IDENTIFICATION OF FAULTS BY EFFICIENT MONITORING METHOD IN ALL OPTICAL NETWORKS

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Abstract—Achieving accurate and efficient fault localization in large transparent all-optical networks (TONs) is an important and challenging problem due to unique fault-propagation, time constraints, and scalability requirements. In this paper, we introduce a novel technique for optimizing the speed of fault-localization through the selection of an active set of monitors for centralized and hierarchically-distributed management. The proposed technique is capable of providing multiple levels of fault-localization-granularity, from individual discrete optical components to the entire monitoring domains. We formulate and prove the NP-completeness of the optimal monitor acti-vation problem and present its Integer Linear Program (ILP) formulation. Furthermore, we propose a novel heuristic whose solution quality is verified by comparing it with an ILP. Extensive simulation results provide supporting analysis and comparisons of achievable alarm-vector reduction, localization coverage, and time complexity, for flat and hierarchically distributed monitor-ing approaches. The impact of network connectivity on fault localization complexity in randomly generated topologies is also studied. Results demonstrate the effectiveness of the proposed technique in efficient and scalable monitoring of transparent optical networks.

Index Terms—Transparent optical networks, fault detection, fault localization, monitoring, alarm processing.

INTRODUCTION

Merging transparent optical networks (TONs) intro-duce many advantages, including the ability to efficiently leverage large bandwidth potential and provide transparent support for diverse transmission protocols. However, optical transparency also introduces a requirement for a new monitoring and fault-localization approach at the optical layer. Due to the lack of optical/electro/optical (O/E/O) regeneration in TONs, a single fault may propagate throughout the network, thus generating a flood of redundant alarms, increasing the processing overhead and localization time, and ultimately delaying service restoration. With inherently high data rates, even a short interruption may have a catastrophic effect. Frequent disruptions in TONs include: bending or cutting of fiber, equipment failure, human error, and sophisticated attacks

Ideally, physical failures should be detected, localized, and resolved at the optical layer before they are noticed and handled by the higher layer protocols. Legacy monitoring techniques in SONET/SDH provide 50ms optical layer restoration, but cannot be directly applied in TONs due to required O/E/O conversion at each node.

Most of the recently proposed TON monitoring techniques are based on different schemes for establishment of dedicated supervisory cycles or paths which are provisioned on dedicated wavelengths through the monitored network elements. However, these schemes introduce additional overhead in terms of the required bandwidth, dedicated transponders and monitors, supervisory-path computation and provisioning time, added channel interference, and necessary maintenance. Furthermore, only monitoring of the edge failures is commonly considered, and the proposed techniques may become inefficient for detailed localization of individual fiber-spans and discrete optical components in large topologies.

In order to address the above mentioned decencies, we propose a new approach to fault-localization in TONs that efficiently utilizes the existing traffic light paths and commonly integrated monitors. The redundant alarms due to optical transparency result in suboptimal alarm codes that increase the complexity of the fault-localization problem. Minimizing the number of alarms reported to the network manager without compromising on fault coverage is crucial for rapid and accurate localization of faults as well as the stability of management systems against ever-increasing amounts of alarm data.

We formulate the problem for optimization of alarm-vectors and present the optimal and heuristic solutions. To address the localization accuracy in large network topologies while maintaining low complexity, we also expand this problem into a hierarchically-distributed monitoring model.

The proposed hierarchical monitoring model enables parallel optimization of fault-localization within independent monitoring domains, scalability, and multiple fault-localization granularity levels. Since the approach is not dependent on dedicated propagates downstream on all light paths from the point of fault origin is considered. A single-link failure detection scheme in performs failure detection by assigning monitors to each optical multiplexing and trans-mission section. In a central manager is assumed, and an algorithm for single fault identification is presented. The central manager periodically tests all source and destination powers using the routing table information. If some node's power is out of expected bounds, the possible source of the fault is identified. In fault identification through filtering alarms is discussed. Using a fault identification tree of depth equal to the number of alarming components, the set of potential fault sources is narrowed down. A survey of fault detection capability at each layer is presented in approaches to the fault location problem are also classified.

The authors show that a wavelength to be used for probing other nodes from a monitor node is highly likely to be available in dynamic traffic conditions. Based on this, it is claimed that fault detection and identification can be done successfully with high probability with a small number of monitor nodes. A heuristic algorithm for monitor placement that is based on clustering, as well as the idea of setting up additional test connections to collect diagnostic information, is proposed. In a fault detection scheme for optical mesh networks based on decomposition of network topology into monitoring-cycles (test-light path loops) is presented. The authors present heuristics for the construction of a monitoring cycle cover that minimizes cycle overlap for a given network topology.

A monitoring scheme in partitions the network into islands and determines a node or link failure using an island-by-island restoration protocol. Islands are recomputed when-ever the topology changes. A fault-localization protocol in monitoring has identical fault-detection capabilities as centralized fault monitoring. supervisory light paths, it is applicable for efficient integration within the existing TON monitoring and management system fault diagnosis and localization includes the problem of identifying faults assuming that a determines a limited-perimeter around the shortest affected path through flooding, and then locates the failure within limited-perimeter through the exchange of multicast fault-vectors. Pointurier consider estimating the Q factor for all light paths given that only some nodes have monitors by establishing additional test light paths and using Q factor correlation between established paths to monitor paths that terminate at nodes without monitors.

In authors present a scheme of utilizing supervisory cycles and paths to localize a single link fault from a single monitoring location. The propose the use of m-trails as a more flexible monitoring scheme for minimizing the total monitoring cost. It is shown that the use of m-trails outer-forms the m-cycle counterpart. A work in investigates the use of m-trails for fault-localization such that the sum of monitoring cost and bandwidth cost is minimized. Introduced is a simple heuristic based on random code assignment and swapping for m-trail design problem.

MONITORING:

It investigates the optimization of fault localization in transparent optical networks through the selective activation of available monitors in flat and hierarchically-distributed monitoring architectures. The paper makes the following contributions: Introduces a novel approach for efficient TON monitoring that utilizes the available traffic light paths and reduces the complexity of fault localization through the fault-vector optimization for centralized and hierarchically-distributed fault-management. Resulting rapid fault localization enables the use of fast and efficient link-based restoration techniques. Proves that the proposed hierarchically-distributed

Formulates the monitor optimization problem, presents complexity analysis, and proves the

NP-completeness. Formulates an Integer Linear Program (ILP) for the optimal monitor set activation problem. Introduces an effective heuristic algorithm for centralized and monitoring and presents its complexity. Provides extensive numerical results and performance comparisons for the centralized and hierarchically-distributed monitoring in common and random network topologies.

Paper Organization

The rest of the paper is organized as follows. Section II covers common optical monitoring techniques and fault propagation models, defines monitoring models used throughout the rest of the paper, and proves equivalent fault-detection between hierarchical and centralized monitoring. Section III provides a simple illustrative example of the optimized monitor activation. In Section IV we formulate the problem, address its complexity, and prove its NP-completeness. Section V provides an ILP formulation for the fault-vector optimization problem. Section VI presents an efficient heuristic algorithm for the problem. In Section VII we provide extensive numerical results and performance comparisons for different monitoring scenarios and topologies. Finally, Section VIII concludes the paper with a brief summary of contributions and presents interesting ideas for possible extensions.

NETWORK MODEL

To assign fault manager to perform fast fault localization. If some monitors are not configurable, the manager could also filter the required set of received monitors.

Optical Layer Monitoring

In TONs the optical layer includes the optical channel (OCh) layer, the optical multiplex section (OMS) layer (line layer), and the optical transmission section (OTS) layer [24]. Our approach considers all available monitors within these three optical sub-layers. Table I shows some of the commonly used monitoring techniques. They include: Wide-band and wavelength optical power monitoring, optical spectrum analy-sis, eye-diagram, optical pilot tones, Q-factor, Optical Time Domain Reflectometry (OTDR), and Bit-Error-Rate (BER).Based on their monitoring capabilities, common optical net-work components can be categorized as passive or active. Some passive optical components (i.e. optical fiber) do not have any monitoring capabilities, and depend on other components monitors for fault localization and restoration. Other optical components (i.e. optical amplifiers) have monitors and are able to report alarms, but cannot handle restoration. Finally, active optical components such as Optical Cross Connect (OXC) have built-in monitoring and service restoration capabilities and are able to report and manage alarms when an abnormal condition occurs. Throughout this paper we assume that the optical layer is monitored with optical power monitors due to their common availability in network components [9]. Each monitor is capable of reporting a binary alarm to its assigned network manager when the input optical power level is outside of the configured threshold level. Furthermore, each monitor's alarm reporting can be activated or deactivated by its assigned fault-manager.

FAULT PROPAGATION MODEL

Due to the lack of O/E/O regeneration at each optical node, faults may propagate throughout various parts of network resulting in a large number of redundant alarms. Similarly, imperfections in optical devices may lead to complex fault/attack propagation models due to optical crosstalk, amplifier gain competition, and fault masking. Failure types can be categorized by the effect they have on the individual wavelengths into wavelength-specific and shared risk link groups [17]. Some failures, such as switch-fabric failure, affect individual wavelengths. Other failures, such as optical amplifier-failures, affect all wavelengths that traverse that component. We consider both types of failures. It is assumed that faults propagate in the downstream direction along all the light paths that pass through the fault origin. Such a model is consistent with the ones used in the fault propagation model due to a bidirectional edge-cut for an expanded view of the network edge. All downstream monitors through which affected light paths pass will report an alarm to their assigned fault-manager.

D. Monitor and Alarm Management

The complexity of the monitor optimization and fault localization problems grows with increasing network size and granularity of fault-localization. Management systems can be divided into: centralized management, distributed management, and hierarchical management. The centralized management is primarily used in small networks; distributed management is scalable and can be applied to networks of moderate size, and hierarchical management is usually used in large scale networks. In this paper we consider fault lo-calization within centralized-flat and hierarchically-distributed management models.

1) Centralized Monitoring: A centralized monitoring model consists of a single central fault-manager which re-ceives alarms from all monitors in the network and processes them as a fault-vector to localize a fault. As shown in Table II, we consider two centralized monitoring models: Flat Centralized Top Level (OXC and edge level monitoring) and Flat Centralized Detail Level (discrete optical component level monitoring), Table II defines the monitor placement as well as the fault detection and localization capability for both models. With centralized monitoring, fault propagation can flood the central manager with a large number of redundant alarms, delaying fault localization and service restoration. Optimizing the set of activated monitors can effectively reduce the number of redundant alarms reported to the central manager and simplify centralized localization problem.

2) HierarchicallyDistributedMonitoring:

In hierarchically-distributed monitoring, the network topology is partitioned into monitoring domains, each of which is assigned a hierarchy level. We consider two hierarchical levels: Hierarchically Distributed Top Level (HDTL) and Hierarchically Distributed Detail Level (HDDL). Table II defines the monitor placement as well as the fault detection and localization capability for both models. Fig. 6 shows a simple two-level monitoring hierarchy. In accordance with our assumed fault-propagation model, we define a HDTL monitoring domain to consist of all nodes' input and output ports. Each HDDL domain consists of all discrete optical components within that OXC and all incoming edges to that OXC. This is shown in Fig. 6 by shaded regions. Every domain is assigned a local fault-manager responsible for computing the optimal set of activated monitors and performing the fault localization for all of its components. The HDTL manager receives only alarms from each node's port numbers, and is able to localize failures to node and edge granularity level. When it localizes failure to a particular monitoring domain, it can query the corresponding HDDL manager for detailed fault localization, or the HDDL manager could report it when it detects a fault. This approach can also be extended to multiple hierarchy lev

EFFICIENT HEURISTIC FOR MONITOR ACTIVATION

In Section IV we proved that the optimal monitor activation problem is NP-complete. Thus, in practice, computing the op-timal set of activated monitors for a dynamically provisioned set of lightpaths might not be feasible within the allotted time limits. Accordingly, here we present a heuristic algorithm that is far more applicable as it provides near-optimal solutions with much smaller time complexity.

The heuristic algorithm is based on a simple greedy method. It starts by selecting a monitor column in the alarm-matrix with a minimum sum and deletes it if the following two fault-vector constraints are not violated: 1. All rows remain non-zero, 2. All rows remain distinct. The reason for selecting the minimum sum column first is because such a column is least effective in splitting a fault set into two equal fault sets (assuming a binary tree splitting of a fault set) and yields the best results when compared to other orders of column removal for this problem. The algorithm proceeds to test and delete if possible all untested columns in order of increasing column sum until all columns are tried.

A. Time Complexity

The time complexity consists of two components: (1) time required to optimize the alarm matrix using the proposed heuristic, which is computed only when the set of light paths changes, and (2) time required to locate

In the detail-component monitoring model, all discrete optical components within an OXC and along each directed edge were considered as possible EF. Each OXC model has a maximum of input and output ports (maximum node-degree for both topologies is

Centralized-Flat Monitoring Results

Initially, the simulation was run with a single central network manager monitoring all discrete optical components in the network to estimate the complexity of the centralized component-monitoring problem. Results for the NSF topology are shown in Fig. 11, and the results for the Pan-European topology are shown Results compare alarm vector lengths of naïve monitor activation and the effectiveness of heuristic alarm-vector reduction. Solving the ILP with CPLEX for optimal activation in a large centralized monitoring scheme was too complex even for a very small number of light paths. However, optimal results for all other monitoring models in the next section demonstrate that the heuristic provides a nearly-optimal solution in terms of the alarm-vector length.

For both topologies, heuristic reduction increases with the increasing number of provisioned light paths due to the effect that the fault propagation model has on the larger number of light paths.

The discrete optical-component monitoring coverage for each topology is shown in Table VI. The results represent the average number of uniquely localizable network element faults averaged over all simulation runs, each of which considers a

CONCLUSIONS AND FUTURE WORK

In this work we addressed the important problem of optimizing the fault-localization in transparent all-optical net-works through minimization of activated optical monitoring equipment while maintaining full localization coverage. The presented approach enables scalable and rapid monitor optimization and multiple granularity levels of fault localization through the creation of a monitoring hierarchy. It enables distributed optimization of alarm-vector length and fault-

received fault vector through matching with the corresponding row within the reduced alarm matrix.

localization. We defined the construction of monitoring domains and proved that such hierarchically distributed fault localization achieves identical fault-localization as the centralized monitoring. We also proved that the minimum monitor activation problem is NP-hard, and introduced a novel heuristic algorithm with nearly optimal performance. The ILP formulation with CPLEX implementation provided an optimal reference for evaluating performance of the proposed heuristic. Extensive simulation was conducted to evaluate the performance of the proposed approach. We have shown that the proposed algorithm can provide high quality results in much shorter computation time than ILP. Combined with the proposed hierarchical monitoring, we have shown that it is applicable for use in emerging dynamically-provisioned TONs.

This can be extended in several interesting ways. For example, including other types of monitors would al-low detailed analysis of the optical layer. Different fault-propagation models could be considered to examine their im-pact on fault localization. Furthermore, although the proposed heuristic is fast enough to be recomputed when light paths change, a more adaptive heuristic could be developed to allow progressive optimization of the alarm-vectors as the light paths are reconfigured. Finally, the proposed approach can be easily extended to other areas of monitoring and sensor data reduction (assuming that appropriate propagation models are considered) including: sensor array networks, signal cross-talk monitoring, process monitoring, circuit design and testing, perimeter surveillance, and other related applications.

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