Dynamic Traffic grooming in hybrid elastic optical and WiMAX networks

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Abstract. Designing low cost scalable networks is driven by increased internet traffic and high bandwidth demand. Optical networks combined with WiMAX forming a hybrid network is one such structure. The existing Wavelength Division Multiplexed Passive Optical Networks suffer from huge bandwidth wastage when the demands are very small compared to the channel capacity. To overcome this drawback, we have replaced passive optical network with an elastic optical network. The routing and resource allocation algorithms are formulated for this hybrid network. Our proposed algorithms efficiently utilize channel capacity and network resources.

Keywords: Bandwidth Blocking Ratio (BWBR) Elastic Optical Network (EON) programmable Optical Line terminal (POLT) Programmable Optical Network Unit (PONU) PON (Passive Optical Network) Traffic grooming World Interoperability for Microwave Access Network (WiMAX) Wavelength Division Multiplexing (WDM)

1. Introduction
Mobile internet growth has led to a growing number of users seeking high bandwidth. WiMAX is used for end-user networking over a wide geographical area [1]. The conventional Passive Optical Networks (PON), which are used as a back end to a wireless network, are inflexible. Resources are poorly used as full channel bandwidth is allotted even though traffic requests may require a limited bandwidth. Also, the hardware cost is high. The Elastic optical network allocates network resources dynamically according to each connection’s demand [2–4]. With its versatility, the Elastic Optical Network [5] minimizes bandwidth wastage. EON allocates bandwidth based on traffic demand thus meeting consistency of the bandwidth and limitations of contiguity. In traffic grooming, various traffic demands are aggregated thus eliminating the need for guard bands. This increases the efficient usage of network resources. In traffic grooming, either light paths or light trails are used. Intermediate nodes participate in light trails whereas in light paths only s-d pairs participate. Network flow [6] in the light trail is unidirectional. Traffic is added/dropped at intermediated nodes. Adjacent channels interfere in subcarriers when OFDM signal travels multiple bandwidth variable switches. Guard bands are used for interference removal. They also consume bandwidth [7].
In WDM, various class of services is provided per wavelength channels and several wavelengths required by each PONU are continuously updated. However, the assigned channel capacities are not fully utilized. This problem of underutilization is addressed using traffic grooming technique in the hybrid networks. There are separate grooming techniques for optical and WiMAX networks. We have approached traffic grooming for hybrid optical WiMAX networks. Optical and WiMAX networks are connected by the programmable Optical Network Unit (PONU). These ONU’s increase the coverage area. Base stations are connected to ONUs. The relay stations(subscribers) are attached to the respective base station.

The survey concerning hybrid networks are delved in Section 2. The problem is formulated in section 3. The algorithmic solution to the formulated problem is described in Section 4. Results are simulated and analyzed in Section 5. Section 6 draws conclusions and discusses future scope.

2. Related work
In [8–12] the authors studied the influence of connecting optical networks to a wireless network to serve the high-speed broadband connectivity to end-users. Admission Control (AC) mechanism, by Ahmed et.al [8] proposes a hybrid RPR-EPON-WiMAX network and corresponding schedulers. They proposed a which depends upon the network status and frame duration of WiMAX. In [12], capacity and Delay Aware Routing protocol do load-balanced routing. This reduces network delay. Musumeci et al. [13] proposed the application of WDM optical networks as support for wireless networks in the front haul. Most of the internet traffic [14] is routed by core networks and wireless networks. The authors Asad et al. in [15] proposed an algorithm for fiber wireless networks optimizing delay and energy. Sarkar et al. [16] selected the shortest delay path for delay optimization in wireless mobile networks. Reduced congestion and load balancing are other benefits here. However, all the routing algorithms only focused on the front end wireless mobile networks. The integration of optical and wireless remained untouched in most of the research papers. In [17], the author’s Ann et al. proposed the route selection policies confirming IEEE 802.16 mobile nodes. High throughput is achieved by the lowest latency and optimal path. The authors in [18] suggested to place the multiple radios only at the gateway wireless nodes rather than placing the radio in all the wireless nodes. The gateway nodes are responsible for forwarding more traffic toward end-users. This minimizes radio costs in all the wireless nodes.

Traffic grooming is suggested by Dutta et al. in [19]. The shortest path first Traffic Grooming used to enhance WDM network throughput in [20]. Network resource used optimally and survivability is studied by Zhang et al. in [21] using dynamic light trails. For light paths in wavelength-routed mesh networks, De et al. in [22] proposed Clique Partitioning (TGCP) based Traffic grooming resulting in enhanced network throughput. Forming Light trail clusters by [23] reduced wavelength requirements. Underutilization of channel capacities in the fixed grid is addressed by Jinno et al. [5] by their SLICE technique. This results in flexible network architecture and spectrum are utilized efficiently. OFDM has been proposed [24],[25] for flexibility in allocating the subcarriers according to the traffic demand. For transmission in OFDM, multi-carrier is used. Further data stream requiring high Bandwidth is split into many parallel data streams that require low Bandwidth. The spectrum consumption depends on the traffic pattern, distance, and the modulation technique used to establish the request [26]. Dependence of spectrum saving in the elastic network on guard band values is explained in [27]. In [28, 29], the static RSA problem is designed and formulated as ILPs. In [30] proposed the RSA problem in EON using the artificial bee colony algorithm. The advantages here are minimum spectrum utilization and sharing spectrum slots among adjacent connections due to path length criteria.

Motivation
- Traffic grooming without differentiating between individual Quality Of Service
requirements. In contrast, Elastic Optical Network (EON) can provide flexible spectrum depending upon the bandwidth requirements, higher data rates and modulation format meeting quality of service requirements.

- The elastic network integrated with a wireless network will reduce deployment cost and enhance the area of coverage.
- The hybrid network has gained popularity due to the high bandwidth requirement, low latency, higher security and resilience, lower energy consumption, and low-cost solutions. Compared with other back haul options, the optical network plays the strongest role in all respects.

3. Problem formulation

Formulation here is traffic grooming over light trails in hybrid networks. The network \( G(V, E) \) consists of node set \( V \) and link set \( E \). Each frequency slot in links equals to a subcarrier of 12.5 GHz. Bandwidth Variable Transponder (BVT) used here to support the maximum \( T \) number of subcarriers. Each station is occupied with multiple radios for communication. Arriving requests are denoted by a triplet \( (s, d, B) \). Required frequency slots \( B \).

Objective:

Objective here is to use network resources efficiently and at the same time minimize Bandwidth Blocking Ratio (BWBR) of the given network.

4. Proposed algorithm

Here four traffic grooming algorithms are proposed. They are based on Light trail formation in hybrid networks and consider Congestion, Delay, Shortest Paths and Maximum Traffic Grooming policies. In dynamic routing, traffic requests are not known ahead. Traffic requests arrive/depart dynamically as and when required. The paths between node pairs are not computed previously. Paths between any node pair are generated, only when there is traffic demand. It adds to some computational complexity but saves a lot of space for storing all possible paths between every node pair. The request can be groomed with existing requests if the fiber link traversed by the request satisfies the RSA constrains. Else these connection requests are treated as new requests and served individually. To serve the new connection request \( B+2*g \) consecutive frequency slots should be available along with the link traversed by the requests \( r \). Here \( B \) is bandwidth requirement of request \( r \) and \( g \) the guard band required for an individual connection request. Path status changes per the dynamic arrival of traffic requests. In the absence of network resources, unserved traffic requests are blocked after the expiry of some preset time. After that status of the resources is updated. Table 1 depicts the shortest path Grooming (SPG) algorithm which first considers traffic demands with minimum hop count.

| Index | s-d pair | Path | hop count | Traffic demand | Trails |
|-------|----------|------|-----------|----------------|--------|
| s0    | 0-5      | 0-1-2-3 | 3         | 3              | Main trail |
| s4    | 1-2      | 2-5 | 1         | 3              | Sub trail |
| s1    | 0-1      | 0-1-2-3 | 1         | 1              | Sub trail |
| s5    | 0-2      | 0-1-2-3 | 2         | 5              | Sub trail |
| s2    | 1-5      | 2-5  | 1         | 2              | Sub trail |

The Maximum traffic grooming (MTG) algorithm is inverse of congestion aware algorithm (as depicted in Table 2. Route which packs maximum amount of traffic between the node pair is selected. Sorting of intermediate requests depends on the traffic demands. The requests which has maximum
traffic get served first.

**Table 2. Maximum Traffic Grooming**

| Index | s-d pairs | Path   | Traffic demand | Trails   |
|-------|-----------|--------|----------------|----------|
| s0    | 0-5       | 0-1-2.5| 3              | Main trail |
| s5    | 0-2       | 0-1-2  | 5              | Sub trail |
| s4    | 1-2       | 1-2    | 3              | Sub trail |
| s3    | 2-5       | 2-5    | 3              | Sub trail |
| s2    | 1-5       | 1-2-5  | 2              | Sub trail |
| s1    | 0-1       | 0-1    | 1              | Sub trail |

The congestion aware grooming (CAG) considers only the amount of traffic between the node pair. If there exist multiple routes for source-destination pair, select the route with a minimum amount of traffic along the selected route to avoid the congestion in the network. The intermediate requests between the route get sorted according to the traffic demands. The node pair which has minimum traffic gets served first.

Congestion and Delay Aware algorithm (CADTG) consider both delay and minimum congestion (depicted in Table 3). When the delay is less than some threshold value traffic requests are allowed by Path establishment and requests are blocked when the delay surpasses the threshold limit. If this threshold criterion is not possible to alternate routes are considered for traffic routing. Network link balancing is done by CADTG, CATG algorithms. The flow of algorithm is discussed in Algorithm 1.

**Table 3. Congestion and delay aware traffic grooming**

| Index | s-d pairs | Path   | Traffic demand | Trails   |
|-------|-----------|--------|----------------|----------|
| 0     | 0-5       | 0-1-2.5| 3              | Main trail |
| S1    | 0-1       | 0-1    | 1              | Sub trail |
| S2    | 1-5       | 1-2-5  | 2              | Sub trail |
| S3    | 2-5       | 2-5    | 3              | Sub trail |
| S4    | 1-2       | 1-2    | 3              | Sub trail |
| S5    | 0-2       | 0-1-2  | 5              | Sub trail |

Mainly four types of delays are considered during routing in our proposed algorithm congestion and delay aware grooming [12]. The parameters responsible for delay calculation are given below.

**Transmission delay** - Determined by the link capacity $C_{sd}$. For large link capacity, the transmission delay is smaller (average packet size $\mu$).

\[
\text{Transmission}(\text{delay}) = \frac{1}{2 \times \mu \times C_{sd}}
\]  

**Slot Synchronization delay** - Packets are time synchronized between source destination nodes. This leads to some delay. Average time slot delay, is

\[
\text{Synchronization}(\text{delay}) = \frac{1}{2 \times \mu \times C_{sd}}
\]  

**Queuing delay** - It is affected directly by arrival rate of packets and inversely by rate by which packets are serviced at nodes. The queuing delay is cumulative. Hence queuing delay at nodes
traversed by packets along selected route gets accumulated. For independent arrivals and exponential distribution of packets delay is given by

$$\text{Queuing (delay)} = \frac{1}{\mu \times C_{dd} - \lambda \times d}$$  \hspace{1cm} (3)

**Propagation delay**-Propagation delay is very negligible.
So total delay is the summation of transmission delay, slot synchronization delay and Queuing delay. The routing in the hybrid network discussed below with examples.

**Routing in EON**
Here s-d pairs are in EON (depicted in Fig.1). As such RSA algorithms are used. The objective is to find the optimal route between the node pair and allocate the spectrum resource without violating the RSA constraints. BVT is used at each node. Once a path is selected using spectrum assignment policies intermediate requests are allotted frequency slots. Alternate routes are selected when sufficient frequency slots are not available.

**Routing in the WiMAX network**
The wireless part, consists of wireless mesh networks (WMN). In our study we have considered the relay nodes connected to any one of the base stations. End users establish network connection through relay nodes and are static. When s-d pair is in wireless, Routing is depicted in Fig.2. Here establishment of light trail is after confirmation of transmitter and receiver availability as also of contiguous frequency slots.

![Fig. 1. Traffic grooming using light trail in elastic optical network](image1)

![Fig. 2. Traffic grooming using light trail in elastic wireless Network](image2)
Hybrid requests

Here both optical and wireless nodes are involved in traffic flow. POLT allocates resources to ONU-BS. For relay stations resources are allocated by ONU-BS. Both POLT and Path computational units are housed in the central office. The traffic database (TD) unit maintains a record of the traffic flows through nodes and the network resources status to establish the connection.

Consider an example of downstream traffic (Fig.3) where in there are requests from Node0-RS (Node0 is optical and node RS wireless), the path between the Node0 to RS is Node0 Node1 BS RS. The traffic may be in the upstream from the source at the wireless node and destination node in the optical network. The end user’s requests are groomed by the relay station and the forwarded to a base station. Wireless optical conversion is done in integrated PONU Base station. The POLT associated with PCE, which finds a suitable route to a destination.

Allocation of EON Bandwidth to wireless networks

To assign the dynamic bandwidth to the wireless network, the POLT has a line card that receives the baseband signals at a different optical frequency and forwards them to the PONU. And it is combined with the processing of the signals by a base station. These are installed with flexible bandwidth transponders which are responsible to tune the PONU transmission. Each PONU aggregates the requests from the base station and sends bandwidth requests to POLT. Once POLT receives the traffic requests it assigns PONU the collection of contiguous frequency slots in such a way as to accommodate the maximum amount of traffic. The slots allocation depends on the slot’s total available slots with the POLT.

For example, consider a network that requires a lower data rate. In EON, POLT can allocate a narrow spectral width. Suppose another network requires higher data rates, which are to be assigned a wider spectral width. The same optical fiber can serve multiple network slices using multiple inputs and multiple outputs with different numbers of networks. The EON is capable of serving the right amount of spectrum to transponders.

However, the guard bands are required between the narrow spectrum channels. This usage of guard bands leads to huge wastage of spectrum resources. So, we have introduced different types of traffic grooming policies to address the spectrum resource wastage and blocking of the traffic requests due to subsequent spectrum unavailability.

The flow of the proposed algorithms is given below.

Algorithm 0: The paths are pre computed and stored between the node pair.
Input: \( G(V, E) \) and a unicast traffic demands request \( R_{ui} \)

Output: A path for traffic demands \( t \)
- for Selected node pair \((s, d)\) compute
  1. \( p = \text{path}(s, d) \)

Return(p)

**Algorithm 1**: Congestion and Delay Aware Traffic Grooming (CADG)

Input: \( G(V, E) \), A Traffic demand matrix \( [s, d, B, t] \) Where \( s, d, B \) represents the source, destination nodes and traffic demand for unicast traffic demand \( R, R = D_1, D_2, D_n \), and wavelength capacity/channel \( C \)

Output: Bandwidth blocking ratio (BWBR) of the given hybrid network

1. Generated traffic demands between the node pair \( s-d \) at a time instance \( t \). A list stores traffic requests generated between node pair.

2. Initially paths between all \( s-d \) pairs are arranged as per decreasing order of traffic demands

3. for \( i = 1 \) to \( P \) do #path computed in algorithm0
   - Select the topmost request from the list
   - Check for resource availability (trans receivers and slot availability)
   - Check for resource availability (trans receivers and slot availability)
   - if (Resources are available == TRUE) then
     - Compute contiguous slot index for entire selected path
     - while Resource are available do

   - There may be a intermediate nodes which generates traffic requests,
   - Generates sub paths for those intermediate nodes) from algorithm0.
   - Intermediate requests are also sorted in decreasing order of their traffic demands
   - Compute delay for each sub paths
   - Select those sub path whose delay is less than the threshold value.
   - Check for resource availability and common slot index for each sub paths.
   - Sub paths that satisfying both the conditions are selected.
   - Assign slots to the main and sub paths.
   - Update the resources availability along the selected path.

   Else
   - Alternate path from list of paths is selected for the given node pair
   - Repeat the same process for \( P \) alternate path
   - Block this traffic request is blocked, after \( P \) alternate path traversals when
   - network resources are unavailable to establish the connection requests.
   - Connection terminates after time interval \( t \)
   - Traffic matrix list is being updated at every instance of time within the given range
   - Release the network resource. (e.g spectrum, transponders)
   - Repeat the process until the simulation time gets over.

Source destination pair may be optical or wireless or hybrid (optical to wireless and /wireless to optical). Following flowchart illustrates traffic grooming for the same Fig.4.
Assume a hybrid network consists of \( n \) nodes, \( c \) be available slots, \( K \) be selected path from source to destination nodes. Traffic requests are randomly generated and stored in list for randomly selected source and destination. For \( n \) nodes, time complexity to generate traffic request will be \( O(n) \). To find the available light trails for \( n \) nodes algorithm takes \( O(n^2) \). For \( K \) paths it will be \( O(Kn^2) \). For Checking the continues slots and transponder availability the algorithm consumes \( O(Kn^3) \). Algorithm takes \( O(n^3) \) time for total computation.

5. Performance evaluation

**Network Scenario**

Two standard network topologies NSF and German network as backhaul is used for algorithm performance evaluation. (depicted in Fig.5 and Fig.6). In EON, links are divided into slots of fixed capacity (of size 12.5 GHz). Here we used Binary Phase Shift Key (BPSK) modulation. The traffic demands are uniformly distributed in the range of 1, 3, and 12.


**Performance parameter and policies choose**

Algorithm performance is evaluated by simulation. IDE eclipse using JAVA is used for simulation. Results are plotted using MATLAB. The performance parameter is the average bandwidth blocking ratio. Three paths are set for each node pair. The following policies can be used to study the BWBR of the given network:

- **Shortest Path traffic Grooming (SPTG):** This strategy selects the shortest route to route the requests between the node pair.

- **Congested Aware traffic Grooming (CATG):** This policy selects the route with the minimum amount of traffic requests. So that the blocking of traffic requests are minimized.

- **Congestion and Delay Aware Grooming (CADAG):** This policy takes the delay factor and the minimum traffic along the selected route to route the requests.

- **Maximum Traffic Grooming (MTG):** Here path with maximum traffic load is selected for routing the traffic requests.

![Fig. 5. Hybrid network with optical nodes in NSF net configuration](image1)

![Fig. 6. Hybrid network with optical nodes in German net configuration](image2)
Fig. 7. Relation between BWBR and traffic generation time in hybrid network (optical nodes are configured in NSF net formation)

The Fig.7 demonstrate the BWBR vs time. The parameter is measured in the interval of milliseconds. Among the proposed algorithms the SPT, CAG, MTG performed. Similar performances in terms of BWBR and The CDAG algorithm performed worst performance compared to SPT, CAG, MTG. The main reason behind this is NSF network is a densely connected network and the routing algorithms are sharing the common link while choosing the different policies for routing. However, the CDAG chooses the path with least congestion and delay to serve the requests. If the delay parameter crosses the threshold limit, it drops the requests which are unable to fit while grooming the intermediate requests. So, the maximum number of requests get blocked due to the delay constraints associated with this algorithm.

Fig. 8. Relation between the total traffic generated in the network, BWBR and the traffic generation time in hybrid network (optical nodes are configured in NSF net formation)

The Fig.8 depicts the relation between the total traffic generated in the network, bandwidth blocking ratio and the traffic generation time in hybrid network. The CDAG performed worst performance in the dynamic scenario. The remaining three algorithms performed similar performance due to the reason mentioned earlier in Fig.7.
The relationship between total live nodes present the network, total live nodes blocked and time in the hybrid network are depicted in Fig. 9. In the SPT, CAG, MTG algorithms almost similar amounts of live nodes are generated and served. But in CDAG the total live nodes are generated less compared to other algorithms and the live nodes blocked also less. This selects the path with minimum congestion and delay. So more network resources are available to serve the requests.

Relationship between total traffic generated, total traffic served and time in hybrid network are shown in Fig. 10. Fig. 11 depicts Relationship between BWBR and time in a network. Here CDAG algorithm minimizing the BWBR better. The German network is sparsely connected. The SPT algorithm performs worst compared to other algorithms. In SPT algorithm, traverse the shortest route and more resources get consumed along this route. Hence this algorithm performs worst performance. The CDAG performs better performance by selecting the path with less congestion and delay. The MTG and CAG algorithms perform better than SPT algorithm.
Fig. 11. Relation between BWBR and time in hybrid network (optical nodes are configured in German network formation)

Fig. 12. Relation of total number of live nodes generated, total number of live nodes blocked ratio and time in hybrid network (optical nodes are configured in German network formation)

Fig. 13. Relation between total traffic generated, total traffic served and time in hybrid network (optical nodes are configured in German network formation)

The relation between the number of live nodes in the network, total live nodes blocked and time in the network are shown in Fig.12. In the SPT, CAG, MTG algorithms almost similar amounts of live nodes are generated and served. But in CDAG the total live nodes are generated less compared to other algorithms and the live nodes blocked are also less. This selects the path with minimum congestion.
and delay. So more network resources are available to serve the requests.

6. Conclusion
In our study, we have investigated the routing and resource allocation algorithms for hybrid networks. When traffic demands dynamically vary, the elastic optical network can offer versatile bandwidth to end-users. The elastic network connected as the rear-end can serve wireless network end-users as if they are connected to broadband services cost-effectively. Wireless access supports the individual users and the costs associated with cable and bulky network equipment are reduced. Traffic grooming using a light trail strategy has reduced the use of network resources and minimizes the bandwidth blocking ratio. In future studies, we will be formulated traffic grooming policies for energy-aware hybrid networks.

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