# Optimization of Traffic Distribution Coefficients in IP Radio-Relay Network with Path Diversity

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*Abstract* - **This paper presents results of optimization of traffic distribution coefficients between primary and backup route in IP radio-relay network. For generation of primary and backup route NOPHY algorithm is used which ensures that they don't have common links. Results of network performance simulation with random link degradation are given.**

*Keywords* - ***load balancing, backup routes, fading, traffic protection***

## I. INTRODUCTION

Radio networks can be used for transmission of IP traffic between computer networks. Achievable throughput of individual point-to-point link that is used for router interconnection in these networks is greater that 1 Gbit/s, especially in the case of millimeter wave links [1]. This solution is competitive to fiber optics and free space optics for short distances in urban areas, and its advantage is quick installation and reconfiguration. Main drawback of high capacity radio link is its susceptibility to additional signal attenuation (fading) caused by multipath propagation or rain attenuation, that can cause link outages [2]. In order to reduce influence of fading on an individual IP link various techniques of tradeoff between link capacity and signal level are performed like: adaptive rate, adaptive coding and adaptive modulation [3]. Such radio link could be described as a function of link capacity vs. receiver signal level. Using propagation model described in [4] for each individual link, percentages of time when it operates at full capacity, reduced capacity or when it is unavailable (in link down state) could be calculated. In the procedure of radio link planning, radio link parameters like transmitter output power and antennas gains are chosen to meet link performance and availability objectives. Usually telecom operators accept link performance objectives given in ITU-R recommendations [5], [6]. Depending on link class, unavailability objectives are in range from about 0.01% to 0.05% (about several tens of minutes to several hours at annual level). When link is available, the majority of time (typically about 99.9% of time) it operates with full capacity. In smaller percentages of time 0.01% to 0.09% link operates with reduced capacity.

When smaller percentage of unavailability is needed, the only solution is to use diversity techniques in radio network, when signal is transmitted over independent links. Switching between paths could be done by simple rerouting [11], when unavailable links are not used for IP packet transmission. However, for rerouting network convergence process might not be fast enough to track network changes caused by fading [7]. In order to overcome this problem, cross-layer routing techniques could be used [8].

One of such methods, described in [9],[10], exploits traffic distribution on primary and backup routes, that can serve both as unavailability protection and network performance improvement method. It is shown that pre-calculated backup routes could be good protection mechanism and algorithms for backup route generation are explained. Network performance improvement is achieved because traffic distribution over primary route and backup route can also serve as load balancing and therefore decrease possibility of link congestion [11].

This paper is focused on traffic distribution between primary route and backup route. It is shown that it could be used both for traffic protection and load balancing.

## II. MODEL OF IP RADIO NETWORK

Network consists of $N$ nodes with IP routers, nodes are connected with $E$ links, with capacities $\mathbf{C}=\{c(e)\}$, $c(e)=1,...,E$. Traffic demands between two nodes are denoted by $h(i,j)$, $i=1,2..,N$, $j=1,2,..,N$. It is assumed that traffic demand exists for each pair of nodes in the network, and they define traffic demand matrix $\mathbf{H}=\{h(i,j)\}$, $h(i,j)>0$, $i\neq j$, i $h(i,j)=0$, $i=j$ .

$$\mathrm{H}=\begin{bmatrix} 0 & h(1,2) & .. & h(1,N) \\ h(2,1) & 0 & .. & h(2,N) \\ .. & .. & 0 & .. \\ h(N,1) & .. & h(N-1,N) & 0 \end{bmatrix} \tag{1}$$

Each traffic demand $h_{ij}$ can be served by different flows $x(i,j,k)$, $k=1,..,N_k(i,j)$. Number of flows $N_k(i,j)$, can be different for every pair of nodes $(i, j)$, with $N_k(i,j)\geq 1$.

Routing algorithm assigns route $r(i,j,k)$ to each flow $x(i,j,k)$. Routes are then memorized in the routing table $\mathbf{R}$. For path $r(i,j,k)$, vector $Dr(i,j,k)$ indicates if link belongs to path is:

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$$\begin{aligned} &Dr(i,j,k)=\{\delta(i,j,k,1),\ldots,\delta(i,j,k,e),\ldots,\delta(i,j,k,E)\} \\ &i=1,2,..,N,\ j=1,2,..,N,\ k=1,2,..,N_k(i,j) \end{aligned} \qquad (2)$$

where:

$$\delta(i,j,k,e)=\begin{cases}1, & \text{if link } e \text{ belongs to route } r(i,j,k)\\ 0, & \text{otherwise}\end{cases} \qquad (3)$$

for each link $e$=1,…,$E$.

Using this notation, maximum number of flows using link $e$ is defined by capacity of that link $c_e$ [11]:

$$\sum_{i=1}^{N}\sum_{\substack{j=1\\ i\neq j}}^{N}\sum_{k=1}^{N_k(i,j)}\delta(i,j,k,e)\cdot x(i,j,k)\le c_e,\ e=1,..E \qquad (4)$$

It is assumed that each individual link is realized by point-to point microwave link, which capacity varies with receiver signal level:

$$C=C(n_R) \qquad (5)$$

In absence of fading the link operates with full capacity $C_0$., while in fading condition it could be reduced by capacity reduction factor $c_R$, or be in link down state, when its capacity is equal to zero.

## III. PERFORMANCE CRITERIA BASED ON LINK LOAD

Two performance criteria are defined, both based on link load, with purpose to monitor the highest link load in the network. Traffic demand $h(i,j)$, $i$=1,2,..,$N$, $j$=1,2,..,$N$, $i\neq j$ is served by load balancing among flows $x(i,j,k)$, $k$=1,...,$N_k(i,j)$. Balancing factor $b(i,j,k)$ is calculated as ratio of the flow $x(i,j,k)$ and the demand $h(i,j)$ and it is the element of traffic load balancing matrix **B**.

$$b(i,j,k)=\frac{x(i,j,k)}{h(i,j)},\ k=1,\ldots,N_k(i,j) \qquad (7)$$

It is clear that sum of balancing factors for all flows equals one:

$$\sum_{k=1}^{N_k(i,j)}b(i,j,k)=1,\ \ b(i,j,k)\le 1 \qquad (8)$$

Using elements of the matrix **B**, the vector of link loads is formed $L_l$ with elements equal number of paths that include link e.

$$L_l(e)=\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N_k(i,j)}b(i,j,k)\cdot\delta(i,j,k,e),\ e=1,..,E \qquad (9)$$

In special case, when $N_k(i,j)$=1, $i$=1,...,$N$, $j$=1,...,$N$, each traffic demand is served by only one path, $L_l(e)$ is an integer that represents number of traffic demands served by given link. If traffic load balancing is applied, $L_l(e)$ is a rational number that represents equivalent number of flows that serve given link.

Since the link load increases when the number of flows that this link serves increases, and decreases when this link capacity increases, by simple division of $L_l(e)$ with link capacity we obtain the vector of normalized link loads:

$$L(e)=\frac{L_l(e)}{c(e)},\ e=1,\ldots,E \qquad (10)$$

A bottleneck in the network is the link with maximum load, so criteria for network performance measure is obtained by maximization of normalized link loads.

$$L_{\max}=\max_{e\in\{1,..,E\}}L(e) \qquad (11)$$

Links that have $L_l(e)$ equal to $L_{max}$ are actually bottleneck of the network because they are most susceptible to congestion. Apart from maximum load, we can monitor average load:

$$L_{\text{ave}}=\frac{1}{E}\sum_{e=1}^{E}L(e) \qquad (12)$$

In both cases, smaller values of $L_{\max}$, $L_{\text{ave}}$ indicate that network has better performances, i.e. it has small possibility of congestion in real traffic conditions. In cases when traffic demand cannot be served because it is directed to zero capacity link, criteria become infinity.

## IV. TRAFFIC DISTRIBUTION ALGORITHMS

Even load balancing scheme implies that traffic is equally distributed among available paths. This scheme acts as load balancing and is implemented in many commercially available routers [12]. According to it, service of traffic demand $h(i,j)$ is equally split between flows $x(i,j,k)$. Load balancing coefficients $b(i,j,k)\big|_{equal}$ between nodes $i$ and $j$ by $x(i,j,k)$ are defined by expression:

$$\begin{aligned} &b(i,j,k)\big|_{equal}=1/N_k(i,j), i=1,\ldots,N,\\ &j=1,\ldots,N, k=1,\ldots,N_k(i,j)\end{aligned} \qquad (13)$$

where $N_k(i,j)$ is number of flows serving traffic demand $h(i,j)$.

Simplicity of implementation is a very strong advantage of this scheme, but it has two drawbacks.

The first drawback is that coefficients calculation is based only on number of flows that serve traffic demand, without consideration of other traffic demands in network. That is why traffic is unequally distributed in network.

The second drawback of this method is that if one route contains radio links that are temporarily unavailable due to fading, traffic distributed to those links would be lost.

In order to overcome these two drawbacks, we propose traffic distribution optimization by varying balancing factor according to link load $b(i,j,k)$ to gain either minimum value of $L_{max}$ as optimization goal, which we denote as **Opt-L$_{\mathbf{max}}$**, or to gain minimum value of $L_{ave}$ as optimization goal, which we denote as **Opt-L$_{\mathbf{ave}}$**. Due to nonlinearity of Opt-L$_{\max}$, for its implementation NMinimize function for constrained numerical global optimization is used. NMinimize function implemented in software package Mathematica [13] and it is state of the art combination of several optimization methods like: Nelder-Mead, differential evolution, simulated annealing and random search. Due to very intensive calculation caused by a large number of optimization variables, this algorithm does not have practical value, and it is used just to obtain lower limit value of $L_{max}$. Unlike the first one, the second Opt-L$_{\text{ave}}$ is linear and could be treated as a linear programming problem.

## V. PERFORMANCE ANALYSIS OF TRAFFIC DISTRIBUTION ALGORITHMS

### A. Network topology

Analysis and performance calculation of proposed methods are performed on test network with topology given in Fig. 1 Network consists of $N$=7 nodes, connected with $E$=18 unidirectional links (9 bidirectional links). It is assumed that every node communicates with all other nodes in the network, therefore 42 traffic demands should be served.

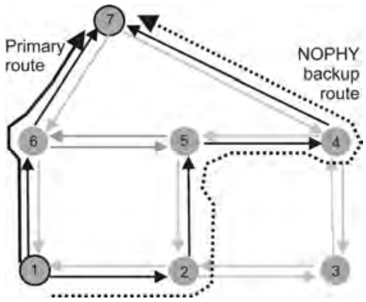

Fig. 1. Network topology and example of NOPHY routes

### B. Traffic routing

Primary route that serves specific traffic demand in network is chosen by Dijkstra - shortest path algorithm [14] with link costs inversely proportional to maximum link capacity. It is assumed that full link capacity is $C_0$=1Gbit/s for all links in the network.

In addition to primary route one backup route is defined, for certain number of traffic demands. For performance analysis in this paper, backup routes are calculated using two algorithms: ECMP2 and NOPHY.

For some traffic demands there are several shortest path routes. In this network 18 from 42 traffic demands have multiple shortest path. For each of them two equal cost routes are chosen and traffic is balanced between them. This algorithm is denoted as ECMP2 - Equal Cost Multi Path with two routes.

The second algorithm for backup routes calculation is denoted as NOPHY and it is described in [9], [10]. The key idea of this algorithm is traffic protection in case of link outage, so the backup route is chosen as a shortest path route that has no common links with primary route. Example of NOPHY backup route choice for one traffic demand is shown in Fig. 1. Where multiple shortest path route exists, the one of them is chosen to be primary route, and according to it NOPHY backup route is calculated. In this case each of 42 traffic demands is served by two routes.

### C. Network performance in absence of fading

Values of network performance criteria $L_{max}$ and $L_{ave}$ in absence of fading, when all links in network operate with maximum capacity of 1Gbit/s are shown in Table 1.

As expected results have shown that, in majority of cases, some gain in load balancing could be achieved by varying traffic distribution coefficients. Also it is shown that Opt-$L_{max}$ give good values both for $L_{max}$ and $L_{ave}$, while Opt-$L_{ave}$ in this case gives result for $L_{max}$ even worse than equal distribution.

TABLE I. NETWORK PERFORMANCE IN ABSENCE OF FADING

| Perform. criterion | Balancing algorithm | BUR type | |
|---|---|---|---|
| | | ECMP2 | NOPHY |
| $L_{max}$ [paths / Mbit/s] | Equal | 0.0050 | 0.0070 |
| | Opt- $L_{max}$ | 0.0040 | 0.0040 |
| | Opt- $L_{ave}$ | 0.0080 | 0.0080 |
| $L_{ave}$ [paths / Mbit/s] | Equal | 0.0040 | 0.0053 |
| | Opt- $L_{max}$ | 0.0040 | 0.0040 |
| | Opt- $L_{ave}$ | 0.0040 | 0.0040 |

### D. Network performance in presence of fading

For performance analysis in presence of fading, it is assumed that fading cause link capacity reduction of ten fold $c_R$=10, that gives new link capacity values of 100Mbit/s. In the case when one link operates with lower capacity, due to network redundancy, performance is not noticeably degraded. Therefore, performance analysis considers the case when two links simultaneously have lower capacity. Other cases when three or more links have degraded capacity, for properly tailored individual link fading margins have very low probability, and therefore are not considered in this analysis.

Two links in network are randomly chosen to have degraded capacity. Results are represented in form of cumulative distribution function of performance criteria in such cases.

### E. Performance Analysis Results

In Fig.2. and Fig.3. values of CDF for performance criteria $L_{max}$ and $L_{ave}$ respectively are given in case of ECMP2 when two links have ten fold capacity reduction.

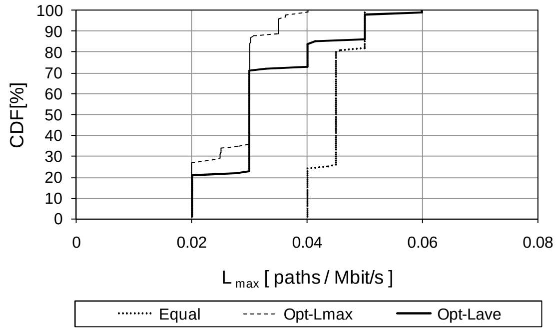

Fig. 2. $L_{max}$ in case ECMP2 two links have ten fold capacity reduction

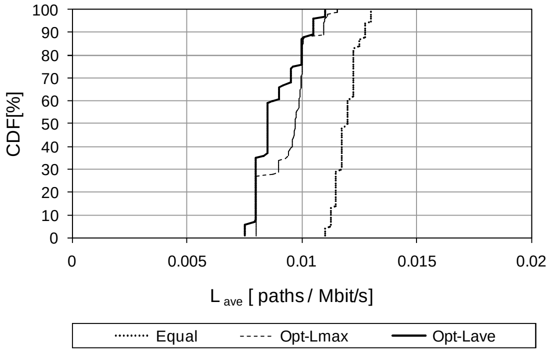

Fig. 3. $L_{ave}$ in case ECMP2 two links have ten fold capacity reduction

Fig.2. shows that according to $L_{max}$ criterion Opt-$L_{max}$ has in 42% of cases better results than Opt-$L_{ave}$, while both

algorithms have considerably better results than equal traffic distribution. Similarly, according to $L_{ave}$ criterion Opt-$L_{ave}$ has the best results (Fig 3.). Note that differences between CDF curves for Opt-$L_{max}$ and Opt-$L_{ave}$ algorithms are much higher for $L_{max}$ criterion than for the $L_{ave}$ criterion.

For NOPHY backup route choice algorithm, compared to ECMP2, the difference between Opt-$L_{max}$ and Opt-$L_{ave}$ CDF curves is greater according to $L_{max}$ criterion (Fig.4.). According to this criterion Opt-$L_{max}$ has from 25% to 40% better performance according to $L_{max}$ criterion in 75% of cases, while in 25% of cases the performance is the same. On the other hand, difference between Opt-$L_{max}$ and Opt-$L_{ave}$ CDF curves according to $L_{ave}$ criterion is only about 10% but in all cases (Fig.5). For NOPHY algorithm both optimization algorithms have about three times better results than equal traffic distribution (Fig.4., Fig.5.).

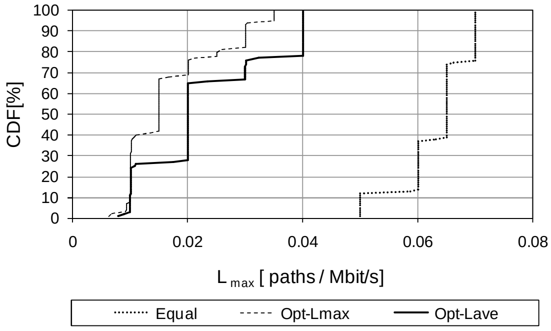

Fig. 4. $L_{max}$ in case NO PHY two links have ten fold capacity reduction

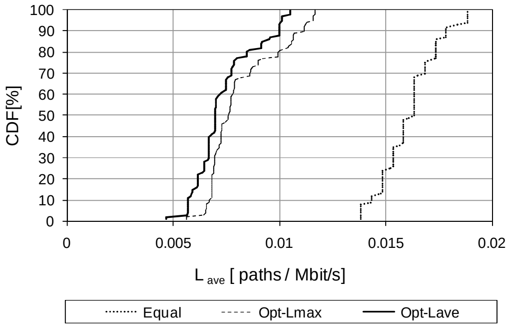

Fig. 5. $L_{ave}$ in case NO PHY two links have ten fold capacity reduction

## VI. REMARKS FOR PRACTICAL IMPLEMENTATION

For practical implementation of traffic distribution coefficient optimization, it is important to have information about current link capacity, which is adjusted to actual fading condition. Typical multipath fading event, known also as fast fading has noticeable signal level changes at about 10ms, while reaction time of adaptive modulation techniques is about 40ms [1][3][4]. For rain attenuation fading [4] signal level changes are much slower about 10s. According to this, for frequency bands above about 18GHz, where rain attenuation is predominant effect, information about link capacities, could be obtained from the link hardware by traffic monitoring protocol such as SNMP [15]. For lower frequency bands more agile technology should be used.

When information about link capacities are obtainable in entire network, since routing tables are known to all routers, calculation of traffic distribution coefficients could be performed in each router. The straightforward implementation of optimization algorithm, especially for Opt-$L_{max}$ which is nonlinear, could be difficult and time consuming, and therefore it could be subject for future work.

## VII. CONCLUSION

Usage of unequal traffic balancing coefficients between main and backup route in IP radio-relay network with path diversity can serve both as traffic protection and load balancing method. Simulation on test network confirmed that unequal traffic distribution gives up to three times better results for link loads than equal traffic distribution. It is also showed that optimizing the maximum of link load, besides from giving the best values of the maximum link load, also gives good performance according average link load criterion. The main drawback of minimizing maximal link load in optimization process is its nonlinear character, which requires much more processing time for its calculation than minimizing average link load.

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