WDM Based Passive Optical Network Enabling Security Enhancement and Reliable Protection

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***Abstract*-Passive Optical Network (PON) solves the bandwidth bottleneck issue as they extend optical network to homes and business. Time Division Multiplexed Passive Optical Network (TDM PON) was implemented using a point to multipoint network architecture that introduces the need for the inclusion of filtering or encryption scheme to maintain user security in the downstream direction. This possibility for security breaches introduces the need for an enhanced security mechanism in PONs. A secure PON can be obtained using Wavelength Division Multiplexed Passive Optical Network (WDM PON). The physical security enhancement can be obtained through inclusion of broadband light source in the Optical Line Terminal (OLT), to create a signal in which each data frame is transmitted at unique wavelength. Security features in PON structures has been studied by introducing eavesdropping. Further fiber fault monitoring approaches for Fiber-to-the Home (FTTH) with a Passive Optical Network (PON) has been presented where Fiber Bragg Grating (FBG) is placed on each branch of the Optical Network Unit (ONU). To provide protection restoration a set of fifteen 2×2 optical switches was designed to allow multiple switching signal routes especially in the drop region (optical splitter to OpticalNetwork Units (ONU)), thus improving the survivability of i-FTTH applications. Simulation is done by using OPTISYSTEM ver.12.**

Keywords:Access network, Fiber-to-the-x, Passive optical network, Fiber Bragg grating.

I. INTRODUCTION

Fiber to the home (FTTH) is currently experiencing technological advance that provides enormous band width and long reach offering Triple Play services (data, voice, and video) on a single fiber. FTTH is being the best solution for providing add-on services such as Video on demand; Online Gaming, High definition television (HDTV) etc. Among various FTTH implementations, Passive Optical Network (PON), which can provide very high bandwidths to the customers, appears to be an attractive solution to the access network. In contrast to conventional networks, a PON has no active components between the central office and the customer's premises. Instead only completely passive optical components are placed in the network transmission path to guide the traffic signals contained within specific optical wavelengths. A PON is a Point To Multi Point (P2MP) optical network, where an Optical Line Terminal (OLT) at the Central Office (CO) is connected to many Optical Network Units (ONUs) at Remote Nodes through one or multiple 1:N optical splitters. The network between the OLT and the ONU is passive, i.e., it does not require any power supply. PONs use a single wavelength in each of the two directions—downstream (CO to end users) and upstream (end users to CO). Other than offering high bandwidth, a PON system offers a large coverage area, reduced fiber deployment as the result of its P2MP architecture, and reduced cost of maintenance due to the use of passive components in the network.

At present, most of the PON deployments utilize Time Division Multiplexing (TDM) technique, in which dedicated time slots are assigned to each subscriber connected to the PON. Time Division Multiplexed Passive Optical Network (TDM PON) was implemented using P2MP network architecture. The bandwidth provisioned by an optical channel and the hardware in the CO are, thus shared among all the users, which is highly desirable to reduce the cost of access networks. Due to its cost effectiveness, the TDM PON has emerged as the current generation PON. However it is quite likely that the TDM-PONs today cannot support the bandwidth-exhausting multimedia services like IP-television and HD quality VOD. Besides, TDM-PONs are never economical from the network investment point of view, i.e., TDM-PONs has not fully taken advantage of the optical fiber bandwidth, which is actually infinite. Also there are several security vulnerabilities in TDM PONs. On the other hand, WDM-PON currently available offers enough bandwidth not only for present but also for future multimedia broadband services and fully utilize the optical fiber bandwidth. Incorporating Wavelength Division Multiplexing (WDM) in a PON allows one to support higher bandwidth since each wavelength is dedicated to a single subscriber. The WDM PON offers other advantages such as ease of management and upgradability, strong network security, high flexibility with data and protocol transparency, so that it has been considered as a future proof access technology [1-6].

II. SYSTEM ARCHITECTURE

A. PON Security

TDM PONs are susceptible to two types of security concerns: eavesdropping and theft of service. The point-to-multipoint downstream nature of TDM PONs is the source of potential eavesdropping occurrences. Fig 1 shows how potential eavesdropping can be achieved in the downstream of a TDM PON. A conventional PON uses a filter to prevent users from accessing frames not intended for them. Eavesdropping can be implemented by disabling the filter at the first ONU. Once the filter has been disabled, the user will have access to all frames that are being transmitted on the network.

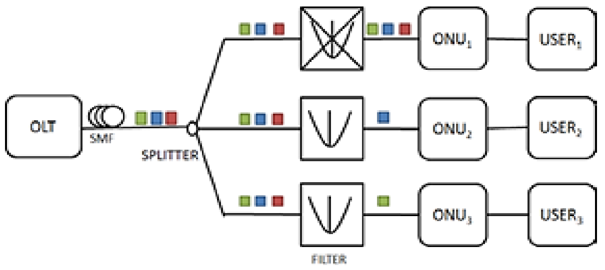

Fig 1: Eavesdropping in a TDM PON

For eavesdropping to occur in the upstream of the PON, the eavesdropper would need to have physical access to either the other users ONU or to that users input to the splitter. This situation arises due to the multipoint-to-point nature of a PON, which is inherently more secure than the downstream. Because eavesdropping is possible in TDM PONs, encryption techniques are implemented as a deterrent to potential eavesdroppers. The implementation of encryption occurs in or above the MAC layer in order to create a point-to-point link between each OLT and user in the network. However, implementation of an encryption scheme above or in the MAC layer still allows ONUs to discover neighbouring MAC addresses, and the use of an encryption key is not a foolproof security measure [7-10].

B.Physical Security Enhancement

A preferable approach to security implementation in PON has been accomplished through the use of WDM-PON. A WDM PON scheme allow for creation of point to point link at unique wavelength between OLT and ONU. A schematic view of the WDM-PON is shown in Fig 2. Data from the different transmitters are multiplexed and then circulated with the help of Broadband Light Source (BLS). The Broadband Light Source injects the signal to lock the OLT and allow the single wavelength to move from input port to the output port.

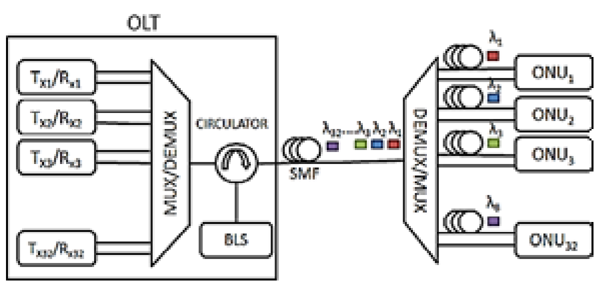

Fig 2: Physical Security in WDM-PON

In order to verify the physical operation of WDM PON, a 2.5Gbps data source was configured in the Optical Line Terminal using Optisystem. Data from the OLT is then circulated with help of the Broadband Light Source (BLS) and transmitted onto a 20 km length of single mode fiber (SMF), at that point data was demultiplexed and then transmitted to each destination ONU through 5 km single mode fiber (SMF)[11-14].

The secure nature of the WDM-PON design is verified by attempting to eavesdrop information intended for ONU 1. In this eavesdropping attempt the optical filter used after demultiplexer to filter out the λ1 wavelength of first ONU is followed by a second filter and further amplified by an Erbium Doped Fiber Amplifier (EDFA) to increase the power level of the signal that is intercepted.This setup is done in order to attempt to access the wavelength intended for the second ONU at the input of the first ONU. Further enhanced PON architecture can be designed by the use of matched Tunable Lasers (TLs) in the OLT [15-16].

C. Fiber Fault Monitoring

Passive Optical Network (PON) monitoring is very important in order to reduce the operational expenses. For Wavelength Division Multiplexed Passive Optical Networks (WDM PONs) the reliability might be more critical as the aim is to transport high capacity services. A conventional Optical Time Domain Reflectometer (OTDR) which operates at single wavelength is not able to detect branches beyond the wavelength selective component of the Remote Node (RN) of a WDM-PON. In this study, a simple and robust method to detect optical fiber cut in Passive Optical Network (PON) has been proposed. The unique reflection spectrum from Fiber Bragg Grating (FBG) that is located in each Optical Network Unit (ONU) is manipulated inorder to detect the fault in the network.

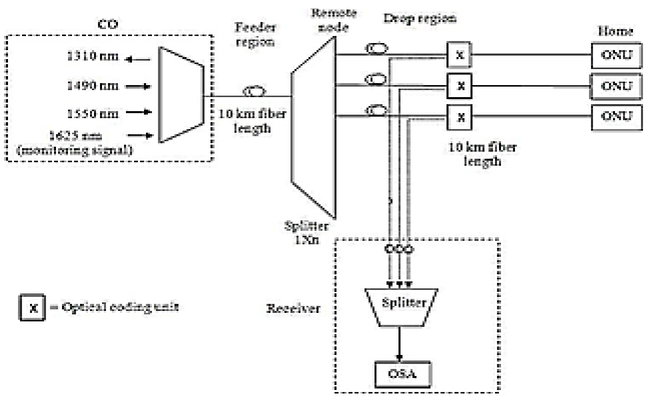

Fig 3: Block diagram of PON monitoring system

Fig 3 shows the block diagram of Passive Optical Network (PON). The laser source used is the Distributed Feedback (DFB) laser. The wavelength of the downstream signals is 1490 and 1550 nm while the upstream signal is 1310 nm. The monitoring signal wavelength is 1625 nm. The optical link distance for this PON system is 20 km. The downstream signals and the monitoring signal will pass through the 20 km optical fiber length. Using a splitter the signals will be separated to each Optical Network Unit (ONU). The optical coding unit consists of a Fiber Bragg Grating (FBG). Each ONU will have a unique FBG reflection signal to differentiate each network.The unique reflected signal from each network will distinguish the network.In real application, only the Optical Spectrum Analyzer (OSA) is required to analyze the reflected signal from the FBG [17-19].

D. Protection Restoration

A basic 2×2 switch contains two inputs and two outputs and exhibits two switching states one is the straight state, which is also known as the bar state, and the other is the swap state,which is also known as the cross state. A new switching configuration is proposed through an optical matrix switch for the selection of an optical propagation route between input and output ports. Optical switch matrices, as key components in the optical communication systems, are the signal routing modules in the optical layer. However, there are several types of optical switching matrix that are based on different mechanisms, such as micro-electro mechanical systems based optical switching, thermo optical switching, and electro-optic switching matrices .

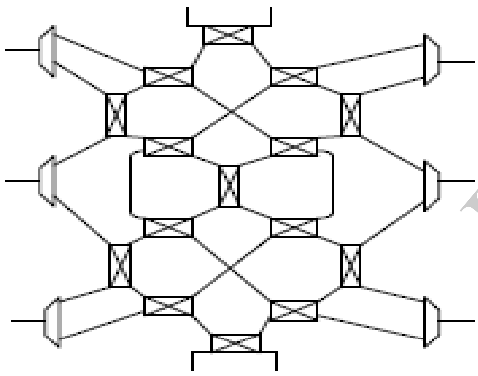

Fig 4: Optical switching matrix architecture

As for this work, the design of the matrix switch consists of fifteen 2×2 electro-optical switches arranged in a unique manner (as shown in Fig 4) to increase the number of signal routes (possible 8 routes with good bit-error-rate BER characteristics). An attractive access network restoration candidate employing an optical matrix switch is designed and characterize its diversion capacity and flexibility in a proposed Ethernet Passive Optical Network (EPON) intelligent fiber-to-the-home (i-FTTH) network. A set of fifteen 2×2 optical switches was designed to allow multiple switching signal routes especially in the drop region (optical splitter to Optical Network Units (ONU)), thus improving the survivability of i-FTTH applications.

In the proposed protection scheme, routes can be classified into three failure orders. Failure Order 1 is characterized by the detection of one fiber fault in a working line fiber (see Fig 5). In this case, the optical signal is routed to the neighbouring line for protection and returned to the end user. In Failure Order 2 (i.e., two fiber faults detected in a sequence line), neighbouring-line protection is used as a restoration route to return the optical signal to the original path. Similarly, in Failure Order 3 (i.e., three fiber faults), the optical signal finds a standby neighbouring line protection to use the alternative protection path.

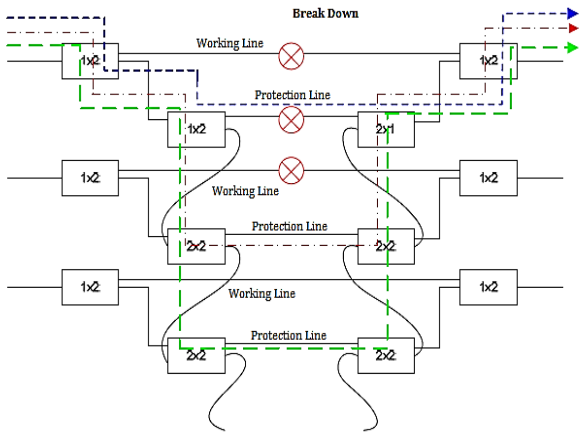

Fig 5: Multiple failure order routes according to proposed restoration mechanisms.

In the protection restored network mixed WDM systems with equal transmission technique to distribute both IM and PSK signals simultaneously are designed. This work demonstrates a simultaneous IM and PSK formats utilization in WDM system and show potentialities of future mixed transmission.

III. SIMULATION RESULTS OF PON NETWORK

To verify the proposed physical security implementation scheme, a 2.5 Gb/s single data source was configured in the OLT using OptiSystemver.12. The design of the PON is such that the OLT generates a transmission spectrum consisting of four wavelengths with 100 GHz spacing between adjacent wavelengths.The transmission spectrum of the PON at the input to the demultiplexer is shown in Fig 6.

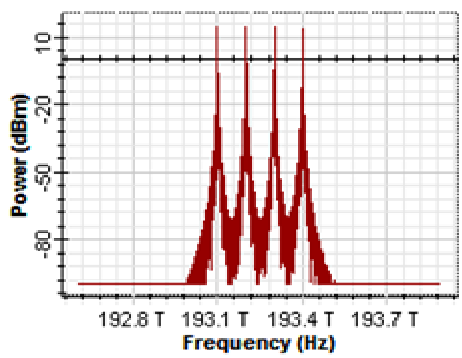

Fig 6: Transmission spectrum at demultiplexer input

At the demultiplexer, the data stream is divided into its component frequencies, each of which is routed to its corresponding ONU. The transmission spectrum verifying that only the wavelengths intended for each of the first ONUs is received at their inputs is shown in Fig 7.

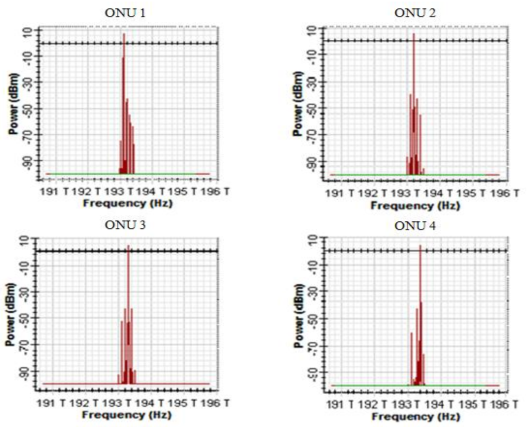

Fig 7: Optical spectrum at ONU 1, 2, 3 and 4

In order to show the secure nature of WDM PON both the PONs simulation results are compared. Fig 8 shows the simulation results of TDM PON and WDM PON without filter.

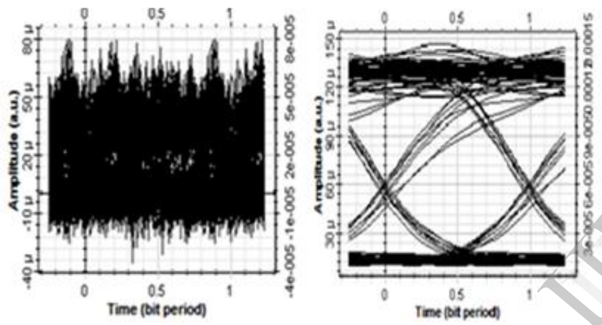

Fig 8:Eye diagram of TDM PON and WDM PON without filter

From the first eye diagram in Fig 8 we can state that if one of the filter in the ONU section of TDM PON damages the user at that ONU will not receive the correct data. In a WDM PON absence or damage of the filters does not affect the data output at the ONU. Second diagram in Fig 8 shows the eye diagram of WDM PON without the filter at the ONU. And we obtain a clear eye diagram indicating that almost full data is present at the ONU.

TABLE 1: Comparison of TDM PON and WDM PON

PON STRUCTURES		Q Factor	BER	Eye Height
TDM PON	With filter	3.343	1.984e-003	1.0571e-007
	Without filter	2.0032	1.9937-002	-1.8662e-005
WDM PON	With filter	7.9658	5.855e-016	3.6535e-002
	Without filter	7.7539	3.5e-015	3.756e-002

The Q factor, bit error rate and eye height of the PON structures are compared in Table 1. It is inferred that WDM PON has no effect on the removal of filter from the ONU. So even if the filter at the ONU of the WDM PON damages or malfunctions there is no chance of security breach in the structure of WDM PON. Thus it provides a better security than that of TDM PON if the filter fails. The eye diagram display at one of the ONU and eavesdropped ONU of WDM PON is shown in Fig 9. From the second eye diagram it is clear that the original information of the particular ONU cannot be reconstructed from the adjacent ONU. The eavesdropped eye diagram has a maximum Q factor of only 3.97902, minimum bit error rate of 0.0001508 and eye height of 3.03e-005.

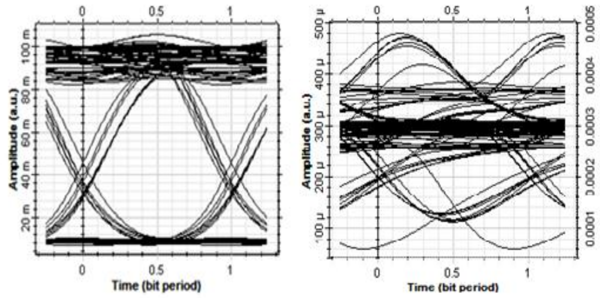

Fig 9: Eye diagram of errorless ONU and eavesdropped ONU

Fiber break is yet another problem associated with PON structures. Restoration of the fiber break can be done if proper monitoring is done. Here a monitoring system with FBG is designed. Each ONU will have a unique reflected signal from the Fiber Bragg Grating (FBG). In this simulation, the grating length of the FBG is manipulated in order to obtain a unique reflected signal from the FBG. Fig 10 shows the result from OSA when there is no cut in the optical network. This is the accumulated reflected spectrum from the FBGs from each network.

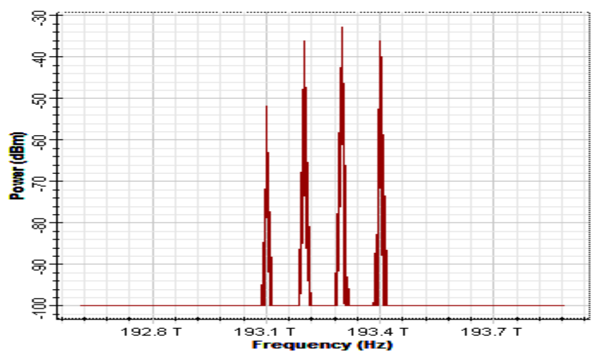

Fig 10: Optical Spectrum which shows that there is no fiber cut in the PON system

Fig 11 shows the result when there is a cut in ONU. Based on the comparison with the Fig 10 and Fig 11, the status of the cable connected to the ONU can be determined.The fiber break restoration can be done using a new optical device model named as an optical cross add and drop multiplexer (OXADM) which has potential use in CWDM metro area networks. OXADM is capable to restore the network during the failure condition by means of ring protection and linear/multiplex protection. If there is a fiber breaks in working line, the protection mechanism uses neighbouring line protection to provide an alternative path for the working line.

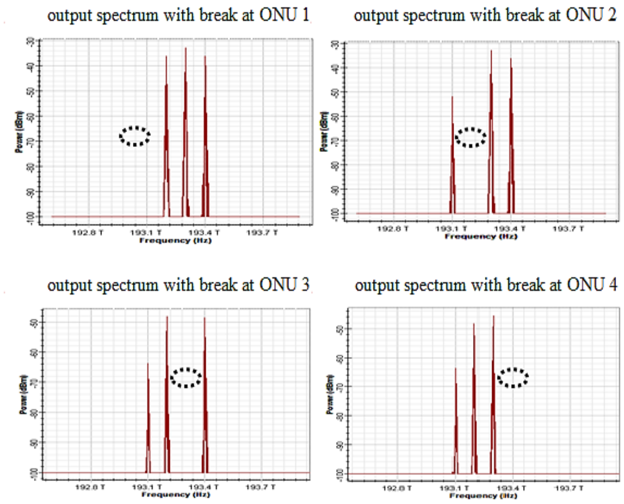

Fig 11: Optical Spectrums which shows that there is fiber cut in the PON system at ONU 1, 2, 3 and 4

The protection restoration is done in the PON network through optical matrix architecture. The routes available for re-route capability offered by the device is being classified according to number of optical switch involved in a route. Routes can be classified into three failure conditions. Condition A is characterised by the detection of one fiber fault in a working line fiber. In condition B, two fiber faults are detected in a sequence line. Here neighbouring-line protection is used as a restoration route to return the optical signal to the original path. In condition C (i.e., three fiber faults), the optical signal finds a stand by neighbouring line protection to use the alternative protection path.Wide opening eye diagrams can be seen for condition A and B for both wavelength type but not for condition C. This is due to the increase number of switches hence the amount of insertion loss. This is illustrated in Fig 12.

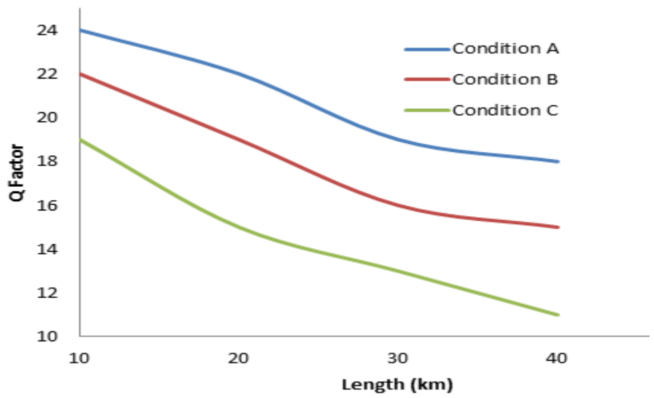

Fig 12:Graph showing Q factor versus length

CONCLUSION

PON system offers a large coverage area, reduced fiber deployment as the result of its point-to-multipoint (P2MP) architecture, and reduced cost of maintenance due to the use of passive components in the network. In the PON structures eavesdropping attempt is carried out and it is observed that due to the reflections from optical distribution network eavesdropping occurs in a TDM PON whereas WDM PON is secured from eavesdropping. Thus WDM PON provides improved performance and better security than TDM PON. Fiber bragg grating provides fiber fault monitoring and protection restoration is provided by optical matrix switch architecture. In the protection restored network mixed WDM systems with simultaneous IM and PSK formats utilization in WDM system is designed and it shows potentialities of future mixed transmission.

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