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Research Article

Energy-Efficient Regional Area Metropolitan Optical Access Network (RAMOAN) Using Modified Load Adaptive Sequence Arrangement (M-LASA) Methodology

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Energy efficiency in optical networks is one of the important criteria to attain enhanced performance. Better energy efficiency can be attained in optical networks if the resources are properly scheduled. Polling sequences perform resource scheduling based on load requirements, and various methodologies have evolved in recent times for better efficiency. Load adaptive sequence arrangement (LASA) is one of the familiar and efficient methodologies adopted in various methodologies. However, the power consumption and idle time of optical network units are high which should be reduced to attain optimal network performances. Considering this, a modified LASA is presented in this research work for the regional area metropolitan optical access network (RAMOAN). The modified LASA is obtained by integrating the first-in-last-out polling sequence such that the proposed arrangement provides a better coverage radius, minimal power cost, maximum access reach, maximum energy saving, and minimal delay and energy cost. The better performance of the proposed approach is compared with traditional time and wavelength division multiplexed (TWDM), TWDM-protected, and RAMOAN with LASA through simulation analysis to validate the better performances of the proposed model.

1. Introduction

The wide range of optical access networks provides numerous applications in various domains. However, this optical access network faces issues in terms of energy efficiency due to high idle time, switching, and other data transmission between the layer elements. Researchers provided numerous energy-efficient strategies to minimize the energy consumption in optical access networks based on transmission procedures, communication protocols, and scheduling of resources. The research to attain energy-efficient optical access networks introduces numerous challenges. Specifically, energy efficiency in passive optical networks gains more attention due to the dynamic traffic, increased data volume, and diversity. Different types of passive optical networks (PONs) are introduced in recent times based on wavelength, time, and a combination of time and wavelength. These variants of PONs lag in performance due to unique wavelength and switching characteristics. Among all, time division and wavelength division multiplexed PON gains more attention due to better energy efficiency.

The major objective of this research wordk is to provide an energy-efficient RAMOAN. To attain better energy efficiency, the existing approaches utilize different polling sequence arrangement methods. However, the energy efficiency of the RAMOAN can be enhanced by combining the sequence arrangement with polling methodologies. Resource scheduling in the RAMOAN through a modified load adaptive sequence arrangement is presented in this research work to reduce energy costs and enhance energy efficiency. Some of the major contributions of this research work are presented as follows:

(1) The energy-efficient RAMOAN using modified LASA is presented to enhance the coverage radius, minimal power cost, maximum access reach, maximum energy saving, minimal delay, and energy cost
(2) Comparative analysis of the proposed model and existing TWDM, TWDM-Protected, and the RAMOAN with LASA structures to demonstrate the better performance of the proposed model

The following is the sequence in which the research is organized: Section 2 presents a brief assessment of the existing literature. Section 3 describes the proposed modified LASA-integrated RAMOAN. Section 4 presents simulation results for the proposed model as detailed comparative analyses. Finally, Section 5 presents the summary of the research.

2. Related Works

A detailed literary analysis of energy efficiency approaches that evolved in recent times is summarized in this section. Energy efficiency in PON Optical Network Units (ONUs) is analyzed based on TWDM [1]. The TWDM reduces the energy consumption of the optical line terminal (OLT) by providing idle periods through scheduling. The traditional systems acquire an energy-efficient system by switching on the OLT receivers only for specific wavelength scheduling and remaining off for other wavelengths. However, this introduces a delay in the upstream data and it is overcome by the proposed online scheduling protocol. The presented approach overcomes the limitations of traditional approaches and improves energy efficiency with minimum computation complexity. The TWDM-PON considered for analysis in [2] presents a node aggregation model based on a lightweight software-defined networking approach. The presented approach allows the node to connect with an optical line considering the dynamic bandwidth and wavelengths.

In general, the energy efficiency analysis in traditional approaches considers the transitions between active mode and sleep mode. However, this leads to quality of service degradation due to device temperature cycling and wavelength reassignment processes. To overcome this, a wavelength-postponed switching-off approach was presented in [3] to minimize the power state transitions. The presented approach postpones the power off redundant wavelengths and provides a better balance between device lifetime and energy efficiency than traditional approaches. An adaptive scheduling algorithm for ONU was presented in [4] for the virtual PON to reduce the delay and establish a better balance between load and resource wastage. The scheduling algorithm is presented for the multiwavelength PON with different tuning times to reduce the queue delay and bandwidth wastage in the network.

An efficient clock gating-based approach for orthogonal frequency multiplexing PONs was reported in [5] to enhance the energy efficiency of ONU applications. Traditional approaches categorize the received frames based on ONU, and later, it is used to control the orthogonal frequency division multiplexing (OFDM) demodulation module clock. However, for the nonlocal frame, the demodulation is deactivated in the traditional approaches due to the low operating clock. To overcome this, the presented approach introduces clock control modules and frame identification techniques to enhance energy efficiency. A similar OFDM-PON was considered for analysis in [6] to enhance the energy efficiency in upstream data transmission. Traditional schemes consider the time and frequency domains to ensure the energy efficiency of upstream data transmission. The presented approach provides a flexible energy-efficient configuration to enhance the energy efficiency in upstream data transmission by formulating a heuristic algorithm and solving the short-span of time problem.

To attain better energy efficiency in elastic optical networks, an adaptive power-aware algorithm was reported in [7] using learning automata. The presented approach controls the operations of bandwidth-variable optical transponders to balance the utilization. In the event of low utilization, these transponders are switched off by the presented algorithm to maintain energy efficiency. Meanwhile, the learning mechanism monitors the network and finds the optimal energy-saving point to avoid congestion, which further reduces energy consumption compared to traditional optical networks. A flex grid elastic optical network energy consumption analysis was presented in [8] considering the mismatch between optical channel capacities and IP traffic. The presented traffic grooming model formulates the issues as auxiliary graphs and introduces a weight assignment scheme to establish a better relationship between energy consumption and traffic operations. The weight-minimized path in traffic grooming operations is considered as the final optimal solution and attains the optimal balance between blocking probability and energy consumption.

The energy consumption and intercore cross-talk in space division multiplexing elastic optical networks were considered for analysis in [9], which presented an energy-efficient grooming and hybrid crosstalk solution (EEG-HCS) algorithm to minimize the cross-talk and minimize the energy consumption. The presented approach initially utilizes a candidate path sorting algorithm to balance the load and select the candidate paths. From the sorting results, the energy grooming conditions satisfaction criteria are evaluated to minimize the transmission energy. An access control protocol for passive optical interconnects was reported in [10] to provide energy-efficient collision-free communication. The access control model incorporated arrayed waveguide gratings to overcome the collisions and presented a tailored dynamic bandwidth allocation policy to schedule the resources in time and spectrum to accommodate the traffic generated by the servers. Reduced latency, frame drop ratio, and enhanced energy efficiency are the merits of the presented model.

Power consumption reduction in passive optical networks through different sleep periods is achieved in [11] to enhance the power efficiency of remote nodes. Sleep modes and sleep period variation patterns of multiple ONUs are considered for analysis. A Markov chain model is used to model the sleep modes, and the key parameters are analyzed for different patterns such as constant, linear, and exponential. The impacts are analyzed, and a minimum normalized cost function has been obtained for different patterns to establish a better tradeoff between the sleep modes. A resource management scheme to balance the energy efficiency of optical devices is reported in [12] through reconfigurable bandwidth allocation and energy-efficient operation. The presented approach analyzes the power consumption characteristics of channels used for downstream transmission to define the optimal use of components in the network. The analysis shows that free spectral range wrapping provides better device utilization and energy efficiency than traditional methods.

Energy consumption minimization in ethernet PONs was attained through a dynamic bandwidth allocation algorithm in research work [13]. The presented approach switches off the ONU transceivers when there is no traffic. The packet delay of distributed dynamic bandwidth allocation (DBA) is less than centralized DBA, which means the ONU energy consumption is minimized compared to existing approaches. Energy efficiency analysis in ethernet PONs is reported in [14] considering the ONU power consumption and sleep mechanisms. The presented approach exploits the energy efficiency of EPONs in the downstream transmission and builds a holistic model to define the sleep periods and enhance energy efficiency. The propagation delay in EPON's scattered optical network units is analyzed in [15] using interleaved polling and an adaptive cycle time scheme to improve energy efficiency in low latency services. The presented approach initially introduces an upstream, postponing with ONU dozing to postpone the upstream transmissions that introduce delay. Furthermore, the identical fiber length with an ONU sleeping scheme was introduced to improve channel utilization and energy efficiency.

Recently, numerous works are introduced to improve the performance of the passive optical network (PON). The demonstration given in [16] for TDM-PON provides solution to handle the traffic in remote nodes in a distributed network. In order to obtain better transmission in the TDM-PON, a booster semiconductor optical amplifier is used in the saturation region. A similar passive optical network presented in [17] handles the traffic demands through peak to average power ratio optimization. The presented approach integrates subframes with TDMA to attain better throughput. The noise cancellation and clipping operations improve the optimization performance and attain a wide range of data rates. A nonorthogonal multiple access with power sparse code division is presented in [18] to minimize the path loss and improve the overall performance. The presented approach considers the user information and allocates optical network units with different power levels. The allocation is performed based on the path loss. A maximum ratio combined receiver model is presented in [19] for overcoming the performance degradation in passive optical networks (PONs) due to an improper modulator. The presented approach attains reliable transmission compared with the direct detection receiver and the lite coherent receiver. In terms of sensitivity, the presented approach attains better performance than the lithium niobate modulator. A cost-effective bus type for the OAN is presented in [20] through nonrepeater configuration. The presented approach provides Raman amplification for upstream transmission and utilizes asymmetric power splitters to improve the gain and reduce the loss in the transmission. A dynamic wavelength and bandwidth allocation procedure is presented in [21] for the upstream channel in the EPON. The presented adaptive threshold grouping reduces the bandwidth requirements. Additionally, the scheduling order of ONUs is modified to minimize the round trip time. The presented approach provides better bandwidth utilization, reduces the package delay, and improves the network throughput compared to traditional networks. From the analysis, it can be observed that sleep time and bandwidth allocation are mainly considered in most of the existing approaches to enhance energy efficiency. Resource scheduling is explored in a few research works; however, the research opportunity for enhanced energy efficiency has huge challenges, and based on this, an energy-efficient strategy for optical access networks is presented in the following section. On the other side of the research, lots of investigations are going in the field of solitons [22, 23].

3. Proposed Work

The proposed energy-efficient RAMOAN using M-LASA with FILO polling is presented in this section. Figure 1 depicts the schematic of the RAMOAN in detail. The network includes four layers in which the first layer represents the OLT group and the second and third layers represent the distribution node layer; specifically, it is represented as the first distribution node layer (FD-NL) and the second distribution node layer (SD-NL). ONU occupies the last layer. The initial OLT layer includes four general TWDMOLTs which are represented as G-OLTs along with an additional OLT included as B-OLT which represents the backup OLT. The characteristics of G-OLT and B-OLT are similar, and these OLTs provide a feeder link using optical fibers and splitters. The range of the initial general OLT feeder link is 20 km. Similarly, the backup OLT is connected to feeder links so that it can be used when there is a malfunction in the G-OLT. The OLT group includes a transceiver module that has a center controller so that the controller can communicate to remote nodes through specified wavelengths and controls the nodes. The subordinates of G-OLTs are similar to the TWDM tree so that, for real instances, it is mentioned as the TWDM tree in Figure 1. Four TWDM trees are included to represent the subordinate to G-OLTs.

The feeder link from the OLT layer is connected to remote nodes in the first layer which is represented as the remote node first layer (RN-FL). The RN-FLs in the distribution node layer are interconnected, and it includes a coupler, bandpass filter, transceiver, and three optical switches. The controller function in this layer is to manage the node operations, monitor the control signals from OLT, and send feedback to the center controller. The changes or unexpected events are immediately identified, and the details

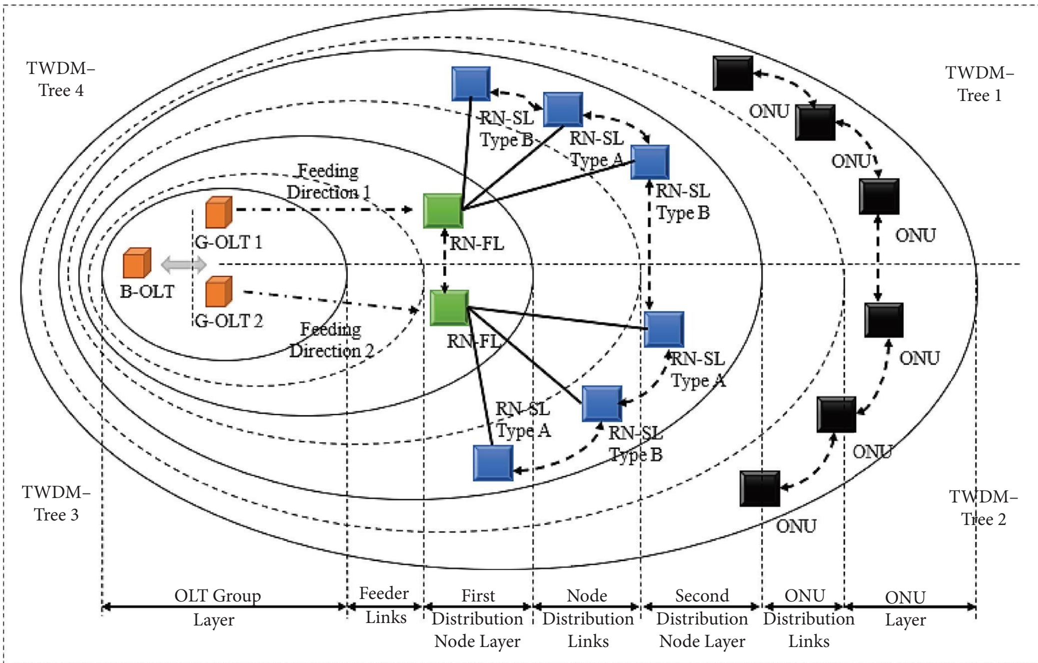

Figure 1: Illustration of the regional area metropolitan optical access network (RAMOAN).

are forwarded to the center controller for further action. The optical switches in this layer are used to construct different paths such as distribution path, amplification path, and interconnection path to transmit the signals.

The distribution path is a direct link in which the switch transfers its connection to a splitter and switches off the amplifier. Whereas in the distribution path, the switch shifts to an amplifier so that the signals will pass through the amplifier, coupler, and splitter. Due to this process, the network reach will be extended so that the distribution path is generally termed as an amplification-distribution path. The interconnection path shifts the switch connected to the amplifier and coupler simultaneously so that the signal can pass through the switch, amplifier, and coupler. The interconnection path can deliver signals to two RN-FLs and establish a connection between them. The RN-FL which has a shorter distance is considered as the main RN-FL, and other elements are considered as sub-RN-FL. The traffic from all the sub-RN-FL is aggregated by the main RN-FL using an interconnection link. This process is performed to reduce the energy consumption of sub-RN-FLs. If there is a fault in sub-RN-FL, then using this interconnection link, the faults are indicated using a feeder link so that the traffics are delivered to the main RN-FL and reaches the B-OLT using different wavelengths without any interferences.

The characteristics of SD-NL replicate the FD-NL. The SD-NL has remote nodes which are represented as the remote node-second layer (RN-SL). The nodes are interconnected, and their distribution link range is 10 km. Two types of RN-SLs are used, such as RN-SL-Type A and Type B, where Type A is similar to the RN-FL with slight modification in the splitter arrangement for distribution port quantity enhancement. If Type A is included without an optical amplifier, then it represents the Type B-RN-SL. Similar to the RN-FL, the RN-SLs have three different paths such as distribution path, coupled distribution path, and interconnection path to deliver the signals. The first distribution path is a direct path that constructs a path by shifting the connection to the splitter. The second coupled distribution path is similar to the RN-FL amplification-distribution path; however, if Type A is employed, it will shift the connection to the amplifier such that the signals will pass through the amplifier, switch, and splitter. If Type-B is employed, the switch directly shifts the link to the coupler and splitter since it does not have amplifiers as like Type-A. The last interconnection path of the RN-SL shifts the connection of the switch to the amplifier and coupler simultaneously. Similar to the RN-FL, an interconnection path can be used to connect two RN-SLs. Also, traffic aggregation is performed similarly to the RN-FL, and faults are identified and informed to the RN-FL.

The last layer in the network is the ONU layer which has optical switches, tunable transceivers, and system on chip (SoC) to hold the media access control (MAC) and customer premise equipment. The ONUs are connected through fiber links, and their range is 10 km. A ring-like structure has been established to connect the entire ONUs. Two types of ONUs are used in the architecture such as normal and standby ONUs. The standby ONUs are used when there is a malfunction in normal ONUs. An interconnection link is used for ONUs communication, and the nearby ONU is used to deliver the data to the OLT group using transceivers. Thus, using two transceivers and interconnection links, ONU overcomes link failure and other malfunctions. All the OLTs can be accessed through this tunable ONUs. For energy efficiency, some of the G-OLTs can be switched off in the network and their corresponding ONUs will access the other G-OLTs in the network using FD-NL and SD-NL interconnection links. Due to the multilayer structure, numerous backup paths can be established for data transmission which enhances network protection. The faults and malfunctions are identified in a short duration using the controllers. Thus, the links can be reconfigured immediately in an automatic manner. The remote node amplification factors enhance the network cover radius and adapt different demands to reduce energy consumption. Aggregated traffic also reduces energy consumption by adopting resource scheduling schemes. To attain an energy-efficient network, resource scheduling is considered in this research work in the following part.

The proposed energy-efficient resource-scheduling model for the RAMOAN accesses the OLT transceivers through time division multiplexing. The load adaptive sequence arrangement scheme was modified in the proposed work for enhanced energy efficiency in the RAMOAN. The communication between ONUs and OLT adopts time division multiplexing, and the return labels are expressed as $\theta_0 + 1, \theta_0 + 2, \theta_0 + 3, \ldots, n, 1, 2, \ldots, \theta_0$ for "n" number of ONUs. In the above expression, the delayed ONUs are indicated as "θ" for the next polling cycle and the last value is represented as "θ_0." In the next step, considering the threshold ($\mathcal{T}_{th}$), polling sequences are arranged by comparing the current cycle time ($\mathcal{T}_{cy}$). This process is mathematically expressed as follows:

$$\mathcal{T}_{th} = \frac{\mathcal{T}_w}{2} + \mathcal{T}_{\mathrm{ONU}}, \quad (1)$$

where the transmission time of ONU is described as $\mathcal{T}_{\mathrm{ONU}}$ and $\mathcal{T}_w$ indicates the wakeup transition time. If the cycle time is lesser than the threshold, then there is no chance for enlarging the idle time than the wakeup time. In that case, θ is set into zero and the idle time of ONU is calculated by OLT considering $\mathcal{T}_{\mathrm{ONU}}$ and $\mathcal{T}_{cy}$. Mathematically, it is expressed as follows:

$$\mathcal{T}_{id} = \mathcal{T}_{cy} - T_{\mathrm{ONU}}. \quad (2)$$

Once the idle time is obtained, considering the bandwidth requirements, a new label of ONU and a gate message are generated. If suppose the threshold is lesser than the cycle, delayed ONUs are obtained through the formulation given in

$$\theta = \mathrm{Prox}\left[\frac{\left(\mathcal{T}_{cy} - \mathcal{T}_w + (n-1) \times \mathcal{T}_{\mathrm{ONU}}\right)}{2 \times \mathcal{T}_{\mathrm{ONU}}}\right], \quad (3)$$

where Prox$[l]$ denotes calculating the integer most proximal to l. Based on this, the idle time of ONUs is calculated for the present cycle as follows [24]:

$$\mathcal{T}_{idle\_i} = \mathcal{T}_{cy} - (n - \theta - 1) \times \mathcal{T}_{\mathrm{ONU}}. \quad (4)$$

Similarly, the ONU idle short time is formulated as follows:

$$\mathcal{T}_{idle\_s} = \mathcal{T}_{cy} - (\theta + 1) \times \mathcal{T}_{\mathrm{ONU}}. \quad (5)$$

The OLT has determined the ONU's sleep schedule using the aforementioned idle hours. Further, a gate message with the sleeping and idle times, the label for each ONU, and the assigned bandwidth details have been generated. Each ONU simultaneously examines the label using gate messages to obtain the sleeping time and idle time and then executes exactly following the indications. By allowing ONUs to connect with the same OLT transceiver, the optical access network (OAN) under low traffic load has been protected from having a short cycle time. Thus, in the cooperative approach, the optical access network first evaluates the traffic load and then decides the number of active OLT transceivers [25]. Once the traffic load and number of active OLT transceivers are evaluated, then all the ONUs are identically divided into groups and each group of ONUs will access an active OLT transceiver. When this process is completed, traditional LASA is adopted among the ONUs which shares the same OLT transceiver. In this way, more ONUs will access a same OLT transceiver and avoids energy inefficiency under low traffic loads. Further to improve the performances, the ONUs are dynamically configured using the proposed modified LASA.

The polling of ONUs is delayed in the next cycle based on the volume of traffic. For experimental simplification, in the following discussion, OLTs are deployed with one transceiver. Each ONU is given a label to validate the polling sequence in each polling cycle, which is added to report/gate messages. The label is provided by the gate message to the ONU, and the report message returns it for the bandwidth needed.

The proposed modified LASA includes a first-in-last-out polling sequence instead of a fixed polling sequence. Earlier the modified LASA is used in an EPON [26] and attained better performance over the traditional fixed pooling sequence. Thus, in the proposed work, modified LASA is adopted to improve the performance of the RAMOAN. Each ONU is assigned with an upstream channel through a multipoint control protocol gate ($\mathcal{G}$) and report ($\mathcal{R}$) messages. Based on the transmission duration for data transfer, sequence label idle time, and the bandwidth requirements of ONUs, a gate message is generated and broadcast. The fixed point polling sequence limitations are eliminated through the FILO polling. This has been achieved by including a delay in the polled ONU present cycle. Due to this, the present ONU is forced to poll in the last of the next sequence and all of the ONUs goes through this process again. The FILO polling sequence is pictorially explained in Figure 2. From the discussion given in [26] for FILO, it can be observed that the FILO sequence is utilized for the regions in which the sleep count of ONU is poorer. From the discussion, it is considered that if the ONU has a poor sleep count, then FILO will be the best choice. Also, the author highlights that due to polling sequence rearrangement, the ONU idle time value increases or decreases compared with traditional idle time. The ONUs that accesses the upstream channel are used to calculate the idle time which is formulated in the following equation:

$$\mathcal{T}_{idle-i} = \frac{2(n-i)}{n-1} \times \mathcal{T}_{idle}, \quad (6)$$

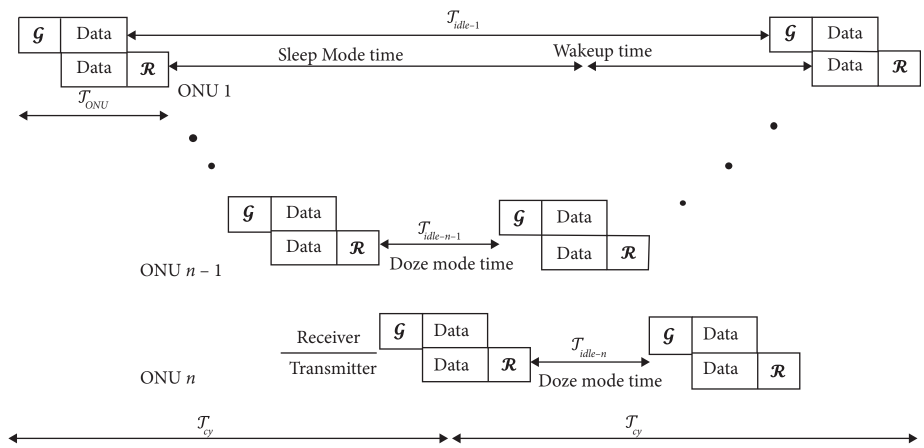

Figure 2: The FILO polling sequence.

where the idle time measured using FILO is indicated as $\mathcal{T}_{idle-i}$, and fixed polling sequence idle time is indicated as $\mathcal{T}_{idle}$. When the sleep mode wakeup time is lesser than the polling sequence, then FILO has been selected. Thus, sleep mode time and wakeup time are used to represent the idle time of ONUs.

In the presented modified load adaptive sequence arrangement, the ONU sleep mode is specified considering the idle time which is derived through FILO to overcome the different ONU cycles in the traditional scheme. The power consumption is minimized by switching the ONU to active mode when it does not meet up the threshold requirements. Considering the sleep time and delayed ONU, the optimum sequence arrangement reference is formulated as follows:

$$\theta = \frac{\mathcal{T}_{cy} - \mathcal{T}_{w} + (n-1) \times \mathcal{T}_{\text{ONU}}}{2\mathcal{T}_{\text{ONU}}}. \quad (7)$$

From equation (7), the idle time for the conventional process is derived as follows:

$$\theta = \frac{n \times \mathcal{T}_{\text{ONU}} - 2 + (n-1) \times \mathcal{T}_{\text{ONU}}}{2\mathcal{T}_{\text{ONU}}},$$
$$\theta = \frac{(2n-1) \times \mathcal{T}_{idle} - 2 \times (2n-1)}{2\mathcal{T}_{idle}}. \quad (8)$$

Now, considering the idle time of fixed polling and SAR, the delayed ONU idle time is formulated as follows:

$$\mathcal{T}_{\text{LASA}} = \mathcal{T}_{cy} + \mathcal{T}_{idle} - \theta \times \mathcal{T}_{\text{ONU}}. \quad (9)$$

Similarly, the proposed model cumulative power is derived using sleep mode, doze mode, and active mode of ONUs as follows:

$$\mathcal{P}_{cum} = \left(\mathcal{P}_{a} \times a_{tot}\right) + \left(\mathcal{P}_{d} \times d_{tot}\right) + \left(\mathcal{P}_{s} \times s_{tot}\right), \quad (10)$$

where active power and total active count are represented as $\mathcal{P}_a$ and a_{tot}. Similarly, doze power and total doze count are represented as $\mathcal{P}_d$ and d_{tot}. The sleep power and total sleep count are represented as $\mathcal{P}_s$ and s_{tot}, respectively. Based on the cumulative power, the power cost is calculated and the energy savings are measured as energy efficiency and it is calculated considering the factors in equation (10) as follows:

$$\eta = \left(1 - \frac{\left(\mathcal{P}_{a} \times \mathcal{T}_{a}\right) + \left(\mathcal{P}_{d} \times \mathcal{T}_{d}\right) + \left(\mathcal{P}_{s} \times \mathcal{T}_{s}\right)}{\mathcal{P}_{a} \times \left(\mathcal{T}_{a} + \mathcal{T}_{d} + \mathcal{T}_{s}\right)}\right) \times 100\%, \quad (11)$$

where active time duration is indicated as $\mathcal{T}_a$, and doze time and sleep time duration are indicated as $\mathcal{T}_d$ and $\mathcal{T}_s$, respectively. The pseudocode for the proposed model is summarized as follows:

For each cycle, ONU will send a report message in traffic to OLT
Based on the average bandwidth, $\mathcal{T}_{idle}$ and $\mathcal{T}_{cy}$ are computed for the modified LASA scheme
Variations in traffic vary the ONU idle time
For $\mathcal{T}_{idle}$ = 1: 0.2: 3ms
If ($\mathcal{T}_{idle} > 2$ms)
$\mathcal{T}_{s} = \mathcal{T}_{idle} - 2$, $s_{tot} = s_{tot} + 1$
else ($\mathcal{T}_{idle} > 2$ms)
$\mathcal{T}_{d} = \mathcal{T}_{idle} - 330$, $d_{tot} = d_{tot} + 1$
end
compute cumulative power $\mathcal{P}_{cum}$
compute energy efficiency η
end
end

4. Performance Analysis

Simulation analysis of the proposed energy-efficient RAMOAN using M-LASA methodology is presented in this section. The simulation tool used for experimentation is MATLAB, and the simulation details such as traffic load, upstream rate, cycle time, number of ONUs, delay constant, distance, idle time range, and transition time are listed in Table 1. The parameters are selected based on the existing research work which measures the energy efficiency of the optical network [27, 28]. Performance metrics such as

Table 1: Parameters used for simulation.

Parameters	Value
Number of ONUs	10
Maximum cycle time	10 ms
Upstream line rate	10 Gbps
Normalized traffic load	0.01-1
Idle time variations	0.1 ms : 0.1 ms : 1 ms
Delay constant	4 ms
Inner frame gap	1 microsec
Distance reach	10 km
ONU wakeup transition time	2 ms

coverage radius, access reach, average packet delay, total power cost, energy cost, and energy saving are considered for analysis. Traditional methodologies such as TWDM, TWDM-protected, and the RAMOAN with LASA structures are considered for comparative analysis. The results of traditional methods are obtained from Lv et al.'s [25] research work. The performance of the proposed model and existing models is observed under different traffic loads, and the observations are presented in detail with suitable illustrations for better validation.

Figure 3 depicts the utilization of transceivers at the OLT side for the proposed model and traditional structures. The traffic loads are gradually increased in the range of 0.1 to a maximum of 1, and the usage of transceivers is measured for all the methods. Results validate that the proposed methodology has minimum active OLT transceivers which indicates the better wavelength efficiency of the proposed model, whereas TWDM approaches exhibit similar performances which are poor due to their inactive standby components in the network structure.

Figure 4 depicts the minimal cover radiuses for proposed and existing techniques. The minimal cover radius of the proposed energy-efficient RAMOAN is calculated based on the shortest link used for ONU-OLT transmission. If the link has interconnections, then the link access reach is calculated along with the feeder link length, node distribution link length, and final available distribution link. Initially, when the network cover radius is small, it provides a minimum radius of 45 km and it increases by 5 km when the traffic load is increased to 0.6. In the same scenario, the minimal cover radius of existing methods is high which indicates poor performance. How far the cover radius is minimum, the performance will be better, and this is attained by the proposed model. The minimal cover radius attained by the proposed model for the maximum traffic load is 55 km. Based on results and discussion given in [25] for existing TWDM methods, the minimal cover radius does not provide any variations due to the high ONU losing rate and makes them unsuitable for practical cases.

The maximal access reaches for the proposed and existing approaches are comparatively depicted in Figure 5 under different load conditions. Based on the ONU-OLT transmission link's maximal available reach with activated amplifiers, the maximum access reach is measured for the RAMOAN and existing access networks. From the results, it can be observed that the proposed methodology provides

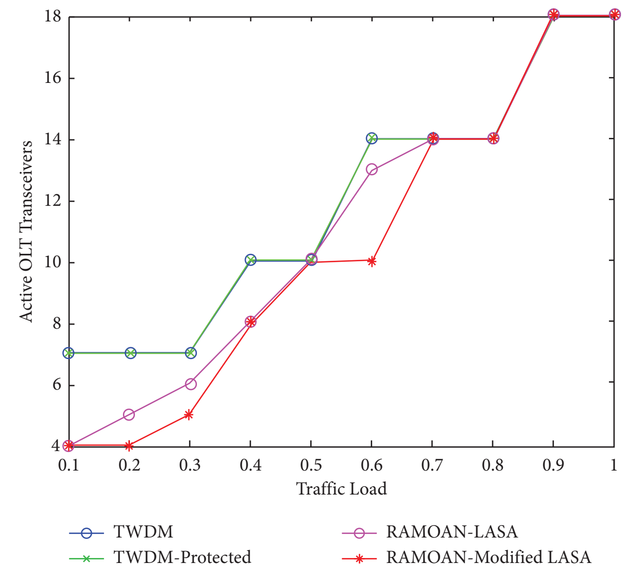

Figure 3: Active OLT transceivers.

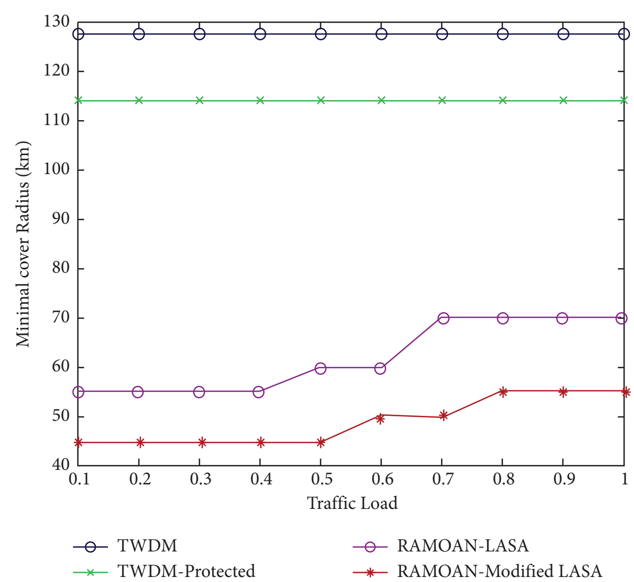

Figure 4: Minimal cover radius.

better access reach than existing approaches. However, the maximum access reach of all the methods gradually decreases when the traffic load increases. This is observed because of the traversing nature of the ONU-OLT transmission link to remote nodes for different load scenarios, and this can be improved by including optical amplifiers in the network. It can be observed that the maximum access radius attained by the proposed model for maximum traffic load is 155 km, whereas existing methods attain 145 km, 135 km, and 115 km, respectively, which is lesser than the proposed model. Figure 6 depicts a comparative analysis of the average packet delay. Results demonstrate that the packet delay of the traditional LASA-based RAMOAN gradually increases over different traffic loads as more data are stacked for transmission, whereas the proposed modified LASA-

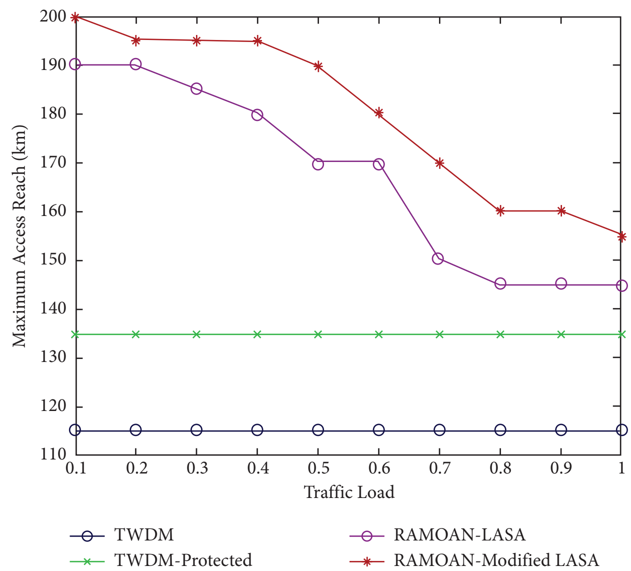

Figure 5: Maximum access radius.

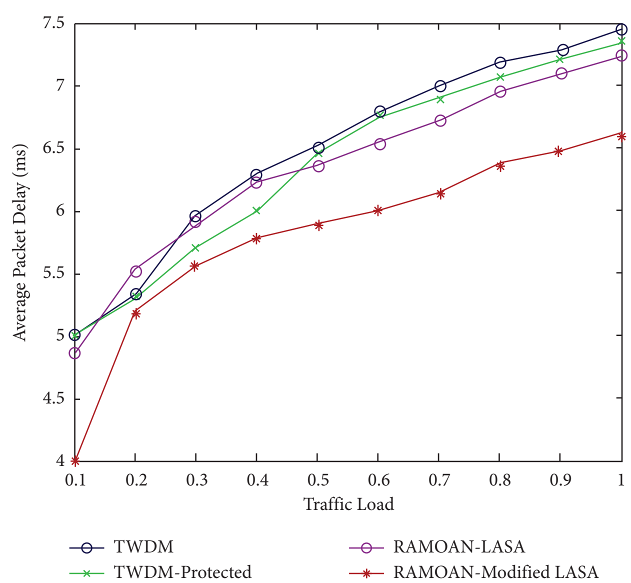

Figure 6: Average packet delay analysis.

based RAMOAN exhibits minimum packet delay due to the efficient polling sequence arrangement. Due to shorter polling cycle lengths and no change in polling sequence, the performance of TWDM approaches is relatively lower than the proposed model. It can be observed that the delay exhibited by the proposed model is 6.62 ms, whereas the RAMOAN LASA exhibits 7.24 ms and TWDM approaches exhibit 7.36 ms and 7.46 ms, respectively, which are quite higher than the proposed model.

The total power cost for the proposed and existing models are comparatively depicted in Figure 7 for different load conditions. Power cost defines the total network power consumption where it is obtained by adding up the power utilization of active network elements. As the network includes multiple components, the power cost reaches above 3000 W for all the loads. However, the results of proposed model are better than the traditional LASA based RAMOAN networks. Results validate the better performance of the proposed model compared to conventional TWDM methods and the traditional LASA-based RAMOAN scheme. The total power cost attained by the proposed model for maximum load is 3612 W, whereas traditional LASA exhibits 3866 W for maximum load. TWDM and TWDM protected schemes exhibit 3880 W and 4090 W of power cost, respectively, for maximum load, comparatively indicating the better performance of the proposed modified LASA-based RAMOAN approach.

Comparative analysis for the energy cost parameter is presented in Figure 8. Energy cost defines the amount of energy consumed by the network. Results demonstrate

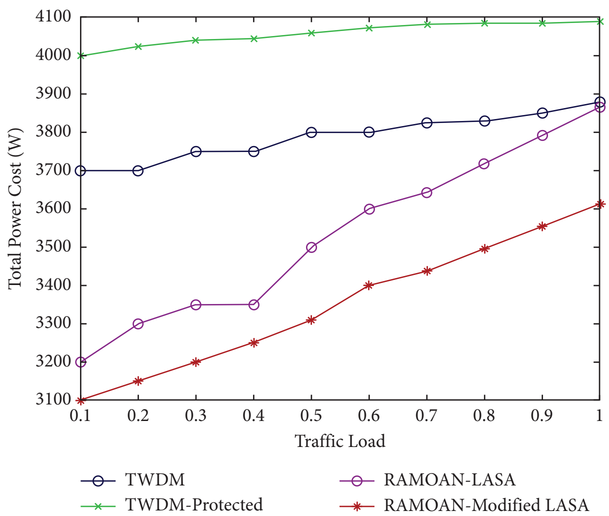

Figure 7: Total power cost comparison.

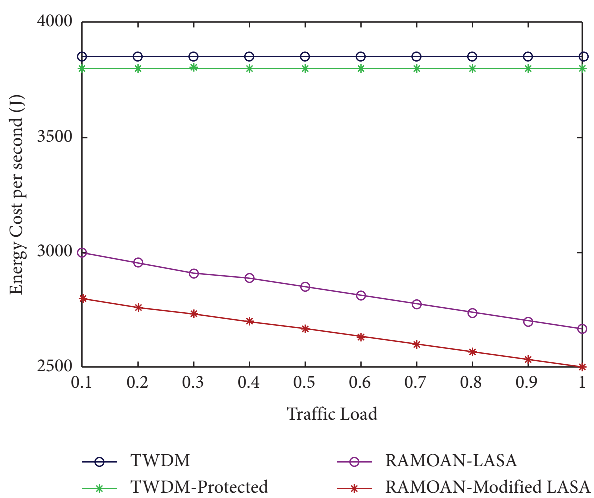

Figure 8: Energy cost comparison.

that a minimum energy cost of 2506 J was attained through the proposed model for the highest traffic load, whereas the traditional LASA-based RAMOAN exhibits 2665 J. The performance of TWDM schemes for maximum traffic load is 3800 J and 3850 J, respectively, which is higher than the proposed model. The increased energy cost in existing methods is overcome by the proposed approach.

A comparative analysis of energy-saving factors based on traffic loads for all the algorithms is depicted in Figure 9. Results demonstrate that the proposed modified LASA-based RAMOAN exhibits maximum energy savings due to the efficient polling sequence arrangement. The maximum energy saved by the proposed model is 28.53%, whereas the traditional LASA-based RAMOAN attains 23.45% which is 5.1% lesser than the proposed approach. The performances of TWDM and TWDM protected are 20.2% and 21.6%,

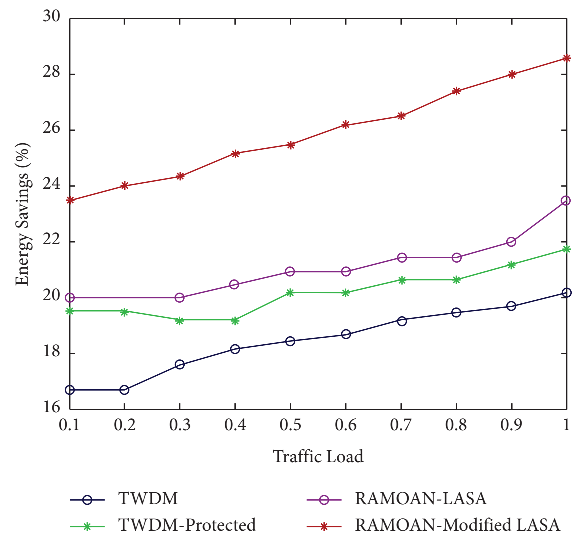

Figure 9: Energy-saving analysis.

respectively, which is much lesser than the proposed model. From the simulation analysis, it can be observed that the proposed modified LASA-based RAMOAN attains maximum performance for all the performance metrics compared to traditional approaches.

5. Conclusion

An energy-efficient RAMOAN using M-LASA methodology is presented in this research work for enhanced performance of optical access networks. The limitations such as high power consumption and idle time for optical network units are overcome by the proposed modified LASA which incorporated first-in-first-out polling to schedule the resources. The proposed model performance analysis is demonstrated through simulation, and different metrics related to cost and energy are considered for analysis under different traffic load conditions. For comparative analysis, existing TWDM and TWDM-protected schemes are considered. Similarly, the traditional LASA-based RAMOAN has also been considered for comparative analysis, and the results demonstrate the superior performance of the proposed model for all the performance metrics. The proposed approach reduces the total power cost and energy cost and enhanced the energy savings compared to existing approaches. Results indicate that the proposed modified approach enhances the overall performance of the optical access network.

Data Availability

The data used to support the findings of the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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