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A Novel Feedback-based Integrated FiWi networks Architecture by Centralized Interlink-ONU Communication

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***Abstract*—**Integrated fiber-wireless (FiWi) access networks are a viable solution that can deliver the high profile quadruple play services. Passive optical networks (PON) networks integrated with wireless access networks provide ubiquitous characteristics for high bandwidth applications. Operation of PON improves by employing a variety of multiplexing techniques. One of it is time division/wavelength division multiplexed (TDM/WDM) architecture that improves the performance of optical-wireless access networks. This paper proposes a novel feedback-based TDM/WDM-PON architecture and introduces a model of integrated PON-FiWi networks. Feedback-based link architecture is an efficient solution to improves the performance of optical-line-terminal (OLT) and interlink optical-network-units (ONUs) communication. Furthermore, the feedback-based WDM/TDM-PON architecture is compared with existing architectures in terms of capacity of network throughput.

***Keywords*—**Fiber-wireless (FiWi), Passive Optical Network (PON), TDM/WDM architecture

I. Introduction

NOWADAYS the interest in high data-rate and demand for wireless broadband communication is growing rapidly. The congestion and the limitation of radio spectrum bandwidth have initiated growth of integrated optical and wireless networks [1].

An integrated optical wireless broadband access network is known as a fiber-wireless (FiWi) network [2]. FiWi is an efficient network for long reach wireless clients and it is an optimal solution for bandwidth hungry quadruple play (video, data, voice and mobility) applications [1, 3]. FiWi access networks are becoming rapidly popular due to its extra characteristics. It is a promising smart candidate for future access networks [3]. Integrated FiWi networks connects PON network with WMNs. It is consists of optical line terminal (OLT) and optical networks units (ONUs). The ONU acts as intermediate optical components between optical and wireless networks/WMNs.

At one end ONU's are connected with OLT through optical fiber (backbone) network, and at the other end ONUs connected to the users premises or WMNs. Traffic from the OLT to the ONUs (downstream direction), and traffic from ONUs-to-OLT (upstream direction). WDM/TDM architecture multiplexed an optical network that resides in a central switching office (OLT) and allocates wavelength as per time slots for data upstream\downstream to ONUs.

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The data (traffic) in wireless mesh networks reaches through the multiple wireless access point to the ONUs such as traffic (data) routes into two ways, first from one wireless client to another wireless client in the WMNs [3]. Second, traffic goes via wireless-optical-wireless (wireless-ONUs-wireless) is known as peer-to-peer communication. In the peer-to-peer communication, the throughput decreases due to the limitation of wavelength, bandwidth bottleneck and interference in the WMNs.

The performance of access network declines when traffic load increases on ONUs (gateways), causing link failures and data-rate losses [2]. Recently, researchers have been proposed dynamic solution to improve FiWi networks performance by using many design techniques in order to control degradation problem in FiWi networks [4-6]. In this paper, our design objective is to improve performance of FiWi access networks subject to peer-to-peer communication. Therefore, we introduced novel dynamic mechanism is "*to transmit link-status (queries) to OLT in the shortest possible time, this queries having information about link failure and traffic load on ONUs, so as to maintain overall network performance from OLT*". This technique is provides a feedback mechanism in the WDM/TDM architecture. The feedback process accomplish by feedback-based link, that improves the overall performance of FiWi networks by communicating operational information between interlink-ONUs and OLT. To efficiently support the (wireless-optical-wireless) peer-to-peer communication and adaptively adjust traffic load on ONUs, interlink-ONU communication is required. In FiWi networks, lack of throughput and delay are the challenges subject to peer-to-peer communications, the performance of peer-to-peer communication can be improved by using interlink-ONUs communications [4, 7]. In the conventional PONs [3], interlink-ONUs communication is done by OLT. We propose the centralized interlink-ONUs communication approach in this paper. The centralized interlink-ONUs communication is efficient technique and it is an allowing direct support to interlink-ONUs communication from OLT.

The centralized ONU is select in the groups of ONUs, known as intelligent (ONU_{int}). The ONU_{int} collected the link-budget status (query) from the all connected ONUs and transfers it to the OLT by using feedback based. This link-budget status (query) is cooperative indicators to allocate appropriate wavelength to ONUs. The development of the centralized interlink ONUs approach improves efficiency, reliability and scalability of the FiWi networks. Thus, wavelength allocation and availability of bandwidth capacity among optical-wireless (FiWi) networks can be improved by employing feedback based link in the WDM/TDM architecture. This paper also compares the feedback-based WDM/TDM architecture with recently presented wireless-optical WDM/TDM-PON architectures [4-6]. The rest of the paper is organized as follows: Section II reviews the related challenges.

Section-III presents feedback-based WDM/TDM PON architecture by supporting interlink-ONUs communication and compares with cutting-edge architecture. Section-IV presents the FiWi networks model. Section-V, simulation setting and Section-VI, conclude and state future work.

II. Related Work

A. Related Work on WDM/TDN PON FiWi Architecture

A several of researchers have proposed hybrid WDM or TDM architecture for optical-wireless networks [8]. These architectures have improved the performance by using diverse techniques, however the optical-loss remain exist in PON while uniform (fix) wavelength allocation broadcast from OLT to all ONUs due to the fluctuation of the user load. In [9, 10], direct interlink-ONU communication have been proposed, in which optical wavelength broadcast is achieved by spread-out techniques. In spread-out technique broadcast wavelength is selected by ONUs through coupling such as star-coupling (SC). Such techniques are effective for TDM PON. The main problem in this technique is that it has high optical-power loss and delay due to physical SC.In [11] a focused analysis has been carried out to compare the performance ofthroughput and delay in global passive optical networks EPON/GPON. Such an optical networks passive-star-coupler (PSC) connects with array waveguide grating (AWG) to maintain uniform and non-uniform traffic loads. In [12], placement of ONUsare considered to improve coverage in relation to interlink-ONU communication. The theoretical aspects [4, 13, 14]mentioned arrangements of the foundation, to propose further advancements in WDM/TDM-PON access networks.

B. Related Work on Interlink-ONUs Communication

In [15], interlink-ONU communication has been proposed to balance traffic load among ONUs. In [8], another inter-ONUs communication has been investigated to enhance the network configurability. This inter-ONUs communication is based on the wavelength assignment control via tunable radio-frequency. The drawback of such architecture is that it produces distortion due to tunable frequency. In [13], authors presented interlink-ONU communication based LP-based routing algorithms to improve distribution of bandwidth in FiWi networks.

III. Integrated WDM/TDM Architecture For FIWI Networks

In this section, a feedback-based WDM/TDM architecture is introduced to support interlink-ONUs communication, and its comparison with existing architecture in terms of inter-ONUs communication and overall functionality is presented.

A. The WDM/TDM FiWi Architecture

Use WDM/TDM architecture consists of OLT in the central switching center, an interlink-ONUs between the OLT and user side. OLT consists of two cascaded Array Waveguide Gratings (AWGs). AWG_{1*w} controls the internal functions and AWG_{2*w} is connected to ONUs. The AWG_{2*w} is used for downstream and upstream transmission and AWG_{1*w} for downstream transmission.

We propose feedback-based link in an integrated WDM/TDM-PON architecture which is shown in figure 1. A feedback link connects with a combiner and the AWG_{2*w} ports.

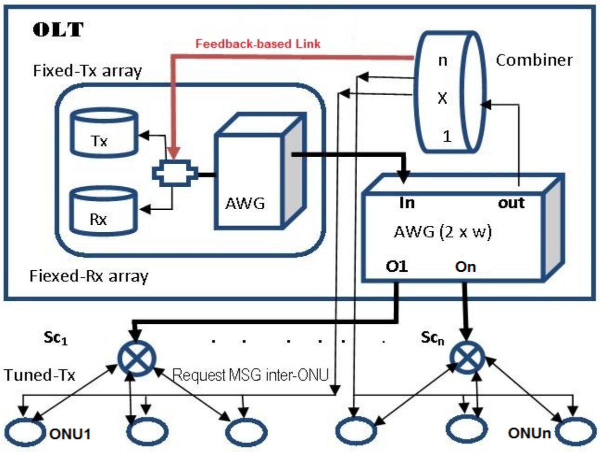

Fig. 1 Feedback-based WDM/TDM FiWi architecture

1. Optical line terminal (OLT)

Arrays of fixed number of transmitter and receivers that are used for upstream transmission of data using (AWG_{1*w}) (w*1, λ_{1s} λ_{2s} λ_{3s} λ_{4s}….. λ_{ns}) and for downstream transmission(w*2, $\lambda_{is}=\lambda_{ins}$)+FSR ($1 \leq i \leq w$), where Free Spectral Range (FSR) function used to distribute wavelengths [4]. The novel contribution, feedback-based link is employed in the WDM/TDM architecture to transmit link-budget status (query) to (AWG_{1*w}) in order to maintain the downstream and upstream wavelength as per demands of the nth ONUs. The feedback link estimated the performance of ONUs with respect to symmetrical and asymmetrical situations of FiWi networks. For example, inappropriate wavelength utilization from OLT to ONUs, if the inappropriate wavelength utilization values crossed the threshold level, the condition is called asymmetrical and if does not exceed the threshold level it is called symmetrical condition. The asymmetrical situation can be detected from the combiner ports.

Inputs port I_n is connected with AWG (1*w), with In using both upstream and downstream transmission and output port I_{out} is coupled with combiner (n*1), which is used to control the numbers of wavelengths and traffic load demands of interlink-ONU communication. The feedback-based link carries the link-budget status (query) of threshold levels from combiner ports and transmit to AWG_{1*w}. At this point, OLT activates the parameters such as reserved wavelength capacity, or add more wavelengths into the system in order to resolve the asymmetrical situation on the basis of demand of wavelength which is received from ONUs.

2. Feedback-based link

Feedback-based link accomplishes the feedback process and it offers the dynamic capability to access link-budget (query) ONUs to OLT in terms of the following mechanisms.

- It is challenging to integrate the feedback process for the WDM/TDM architecture between ONU_{int} to cascaded AWGs. Therefore, we have employed physical link of feedback in WDM/TDM architecture between two components AWG_{1*w} to combiner ports and combiner ports are coupled with AWG_{2*w} as shown in figure 1. This feedback-based link accomplished the closed loop feedback process for access link-budget (query) from ONUs to AWG_{2*w}/OLT.
- The feedback-based link established the tuning path to tune centralized ONU_{int} so as to control other connected ONUs via interlink-ONU communication according to traffic demands.

3. Interlink-ONU Communication

Centralized ONU_{int} is nominated in the group of ONUs. ONU_{int} receives the link-budget (query) and transmit it to OLT by the message-streams oriented function. The combiner can tune to ONU_{int} on the basis of wavelength driving capacity of AWG_{1*w} via message oriented hybrid slot allocation protocol (MOHSAP) protocols [16].We compares the existing interlink-ONUs communication patterns with our introduced centralized interlink-ONUs communication approach for routing traffic among wireless clients.

The existing pattern of interlink-ONUs communication in FiWi networks is ONU-to-ONU communication based on fixed wavelength allocation from OLT to all ONUs. This interlink-ONUs allows exchanging link-budget (query) to other ONUs [3]. Based on this exchanging (query) process, ONUs allocates the wavelength slots of upcoming wireless client.

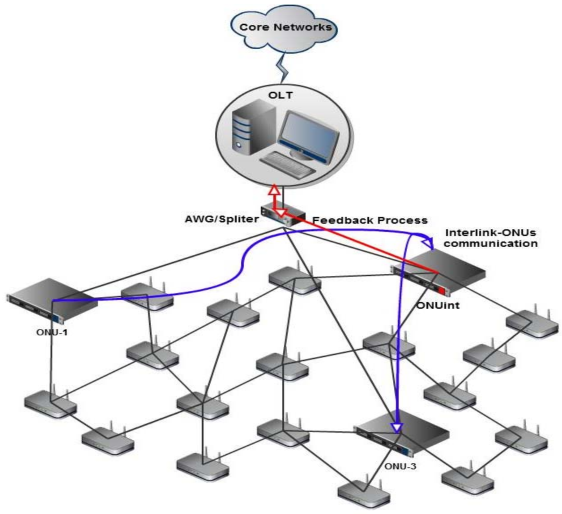

Fig. 2 Centralized Interlink-ONU communication

The introduced centralized approach ONUs-to-ONU_{int} communication pattern is maintained wavelength allocation according to demands for the link-budget (query) which is received from ONUs via ONU_{int} to OLT as shown in figure 2.

B. Comparison with WDM/TDM OLT Architectures

Feedback-based link WDM/TDM architecture supports directly to interlink-ONU communication in terms of wavelength allocation of desired ONUs. We compare the recently representative architectures [4-6] with our proposed feedback-based WDM/TDM-PON architecture. The architectures are referred as follows. A1 is referred in [6], A2 is referred in [4, 5], A3 in [5] and feedback-based adaptive architecture in A4.

The novel characteristics of A4 architecture is highlighted in contrast to pros and cons of A1, A2 and A3 architectures.

1. All architectures A1-A4 have same the connection i.e. ONUs connects with one fiber links to OLT and it further connects all ONUs.
2. Preliminary parameters of architectures in term of an array of wavelength for upstream/downstream transmission are fixed A1-A3. However, in architecture A4, ONU_{int} can be tuned from OLT.
3. AWGs are cascaded in A1, A2 and A4 architectures but in A3 it uses more than two AWGs, which is main reason to increase the cost of architecture A3.
4. A traditional architecture is based either on WDM-PON or TDM-PON. A4 architecture supports both WDM and TDM PONs.
5. The capability of interlink-ONUs communication is limited in architecture A1-A2. In A4, we introduced centralized interlink-ONU communications.
6. Feedback-based architecture A4 support downstream transmission of ONUs, while in architecture A1, A2, and A3 are not fully furnished to support ONUs.

IV. System Model

The preliminary structure of FiWi networks model is the same as [3]. The model of FiWi networks is a directed graph G= (T, E), where T is the collection of nodes, E is link range denoted as n_0, a sub-network component of ONUs (gateways) denoted as O_G and wireless mesh routers denoted as M_R.

Assume that each wireless router has channel capacity c and all wireless nodes use the fixed transmission range, and the interference ranges are D_t and D_i, respectively. Normally, D_i is α times of D_t where $\alpha \geq 1$. All nodes are connected to each other $n \approx M_R \in O_G$, wireless transmission $\nu \approx M_R$ and wireless networks link range e_{nv} ,evn ≈ E . The e_{nv} ,e_{vn} denoted as two way link range and E is the edges. System model of FiWi-PON networks is shown in fig. 3.

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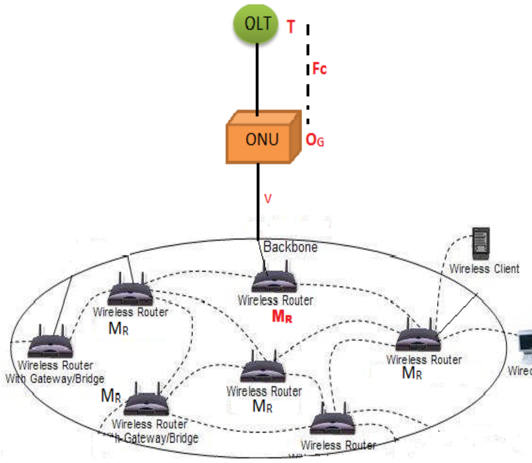

Fig. 3 System model of FiWi networks

Assume that, wavelength Δλ (variant wavelength demands) of ONU can be control from OLT through feedback-based link OG →T. Further, interlink-ONU communication is supported by feedback-based link.

The system model is divided into three sections according to the FiWi networks model.

- *Multi-flow traffic Model*

In FiWi network, wireless clients are connected with OLT through ONUs (gateway). Considering f_v is the flow vector between the nodes of the FiWi networks. The traffic i_{th} flow in the f_v which consists of s_i, l_i, and r_i denoted as source node, destination node, and traffic demand of flow i respectively. The main consideration, s_i is connected with MR ($s_i \in M_R$) and $l_i \in M_R$. In the first situation $s_i \in M_R$ source node connected with wireless mesh router and destination node l_i. If the i_{th} traffic is increasing and equal f_v to all no, then, multi-flow traffic is high among wireless clients, and traffic-load Qv (excesses-load) will increase in the dedicated path of f_v. If Qv flow in f_v, then feedback based link is activated to adjust the transmission as per demands of ONUs.

- *Feedback-based link wavelength control (FBLWC) Model*

This model offers the effective wavelength allocation setup for ONUs according to the traffic load. FBLWC reduces the wavelength utilization and improve the capacity of transmission. There are three modes of operation in order to have a functional feedback based link, *link de-active mode*, *nap-mode*, and *active mode*.

TABLE I
MODE OF FUNCTIONALITY

Modes	Function of Mode
De-active mode	Log-off users
Nap-mode	Message streaming between ONUs to OLT
Active mode	Increase capacity of ONUs

If there is no excess wavelength requirement, the user is in "*log off*" condition, and the deactivate mode will be activated. *Nap-mode* will be activated when high traffic is expected on ONUs by receiving a message from OLT as shown in figure4.

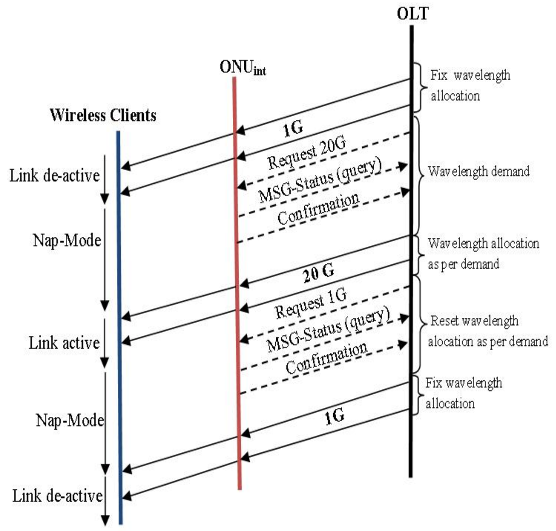

Fig. 4 Message exchange in Feedback-based link

For example, assume two transmission data-rates such as 1G and 20Gb/s between OLT-to-ONU. With the 1Gb/s mandatory data-rate the link is in deactivate mode. In the second stage, systems will go to the nap-mode condition for signaling. It applies similarly for downlink data transmission too. There are three tracking signals that represents three modes, denoted as request R_q(request), nap-mode M_g(log-off), and confirmation C_n. The first tracking signal M_g transmits to ONU_{int} for tracking expected downlink traffic of overall network. If Mg received D=20G, OLT manages the appropriate wavelength for upcoming traffic load. With the C_n signal from ONU_{int} to OLT, it tracks the status of bandwidth in terms of throughput (Th_r) either $B<Th_r$ or $B \geq Th_r$ [4]. If $B \geq Th_r$, OLT adjust wavelength systematically.

- *Interference Model*

In the feedback-based interference model, interference is controlled by using spatial time division multiple access (STDMA) scheme for scheduling the transmission as per physical interference [17]. The number of routers is M_R and M_s is cluster set of wireless mesh networks (WMNs). The edges (n,v) of MR is connected with $M_s(n,v \in M_s)$. Further, e is unidirectional and Q represents the flow-rate. Each edge e=(n,v) and Q flow f_v . STDMA scheduling period depend on the rate of Q. If the rate of Q fluctuates rapidly, instantly interference adjusts periodically by the input values of OLT.

Suppose, D_{nv} is interference between n and v, $D_{nv} = D_n + D_v$, if the ratio of interference increases between n and v, it is requires to adjust D_{nv} periodically. Interference between D_{nv} crosses the threshold level of adjustment; this link-budget information (query) is conveying to OLT by using feedback-based mechanism.

A packet correctly received, if the conditioned stated below is satisfied.

$$\frac{Pv(n)}{I} + \sum\nolimits_{Qnv'} Pv(Q) \geq C \quad (1)$$

D_{nv}denoted as interference, Q is traffic and Pv(n) is the received power at v and external parameters such as I is the background noise, V' is the transmitting capability and C is a constant which is depends on the desired data-rate.

Suppose, the condition of interference (high noise), which is greater than capability of desired data C.

$$\frac{Pv(n)}{I + Dnv, \max\,(Pv\,(i), Pv(i))} + \sum\nolimits_{Qnv'} Pv(Q) > C \quad (2)$$

As per equation (2), $C<D_{nv}$or ,$D_{nv} \geq C$, instantly that the below messages (request) is transmitted to the OLT through feedback-based process, than OLT will be operational to adjust the high noise.

V. Performance Evaluation

The A small scale of interlink-ONU communication network that communicates through digital signaling is shown in fig. 5.

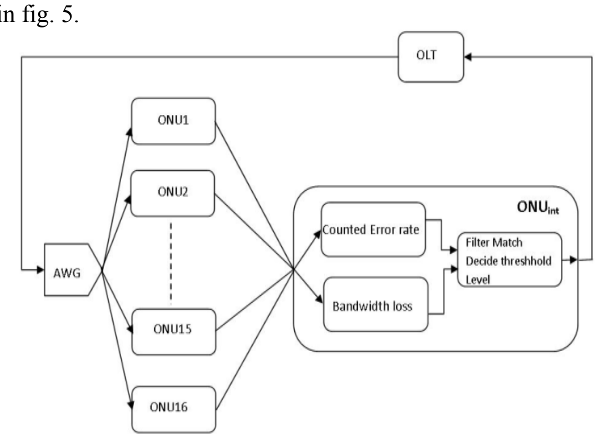

Fig. 5 Centralized Interlink ONUs Communication

In the simulation, 25-ONUs including ONU_{int} for interlink-ONUs communication are simulated in the tool of Matlab[15].ONU_{int} is collecting 25-ONUs signals and computes these signals in terms of error-rateof each ONUs. The error-rate evaluated into two forms (counted error and bandwidth loss) and then match filter set the threshold level of generated errors. If error-rate crossed the given threshold level then ONUint transmit (link-budget query) to OLT. Assume errors probability of ½ and received signal is corrupt due to addition of noise, such a channel is called an additive white Gaussian noise (AWGN) channel. ONUint observed the matched filter outputs to decide threshold level whether output is 0's or 1's respectively.

Based on error-rate threshold level, ONUint demonstrated the two scenarios.

First, high traffic load on ONUs, it causes an increased bandwidth distribution loss. Secondly, minimum traffic load on ONUs, which decreases bandwidth distribution loss, takes place error-free communication between ONUs.

In the first scenarios, the increasing traffic load on ONUs, it causes that increase counted error-rate and thus overall networks performance degrades due to increased demand of each ONUs as shown in figure 6.

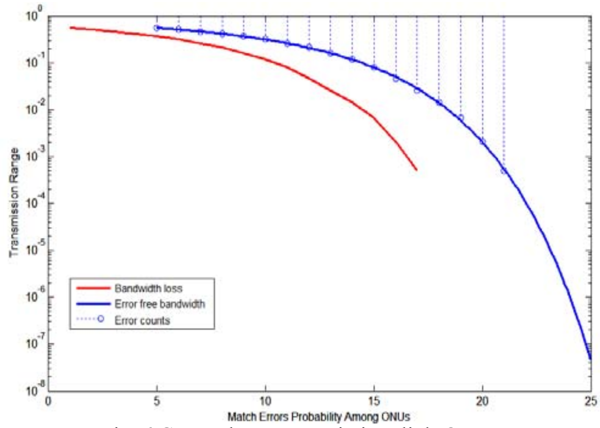

Fig. 6 Counted-errors rate in interlink-ONUs

In the second scenarios, the traffic load on ONUs is minimizing, and then transmission counts errors-free and less bandwidth distribution loss. In this scenario, ONU_{int} bandwidth-loss and there it is not shown in figure 7.

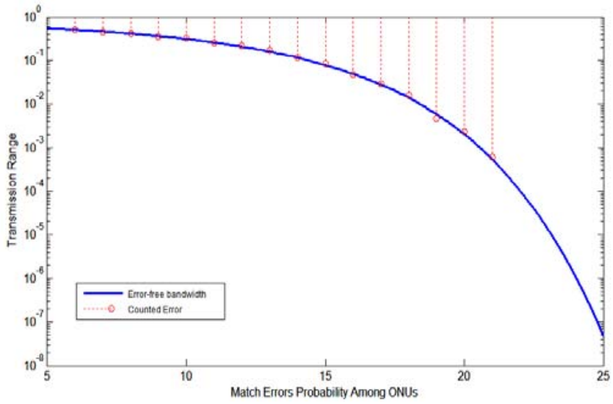

Fig. 7 Error-free bandwidth in interlink-ONUs

The evaluated results demonstrate the interlink-ONUs communication performance, which is directly influence by heavy traffic load on ONUs. Due to extraordinary traffic load on ONUs, we see an increase in error rate. OLT requires this link-budget (query) information so as to improve or utilize reserve wavelength and support directly to the ONUs as per traffic load.

Hence, feedback-based link is essential in the WDM/TDM architecture for dynamically improved performance of FiWi networks. Feedback link is therefore playing an important role to establish the feedback process and the path between ONU_{int} and OLT.

VI. Conclusion

An integrated FiWi network model has been discussed in terms of a feedback-based architecture and interlink-ONU communication. In this paper, a novel feedback-based architecture has been introduced by employing a feedback-link in WDM/TDM architecture. We also proposed centralized technique of interlink-ONU communication. The proposed feedback based architecture supports to ONUs, also it maintains over-all networks performance in terms of bandwidth allocation and wavelength demands of ONUs. In addition, feedback-based WDM/TDM architecture compares with conventional WDM/TDM architectures in many aspects. In future, this novel approach enables the dynamic fault allocation self-healing and it is important for applications demanding high data-rate transmission.

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