HUBBLE: An optical link management system for dense wavelength division multiplexing networks

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Abstract: Timely detection of Dense Wavelength Division Multiplexing (DWDM) link quality and service performance problems of fiber deployment are important and critical for telecommunication operators. In this paper, we propose a new methodology for network fault detection inside optical transmission systems deployed in a real-operator environment and present the working principles of the system. Our new calculation methodology is used for joint fiber and DWDM link quality evaluation inside the proposed High-level Unified BackBone Link Examiner (HUBBLE) platform. At the end of the paper, We also detail some of the benefits, challenges and opportunities of automation in DWDM networks using the proposed HUBBLE platform.

Key words: Dense wavelength division multiplexing, service provider, fault management, link quality.

1. Introduction

The target of optical transmission systems is to carry all the payload that is wrapped transparently into containers with minimum loss and latency while providing maximum capacity. In optical transmission domain, Dense Wavelength Division Multiplexing (DWDM) technology constitutes a big portion of transmission process. It is used to carry huge amounts of data to long distances while guaranteeing the service level requirements of end-users. For reliable and seamless connection, measuring the quality level of fiber cable is quite important for the operation of DWDM systems. The reason is that attenuation in fiber cables might have detrimental effects on service delivery process of network operators that have already deployed DWDMs networks inside their infrastructures.

For reliable networks, it is mandatory not only to solve the occurring problem (fiber cuts, board problems) on fine grained timescales (e.g. milliseconds levels), but also to create preventative operations before any trouble appears in the network. Some protection mechanisms in optical networks such as Automatically Switched Optical Network (ASON) [1] which come into play when fiber outage occurs in optical network exist. Although ASON can be updated to work in case of attenuation with a very sensitive process, it can create a potential risk of continuous switching inside the network. Too many switching is not preferred and determining the root cause of the problem with ASON systems and Network Management System (NMS) becomes difficult. Network performance measurements such as Bit Error Rate (BER) and Forward Error Correction (FEC) measurements

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should also be checked properly. By automated and scheduled controls of these online and offline parameters, networks service quality will always be under desired thresholds and DWDM network can operate reliably.

Providing automation in the network is one of the important enablers for the management of next generation wireless network services. The mobile backhaul, which is owned by the mobile service providers themselves or used by leased lines from fixed service providers, consists of high capacity optical networks. The slightest problem in this optical network will have a significant impact on the quality of next generation wireless services. Therefore, it is important to improve the transmission quality of the optical signal and to reduce the error rate in the received signal. There are various types of developed optical receivers using different types of modulation to decode far-end transmitted optical signals. Choosing the best modulation method with the most available physical conditions for fiber links and repeater points for field conditions is quite significant. Error Correction mechanisms are also important for DWDM technology. By developing technology on receiving sensitivity and signal processing techniques, software and hardware decision FEC can provide extra performance to the selection of the signal if it is "1" or "0". To ensure continuous improvement, network should always check critical parameters such as fiber quality, DWDM optical channel's flatness and the updated value of the design tool's pre-calculated Beginning of Life (BoL) and End Of Life (EoL) attenuation values. BoL attenuation is measured in the beginning of network deployment and EoL attenuation is the maximum limit of span attenuation. In addition, network performance measurements such as BER and FEC measurements should also be checked properly. By automated and scheduled controls of these parameters, networks service quality will always be under desired thresholds and DWDM network can operate reliably.

1.1. Related Work

In the literature, some studies that focus on automation of fault management in optical networks exist [2? –4]. An Network Configuration Protocol (NETCONF) or Representational State Transfer (REST) based automation system is demonstrated in [2]. A Software-Defined Networking (SDN) controller based network abstraction layer for the implementation of cognitive controls and autonomic operation policies is presented in [3]. In [4], the necessary information elements and processes are identified to be used by control or management systems of optical systems. The studies in [6] and [7] propose architectures for the management of SDN based optical networks that also include fault analysis approaches. A white paper in [?] discusses a new control plane structure to support flexibility in control plane. Fiber problems can be detected with in-service Optical Time Domain Reflectometer (OTDR) [8, 9]. In-service OTDR suggests a costly and complex structure compared to the system that is proposed in this paper. At the same time, currently existing and deployed equipment do not support in-service OTDR, and the inclusion of this feature adds a high cost when considering thousands of nodes. A decision system for the determination of the alarms correctly is described in [10]. The work in [11] proposed a machine learning solutions for quality analysis for the links. The article in [12] studied the performance of raman amplifier in the DWDM transmission systems that can be extended to be used for fault management purposes. Similar to our analysis in this paper, the authors in [13] are proposing a Geographical Information System (GIS) based fiber optic monitoring system that can be used as a fault or degradation detection tool. However, the approach in [13] is based on positioning remote testing units, whereas in this study, we use our own proposed quality measurement system that calculates collected Key Parameter Indicator (KPI) values from deployed equipment and from NMSs without using any additional remote probes.

There are also many studies that focus on the management of link quality in DWDM systems. In [14], the authors evaluated the performance of several protection and restorations algorithms in optical networks against

potential losses of data in optical links. The importance of fault management ad repair time for the optical links to provide enhancement for reliable transmission and increments in power savings of 5G transport networks that are based on DWDM rings are presented in [15]. Our previous work in [16] demonstrated the benefits of automation for fault management of the links in DWDM networks. The study in [17] is presenting a solution on detecting the link failures caused by fiber breaks or cable damage related to the external intervention to the links. The article in [18] study 100G optical links, and propose a monitoring system for link failures that is based on Field Programmable Gate Array (FPGA) insertion/desertion processing and the usage of in-band tunneling. A method and a system for monitoring/supervising optical fault management for fibres and their connection points in certain Network Equipments (NEs) to resolve and detect some of the problems based on OTDR measurements is presented in [19]. The importance of fast recovery time in case of optical network failures for better flexible optical networks planning is described in [20]. The study in [21] expresses the benefits of using automation for fault management for service continuity in optical network. A signaling-free fault management with monitoring resource allocation that is based on near shortest m-trails can be used to find the failure of neighbouring nodes is studied in [22]. An approach for access links with OTDR testing is described in [23].

1.2. Main Contributions

The existing infrastructure of telecommunication provider includes multiple vendor devices and managing all these heterogeneous devices using the above methods can be challenging for telecommunication operators. The biggest problem with fiber in the service provider domain is the issue of attenuation. Although distance information and attenuation can be measured by OTDR testing, the EoL and BoL values for fiber quality are not taken into account. Different from the above presented related works, we propose a new architecture that ensures all NEs belonging to different vendors can be managed inside the same environment of a telecommunication operator. The proposed High-level Unified BackBone Link Examiner (HUBBLE) platform is running in collaboration with the inventory server that includes inventory and related GIS information of operator's network as well as fault management systems for opening up fault tickets in case faults are detected in the system. Inside HUBBLE platform, fiber attenuation difference, fiber km loss and fiber deviation from expected attenuation values from the systems are used jointly to determine the quality of both fiber and DWDM links. Hence, HUBBLE platform is able to detect problems caused by the fiber quality that cannot be detected by OTDR testing by taking into account the defined EoL and BoL values in this paper, and can also correlate the measured values with the distance information received from the inventory server. Moreover for visualization purposes, the proposed system ensures that the fault and inventory information of the calculations using the proposed methodology can be visualized individually for different vendors.

Our main contributions in this paper can be summarized as follows: (i) We propose a new architecture specific to telecommunication operator that can collect fiber and DWDM related parameters from multiple vendors, perform analysis, visualize the fiber and DWDM alarm severity levels. (ii) We develop new metrics and methodologies that score jointly both the fiber link quality and DWDM link using the measurements collected from various NEs instead of simply adhering to the attenuation values given by the fiber optic cable standards of manufacturers. (iii) We provide benefits, challenges and opportunities of automation of DWDM networks experienced using HUBBLE platform.

The rest of the paper is organized as follows. Section 2 is presenting the fiber quality parameters and network design. Section 3 is describing the our proposal for fault management. Section 4 provides the experimental results and Section 5 discusses about benefits, limitations and opportunities of the proposed
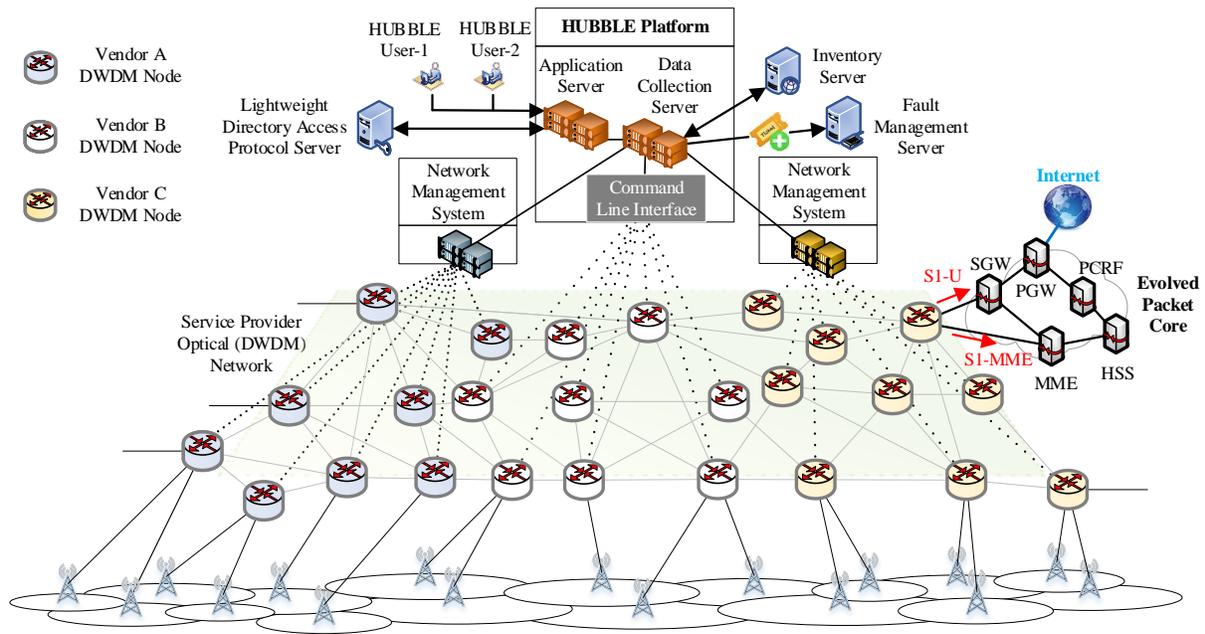
Figure 1: High-level architecture of integration of HUBBLE automation system for DWDM networks with Mobile Network Operator (MNO) infrastructure.

¹ architecture. Finally, Section 6 gives the conclusions and the future work.

² **2. System Architecture, Parameters and Design**

³ **2.1. System Architecture**

⁴ Figure 1 shows a high-level architecture of the proposed HUBBLE automation system for DWDM networks
⁵ which is integrated with the MNO infrastructure. It mainly constitutes three main components: First, the
⁶ networking system that belongs to different vendors are at the bottom of the figure, second HUBBLE platform
⁷ is in the middle and is used for running the proposed analysis and methods in this paper and last components
⁸ are additional helper servers that are connected to HUBBLE either for ticketing to NMSs (fault management
⁹ server) or for user access (Lightweight Directory Access Protocol (LDAP) server) and inventory (via inventory
¹⁰ server) purposes. Vendor specific elements in Figure 1 include DWDM NEs and network management servers
¹¹ that are specific for each vendor as marked with different colors for vendors A, B and C in Figure 1. These
¹² NEs are heterogeneous components of a telecommunication operator's infrastructure that provides nationwide
¹³ connectivity. Therefore, the data stored in NMSs can be in different proprietary formats (e.g, in Extensible
¹⁴ Markup Language (XML), Comma-separated Values (CSV)) which are specific to different vendors. In the
¹⁵ middle, HUBBLE analysis platform has application and data collection servers. Data collection server is running
¹⁶ different scripts (e.g. PERL in our case) that are used to collect vendor specific network information in various
¹⁷ forms (using Structured Query Language (SQL) query and telnet and parsing XML and CSV data formats for
¹⁸ extraction purposes) and transform them into a simple and single data format. HUBBLE analysis platform is
¹⁹ also connected to various helper servers such as inventory server for collecting up-to-date information about

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DWDM elements deployed in server (related to coordinates, fiber distance and the location of the nodes on the map, etc), fault management server (for opening a ticket to NMSs in case failure occurs based on the HUBBLE's proposed analysis outcome) and LDAP server (for authorized user access into the HUBBLE platform). Finally, users of HUBBLE platform are interacting with the platform to infer more up-to-date information about the underlying optical network infrastructure.

2.2. Fiber Quality Parameters and Network Design

At the beginning of each DWDM network deployment, there is a design process in which service providers mostly use network design tools specifically designed and developed for optical networks. Generally, each vendors have their own propriety designed tools that are specific to perform customized and advanced network features. When vendors deploy their own services on top of these devices/products, these tools are used to obtain the best service performance and the most effective equipment usage statistics. Network design tools measure the value of the parameters that are mentioned above and also perform some measurements related to the life-cycle management of the fiber optic cables such as calculation of BoL and EoL [**?**]. Design tools estimate the total amount of attenuation that may occur by taking into account the fiber cable lifespan and the corresponding network measurement parameter values. DWDM network design process is finalized by selecting the available and the most suitable amplifiers on Wavelength Selective Switch (WSS) boards (if it exists), transponder/muxponder boards, multiplexer and de-multiplexers.

For optical transmission over fiber optic cables, it is quite important to have good fiber optic quality for transmission of optical signals. The best DWDM service performance is mostly related to the conditions of the fiber optic cable [**?**]. DWDM vendor companies mostly develop different types of amplifiers and transponders/muxponders. Main fiber quality parameters can be described as attenuation, Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD) [25]. Additionally, there are some non-linear effects like Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM), Four-Way Mixing (FWM), Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS) [**?**] that can affect the quality of the fiber optical cable. For fiber cable sides, fiber attenuation should be 0.20 dB/km for factory values (G.652 Single-Mode Fiber (SMF)-28, 1550 nm) [27]. For deployed fiber cable expected attenuation should be 0.25 dB/km. Due to field conditions, 0.3 dB/km can be acceptable, but fiber cable should be checked and all problems should be solved to have a stable and good quality fiber connection after 0.3 dB/km attenuation. Each span fiber cable attenuation for whole DWDM network should be checked periodically. If the span fiber attenuation becomes bigger than the expected values (0.3 dB/km) and/or difference between Live Network Attenuation (LNA) (where BoL $<$ LNA $>$ EoL) and planned values is higher than expected, the situation becomes risky. Hence, it is possible to have Errored Seconds (ES), Severely Errored Seconds (SES), Unavailable Seconds (UAS) performance problems. Additionally, channel optical power flatness is very important parameter for service performance. All transmitted optical channels should be flat at the receiver side.

DWDM systems can work at very high attenuation. For terrestrial system, Raman amplifiers can be used for long distances and high attenuation cases, but the expected fiber attenuation is fixed. After several years of external and internal factors, fiber quality can be worse than the estimates of the design tools of vendors. If the difference between the estimates and the real values grows higher than the expected attenuation values, service interruption and quality problems can occur. For these reasons, online fiber attenuation control is required for pre-maintenance activities. Based on these observations, in next section we detail our proposed calculation methodology to determine the severity level of the fiber quality and DWDM links in a joint framework.
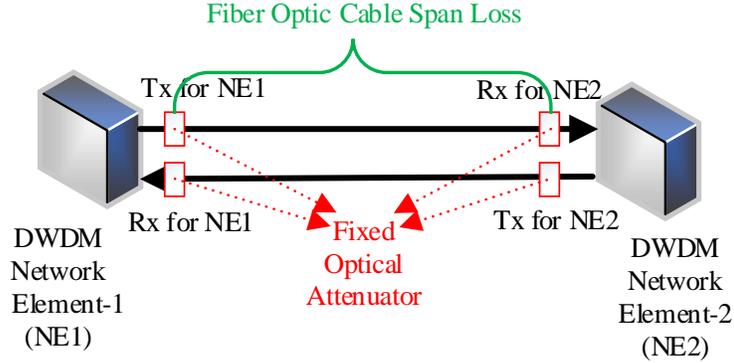
Figure 2: Different interfaces for DWDM link attenuation measurements for HUBBLE platform.

TABLE 1
FIBER OPTIC ALARM SEVERITY LEVELS DEFINED IN HUBBLE.

Alarm Severity	Fiber attunation difference (dB)	Fiber kilometric loss (dB/km)	Fiber deviation from expected attenuation (dB)
No Alarm (Green)	0∼1.0	0.25∼0.30	0∼2.0
Minor (Yellow)	1.1∼3.0	0.31∼0.45	2.1∼4.0
Major (Orange)	3.1∼5.0	0.46∼0.55	4.1∼7.0
Critical (Red)	¿=5.1	¿= 0.56	¿= 7.1

TABLE 2
DWDM ALARM SEVERITY LEVELS DEFINED IN HUBBLE.

Alarm Severity	DWDM deviation from expected attenuation (dB)	DWDM attenuation difference (dB)
No Alarm (Green)	BoL <= LNA < EoL	0∼1.0
Minor (Yellow)	EoL <= LNA < (EoL + 2)	1.1∼3.0
Major (Orange)	(EoL + 2) <= LNA < (EoL + 3)	3.1∼5.0
Critical (Red)	(EoL + 3) <= LNA	¿= 5.1

3. A Proposal for Fault Management of DWDM systems

In this section, we give some of the formulas for calculation of values to determine the severity of the fiber cable inside the HUBBLE platform. Checking all DWDM networks' span fiber attenuation periodically will give up-to-date information about the service quality of the underlying transport network. Three kinds of criteria can be used to give priority to faults performed in DWDM links: (i) Kilo-metric span loss where reference is taken as 0.25 dB/km. The standard kilo-metric span loss for the G.652 fiber optic cable, which is a more commonly used cable types in the network, is actually 0.20 dB/km as also mentioned above. Generally, the service providers keep this value a little higher based on their operational experience. We have used 0.25 dB/km to keep margin a little higher.), (ii) Deviation from expected attenuation where expected attenuation is fiber length ×0.25 dB/km, (iii) Fiber span loss difference between the transit and receive side fiber optic cable.

Additionally, it will be effective to give priority to the fiber span that has the higher attenuation than others. *Critical*, *Major*, *Minor* and *No Alarm* severity levels can be used to describe the span fiber quality. A pictorial explanation of fiber optic cable span loss is given in Figure 2. Fiber optic cable span loss is between transmitter and receiver NE. Optical Supervisory Channel (OSC) can be used for all transmit and receive side

optical measurements where it has fixed wavelength and is not affected from how many channel is working on the measured span. By using graphical user interfaces, it will be easy to extract the location and severity levels of the fiber connection problem. This can ensure the telecommunication operator to focus their efforts more on fiber span for detection of failures.

Fiber span loss and DWDM alarm severity metrics are summarized in Table 1 and Table 2 respectively. Planned attenuation values (BoL and EoL) are used as criteria for comparison purposes in Table 2. The comparisons are used to calculate the difference between the actually measured and expected DWDM attenuation values. Some example values over DWDM and fiber links from node A to node B are given in Table 3 where the values are obtained from nodes and inventory server by HUBBLE platform. The collected parameters include center node names (A or B), transmit and receive power measurements, and transmit/receive physical attenuator values. If there are ES, SES, UAS errors at any of DWDM services, checking the entire service route using the proposed criteria will give very important clue on finding root cause of problem. As a matter of fact, both fiber quality and DWDM span loss comparison between planned BoL / EoL values and real time attenuation measurements have importance in practical applications.

Let us denote transmit power as $P_t(A)$, receive power as $R_t(A)$, transmit physical attenuator as $P_{t_\alpha(A)}$, receiver physical attenuator as $P_{r_\alpha(A)}$ for node A. Additionally, denote fiber distance between nodes A and B as d_{AB}. In HUBBLE platform, DWDM attenuation from node A to node B (AB) in dB is calculated as,

$$\alpha_{AB}^{DWDM} = |P_t(A) - P_r(B)|. \tag{1}$$

Note that similar definition can also be made for DWDM attenuation from node B to node A (BA). Then, DWDM attenuation difference from node A to node B (AB) and from node B to node A (BA) in dB can be calculated as,

$$\alpha_{AB-BA}^{DWDM} = \alpha_{AB} - \alpha_{BA}. \tag{2}$$

acDWDM deviation from planned attenuation (γ_{AB-BA}^{DWDM}) is calculated using DWDM Span Attenuation BoL and EoL values which are taken from inventory servers (an example is given in Table 4). We define LNA in Table 4 as

$$LNA = \max \left\{ \alpha_{AB}^{DWDM}, \alpha_{BA}^{DWDM} \right\}. \tag{3}$$

In HUBBLE platform, fiber attenuation from node A to node B (AB) in dB is calculated as

$$\alpha_{AB}^{fiber} = |P_t(A) - P_t(B)| - \left| P_{t_\alpha(A)} + P_{r_\alpha(B)} \right|. \tag{4}$$

Note that similar definition can also be made for fiber attenuation from node B to node A (BA). Then, the fiber attenuation difference (AB-BA) from node A to node B (AB) and from node B to node A (BA) in

TABLE 3

AN EXAMPLE DWDM LINK PARAMETER VALUES FOR LINK BETWEEN NODES A AND B

Node	P_t (dB)	P_r (dB)	P_{t_α} (dB)	P_{r_α} (dB)	d_{AB} (km)
A	3,19	-8,88	0,00	3,00	36,00
B	3,40	-9,50	0,00	3,00	36,00

TABLE 4

AN EXAMPLE FOR CALCULATED PARAMETERS FOR FIBER AND DWDM SPAN VALUES INSIDE HUBBLE PLATFORM.

α_{AB}^{DWDM} (dB)	α_{BA}^{DWDM} (dB)	α_{AB-BA}^{DWDM} (dB)	BoL (dB)	EoL (dB)	γ_{AB-BA}^{DWDM}	DWDM Alarm Severity
12,69	12,28	0,41	9,50	13,00	BoL <= LNA < EoL	No Alarm
α_{AB}^{fiber} (dB)	α_{BA}^{fiber} (dB)	α_{AB-BA}^{fiber} (dB)	β_{AB-BA}^{fiber} (dB/Km)	$\alpha_{AB-BA}^{fiber,exp}$ (dB)	γ_{AB-BA}^{fiber} (dB)	Fiber Alarm Severity
9,69	9,28	0,41	0,27	9,00	0,69	No Alarm

1 dB is

$$\alpha_{AB-BA}^{fiber} = \alpha_{AB}^{fiber} - \alpha_{BA}^{fiber}. \tag{5}$$

2 Fiber optic kilometric loss β_{AB-BA}^{fiber}, in dB per km is,

$$\beta_{AB-BA}^{fiber} = \frac{\max\left\{\alpha_{AB}^{fiber}, \alpha_{BA}^{fiber}\right\}}{d_{AB}}, \tag{6}$$

3 and fiber expected attenuation in dB is

$$\alpha_{AB-BA}^{fiber,exp} = d_{AB} \times 0.25^1 (\text{dB/km}). \tag{7}$$

4 Finally, fiber deviation from expected fiber attenuation in dB is calculated as,

$$\gamma_{AB-BA}^{fiber} = \max\left\{\alpha_{AB}^{fiber}, \alpha_{BA}^{fiber}\right\} - \alpha_{AB-BA}^{fiber,exp}. \tag{8}$$

5 In the next section, we demonstrate some of the example DWDM link analysis results that are generated using
6 the above proposed methodology inside the HUBBLE platform.

7 **4. Evaluation Results**
8 A general nationwide statistics of the DWDM links for failure detection by HUBBLE platform is given in Table 5.
9 Figure 3 shows the optical fiber cable severity levels that are previously defined between nodes. In Figure 3,
10 green colored lines represent non-existence of problems on fiber optic cable, yellow colored lines represent that
11 the severity of the link is a minor alarm, orange colored lines corresponds to major alarm and red colored lines
12 indicate a critical alarm. Alarm severity level of the optical fiber cable between A and B can be seen as green
13 color in Figure 3.

14 Criteria for calculating the fiber optic alarm severity levels using fiber attenuation difference, fiber km
15 loss and fiber deviation from expected attenuation values from the system are listed in Table 1. Fiber optic
16 alarm severity levels holds true if all of the sub-conditions in Table 1 holds true. For example, even if fiber
17 attenuation difference and fiber km loss are in green region (no alarm case), if the fiber deviation from expected
18 attenuation value is on red region, we mark this fiber as critical. This is again true for DWDM alarm severity
19 levels calculations defined in HUBBLE as given in Table 2. By joint utilization of Table 1 and Table 2, the

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[1]Note that the value 0.25 is selected in this paper based on the decision taken by the planning department of the telecommunication operator. However, it can vary depending on the planning requirements.

TABLE 5
Nationwide statistics of utilized DWDM data-set monitored by the proposed system in Turkey.

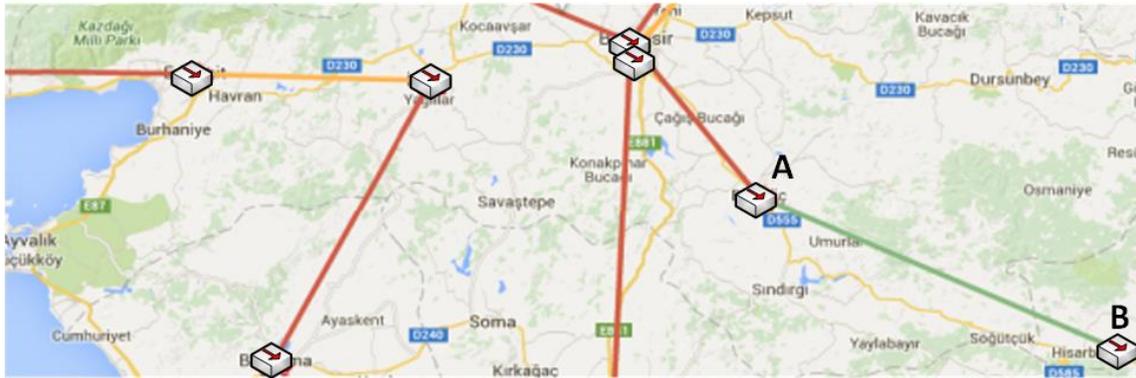| # of cities	81
# of DWDM nodes	2,143
# of DWDM links	7,544
# of DWDM ports	15,088
# of faulty detected DWDM links	776
Total # of subscribers	44,500,000
Fiber Coverage for DWDM	130,000 km

Figure 3: Snapshot taken from the map view of HUBBLE. (Name of the locations are not displayed for privacy reasons.)

1 quality of a fiber optical link can fall into major (orange) category, whereas DWDM link quality can be in
2 minor (yellow) category. Therefore, it is up to telecommunication operator to decide if appropriate action will
3 be taken. Note that based on the proposed methodology in some cases, even if the fiber quality can be poor,
4 DWDM link quality can in turn be in decent condition which may require no specific action by the operator,
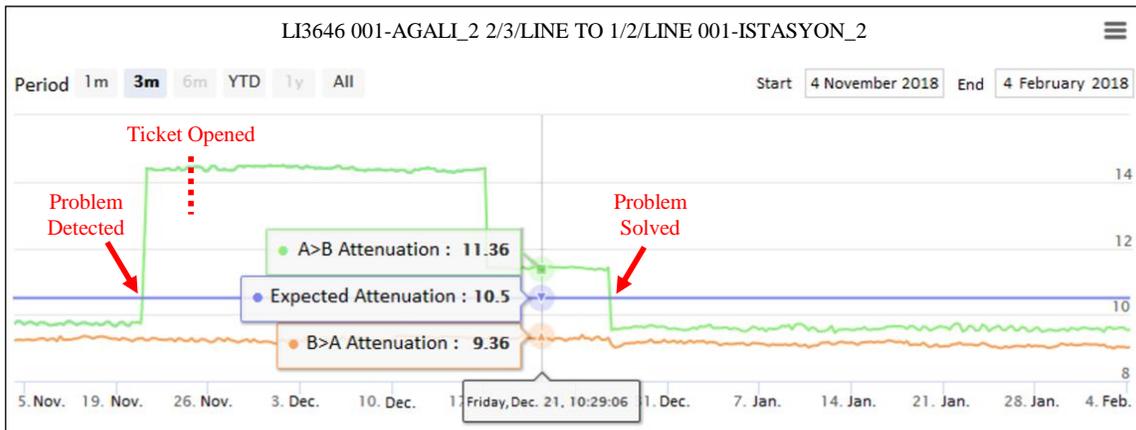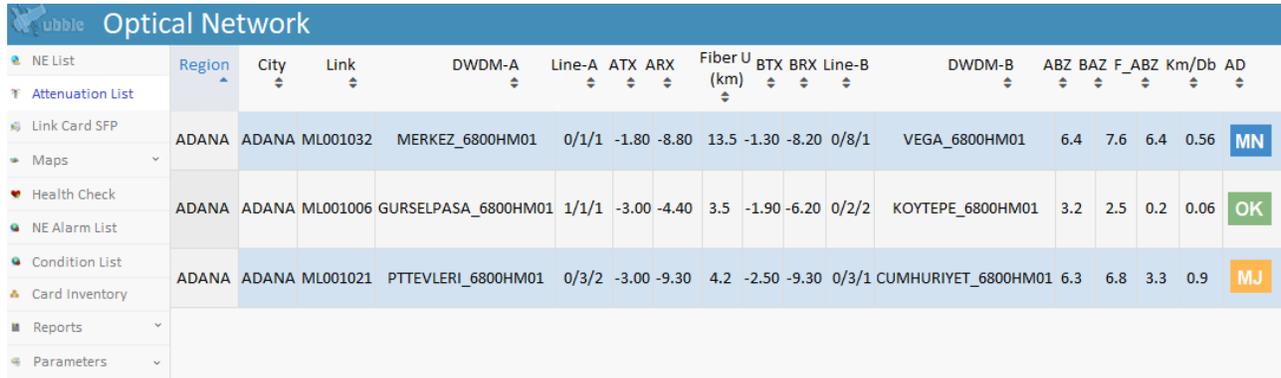5 hence saving both human and equipment resources.

Figure 4: A dashboard view of HUBBLE fault detection and resolution platform.

Figure 5: Alarm list view of HUBBLE platform for the optical links.

A dashboard view of the HUBBLE platform demonstrating a real-time DWDM link status with measured and expected attenuation values is given in Figure 4. These examples demonstrate DWDM NE's attenuation values over the time range from November 5 2018 to February 5 in 2019. When the attenuation from A to B, as marked by green line, becomes larger than the expected attenuation (marked by blue line) as calculated with Table 1 and Table 2 on December 21 2018, a problem with DWDM link is detected, hence a trouble ticket is requested from the fault management server to fix the issue in the link (the problem in this case is related with the fiber connection). Note that, in cases when a problem with DWDM link failure is detected, the fault can be solved either remotely (by adjusting power levels etc.) or on site in case the fault cannot be solved remotely (e.g. problems related to board, port or attenuator, etc). Values after the resolution of the problem are also demonstrated where the green line is below the expected attenuation value after the problem is fixed in Figure 4. Another view for the list of links with measured alarm levels by HUBBLE platform is shown in Figure 5.

5. Challenges, benefits and opportunities of HUBBLE building process for DWDM networks

Huge networks bring together huge problems for network operators. Some of these include difficulties on management of *huge* network, difficulties for viewing all topology on a single plane, performance depredations due to fiber attenuation, difficulties for checking problems at all NEs, standardization difficulties and different know hows with different vendors. Compared to existing works in the literature, the information contained in GIS inventory systems such as coordinates, the fiber distance and the location of the nodes on the map were not integrated with the breakdown tool of the DWDM systems. This capability has been added in our proposed HUBBLE system. Consolidation of the data with different vendors under a single system provides a great benefit for the service providers. This is true especially in border points where the systems belonging to different vendors are working mutually. In this case, fault management takes time because analysis must be performed by checking all NMSs belonging to different vendors. Together with the HUBBLE system, this problem is eliminated and a single fault management screen is displayed under the same data format that is independent of the device model. One of the benefits with HUBBLE is that automation can be integrated into DWDM systems without the need for additional Capital Expenditure (CAPEX) required to update older equipment. Some of the challenges encountered and the potential solutions and the benefits obtained during building the HUBBLE platform are described in the rest of this section.

Data Collection Process: The biggest challenge encountered when automating the existing DWDM systems

was on deciding how to collect the data from each heterogeneous NEs. While newly produced equipment can support NETCONF, Simple Network Management Protocol (SNMP), and even OpenFlow protocols, these protocols are not supported by the currently utilized infrastructure and are relatively four to five years old devices. Collecting data directly from devices and performing this process frequently can bring high load to the processor of the device. For this reason, we decided to obtain data via NMSs to which the devices are connected for efficiency purposes. The NMS periodically collects data from the network infrastructure.

Different Vendor Characteristics: Another challenge that has been encountered when building the HUB-BLE system was the different manufacturers' characteristics to store data with different data formats in the systems. For this reason, while the data from a manufacturer of the NMS can be in XML format, another vendor's system can be in CSV format which needed to be transformed into the same format as used in NMS systems. For this reason, the NMS had to be developed further to be able to export data from different manufacturers into similar data format. However, this was costly and required time-consuming effort for telecommunication operator. Instead of relying on NMS, we collected data directly using SNMP and Transaction Language 1 (TL1) protocols from the devices. To make the collected data in different formats more meaningful, a data pre-processing stage is applied that required further effort to persist the data to HUBBLE database system in a single format.

Non-matching inventory information: Another problem that was encountered during the HUBBLE system build up process was that the circuit/service numbers held on the NMSs and GIS were not consistent. Because each system had their own coding methods, the problem of inventory information could not be matched with the correct circuit numbers appropriately. For this reason, manual and inventory information options that cannot be matched manually have been updated. With the integration of the HUBBLE system into the fault management system, an important opportunity for the telecommunication operators has also been created. Thanks to this integration, fault management and failure tickets are opened jointly for the devices of different manufacturers. In normal operational process, a notification is sent to the fault management system via the NMS of each manufacturer. In this case, two separate tickets are needed. However, together with HUBBLE, these two tickets are merged in a single ticket carrying the malfunctioning system information. At the same time, it has also been possible to update Internet Protocol (IP) and Synchronous Digital Hierarchy (SDH) service information carried over DWDM systems while processing the circuit information on NMS using the inventory system.

In summary after building HUBBLE platform, we can collect data from the equipment/NMSs of different vendors, reach the status of all DWDM networks over a single web page, calculate fiber optic cable's kilometres attenuation to obtain priority values, check NE's problem automatically via customized scripts and integrate with ticket creation and fiber map systems. Moreover, HUBBLE platform provides a common user interface for the equipment from different vendors that collects data from the DWDM networks. An observed operational benefit of HUBBLE for the service provider is that the telecommunication operators' fiber and transmission operation teams can now manage the optical network with high accuracy, whenever the fiber attenuation increases in some links of the network. Another observed benefit with the usage of the HUBBLE is the preventive fault management in DWDM networks which provides an easy way to share know-how about DWDM problems with the existing on site technical teams. Our final observation has been the indirect improvement at speech quality and data throughput which have added great benefit on the service experience of telecommunication operators' end-users.

6. Conclusions and Future Work

In this paper, we introduced a new calculation methodology for joint fiber and DWDM link quality evaluation using the proposed HUBBLE platform and presented the working principles of the system. Our analysis results rely on the fact that both fiber quality and DWDM alarm severity levels need to be utilized to measure the severity of DWDM deployments and trigger the fault management server to open trouble ticket when undesired conditions occur. Through the dashboard of HUBBLE platform, telecommunication operator network optimization experts can easily detect the problems related to either fiber or DWDM links. Later, appropriate actions can be taken into account in cooperation with NMS units thanks to integration with network fault management systems of the operator. At the end of the paper, we provide the benefits, challenges and opportunities of automation in DWDM networks where an implementation of automation method for the management of optical networks which will carry high capacity data for the new generation wireless networks is given with more low-level details. As a future study, we are working to extend the implementation of automation tool for the current deployed DWDM networks into a root cause analysis platform that can relate to the fiber cables problems. Additionally, we are planning to make a link quality analysis by integrating machine learning techniques into our proposed system.

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