A power-efficient design scheme for survivable networks with partial bandwidth path protection

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Abstract: This letter proposes a design scheme for the power-efficient network with partial bandwidth path protection. The network with the proposed scheme utilizes resources efficiently, which leads to less power consumption. This scheme employs a Linear Programming (LP) approach to minimize power consumption by considering the number of active devices and capacity consumption. Simulations show that, with the partial bandwidth path protection, the proposed scheme saves more power than the conventional scheme, which minimizes the power consumption relying on capacity consumption.

Keywords: Linear Programming, partial bandwidth path protection, power-efficient network

Classification: Network

References

1 Introduction

Reducing the power consumption of networks has become a great concern because of the extreme increase in Internet usage [1]. The basic concept of power efficient design is the idea of decreasing active devices as much as possible or switching them into sleep mode by rerouting the traffic through other links [2].

Since the survivable network needs more resources for data protection, its power consumption is high. Survivable network design strategies distribute traffic to many links in order to minimize the damage when a failure occurs in the network. On the contrary, power-efficient network design strategies try to aggregate the traffic to utilize network resources as efficiently as possible. The trade-off between survivability and power consumption has driven research into the survivable network with power-efficient design. The idea of putting the devices on a backup path into sleep mode for saving the power consumption of the survivable network was presented in [3, 4].

Since most network devices do not support sleep mode [5], the power consumption of the survivable network without sleep mode is a concern. In a network without sleep mode, devices used for backup are active and consume power. Therefore, the amount of backup bandwidth used affects the power consumption. The assumption of capacity reduction on a backup path leading a power consumption saving is considered.

In [6] Kuperman et.al. presented the partial bandwidth path protection technique to provide fast recovery with efficient resource utilization. The concept of this technique is to provide partial bandwidth for the backup path. This technique can guarantee that some part of data on the primary path will be sent to its destination when a failure occurs at the primary path. The ratio of bandwidth allocated to the secondary path over that allocated to the primary path lies in the range of zero to one. The work shows the effectiveness of partial bandwidth path protection in reducing the capacity consumption. Work [6] addressed only capacity consumption. No study has considered how to design a network with partial bandwidth path protection so as to reduce power consumption.

This letter adopts the LP approach to propose an power-efficient design scheme for the survivable network with partial bandwidth path protection. Our proposed scheme allows the number of active devices and bandwidth used in the network to be reduced. In other words, the proposed scheme considers not only the capacity consumption but also the number of used links and nodes in the network. The analysis below assumes that sleep mode is not employed.
2 Power-efficient survivable network with partial bandwidth path protection

We consider a network as directed graph \( G(V, E) \), where \( V \) is a set of nodes and \( E \) is a set of links. A link from node \( i \in V \) to node \( j \in V \) is denoted as \((i, j) \in E\). Capacity of link \((i, j)\) is denoted as \(c_{ij}\). The proportional power consumption per unit traffic flow for each transmitter, receiver and switch is represented by \(\epsilon_i^r\), \(\epsilon_i^s\), and \(\epsilon_i^{sw}\), respectively. The proportion of power consumed by the active devices in link \((i, j)\) is denoted as \(\delta_{ij}\). \(M\) is a large constant, e.g., \(M = N \cdot N\), where \(N\) is defined as the number of nodes in the network. \(w_{ij}\) is the working flow assigned to link \((i, j)\). The protection flow on link \((i, j)\) is assigned as \(f_{ij}\). The binary variable \(x_{ij}^w\) is equal to 1 if link \((i, j)\) is on the working path, otherwise 0. In the same way, \(x_{ij}^p\) is equal to 1 if link \((i, j)\) is on the backup path, otherwise 0. \(l_{ij}\) and \(n_i\) are binary variables indicating if link \((i, j)\) and node \(i\) are active or not.

The problem is formulated as minimizing the power consumption of the network with partial bandwidth path protection. The power consumption model consists of two parts, fixed consumption and proportional consumption. The former is due to active devices and the latter depends on traffic load on the active devices. A working path is routed to meet demand \(D\) between source node \(s\) and destination node \(t\). The corresponding backup path protects a fraction, \(q\), of demand \(D\) when a failure occurs on its working path in the network. The problem formulation is shown below.

\[
\begin{align*}
\min \quad & \sum_{i \in V} \phi_i n_i + \sum_{(i, j) \in E} \sigma_{ij} l_{ij} + \sum_{(i, j) \in E; i = s} \epsilon_i^r w_{ij} + \\
& \sum_{(i, j) \in E; i = t} \epsilon_i^s w_{ij} + \sum_{(i, j) \in E; i \neq s, t} \epsilon_i^{sw} w_{ij} \\
& + \sum_{(i, j) \in E} \delta_{ij} (w_{ij} + f_{ij}), \\
\text{s.t.} \quad & \sum_{j:(i,j) \in E} w_{ij} - \sum_{j:(i,j) \in E} w_{ji} = \begin{cases} D, & i = s \\
0, & i \neq s, i \neq d \end{cases} \quad (1a) \\
& \sum_{j:(i,j) \in E} f_{ij} - \sum_{j:(i,j) \in E} f_{ji} = \begin{cases} qD, & i = s \\
0, & i \neq s, i \neq d \end{cases} \quad (1b) \\
& w_{ij} \leq x_{ij}^w, \quad \forall (i, j) \in E \quad (1d) \\
f_{ij} \leq x_{ij}^p, \quad \forall (i, j) \in E \quad (1e) \\
x_{ij}^w + x_{ij}^p \leq 1, \quad \forall (i, j) \in E \quad (1f) \\
x_{ij}^w + x_{ji}^p \leq 1, \quad \forall (i, j) \in E \quad (1g) \\
x_{ij}^w + x_{ji}^w \leq 1, \quad \forall (i, j) \in E \quad (1h) \\
x_{ij}^p + x_{ji}^p \leq 1, \quad \forall (i, j) \in E \quad (1i) \\
w_{ij} \leq c_{ij}, \quad \forall (i, j) \in E \quad (1j) \\
f_{ij} \leq c_{ij}, \quad \forall (i, j) \in E \quad (1k) \\
w_{ij} + f_{ij} \leq l_{ij} M, \quad \forall (i, j) \in E \quad (1l)
\end{align*}
\]
The objective function, Eq. (1a), expresses the total power consumption in the network (without sleep mode). The power consumption is calculated for the devices on working and backup paths. First, the power consumption of the active devices on the backup path are calculated. Equations (1b) and (1c) are the flow conservation constraints for working and backup paths, respectively. Links for working and backup paths are considered in Eqs. (1d) and (1e). Equations (1f)–(1i) are the link disjoint constraints. Equations (1j) and (1k) are the capacity constraints, which guarantee that the flow on working and backup paths do not exceed the capacities of the links traversed. Equations (1l) and (1m) force links and nodes to support active working and backup paths, respectively. The working flow and backup flow on each link, which are non-negative and less than or equal to given traffic demand $D$, are expressed in Eqs. (1n) and (1o), respectively. Finally, Eq. (1p) defines all variables as binary.

3 Results and Discussion

The power consumption of each network without sleep mode is evaluated with different assigned available link capacities. In this letter, we investigate the power consumption in networks with four scenarios, which are the conventional scheme [6] with dedicated path protection, the proposed scheme with dedicated path protection, the conventional scheme with partial bandwidth path protection, and the proposed scheme with partial bandwidth path protection. Two networks, network 1 with six nodes and 11 links and network 2 with 15 nodes and 27 links, as shown in Fig. 1, are examined. The traffic demand between a pair of source and destination nodes is equal to 1.0. The fixed power consumption values of active devices in each node and link are set to 150 W and 30 W, respectively. The proportional power consumption per unit traffic flow for each transmitter, receiver and switch is 2.85 W, 2.85 W, and 1.65 W [7], respectively. The proportional power consumption for active
devices in each link is 9 W. The networks protect 50% of full traffic, i.e. $q$ equals 0.5.

Figures 2 (a) and (b) show the power consumption of network 1 and network 2 with the proposed scheme with dedicated path protection, that with the conventional scheme with partial bandwidth path protection, and that with the proposed scheme with partial bandwidth path protection, normalized by that with the conventional scheme with dedicated path protection, at different assigned available link capacities. There are three cases of link capacity assignment. In case 1, all links have assigned capacity of 1.0 for all networks. In cases 2 and 3, 50% of all links of network 1 and network 2 have assigned capacity of 0.75 and 0.5, respectively. Our discussion about the comparison between the power consumed by the proposed scheme and that by the conventional scheme with dedicated path protection and partial

Fig. 2. Power consumption of (a) network 1 and (b) network 2 with the proposed scheme with dedicated path protection, that with the conventional scheme with partial bandwidth path protection, and that with the proposed scheme with partial bandwidth path protection, normalized by that with the conventional scheme with dedicated path protection, at different available link capacities.
bandwidth path protection techniques on Fig. 2 is described below.

In case 1, the results show that network 1 and network 2 with all the scenarios consume similar amount of power consumption. The reason is that case 1 provides enough bandwidth capacity for all links, i.e. 1.0, corresponding to the given traffic demand.

In cases 2 and 3, however, the power consumption of both networks with the proposed scheme with partial bandwidth path protection is able to save more power than those with the other scenarios when the networks have limited available link capacity compared to the power in case 1. Cases 2 and 3 with partial bandwidth path protection, the networks with the proposed scheme are able to save more power than those with the conventional scheme because the proposed scheme minimizes the power consumption considering not only the capacity consumption but also the number of used links and nodes. In the protection requirement assuming a single link failure, capacity saving can be achieved if the risk is distributed by splitting the working traffic across multiple paths. The working traffic is split to distribute the risk and less working traffic is disrupted, which requires fewer protection resources [6]. The conventional and proposed schemes have the same behavior for the protection requirement but different design for power saving. Since the conventional scheme does not consider the number of used nodes and links, the total power consumption with the conventional scheme is more than that with the proposed scheme.

Note that, with partial bandwidth path protection, for all cases with the proposed scheme, the normalized power consumption of network 2 is less than that of network 1. The normalized power consumption of the larger network is relatively higher than that of the small network due to the longer paths selected by the conventional scheme. However, the proposed scheme selects paths by minimizing the power consumption taking account of the capacity consumption and the number of used links and nodes. This allows the proposed scheme to achieve more power saving for the larger network compared to the conventional scheme.

4 Summary

This letter has proposed a power-efficient design scheme for networks with partial bandwidth path protection. The proposed scheme minimizes power consumption with considering capacity consumption and the number of used links and nodes. Numerical results showed that a network with the same protection technique, the proposed scheme saves more power than the conventional scheme, which minimizes power consumption with considering capacity consumption. If the network has limited link capacity, the proposed scheme with partial bandwidth protection offers greater power savings than the other examined scenarios.