Complete Rerouting Protection

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Abstract

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1 Introduction

Reliability of communication networks has become of major importance in the last decades. This has lead to a significant research in different technologies to make the communication networks more reliable. A communication network may fail in a number of ways: Power outages on switches, switch software failure, switch hardware failure, cable cuts etc. Cable cuts by e.g. entrepreneurs is one of the most frequent types of network failures and they are difficult to prevent. This type of failures, called link failures, is the focus in this paper.

Whenever a component in a communication network fails, communication either has to wait for the component to be repaired or the communication has to be rerouted through unharmed parts of the network. Rerouting in case of component failure can usually be performed much faster than physical recovery of the failed component, but it requires additional capacity on the network.

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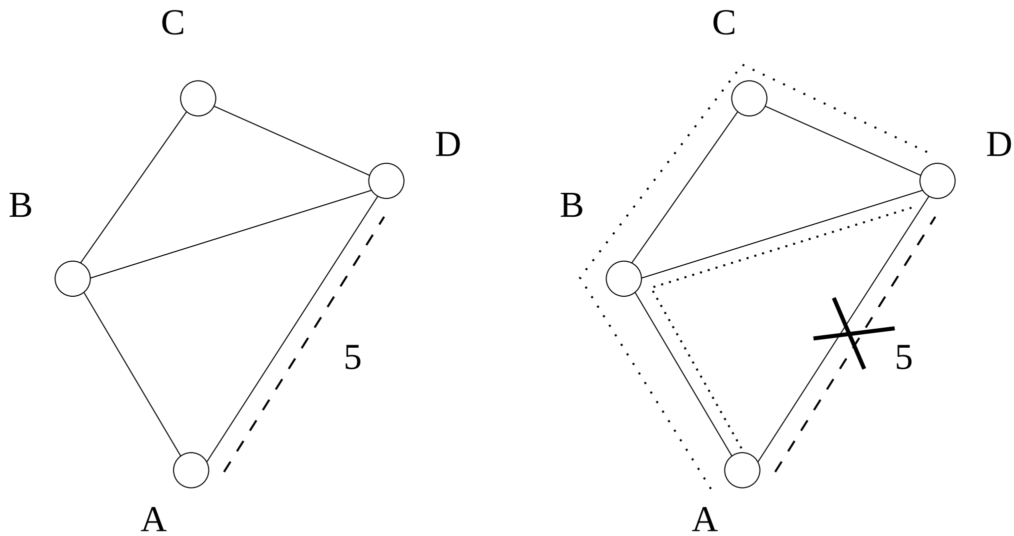
The communication networks considered in this paper are the circuit switched high capacity backbone networks, which transports a wide variety of communication traffic: Telephone calls, internet, etc. We consider the static case where a fixed connection, called a circuit, of a certain bandwidth is setup between two switches (nodes) in the network. In Figure 1(a) a bidirectional circuit is established between node A and node D on the link AD of communication volume 5, marked as the dashed line. Hence there needs to be a communication capacity of 5 on link AD. If link AD fails, see Figure 1(b), two alternative routes marked with dotted lines, can be used to reestablish the circuit: One using the links AB, BD and one using the links AB, BC, CD. Both routes may also be used to collectively cover the loss of communication. In order to be able to recover from the AD link failure, we need at least 5 units of unused capacity on the alternative routes.



(a) A fixed circuit   (b) Reroute after link break

Figure 1: Circuite rerouting

The routing and protection model we describe here is chosen to be as simple as possible. The communication circuits we consider are bidirectional. We only consider single link failures. We assume that there are no limits on the capacity of each link and that the cost of a routing and protection plan is the sum of the cost of the required link capacities. We assume no limits on the paths which may be used, except that failed links cannot be used at all. We further assume that 100% protection is required, i.e. that the full communication flow is re-established. We assume that we can split the communication in any way necessary.

A number of different protection methods have been suggested, see Section 2 for a brief overview of some of these. They differ in (at least) two important aspects: The speed of the recovery and network capacity required. The speed of the recovery depends on a number of intrinsic details in the protection method, see [2] for a detailed discussion of the required recovery time. The required capacity depends both on the protection method *and* on the efficiency of the planning method used for performing the routing and protection planning. It is important to acknowledge that a tradeoff exists: The faster the recovery, the more capacity is required. Hence it is impossible to find one overall best rerouting scheme. The best choice depends on the maximally allowed rerouting time, the technology available for the switches etc.

The fastest protection method is *1+1* (APS) protection [4], where the signal is sent over two physically disjoint paths from start to end of the network. This means that any single link failure can be recovered in the destination node, because if the signal disappears, the destination node can simply use the signal from the other path. Unfortunately 1+1 protection requires more than twice of the non-failure capacity of the network. 1+1 protection is one of the two most widely used protection methods for circuit switched networks, the other is ring protection.

In this paper we present a new protection method: Complete Rerouting. This is the most capacity efficient protection method for circuit switched networks and it is, to the best of our knowledge, the first time it has been described, though we have cited it in [10].

2 Previous Work

Because of the importance of reliable communication networks, a lot of research has been performed. It is beyond the scope of this paper to thoroughly present all the different protection methods and we refer to [4] for a comprehensive and up-to-date survey of the field.

In general the protection methods can be classified according to the structure they protect:

- Span protection, i.e. all circuits using the failed link are rerouted around the failure: [4, 8]
- Path restoration, i.e. the paths which fail are individually protected through re-routing: Global routing [11], 1+1 (APS) protection [4], Shared Backup Path Protection [4].
- Ring protection and p-cycle protection, all the links are part of an overlaid structure, a ring or a p-cycle: Ring protection [4, 9, 10] and p-cycle protection [4, 7, 10]

The above classification is quite broad and many variations exists for each protection method.

3 The Complete Rerouting Protection Model

All of the protection methods described in Section 2 make one crucial assumption: Only circuits which fails are rerouted. While this is a natural and logical assumption, it limits the possibilities when planning the protection. When performing complete rerouting protection, all the circuits can be rerouted in case of a link failure, i.e. if a link failure occurs between Rome and Milan, the circuits between Paris and London may be rerouted. This means that for each possible link failure, a complete routing plan is established in order to minimize the summed worst case capacity requirement on all of the links of the network.

3.1 The Complete Rerouting Protection Linear Program

Consider a network consisting of a set of nodes V indexed by i, j, k, l, q, r and a set of links L. The links are indexed by unordered end-node pairs, $ij \in L : i, j \in V$. The cost per capacity unit of each link is given by the constants c_{ij}. Furthermore, a set of circuit demands D, indexed by unordered node pairs, $kl \in D : k, l \in V$ are defined. The constant $d_{kl} \in N_0$ is the number of circuit demanded between nodes k and l. The failure situations, one for each link in the network, are indexed by unordered node pairs, $q, r \in L : q, r \in V$. For each demand kl and each failure situation qr a set of paths $P^{kl,qr}$ is defined and the constant $PATH^{kl,qr}_{p,ij} \in \{0, 1\}$ has the value 1 if path p for demand kl in failure situation qr use link ij and 0 otherwise. The flow on each path p for each demand kl in each failure situation qr is defined by a variable $x^{kl,qr}_p \in R^+$. The necessary capacity for each link is defined by the variable $y_{ij} \in R^+$. We can now formulate the CompleteRerouting LP model, given a set of allowable paths $P^{kl,qr}$ to use:

CompleteRerouting($P^{kl,qr}$) minimize:

$$\sum_{ij} c_{ij} \cdot y_{ij} \tag{1}$$

subject to:

$$\sum_{p \in P^{kl,qr}} x^{kl,qr}_p \geq d_{kl} \quad \forall\, kl \in D, qr \in L \tag{2}$$

$$y_{ij} - \sum_{kl} \sum_{p \in P^{kl,qr}} PATH^{kl,qr}_{p,ij} \cdot x^{kl,qr}_p \geq 0 \quad \forall\, ij, qr \in L, ij \neq qr \tag{3}$$

$$x^{kl,qr}_p, y_{ij} \in R^+ \tag{4}$$

The objective equation (1) calculates the cost of the required capacities in the network. Equation (2) ensures that the circuit demand d_{kl} is satisfied in each failure situation qr. Equation (3) ensures that for each failure situation qr there is enough capacity on each link ij. Finally, equation (4) defines the domains of the variables.

3.2 Sub Problem

The LP model described in Section 3.1 can be solved by any standard LP solver, but the number of paths can be huge, depending on the density of the network. Instead a column generation algorithm is applied to solve the problem. For each iteration in the column generation algorithm, the LP model 3.1 is solved using a *subset* $P_*^{kl,qr} \subseteq P^{kl,qr}$ of the paths. Using the dual variables $\alpha_{qr}^{kl} \geq 0$ (from equation (2)) and the dual variables $\beta_{ij}^{qr} \geq 0$ (from equation (3)), we can for each demand kl and each failed link qr calculate the reduced cost of the best backup path, see equation (5). The best path for demand kl when link qr has failed is given by the binary vector $a_{ij}^{kl,qr} \in \{0,1\}$, which correspond to one column in the master problem.

$$c_{reduced}^{kl,qr} = \sum_{ij} \beta_{ij}^{qr} a_{ij}^{kl,qr} - \alpha_{qr}^{kl} \tag{5}$$

Given that the dual variables β_{ij}^{qr} are positive, the shortest path can be found using the Floyd-Warshall algorithm [3] for each failure situation qr. The Floyd-Warshall algorithm is an $O(N^3)$ algorithm, which has to be applied, for each failure situation qr. This leads to a worst case solution time of each subproblem of $O(N^5)$ or, as most telecommunication networks are rather sparse, $O(N^3 \cdot L)$.

Proposition 1 *No protection method guaranteeing* 100% *rerouting is more efficient than the CR method.*
Proof *Assume the opposite, that algorithm X is more capacity efficient. For each failure situation this algorithm would then device a routing plan, but then this set of routing plans would be a feasible solution in the CR method, which would hence be at least as efficient.*

3.3 The Column Generation Algorithm

The column generation algorithm is given below in Figure 2. First one dummy column is generated for each demand kl in each failure situation qr and included into the set of current paths $P_*^{kl,qr}$. The dummy columns are given artificially high costs to ensure that they will never be used in the final solution. Then the main loop is entered. The reduced master problem is solved given the current set of paths $P_*^{kl,qr}$. Then new paths are generated, by executing the Floyd-Warshall algorithm for each failure situation qr, using as link costs the dual β_{ij}^{qr} variables. The failed link can either be assigned an artificially high cost or be ignored by the Floyd-Warshall algorithm. All the paths with negative reduced costs, calculated by equation (5) are added to the set $P_*^{kl,qr}$. At the end of the main loop it is checked if any new paths have been added to $P_*^{kl,qr}$, if not, the algorithm terminates.

$P_*^{kl,qr}$ = one dummy path for each kl, qr using all links
do
  Solve CompleteRerouting($P_*^{kl,qr}$)
  for all qr **do**
    $x_{ij}^{kl,qr}$ =Floyd-Warshall(β_{ij}^{qr})
    for all kl **do**
      if $\sum_{ij} \beta_{ij}^{qr} a_{ij}^{kl,qr} - \alpha_{qr}^{kl} < 0$ **then**
        Add improving path $x_{ij}^{kl,qr}$ to $P_*^{kl,qr}$
      endif
    endfor
  endfor
while paths added to $P_*^{kl,qr}$

Figure 2: *The Column Generation algorithm for solving the Complete Rerouting problem*

4 Results

Our column generation algorithm and the integer heuristic is tested on six networks, see Table 1.

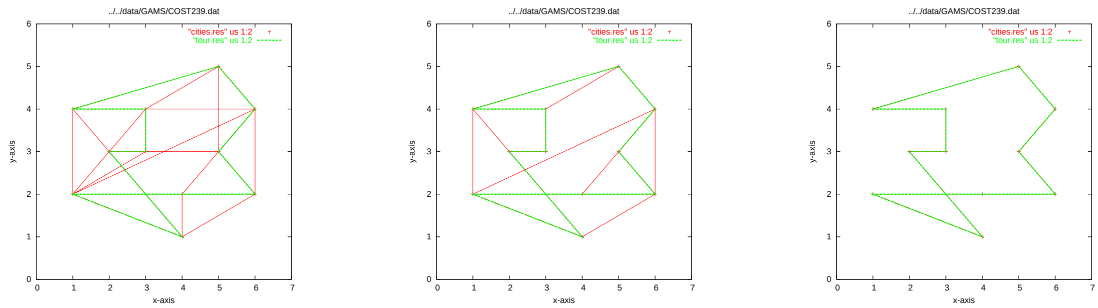
	Nodes	Links	Avg. Node Degree	Working Capacity	Complete Rerouting Abs.	Rel.
Cost239 [1]	11	26	4.73	86	11.6	13 %
Europe	13	21	3.23	158	90.0	57 %
USA [5]	28	45	3.21	1273	641.2	50 %
Italy [6]	33	68	4.12	1718	581.4	34 %
France [5]	43	71	3.3	3473	1604.0	46 %
France 2 [5]	43	71	3.3	4043	3156.3	78 %

Table 1: The tested networks

4.1 Computational Issues

4.2 Computational Issues

What takes the time, how can this be improved ?



(a) Full network (b) Halfnetwork (c) Sparse network

Figure 3: Protection capacity vs. density

5 Conclusion

The complete rerouting scheme proposed in this paper will most likely never be used as a survivability scheme because circuit which are unharmed by a particular link (node) failure will also have to be rerouted. For this to be acceptable, the capacity costs would have to be huge. The primary use of the Complete Rerouting scheme is for calculating lower bounds on different networks given different circuit demands. This is highly useful when evaluating different rerouting schemes. The lower bound could also be used to evaluate different network architectures for the suitability for low cost survivability.

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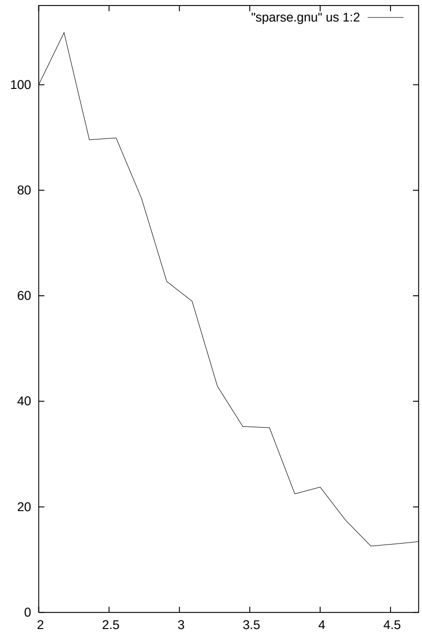

Figure 4: Sparse

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