Availability Analytical Model for Permanent Dedicated Path Protection in Service Differentiated WDM Networks

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Abstract: This paper analyses the connection availability of a protection paradigm, termed permanent dedicated path protection, in service differentiated WDM mesh networks. An analytical model for calculating the unavailability of P-DPP is introduced.

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1. Introduction
With the rapid development of telecommunication technologies, data rate of the backbone optical networks has increased to several terabits per second [1]. Accompanied by the tremendous bandwidth, the risk of a single link failure may lead to disastrous loss of data. To protect the WDM networks from link failures [2][3], various protection schemes are proposed, and can be classified into link protection and path protection [4]. One common path protection scheme is dedicated path protection (DPP). As protection is a proactive recovery scheme, when a request of connection from source node s to destination node d arrives, a working path w and a link-disjoint protection path p are then calculated, using the shortest path algorithm, and established subsequently. When

2. Availability analytical model
Permanent DPP is a simple scheme. When the working path or the protection path fails to work, a new link-disjoint path will be established to ensure that the connection is still in a dedicated-path-protected state if possible. As shown in Fig.1, when a request of connection from source node s to destination node d arrives, a working path w and a link-disjoint protection path p are then calculated, using the shortest path algorithm, and established subsequently. When
the link between node $i$ and $d$ fails, the protection path $p$ is disconnected, and the working path is unprotected. In this case, the P-DPP will calculate and then set up a new protection path $p'$ to make the working path still under protection.

As stated above, Permanent DPP has better performance on availability than DPP, but it is difficult to obtain the (un)availability of Permanent DPP, because of the changing property of the new protection path with the failure events. Next, we derive a formula to evaluate the unavailability of permanent DPP.

2.1. Network hypothesis
Derivations are based on the following hypothesis [2]:
1) Links can only have two states: operating or outage state
2) All link failures occur independently
3) All link failures and repairs are Poisson processes
4) Traffic requests are divided into two survivability classes with DPP and P-DPP, respectively.

For any link, the fault arrival interval and the repair time both follow exponential distribution with corresponding means MTTF and MTTR.

2.2. Event Analysis
For instance with single link failure in the network, no connection will get disconnected. And for triple-link or even higher order failures may appear in addition to dual-link failures, but their contributions to the connection unavailability are negligible as compared with that of the dual failures, only instance with dual failure is considered [8]. When there are two failures in the network, for a permanent DPP connection $s$-$d$, three cases have to be considered [9].

1) $i \in W$, $j \notin W \cap j \notin P$
2) $i \in W$, $j \in W$
3) $i \in W$, $j \notin W \cap j \in P$

Where $W$ is the set of links of working path of the connection, while $P$ is the set of links of protection path of the connection. $i$ represents failed link on the working path, while $j$ is failed link different from $i$.

We can get a conclusion that only case 3), i.e., link $i$ is of the working path and link $j$ is of the protection path, may lead to a connection outage, i.e., the working and protection path of the connection are all fail to work and a new protection path cannot be established.

For multi-failure instance, failures in the network, we can get a similar result as dual-failure instance i.e. the connection fails to work when the current working and protection paths are both interrupted and the request to establish a new path from source to destination node is unsuccessful.

From the analysis above, a conclusion is drawn that a permanent DPP connection fails only under the circumstance that the current working and protection paths both fail and a path setup request fails.

2.3. Theoretic Model
As the result of event analysis, the unavailability of a permanent-DPP connection is given by the formula:

$$U_{\text{permanent DPP}} = U_{wp} P_{\text{block}}$$

where $U_{\text{permanent DPP}}$ is unavailability of permanent DPP, $U_{wp}$ is unavailability of current working and protection paths and $P_{\text{block}}$ stands for blocking probability of a path setup request.

To make the formula more practical, we then focus on the analysis of the parameters and the deduction of the formula. For DPP, based on network hypothesis above, and with the RBD model, we have

$$U_{wp} = U_w U_p \approx \left(1 - \sum_{i \in W} U_{wi}\right) \left(1 - \sum_{j \in P} U_{pj}\right) = \sum_{i \in W} U_{wi} \sum_{j \in P} U_{pj}$$

Then we take statistical average of the parameters:

$$\bar{U}_{wp} = \left(\bar{h}_w U\right) \left(\bar{h}_p U\right)$$

where $\bar{h}_w$ and $\bar{h}_p$ are mean hops of working and protection path. We assume that $\bar{h}_w$ and $\bar{h}_p$ are constant while the traffic intensity of the network increases. It yields that

$$\bar{U}_{wp} = \left(\bar{h}_w U\right) \left(\bar{h}_p U\right) = \text{const} = C$$

$$U_{\text{permanent DPP}} = CP_{\text{block}}$$

Different from formula we derived in [10], \( P_{\text{block}} \) stands for overall blocking probability of DPP and P-DPP requests in service differentiated network, rather than just P-DPP requests.

As analysis above, we drew a conclusion that the unavailability of permanent DPP is in direct proportion to blocking probability of the service differentiated network. And it could be employed for calculation of connection availability of network.

3. Numeric results

To verify the accuracy of the analytical model, we made a simulation on the COST239 European network [11], consisting of 11 nodes with full wavelength-conversion capability in each node, 26 bidirectional links with 16 wavelengths on each link, in OPNET modular. The topology of the network with length of links on edges in kilometers is showed in Fig.2. In simulation, the failure arrival rate of a link is proportional to its length, where failure rate and MTTR were set to 1000 FIT/km (1 FIT (failure in time) =1 failure in 10^7 hours) [12] and 12h, respectively. The length of links is marked on Fig.2.

In the simulation, dynamic traffic requests are uniformly distributed among all node pairs and they are randomly divided into two survivability classes with parameter \( p_e \) which indicates the percentage of traffic requests employed P-DPP (others employed DPP). To make sure that the results are statistically reliable, we simulated almost 1,000,000 link failures in total. To obtain the simulation result of unavailability, operating and outage time of all traffic connections are collected. And the unavailability equals to the proportion of the outage time.

Compared with DPP, P-DPP achieves a lower unavailability with different \( p_e \), and the lower \( p_e \) is, the better availability it achieves, for there is more available spare capacity (Fig. 3). To verify the accuracy of the analytical model of P-DPP, A straight line fitting method is adopted and it shows unavailability of permanent DPP is in direct proportion to blocking probability (Fig. 4).

4. Conclusion

We derived a model for calculating the unavailability of P-DPP, which indicates that unavailability as a function of blocking probability, i.e., the average unavailability of P-DPP in service differentiated WDM networks is proportional to network blocking probability. Simulation results prove the accuracy of our model.

5. References