Failure Localization in Optical Networks

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I. Introduction

Modern telecommunications networks need to be able to detect and locate failures and degrations as fast and as accurately as possible, in order to restore lost traffic and repair the failure. While protection and restoration mechanisms can cope with traffic loss without exact knowledge of the failure type and location, most of the time spent reparing failures is due to finding the precise cause.

There are many types of service disruptions in optical networks, which we can classify in two major types. On the one hand, we have *hard failures*, such as fiber cuts and failure of a network line card. Fiber cuts happen all too frequently, due to human error such as construction workers breaking a cable or due to natural causes, such as earthquakes. Line card failures can for instance happen due to short circuiting. These failures occur suddenly and have a severe impact on services, causing major loss of traffic. On the other hand, we have *soft failures* such as end-of-life of an amplifier. These are more subtle changes in performance, causing a wide spectrum of service degradations which are far more difficult to detect and locate.

II. General Problem Statement

A network consists of a set of elements $E = \{e_1, \ldots, e_n\}$, which can fail with a certain probability $P_E(e_i) \in [0, 1]$. We define a network failure f_j as a set of element failures, so the set of network failures $F = \{f_1, \ldots, f_{2^n}\}$ is the power set of E. The probability of a network failure $P_F(f_i)$ can, in theory, be computed from the element failure probabilities and the dependency between these failures. Each network element failure can trigger alarms through different monitors. Call the set of alarms $A = \{a_1, \ldots, a_m\}$. An observation o_i is a set of alarms that are raised due to some network failure f_i with probability $P_{O|F}(o_j|f_i)$. The set of observations O is the power set of the set of alarms and has 2^m elements. The problem is to find the most likely network failure $f_x \in F$ which explains the observation $o_y \in O$, $f_x = \max_z \left(P_{O|F}(o_y|f_z)P_F(f_z)\right)$.

This general model describes the general problem of network failure localization. Every derived approach (i.e. a failure localization algorithm) will approximate the solution of this problem. The accuracy of the model will depend on the quality of the initial probabilities and the amount of information that is contained in the alarms. We will now assess the efficiency of the approach using the mutual information [3] metric. This metric gives a quantitative measure how sure we can be, given observation o_i, that network failure f_j is indeed the cause.

III. Mutual Information, Self-Information and Entropy

Let $x_1, \ldots, x_k$ be the X sample space and $y_1, \ldots, y_l$ be the Y sample space in an XY joint ensemble. We want a quantitative measure of how much the occurence of y_j in the Y ensemble tells us about the occurence of the possibility x_i in the X ensemble. The occurence of $y = y_j$ changes the probability of $x = x_i$ from the *a priori* probability $P_X(x_i)$ to the *a*

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posteriori probability $P_{Y|X}(y_j|x_i)$. This measure is called the mutual information between y_j and x_i and is defined as

$$I_{X;Y}(x_i;y_j) = I_{Y;X}(y_j;x_i) = \log \frac{P_{X|Y}(x_i|y_j)}{P_X(x_i)} \quad (1)$$

The term *mutual* information comes from the symmetry of equation (1). The (weighted) average mutual information between X and Y is defined as:

$$I(X;Y) = \sum_{i=1}^{n}\sum_{j=1}^{m} P_{XY}(x_i,y_j) \log \frac{P_{X|Y}(x_i|y_j)}{P_X(x_i)} \quad (2)$$

If an event x_i is fully specified by the occurence of y_j, i.e. $P_{X|Y}(x_i|y_j) = 1$ the mutual information between x_i and y_j becomes:

$$\begin{aligned} I_{X;Y}(x_i;y_j) &= \log \frac{P_{X|Y}(x_i|y_j)}{P_X(x_i)} \\ &= \log \frac{1}{P_X(x_i)} = I_X(x_i) \end{aligned} \quad (3)$$

and we call this the self-information of the event $x = x_i$. The entropy of an ensemble X is the (weighted) average self-information of the ensemble and is given by:

$$\begin{aligned} H_X(X) &= \sum_{i=1}^{n} P_X(x_i) \log \frac{1}{P_X(x_i)} \\ &= -\sum_{i=1}^{n} P_X(x_i) \log P_X(x_i) \end{aligned} \quad (4)$$

IV. Efficiency of the probabilistic model

The efficiency of any failure localization in an optical network will strictly depend on the mutual information between monitors and failures. In the ideal case, self-reported failures have mutual information equal to the self-information, meaning that the probability of the reported failure, when we receive the alarm indicating this failure, is 100%. Of course, implementing monitoring for every conceivable set of failures in the network is inconceivable.

From a theoretical viewpoint, all probabilities are considered as input for the model. Of course, from a practical perspective, this is where the real difficulties are encountered. The a priori failure probabilities for the equipment can be more or less estimated from experience [1], but the conditional probabilities for the alarms are far less straightforward to compute. Most models [2] take these to be 1, i.e. if the equipment fails, the alarm will be raised and vice versa. However, for real networks this is not the case. It are these probabilities are modelled using in [1] by using a dependency graph.

V. Conclusions

We use the mutual information between the monitors (i.e observations) and failures as a metric for failure localization. In the ideal case, the mutual information between the monitors and the failures should equal the entropy of the failures. For practical applications, with imperfect monitoring equipment and countless possible failures, the mutual information may be prohibitingly low. Initial analysis of the problem shows that we need intense and accurate monitoring in order to increase the mutual information for the problem and to be able to localize failures accurately.

References

[1] I. Katzela and M. Schwartz, *Schemes for Fault Identification in Communication Networks*, IEEE/ACM Transactions on Networking, Vol. 3 (6), 1995, pp. 753-764.

[2] C. Mas and P. Thiran, *An efficient algorithm for locating soft and hard failures in WDM networks*, IEEE Journal On Selected Areas In Communications, Vol. 18, No. 10, October 2000.

[3] R.G. Gallager, *Information Theory and Reliable Communication*, John Wiley & Sons, New York, 1968