OpenRoutes: Augmenting Backhaul Network Survivability with Reduced Redundancy- A Topology based Analysis

Venmani Daniel Philip*†
*Orange Labs, France Telecom R&D
Lannion, France
danielphilip.venmani@orange.com

Yvon Gourhant
Orange Labs, France Telecom R&D
Lannion, France
yvon.gourhant@orange.com

Djamal Zeghlache
†TELECOM SudParis & CNRS
Evry, France
djamal.zeghlache@telecom-sudparis.eu

ABSTRACT

In this article we illustrate that, management of network resources can yield notably different performances leading to different restoration behaviors – for different network topologies. In consideration towards this, we first briefly summarize our earlier work on a novel fault restoration mechanism. The proposed mechanism addresses the problem of finding the minimum bandwidth cooperative route in the backhaul of mobile network operators that is shared among multiple operators. We then present our recent results on the extended performance evaluations of the same, for four different synthetic network topologies carried out using extensive simulations. Through these evaluations, we conclude on the best topology that mobile network operators should construct in order for them to maximally benefit by the proposed cooperative routing scheme to yield optimum performance for their capital expenditure.

Categories and Subject Descriptors

C.2.1 **[Computer-Communication Networks]**: Network Architecture and Design-*Network topology*; C.2.3 **[Computer-Communication Networks]**: Network Operations.

General Terms

Algorithms, Network design, Network survivability.

Keywords

Maximally disjoint paths, Multi-topology wireless backhaul networks, Path computation algorithms.

1. INTRODUCTION AND BACKGROUND

Network survivability enables communication networks to sustain maximum network connectivity and quality of service (QoS) under failure conditions. Among others, one naive solution to guarantee the survivability is to over-provision the network links, often termed as *Redundancy*. Through a series of our earlier works including [1], we argued that it is not cost-efficient anymore to extend permanent backup paths (redundant paths) for every independent Mobile Network Operator (MNO) within the same geography– because the capacity which is allocated for the already existing backup paths is not *always* actively filled-in as much as the capacity allocated for the primary path. Consequently, we presented *OpenRoutes*, a failure restoration framework that minimizes network disruption - *cost-effectively*, wherein two or more MNOs cooperate with each other and share their already existing unused network resources (bandwidth capacities) on a mutually beneficial understanding, up to a certain extent without exceeding their limits on resource sharing; thereby diligently saving on the over-provisioning costs.

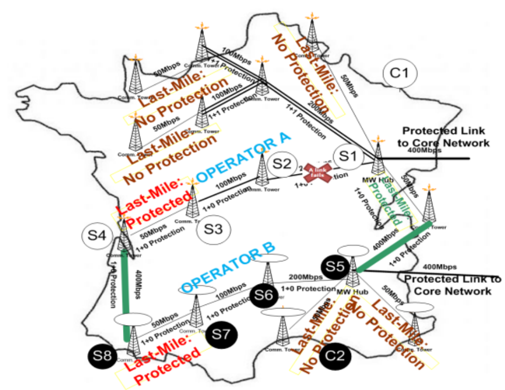

Figure 1. An illustrative example network topology portraying resilience design flow using infrastructure sharing within the country France. Two MNOs: one at the top (north), another in south (with circles) are joined by just another additional link (green colour thick link), making a 'resilient' ring topology.

Precisely, our approach re-routes failed connections according to their respective QoS requirements (according to different traffic classes) over maximally disjoint paths constructed across a backhaul network topology, that has emerged out of sharing between different MNOs, without affecting any of the other MNOs' already existing traffic flows. We formulated the problem as a multi-constrained non-linear optimization problem, providing the MNOs with a parameterized objective function which facilitates them to choose the desired paths based on the traffic patterns of their end-customers. This is defined as:

$$\textbf{Minimize:}\left(\left(\varepsilon\sum_{e\in E}\sum_{\lambda\in\Lambda}\tau_d\right)+\left((\mathbf{1}-\varepsilon)\sum_{n=1}^{\mathcal{K}}\delta_n\right)\right) \qquad (1)$$

The objective function illustrated above in (1) is designed to determine the shortest alternative path out of the $\mathcal{K}$ available paths from the combined backhaul topology while also ensuring that the selected shortest path has the optimal capacity to carry the disrupted connection satisfying its QoS requirements. This is finely tuned by the parameters τ_d and δ_n denoted in (1). τ_d indicates the end-to-end delays of each path. This is obtained by adding the

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individual weights of each link associated with every path and δ_n in (1) represents the binary variable to determine whether the capacity of any link in the network is within the acceptable utilization range (i.e., above a fixed threshold limit that we defined as *Shareability Index*, θ_{ij}) at a time instant t so that a disrupted connection has an optimal capacity path to traverse. Here, ε ∈ [0, 1] is a small weighting coefficient that we have assigned arbitrarily such that it identifies between choosing a path with the least delay and the most optimal capacity. We solved the formulated ILP equation using three heuristics algorithms: (i) Least Length Shortest Paths (LLSP), (ii) Least Delay Shortest Path (LDSP) (*both based on the well-known Dijkstra's algorithm* [2]) for delay-sensitive real time traffic and (iii) Ant Colony Optimization (ACO) (*based on Ant-colony meta-heuristics* [3]) for bandwidth consuming traffic types. We evaluated our framework for the Sprint L3 topology (node: 44; edge: 106; average node degree: 4.82). This concludes the overview of our earlier work (Please refer [1] for extensive details on *OpenRoutes*).

2. EXTENDED ANALYSIS

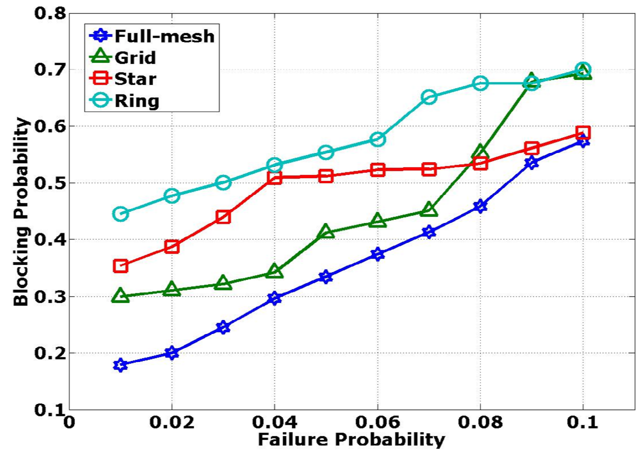
Motivated by our earlier results from [1], in this work, we go forward to present the efficiency of our framework on four different topologies and determine the best topology that can maximally benefit MNOs if they conclude on backhaul resource sharing. This will allow us to quantify the network resource utilization that can be achieved for a particular topology, not just for a particular flow. Now we recall that the centre of our earlier work was heavily quantified, based on a new key metric that we defined as *Shareability Index* (θ_{ij}). This metric characterizes the extent to which available capacity on a link is shareable among MNOs. In a way, it is representative of a specific topology's survivability with respect to the utilization range of the available capacity. We now tune the accuracy of this metric using four different topologies under a range of failure probabilities and present our results. The end result, therefore, accurately predicts the survivability of a given network topology, with reduced redundancy. To do this, we vary the value of θ_{ij} between 0 (0% allowed range- implying no network resource sharing between MNOs) and 0.50 (50% allowed range- implying sharing half of the available network resources in each link), in the topologies where we have carried out the experiments. Table I summarizes the different topologies that were used for the simulation, each exhibiting its own characteristics, such as - mesh, ring, grid and star. To measure the impact of our algorithms on them, we compare our results against the Shortest Path Routing (SPR) [2] and Beam Search Algorithm (BS) [4] as reference schemes.

Table 1. Network Topologies Characteristics

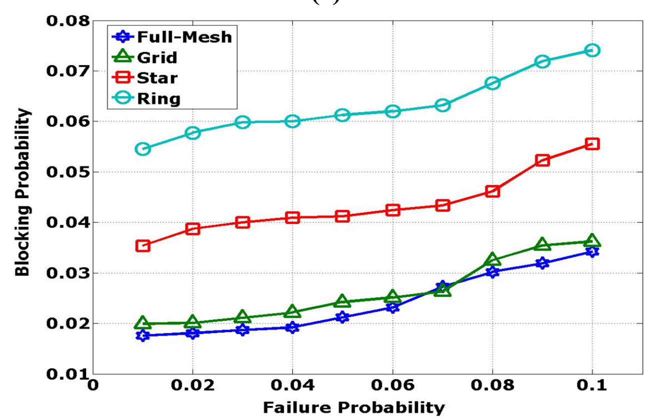
Network Type	Network Characteristics		
	# of Nodes	# of Links	Average Node Degree
Full-Mesh	20	190	19.00
Manhattan Grid	25	40	3.20
Ring	25	25	2.00
Star	25	24	1.92

3. INFLUENCE OF TOPOLOGIES

In this section, we present numerical illustrations towards the realization of our scheme. Here the metric that was considered for the evaluation is *Blocking Probability (BP)*. *BP* is defined as a measure of the number of connection requests rejected against the total number of connection requests. Our methodology for evaluations is described as follows: As a first step, we focus on determining the topology that yields the best performance for the proposed *OpenRoutes* restoration scheme. To do so, we evaluate and compare the performance of all the four topologies by combining the three heuristics (*LLSP+LDSP+ACO)* for the two cases: (i) when the MNOs do not share $(\theta_{ij} = 0)$and (ii) when the MNOs share$(\theta_{ij} = 0.5)$, in figure 2(a) and figure 2(b).



(a)



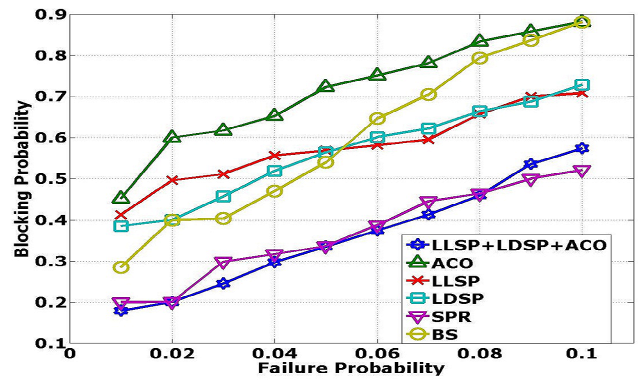
(b)

Figure 2. Illustration of blocking probability for various topologies when all the three heuristics (LLSP+LDSP+ACO) are combined for (a) $\theta_{ij} = 0$ (no resource sharing) (b)$\theta_{ij} = 0.5$ (50% resource sharing).

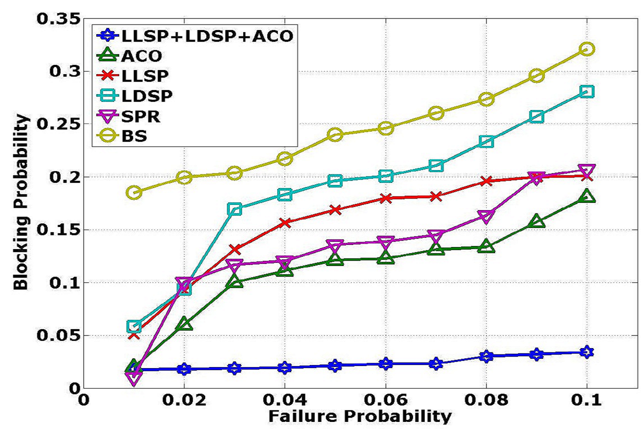
The performances of all three heuristics when combined yield the best results on the *full-mesh topology* than any other topologies in consideration. To give them a ranking, full-mesh performs the best, followed by grid, then star, then ring. Our justification to this is that it is due to the density of this 'mesh-like' topology which is larger than star or ring network topology. As the density decreases, it may no longer be possible for some pairs of intermediate nodes to communicate over short paths. Hence a decrease in density is typically accompanied by an increase in network diameter, which results in larger length, resulting in poor performance. Furthermore, unlike each of the other topologies in consideration such as grid, star and ring, messages sent on a full-mesh network, where every node in the topology is connected to every other node, can take any of several possible paths from source to destination, thus maximally benefitting from our restoration heuristics. On the other hand, considering the case of ring, this shows the least performance because a failure in any link disconnects the entire loop and thus the entire path is not available for the failed connections to traverse-through. Nevertheless, it has to be noted that the performance of all the topologies is better for $\theta_{ij} = 0.5$ than $\theta_{ij} = 0$. (Detailed analysis on the same is in the section below). Nonetheless, through our results, we are able to demonstrate that the survivability of disrupted connections due to resource sharing will have much higher availability in the presence of any number of failures (single or double link failures), if the contribution of the reconfiguration time from primary path to backup path towards unavailability is disregarded [since it is relatively small (on the order of tens of milliseconds) with respect to the manual failure repair time (on the order of hours) and the connection's holding time (on the order of weeks or months).

4. INFLUENCE OF SHARING

Having determined the best topology, we now illustrate the performance of our three heuristics *(LLSP, LDSP, ACO)* individually against the reference approaches and then combine all three heuristics into one *(LLSP+LDSP+ACO)* and compare against the reference approaches for the two cases- (i) when the MNOs do not share $(\theta_{ij} = 0)$ and (ii) when the MNOs share $(\theta_{ij} = 0.5)$. Figure 3 illustrates the performances for the *Full-mesh* topology alone which performs the best as ascertained by our earlier results. Observing from Figure 3, we can conclude that the total number of connections rejected when the MNOs share (Figure 3(b)) is lesser compared to when they do not share (Figure 3(a)). Taking a closer look at the obtained results precisely indicate the following observations. The reference shortest path routing (SPR) algorithm almost always performs well, be it in the case when the MNOs do not share or when they share. However, there is a slight difference in performance observed looking closely. Our algorithms *LLSP* and *LDSP* perform inferior to the *SPR* routing algorithm, when MNOs do not share but the performance gets augmented atleast by 50% when the MNOs share and gets in-par with the performance of the SPR algorithm. This is mainly due to the fact that *SPR* routing algorithm best fits in the case when the network links are not very congested (congested in the sense that there is no failure and hence no congestion encountered) and that there is always sufficient capacity available. As stated earlier, since *LLSP* and *LDSP* address the traffic classes which does not demand paths with more capacity, they find it very feasible to choose abundant paths with less capacity compared to the classic *SPR* - meaning that *LLSP* and *LDSP* succeeds as much as *SPR* routing algorithm in re-routing delay sensitive traffic. Moving forward, the performance of *ACO* shows a huge variation unlike the other two heuristics (LLSP, LDSP), when the MNOs share and when they do not share. Especially, the *BP* is the highest when the MNOs do not allow the others to share. This is because, *ACO* heuristics looks for optimal paths especially with more capacity to re-route bandwidth consuming traffic. Having said that, *ACO* performance is the best when there is resource sharing, implying that more paths with enough capacity to re-route bandwidth consuming traffic can be easily found in the case when the MNOs share. Adding to this, the performance when all three heuristics are combined is notably remarkable, seemingly much better than the reference schemes, when the MNOs share and it is notably not affected by the size of the network or the failure probability. This is because our approaches fundamentally makes sure that the overall congestion due to link failures is reduced as much as possible by "intelligently" using the unused resources of the network. Our simulation results show that, for sharing constraints those are not strict, our proposed heuristics approaches return solutions close to the optimum making their application for multi-constrained routing problems very promising.



(a)



(b)

Figure 3. Illustration of blocking probability (a) for $\theta_{ij} = 0$ (no resource sharing) (b) for $\theta_{ij} = 0.5$ (50% resource sharing) on a Full-mesh topology.

5. CONCLUDING DISCUSSIONS

Topologies remain an important part of network design theory. In this article we extended our earlier analysis on backhaul resource sharing between several MNOs intended for its survivability, for four different synthetic topologies, each exhibiting different characteristics. Based on our results, we could conclude that it is most beneficial when two (or more) MNOs with already existing *mesh* topologies decide to cooperate and share their backhaul resources, in order to maximize their network resource utilization or in other words to minimize the disrupted connections resulting due to failure situations. Regardless, through our results, we have demonstrated that the management of resources can yield notably different performances leading to different restoration behaviors for different network topologies.

6. REFERENCES

[1] D.P.Venmani, Y.Gourhant and D.Zeghlache. OpenRoutes: Multi-operator Cooperative Routing over Maximally Disjoint Paths for the Survivability of Wireless Backhaul. In Proc. of IEEE/IFIP DRCN'13, Budapest, Hungary, Feb. 2013.

[2] E. W. Dijkstra. A note on two problems in connection with graphs. Numerische Mathematik, vol. 1, pp. 269–271, 1959.

[3] M.Dorigo and D.C.Gianni. Ant colony optimization: a new meta-heuristic. In Proc. of IEEE CEC, vol. 2, 1999.

[4] K.H.Kim and K.Y.Kim, Routing straddle carriers for the loading operation of containers using a beam search algorithm. Computers & Industrial Engineering, 36(1), 109-136, 1999.