. If these values differ in percentage that is greater than a defined adjustment threshold, then *MaxAvgBW* becomes a new value of LSP tunnel capacity. With a new value of LSP tunnel capacity, a new path is selected for the tunnel because the existing path probably doesn't provide sufficient capacity for it. Afterwards, the actual value of *MaxAvgBW* is deleted and new samples are obtained until the next adjustment interval expires.

Since the original idea for using Auto bandwidth function [14], [16] is to properly tailor route reservation according to current traffic demands generated by network users, the default value of sample interval duration is one hour. For proper rain cell influence tracking in the implementation of OSPF-BPI and OSPF-BNI in MPLS-TE this value should be shortened to about 30s which might be a problem in some practical implementations of MPLS-TE.

V. Consequences of Radio-Relay Equipment Failures

The primary aim of traffic protection methods, based on NOPHY and PHY backup paths, is network performance improvement in cases when rain attenuation degrades link capacities, but a network graph remains fully conected. Owing to a hello packet mechanism, IP networks with standard routing protocols, in case of radio-relay equipment failure, detect a link unavailability state and activate a traffic rerouting mechanism. Routing protocols consider that a link as unavailable until the failure is repaired, and then confirm a new state of correct work by a successful transmission of hello packet. This feature of IP networks enables having a much longer time needed to repair a digital radio relay equipment failure MTTR (*Mean Time to Repair*), which leads to a maintenance costs decrease.

In the case when traffic protection methods based on NOPHY and PHY backup routes are implemented as described, using MPLS-TE technology, it is necessary to consider an equipment failure scenario in detail. As a backup route is defined using an explicit way, the consequences of a failure of radio-relay equipment that are used for link realization that form a backup route depend on the type and way of backup route configuration.

In the case of PHY algorithm, the main route is determined automatically and can contain the same links that belong to the backup route. Thus, equipment failure in a backup route only causes quality degradation due to missing of a backup route and network has the same performance as in the case when no protection mechanism is applied. Therefore, for PHY protocol implementation using MPLS-TE, no additional configuration besides that described in section IV is required.

On the other hand, in the case of NOPHY algorithm, due to constrained dynamical path selection that forbids the same links in the realization of main and backup routes, a backup route outage can cause considerable link degradation. A method to overcome this problem is to define more paths for the realization of one tunnel. The principle of this method is that in the case when the first of the paths becomes unavailable for some reason, the next defined path is used for the realization of tunnel. Thus, the first path for the realization of backup tunnel is explicitly defined, and the next is defined as a dynamic path. Practically, in case of radio-relay equipment failure in a backup NOPHY route, this alternative dynamic path takes the role of a main route, whilst the previously defined main route becomes a not optimal backup route, because of the constraint considering links that can be used.

Using the described ways, for both types of backup route, additional unavailability due to equipment failure is avoided and the same MTTR time is kept for the same IP network when no protection mechanisms are applied.

VI. Conclusion

A method for the implementation of PHY and NOPHY algorithms for backup routes in MPLS-TE technology is proposed. With this implementation, radio-relay networks at frequencies above 70 GHz have increased availability and an improved performance, without requirements for a router hardware change. It is only necessary to adjust parameters offered by MPLS-TE equipment. For both types of backup routes, it is explained how to avoid additional unavailability due to equipment failure and the same MTTR time is kept for the same IP network. Considering a possible equipment failure scenario, PHY backup route implementation in MPLS-TE technology has advantages over NOPHY backup route implementation.

VII. Appendix

Rain attenuation model: Since rain intensity is changed along the hop, overall attenuation due to rain along the entire route is calculated by integration of a specific attenuation along the hop [19]:

$$A_R = \int_o^L K \cdot R(l)^\alpha \cdot dl \qquad (1)$$

where *R(l)* denotes rain intensity (mm/h) at a distance *l* from a hop starting node, *L* is the total hop length and *K* and α are parameters depending on frequency and polarization and may be found in [19]. Several rain cell models are described in literature [3]. In this paper we use the Gaussian model rain model [20]:

$$R(d) = R_{\max} \exp(-0.5(3d/0.8\rho)^2), d < \rho \qquad (2)$$

where R_{max} is the maximum rain intensity, ρ is a rain cell radius and *d* is a distance from a rain cell center. Literature reports a relationship according to which ρ decreases when R_{max} increases [3].

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