Applying Intelligent Software Defined Network to Improve the Relicense of the long distance Optical Transport Network

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Abstract: - The improvement in the conventional optical Transport network (OTN) is exceptionally moderate regarding the rapid growth in the mobile and the IP-Core technologies, particularly with the requirements of the new 5G advances. There are many challenges in the OTN such the expensive cost of the multilayer services planning, the quality of the services and the quality of the resilience must be recovered first to cope with the changes in the new generations of the access communication networks. The needs to overcome many of these challenges become vital nowadays, and depend on many factors in the OTN such the status of the optical fiber cables, the flexibility, the responsive and the availability of OTN assets to the direct customer control. In this paper for the first time a new proposed model is introduced by reorganizing the OTN to fit the needs of the new generations of the communications market, the model consolidates two promising technologies with each other which are the Software Defined Network (SDN) and the Machine Learning (ML) to overcome the previous challenges and to reconstruct the traditional OTN to be more smart, virtualized and automated. The fundamental role of the SDN is to transform the services on the OTN to be more dynamic rather fixed, at the same time the aim of the ML such the Artificial Neural Network (ANN) is to help the centralized controller of the SDN in the OTN by the past experience of the performance of the optical links in the OTN, this enables the centralized controller to formulate the right decisions about the optimized routes of the services restoration between the different domains and multilayers in the OTN. For the first time, the optical cloud concepts are introduced in the OTN by slicing and virtualizing the various domains with its vendors in the heterogeneous optical network to 3 integrated unified layers, this provides the required resiliencies and the bandwidth on demand between the multilayers and the different domains in the OTN in a more elastic way. The model is tested using 2 methods , the 1'st method is done by a software simulation by using a SPSS software model and its input data was 500 records from real OTN , and the 2'nd method was done by performing practical case study on the long distances heterogeneous OTN network in one of the middle east countries about the integrations between the different optical network domains, slicing the optical network, and the centralized controller to reconstruct the heterogonous OTN to 3 layers to perform the resilience of the services of the multi failure in the same domain through the multilayers in optical network. The results of the new model according to the practical case study in the long-distance heterogamous OTN show that: The dependence on the single vendor is nearly neglected with applying the concept of the clouding and slicing in the heterogeneous OTN, the pay for the end-users bandwidths has become possible and the time to provide the bandwidth on demand has become very short , the meshing between the heterogeneous optical network became available and the resilience for diamond services improved from 25% for double or triple faults to 100% after applying part of our model in the long distance optical network, the available bandwidth of the optical core network in the long distance network is optimized by more than 25% , the revenue from some OTN domains which have free bandwidths more than 50 % is increased by more than 50%, the switching time enhanced by about 50%, and the latency reduced from 27 msec to 742 usec for the selected routes which is optimized from the centralized controller.

Key-Words: - Software Defined Network (SDN), Machine Learning (ML), Optical Transport Network (OTN), Dynamic Services, Network Mesh, Services Resilience, Heterogeneous Optical Network

1 Introduction

At present and soon, the needs to exchange a huge amount of data between the different regions inside the country become a particular commitment especially with the significant expansions of the clouding principles, the data centers and the implementations of many intelligent applications of the 5G in the several fields of the information technologies [1]. The existing model of the core transmission network consists of 3 autonomous zones, the 1'st zone is layer 1 and layer 2 which considered as the physical layer of the backbone optical network such OTN, the 2'nd zone is layer 3 which considered as IP core network, and the last zone is the access and the application layers. The challenge in this model is that; there are no correlations between these 3 zones of the communication network to optimize the capacities and the demanded resources which are needed to transport the data between each of them. Nowadays the optical transport network (OTN) represents the crucial position of carrying a tremendous amount of data between the different sites according to the demands of the consumers of telecom operators. The structure of the optical transport network (OTN) in our case is a practical case study of the long distances optical network in one of the middle east countries, the model consists of multiple domains of transmission equipment's from different vendors, and connected with each other's by thousands of kilometers from the fiber cables, at the same time every area inside the country is covered by 1 or 2 isolated domains from the long distance OTN with the same or different vendor types. The problem in this traditional structure of the long distance optical transport network is the moderate quality of the services resilience and the challenge to reuse the free bandwidths on a certain optical area domains, this is a consequence of the existing optical network was built from thousands of new and legacy network equipment's (NE's) with many different types, capacities, and vendors in long intervals of times. This style of the building the optical network converted it to isolated domains of the optical network with chaotic merging between the legacy layers such the synchronize digital hierarchy (SDH) and the new generations layers as the OTN equipment's. Although there are many efforts were done from many international organizations to create standardizations among the vendors in the optical network fields to shape their network parameters under the same umbrella of the regularities, every vendor has his supervision system, provisioning standard for the operation, and the administrations of his optical network [2]. With the existing structure of the OTN, it's very difficult to restore the traffic from certain area domain to other area domain in case of any crisis will be happen in each of them, especially with different vendors for each area even though these area domains are joined in common get-way stations. Moreover, the routing between the different OTN domains needs more manual and hardware arrangements to implement it, which is not proper during any disaster in the core OTN and the critical needs to return the affected services. The new generations of the communication businesses for the next 3 years will involve the clouding concepts in the various fields of the communication markets, and will expand in the implementations of many intelligent applications following the employing of the 5G technologies around the world, all of these tremendous advances in the communication markets in the near future will need exceptional demands in the infrastructure of the core optical network, which depends essentially on the performance, the latency, the available bandwidth, the dynamically of the recovery of the service from certain paths to others, the switching rate and other parameters in the OTN. To fulfill the conditions of the new generations of the communication markets the current OTN should be reconstructed from a Rigid network to be more dynamic and smart network [3]. Transforming the OTN to be more dynamic will support the operators to extract the most reliable routes in the overall network and will enhance the availability to restore any affected traffic in the most concise time, even though among the various vendors and the complex area domains [4]. In this paper, for the first time proposes an Intelligent Software Defined Optical Network (ISDON) by offering the alliances among the software defined network (SDN), the machine learning technology (ML), and the traditional network management systems (NMS's) of the OTN. This will be done to convert the present rigid OTN to be more dynamic and automatic, this will be done applying just one centralized controller (CC) to maintain and master the OTN in the various vendors' fields, different layers and in the domain of the different areas. The CC will make its choices about the restoration routes, the switching time, the latency and the other network parameters according to the past experiences of the network, which was built by the machine learning (ML) model. Also, the concept of the optical network cloud is offered between the different network areas to deliver the traffic restorations between the different vendors' equipment in the IP and the OTN domains [5-6].

The remaining part of the paper is organized as following: section 2 explains the problem statement and the motivation, section 3 introduces the proposed model with the SDN and machine learning technology, section 4 presents the network scenarios section 5 the experiments and the results, and finally section 6 introduces the future work and the conclusion.

2 The Resilience Challenges and Motivations

Figure 1 demonstrates a practical model of the long distance optical transport network in this paper, the model expresses a small representation of a real long distance transmission network in one of the Middle East countries, and consists from several sectors of the optical transport network, where every sector called domain, and every domain covers large area inside the country, and consists of DWDM equipment and OTN equipment from various or the same vendors, the capacities of every domain reaches to 8 Tb/s on the line bandwidths with 100 Gb/s for each wavelength bandwidth in the domain. In this paper we concentrate on the challenges of the resilience and the routing mechanisms between the different domains in the long distance transmission network and the role of the SDN with the ML to enhance the stability of the services flapping and the routing mechanisms between the different domains of the legacy optical transport network especially in case of the multi failure or any crisis in one or more domain.

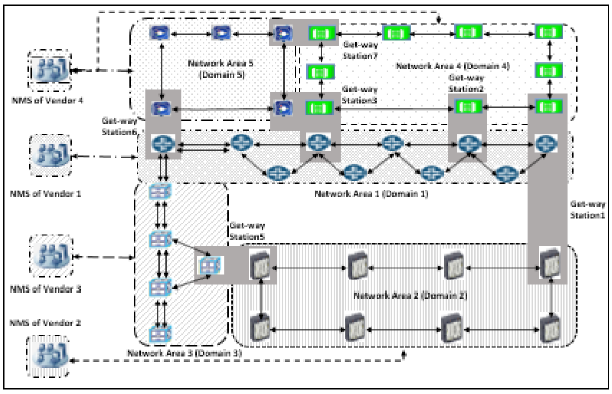

Fig.1: Practical Model of the Long Distance Optical Transport Network

According to the current OTN long distance model as shown in figure 1, there are some constraints which affect the resilience flexibility and the performance of the network, such the few number of the possible routes in the optical fibers cables, which depend on the characteristics of the geographic area inside the country, particularly in the middle east countries which have large area of deserts and mountains with very long distance between the consecutive network elements. As a result of these limitations the traffic in the long distance optical network which connects the essential cites with each other's is protected by 2 routes only, known as working and protection routes, seldom there is 3'rd route or more for restoring the traffic during the multi-failure within the same domain. Other restrictions in the current model is, there is no any integrations or alliances between the different domains of the OTN, which were developed before based on the vendor type, every network area is separated in the topology, the associations between the working and protection routes with the corresponding domain only, one network managing system (NMS) for every vendor type which is network for its domain only, and the available bandwidths are kept for its domain area only. Other difficulties of this model is that although there are many stations are common with more than one network area or domain, it's very difficult to provide backup routes to the working services between the different areas domains in case of any failure or crisis in one of these domains, in other words it will take long time to prepare manual restoration of any impacted traffic from one area through other area domain by using the common get-way station among each of them even though the same NMS or the same equipment type between the different network area domains. Other challenge in the existing long distance OTN model is that, there is no any tools in the OTN network to take the performance and the delay of the backup routes in the consideration before choosing it for the restoration or to keep the services on the routes which have lowest switching rates or lower number of failures, although the network is switched many times within short period as a result of many cable cuts in the long distances routes, at the same time most of the long distance cables had high attenuations due to the multiplied cuts on it, in other words the control planes of the resilience's mechanisms in the different area network has no techniques to select the best backup routes in the performance and the latency according to the past experience of the long distance optical network. Another challenge in this model is that, it's very difficult and need a long time to reuse the free capacities in a certain domain to cover other network areas in case of any congestion in this area without equipping firstly the connections between the get-ways in a manual way. The last challenge in the existing model is the high cost of building long distance optical network with low revenue especially in the areas which has low population density, which makes the high capacities of the OTN are wasted resources.

Each network element has its Generalized Multi-Protocol Label Switching (GMPLS), the GMPLS controller of every network element (NE) communicates with each other's over the data plane, by using the control plane to find the available routes over the OTN network. Each GMPLS controller should have all the information about the topology and the available resources of its domain network, an Open Shortest Path First (OSPF) protocol is used to advertise the situations of the network between the GMPLS controllers of NE's inside its domain as shown in figure 2 [7].

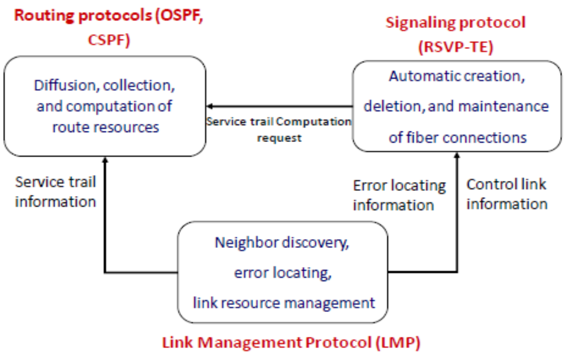

Fig.1: Relation between the ASON-Related Protocols

The network mechanism's which ensure the service availability is divided between the network protection and restoration. The difference between both of them is defined according to the allocation of the network resource before or after the occurrence of the network failure. There are many different types of the restoration and the protection mechanisms inside every network domain, one of these mechanisms is called 1+1 protection, where the essential route which is carrying the services between the sources and the destination is called working path, and the other route which is reserved for carrying the services during the failure is called backup route [8]. This scheme of protection mechanism provisions the backup routes individually in case of any failure in the network rather than managing the overall routes of the network as one unit to provide the best backup paths for the network failure, which is not optimized scheme. Where in the protection mechanism the resources for the recovery paths is reserved all the time before any failure occurring in the network such as 1+1 or 1:1 protection types, and in this case the services are recovered very fast normally in less than 50 ms, however it requires signaling protocol and synchronization between the 2 failure nodes. In the restoration mechanisms, the allocation of the recovery resources is reserved after the occurrence of network failure according to the priority of the affected services, and the recovery processes of the affected services take a long time almost few seconds to finish the full restoration of the traffic [9]. The automatically switched optical network (ASON) is the mechanism which restores the service in the OTN by using dynamic connection capability, this technique is done by performing the call and connections control functions through the control plane. To enable the ASON mechanism in the OTN, it contains discovery functions, routing functions, and signaling functions as the following restoration steps [10]:

In the discovery functions there are several types of discoveries; Neighbor discover its necessary to detect the status of the local links between the adjacencies NE's without using it, and it can be required to configure the status of these links manually at the 3 levels of discoveries, the physical media adjacencies discovery which used to confirm the connectivity between the adjacent ports, the layer adjacencies discovery which is used to confirm the associations between the physical connections and the logical links, and the control entities discovery confirms the association between the control plane and the transport plane of the NE's. The Resources discovery, which determines the available resources, the topology of the network and detects the mismatch in the configuration of the network resources, and finally the services discovery, which verifies and exchanges the grade of the class of the services in the different administrative domains [11].

In the routing functions, the architectures and the requirements for the routing in the ASON mechanisms are described in the ITU-T Recommendation G.7715/Y.1706, which includes path selections, routing resources, and the routing diagram.

The signaling functions are done according to G. 807, where the signaling protocol is essential for fast provision and recovery of the paths after failures, it's necessary for release, create, restore and maintain the connections

The Quality of Resilience (QoR) in the OTN is used to measure the effectiveness of the different types of the service recoveries during the network failure according to the following equations [12].

$$F(x)= P_r(T<x)= \sum_{t_i} P_r(t_{i-1}<T<t_i) \quad (1)$$

$$P_0= P_r\ (T=0)=F(0) \quad (2)$$

$$A = \sum_{t_i \le \alpha} P_r \left(t_{i-1}<T<t_i\right) =F(\alpha) \quad (3)$$

$$MTTR=E\ [T]= \frac{\sum_i T \times P_r(t_{i-1}<T<t_i)}{U} \approx MDT \quad (4)$$

$$MTTF \approx MUT= \frac{A}{U} \times MDT \quad (5)$$

Where:

- F(x) is the distribution functions of the infinite downtime T
- $P_r(T<x)$ the probability of having service interruptions at most x with t_i reparations i times
- P_0 is the probability of having no services down
- A Services exceeds the probability services down exceeds the threshold down
- MTTR is the mean time to repair
- MTTF is the mean time to fail

With The pervious challenges in the current long distance optical network model it will be not accepted from the customers to have services down as a result of the inability to restore the traffic between the different domains particularly with several applications which depend on the availability of the core optical network and with the presence of the service level agreement (SLA) between the customers and the operators it will be very expensive for the operators to compensate their customers about any interruption doesn't meet the service availability percentage in the SLA, which can be reached to in some cases around 99.999%. Although there are many challenges in exiting model of the long distance optical network, which affects the services flexibility and the automation of the routing mechanism, there are also many chances to improve the current state to be smarter and dynamic. One of these opportunities is the dynamic property of the ASON mechanism which can be worked between the different vendors and the various network area domains if it is controlled by only one centralized controller and one control plane for all the optical network. Also other motivation in the current state of the optical network is the new technology of the OTN is extending all over the country with huge capacities, where every wavelength reached to 100G at least, which makes the availability to build one unified virtual OTN network with high capacity he wavelength be more available and easier between the different network areas. More motivations is using the software defined network (SDN) in the optical network to provide the suitable tools to separate the control plane than the data plan and provides only one controller for all the network management, which makes its more easier now to manage all of these different area networks with multi-vendors by using centralized control plane and only one controller. One more motivation to improve stability the current status of the long distance optical network is the ability to learn from the past failure experiences in the multiple domains in the OTN by using the ML technology and support the centralized controller of the SDN by the resolutions about the stability of every optical link in the OTN to choose the best stable routes in the network, and to carry the platinum services high rates of services quality and resilience [13].

3 Proposed Resilience Model in the Long Distance OTN

The suggested model in the long distances optical network to develop the reliance mechanisms and provide effective bandwidths is formulated upon multi-layers smart and dynamics virtual optical network, this don by adjusting the long distance optical network in 3 dimensions as following:

3.1 Developing the Physical Infrastructure of the Optical Network

This is done by building optical clouds in different layers of the core optical network to provide on-demand bandwidths and the backup routes in case of multi-failures or crisis in any domain of the optical networks, the optical cloud slices the long distance optical network into 3 layers, the 1'st layer is the core OTN which will be used to connect the different domains of area optical networks by each other's through the get-ways stations, and by using DWDM connections with high the capacities of the wavelengths over all the long distance areas network. These connections will form the Virtual Cloud Optical Transport Network (VCOTN) on the physical infrastructure of the OTN as shown in figure 3.a.

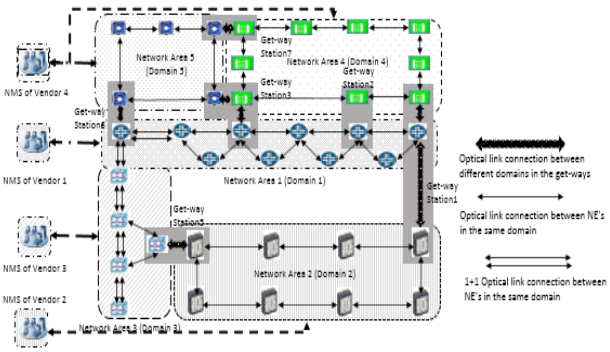

Fig. 3.a: the Virtual Cloud Optical Transport Network (VCOTN) on the OTN

The objective of this layer is to make the OTN more dynamics between the different areas and between the different vendors and to provide the restoration routes with the required bandwidths between the domains for the high capacities services. Figure 3.a shows the proposed layer1 VCOTN of the long distance optical transport network. The 2'nd layer of the proposed model is the Services Optical Cloud (SOC), in this layer a unified OTN network is built between the get-ways stations by connecting every get-way station with each other all over the country with reserving over the various domains, the aim of this layer is to provide the bandwidth-on-demand in the fastest time and support by backup routes for the low capacities services, figure 3.b shows the SOC in the long distance network. The last layer of the core optical network is the optical IP core cloud (ICC) which will be built over layer 2 and in the get-ways stations, the aim of this layer is to provide the shortest paths for the restoration routes for IP services and make the services more dynamics with the many alternatives routes over all the core optical network.

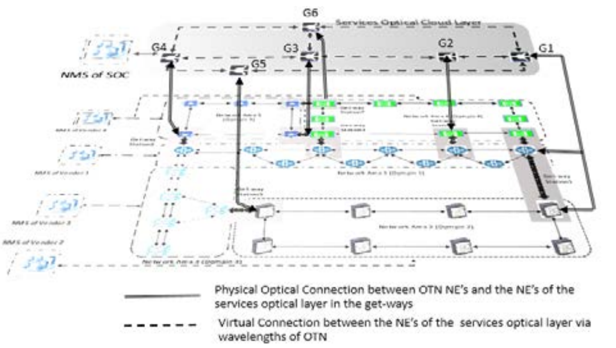

Fig. 3.b: The Services Optical Cloud (SOC) on the OTN

3.2 Building the SDN Orchestration

As our transmission model is heterogeneous network and consists of multiple transport technologies, multiple domains with more than 3 optical network layers and many independent network management systems (NMS) to manage the domains of the network, SDN Hierarchical Multi-domain Controller is used to integrate between the different network domains and different NMS's of the optical network. The controller concentrates on the control techniques among the multiple domains, and The SDN orchestration consists of parent controller, Domain controllers, and abstraction layer as shown in figure 4. The abstraction layer is used to transform between the physical layer of legacy equipment and the SDN layer by virtualizing the network resources. The Parent Controller (PC) has the complete view of the overall network, performs end to end paths computations between the different domains, shares the instructions, and the network information between the other domain controllers. The domain controllers perform the needed actions from the parent controller on its domain only. When a new connection is needed to be established the PC builds the end to end connections and sends the information of the connection to the domain controllers which execute the needed parts form them only [14]. The centralized architecture of the SDN enhances the recovery time in the overall network, where it minimizes the number of node reconfigurations which needed time for the restoration by bundling the configuration policies to the need domain controller. The parent controller distinguishes between the different paths frailer by using field type where the primary path has n = 0 and secondary paths n > 0, according to the filed type of the failure path the parent controller decides the restoration domain of the network [14]. The principle of the operation is developed by an Open-Flow rule, and based on appropriate protocol, such as the Netconfig/YANG data model as shown in figure 5 [15].

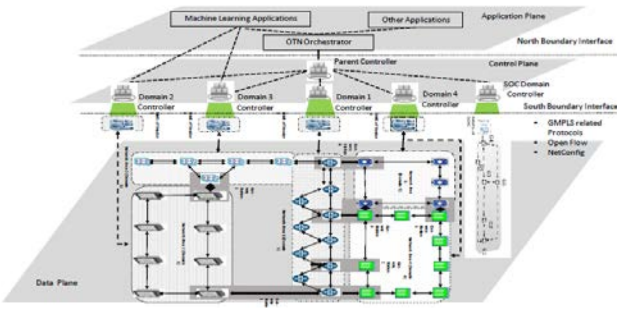

Fig. 4: The Prosed Model of the Intelligent Software Defined Optical Network

```
augment "/ser:set-service/ser:input" {
        ext:augment-identifier "otn-set-service-input";
        list service-constraint{
                key "index";
                leaf index {type ttypes:constraint-id;}
                uses ttypes:common-constraint;
                leaf service-constraint-type {type ttypes:service-constraint-type;}
                ......
        }
        container source {
                leaf node-ref {type tnode:node-ref;}
                leaf node-connector-ref {type tport:node-connector-ref;}
                leaf access-if-type {type taccessif:access-if-type;}
                list port-constraint{
                  key "index";
                  leaf index {type ttypes:constraint-id;}
                  uses ttypes:common-constraint;
                  leaf port-constraint-type {type ttypes:port-constraint-type;}
                }
        }
        container destination {
         ......
        }
}
augment "/ser:service-updated" {
        ext:augment-identifier "otn-service-updated";
        uses otn-service;
}
```

Fig. 5: An example of OTN services YANG Data Model

By assigning appropriate weight values to every optical link in the different domains, the traffic will be distributed according to the available capacities and the stabilities of the optical links. The SDN orchestrator collects the information's about the performance of the status of every link in the different domains.at the time of the network becomes normal the SDN parent controller reverts all the restored links again to its main routes after checking its performance [16-17].

3.3 Past experience of resilience network behaviors

The purpose of the suggested system model of the ML in the long distance optical network is to observe the changes in the performance of the optical links, by analyzing the actual values of the OSNR in the different optical links with its designed values. The monitoring processes will be done from the records on the change management database (CMDB) of the NMS's of every domain, in case of recognizing any fluctuations in the OSNR values, it will signal these variations and will develop its predictions system according to these data, at the same time the model will advise the optical links for the restoration or for carrying working services, the ML will classify all of the optical links according to the experience of its performance and by using a smart optical performance System (SOPS). The model will cover all the OSNR monitoring duties for the primitive links in the DWDM network. Also, it will handle end to end optical layer performance in the complete optical network. The training data is used from the change management database (CMDB) of the NMS systems and are grouped according to every Optical port type in the NE as following: Transmit power, Receive power, Error rates, Receive End of Live power (EOL), Optical Fiber span attenuation and ONSR. Table 1 explains the different types of data which is used as input or output in the SOPS for Every NE [18 -19]. The data set which used to learn the model is a selection from the CMDB of the NMS according to the next parameters:

$$\theta_{att}= r \quad (6)$$

$$\theta_{rx}=1- r \quad (7)$$

$$OSNR_{Tx}=\frac{P_T}{P_Q F_T} \quad (8)$$

$$OSNR_{Rx} = \frac{P_R}{P_Q}\left(\frac{P_N}{P_Q} + \theta_{rx} F_R - 1\right) \quad (9)$$

$$\frac{OSNR_{Rx}}{OSNR_{att}} = \frac{\theta_{att}}{\theta_{rx}} = \frac{r}{1\text{-}r} \quad (10)$$

The evolution of the model will be done according to many example of the data set which is not used in the learning phase and the errors will be calculated by using the root mean square errors (RMSE) will be used as the following [28]:

$$RMSE=\sqrt{\frac{1}{N}\sum_{\bar{k}=1}^{\bar{k}=N}(\hat{r}_{\bar{k}} - r_{\bar{k}})^2}$$

(11)

Table 1. Variables of IOPM.

Parameter	Transmitter port	Receiver Port	Amplifier card
Optical power	Input	Input	Input
BER		Output	
OSNR	Output	Output	Output
Amplifier Gain			Input
Fiber Span Attenuations		Input	
Line Rate	Input	Input	

The initial phase of formulating the model is the training phase and the data set in this phase is collected from the CMDB of the NMS for each NE with optical ports with bit rate 10 Gb/s or more. There are linear associations between output determinants (OSNR & BER) and the input determinants as following [25-26]:

$$OSNR = 10\frac{S}{N} \quad (12)$$

$$10\, log_{10}(BER) = 10.7 - 1.45\,(OSNR) \quad (13)$$

$$Y_{1k}(x) = f\left(\sum_{n=1}^{n=d}\sum_{i=1}^{i=m} a_i x_n^k + w_0\right) \quad (14)$$

$$Y_{2k}(x) = f(\sum_{n=1}^{n=d} \sum_{i=1}^{i=m} a_i x_n^k + w_1) \quad (15)$$

Where:

- S represents the linear optical signal power,
- N represents the linear optical noise power.
- $Y_{1k}(x)$ is the expected output of the OSNR in the port number k
- $Y_{2k}(x)$ is the expected output of the OSNR in the port number k
- a_i the coeffecient value of the hidden layers from
- x_n^k is the input of n variables for port number k inthe network
- w_0 is the fixed wiegth between input variables and output OSNR
- w_1 is the fixed wieght between the input vaiables and the output BER

The design model consists of 3 layers, the 1'st one is the input layer which contains n variables and m ports and the 2'nd layer is the hidden layer and forms the association between input and output with p coefficient and the 3'rd layer is the output as shown in figure 6 [27].

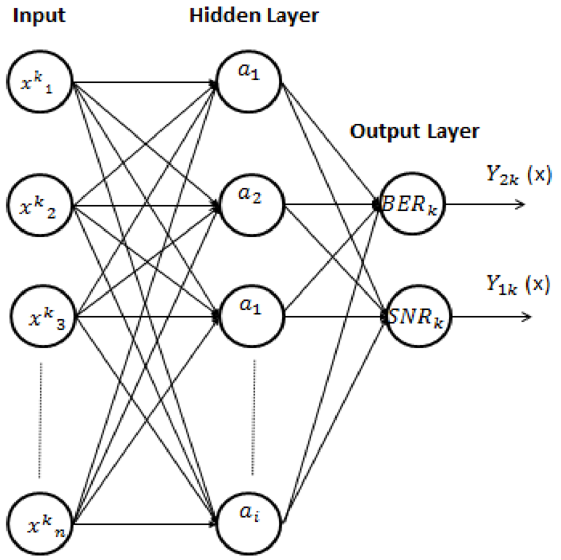

Fig. 6: The Proposed Artificial Neural Network for Optical Performance model

4. Network scenarios and analysis

There are many scenarios for network failure as following:

Network failure with one cable cut in the domains of the network To reduce the overload on the parent controller of the SDN the reaction with one failure will be according to the control plane of every domain or according to the controller of the NMS of the domain the only interact from our system is the recommendations from the ML model about the best performance route for the resilience, by sending the best prediction route to the domain controller directly , Adding the control plane uses the LMP, OSPF-TE, and RSVP-TE to realize functions, such as automatic resource discovery, end-to-end service configuration, and rerouting, on the traditional plane. The signaling module provides the following functions through the RSVP-TE protocol: Sets up or tears down service connections according to user requests, and Synchronizes and restores services according to service status changes. The routing module provides the following functions through the OSPF-TE protocol: Collects and floods the TE link information, and Collects and floods the information about the control link on the control plane. Computes service trails and control routes. The cross-connection management module provides the following functions: Creates and deletes cross-connections, and Reports information, such as the link status and alarms [19-20].

Algorithm 1: Degraded service protection

Inputs: Graph $G(V, L, B)$, where V and L are set of nodes and links, B is the capacity of each link.
Connection request $r(s, d, b, b')$, where s and d are source and destination nodes, b and b' are full and degraded capacity.
Outputs: Primary path ρ_a and backup path ρ_b with capacity c_a and c_b of r.

1. Formulate a new auxiliary graph G' with the links of G, whose free capacity $B_{free} \geq b$.
2. Find the k-shortest path set P_1 in G', and select ρ_1 with minimum risk as working path.
3. *if* ρ_1 is found
4. Formulate a new auxiliary graph G' with the links of G, whose free capacity $B_{free} \geq b$.
5. Find the k-shortest path set P_2 for backup path in G' with link-disjoint and disaster-disjoint constraints, and select ρ_2 with minimum risk as backup path.
6. *if* ρ_2 is found
7. *return* ρ_1 and ρ_2.
8. *else if* ρ_2 is not found
9. Degrade b to b'.
10. Formulate a new auxiliary graph G' with the links of G, whose free capacity $B_{free} \geq b'$
11. Find the k-shortest path set P_2 for backup path in G' with link-disjoint and disaster-disjoint constraints, and select ρ_2 with minimum risk as backup path.
12. *if* ρ_2 is found
13. *return* ρ_1 and ρ_2.
14. *else if* ρ_2 is not found
15. Formulate a new auxiliary graph G' with the links of G, whose free and backup capacity $B_{free}+ B_{back} \geq b'$.
16. Find the shortest path ρ'_2 for backup path in G' with link-disjoint and disaster-disjoint constraints.
17. Degrade all the requests, whose backup path uses the links of ρ'_2.
18. Formulate a new auxiliary graph G' with the links of G, whose free capacity $B_{free} \geq b'$.
19. Find the k-shortest path set P_2 for backup path in G' with link-disjoint and disaster-disjoint constraints, and select ρ_2 with minimum risk as backup path.
20. *if* ρ_2 is found
21. *return* ρ_1 and ρ_2.
22. *else*
23. *return* r is rejected.
24. *end if*
25. *end if*
26. *end if*
27. *else if* ρ_1 is not found
28. *return* r is rejected.
29. *end if*

Fig. 7: Network failure with more than one cable cut in all domains of the network:

The parent controller (PC) of the SDN recognizes failure notification (through some failure detection and scheme), after that PC will try to determine the best possible re-routing trail nearby the failure according to the parameters of the ML output based on the information it has about the current state of the network. After the backup path is estimated, information is sent to all the related domain controllers to reconfigure their switching parts to fit this path. In the multi-layer systems that are recognized failures are either one of two types: logical, such as an IP service, which is ICC in our model, or optical layer such as VCOTN and SOC in our model. There are thus four possible scenarios, depending on the source of the failure, and the layer that produces the resilience [23-24]:

- Failure and restoration in the optical-based on the primary routing as shown in figure 7. a, b. The connectivity in the optical layer and the resulting connectivity in the logical layer throughout a regular mode of administration. The altered light path is retrieved away from the failure using optical capacity that was stored for this object. The administration is transparent from the logical layer, which stays unchanged.
- Failure and recovery in the logical layer. After failure, the service is rerouted using the residual capacity of the logical layer. The operation is transparent to the optical layer.
- Optical failure repaired in the logical layer, as optical failure recovered in the logical layer. If the optical layer fails to overcome from the optical failure after a specific time-lapse, the logical layer can recover the service on a different logical path, using, for instance, implicit Label Switched Path (LSP) protection in MPLS

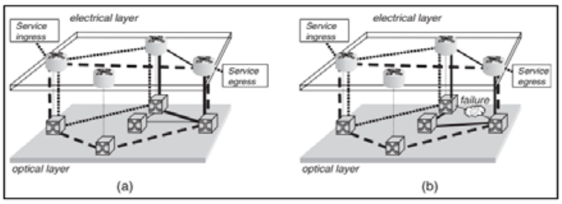

Fig. 8. Failure and recovery in the optical based

Logical failure corrected in the optical layer. Unlike any of the earlier protection schemes, retrieving from a logical failure with advantage from the optical layer includes reconfiguration with the formulation of new associations in the logical and the optical layer. This type of recovery may be necessary if after a logical failure the remaining capacity in the logical layer is insufficient to reroute all the altered services. Further logical capacity can be performed with the provisioning of new lightpaths [21-22]. This situation indicates a minimum of

Synergy between the restorations structures used in each layer; the optical layer does not understand a priori the logical connectivity of the client and

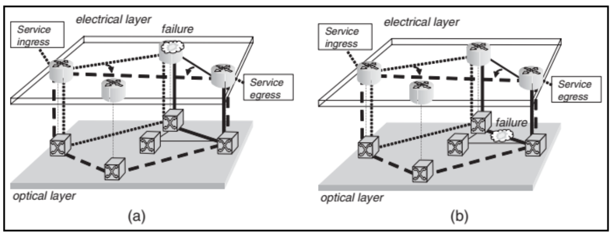

Fig. 9. Optical failure repaired in the logical layer

Hence cannot take the ambition to retrieve from a logical failure. Both layers, however, could organize their effort to return as shown in figure 9.

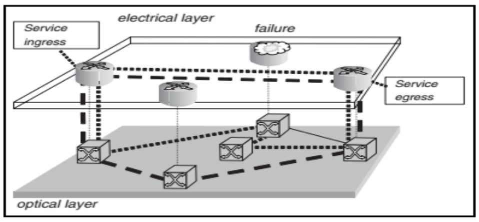

Fig. 10. Logical failure corrected in the optical layer

5. Practical Experiments and Results

The system is designed by using ANN and actual experimental input data of 500 records with 5 input variables (TX transmit power, Rx receive power, ER error rates, OSNRt, and OSNRt) and 2 output variables (BER and FL fault location), table 2 illustrates the correlations between the variables

$$\widehat{\boldsymbol{BER}} = 0.357 + 999.977 * \mathrm{ER} + -4.776\mathrm{E} - 7\mathrm{OSNRt} \quad (15)$$

Table 2. The Correlations between the different variables

		FL	Tx	Rx	SNRt	SNRr	BE
Pearson Correlation	FL	1.000	.	.	.	.	.
	Tx	.	1.000	.816	-.826	.746	.838
	Rx	.	.816	1.000	-1.000	.411	.997
	SNRt	.	-.826	-1.000	1.000	-.412	-.999
	SNRr	.	.746	.411	-.412	1.000	.412
	BE	.	.838	.997	-.999	.412	1.000

Table 2. The Test Model Coefficients

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	3.623E-9	.000		.291	.771
	BE	1000.000	.000	1.000	5090700.061	.000
2	(Constant)	1.856E-5	.000		5.153	.000
	BE	999.977	.004	1.000	227553.304	.000
	SNRt	-4.776E-7	.000	.000	-5.152	.000

We implemented Practical case study was done on the real OTN network in one of the middle east countries by applying the integration between 3 different domains with different management systems in the ASON restoration to work under one controller for important services which have strong SLA with the operator of this we achieved the following results to our significant customers:

Restoration from more than failure in the different domain in the long distance optical network for the selected services were improved from 25% for double or triple faults to 100% after applying part of our model in the long distance optical network .

The revenue from certain OTN domains which installed in the unpopulated areas and its utilization not more than 25% from the available resource the increased by more than 50% as a result of using the free capacities in theses domains in the restorations of the services from other domains

The latency from the important services which will be used in 5G decreased from 27 msec to 742 usec for the selected routes which is optimized from the centralized controller as shown in figure 11.

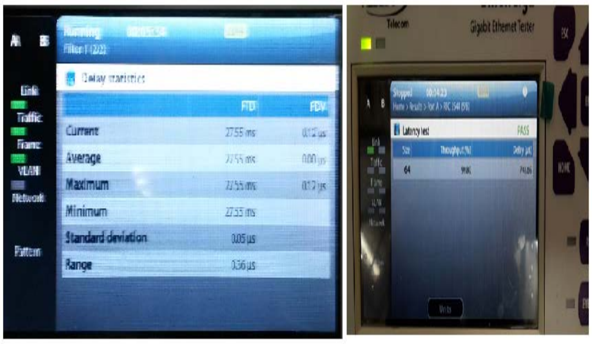

Fig. 10: The latency decreased from 27 msec to 742 usec for the selected routes

The switching time of ASON is improved 72 ms to 32 ms by about 50% if the services is sliced in layers as in our model as shown in figure 11.

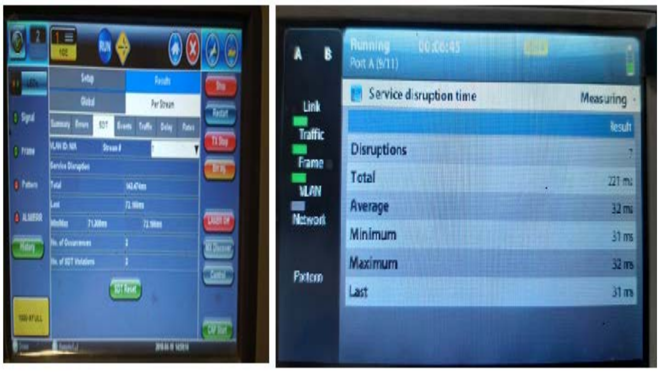

Fig. 11: The switching time decreased from 72 ms to 32 ms for the selected routes

6. Conclusion and Future Work

The future of this work will be complete simulation by using NS3 and Matlab model to implement the integration between the different functions of SDN, ML, and the OTN. The aim of the ML such the Artificial Neural Network (ANN) is to help the centralized controller of the SDN in the OTN by the past experience of the performance of the optical links in the OTN, this enables the centralized controller to assign the right decisions about the optimized routes of the restoration of the service between the different domains and multilayers in the OTN. For the first time, the optical cloud concepts are introduced in the OTN by slicing and virtualizing the various domains with its vendors in the heterogeneous optical network to 3 integrated unified layers, this provides the required resiliencies and the bandwidth on demand between the multilayers and the different domains in the OTN in a more elastic way. The model is tested using 2 methods , the 1'st method is done by a software simulation by using a SPSS software, and practical experiments to integrate between the different domains of optical network, the centralized controller of the SDN and the ANN to perform the routing and the reliance mechanisms between the multilayers and many domains in the heterogeneous OTN , the 2'nd method was done by performing practical case study on the long distances heterogeneous OTN network in one of the middle east countries about the integrations between the different optical network domains and slicing the optical network to 3 layers to perform the resilience of the services of the multi failure in the same domain through the multilayers in optical network. The results of the new model according to the practical case study in the long-distance heterogamous OTN show that: the dependence on the single vendor is nearly neglected with applying the concept of the clouding and slicing in the heterogeneous OTN, the pay for the end-users bandwidths has become possible and the time to provide the bandwidth on demand has become very short , the meshing between the heterogeneous optical network became available and the resilience for diamond services improved from 25% for double or triple faults to 100% after applying part of our model in the long distance optical network the resources, the available bandwidth of the optical core network is optimized by more than 25% , the revenue from some OTN domains which have free bandwidths more than 50 % is increased by more than 50%, the switching time enhanced by about 50% and the latency reduced from 27 msec to 742 usec for the selected routes which is optimized from the centralized controller.

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