A Survey on Regenerator Placement Problem in Translucent Optical Network

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***Abstract*-Recent research work reveals that the performance of translucent optical network is very near to fully opaque network but much better than transparent network in terms of cost and overall blocking. A translucent optical network is capable to reduce the network design cost as well as routing cost by dividing each light-path into one or limited number of segments by selecting some nodes as regenerator nodes in the network which helps retain the original optical signal quality. Minimization of the total number of placed regenerators and selection of their best locations to establish a path between every pair of source-destination nodes in the network are the main objective of translucent optical network design. This is known as regenerator Placement Problem (RPP) which has been proved to be NP-complete. This paper will provide an overview of various research works and heuristics developed on RPP along with their advantages, drawbacks and performance.**

Keywords- Translucent optical network; regenerator; optical reach; transparent optical networks.

1. INTRODUCTION

Wavelength Division Multiplexing (WDM) is an approach to utilize the large available bandwidth in an optical fiber. WDM divides the bandwidth of a single fiber into different wavelength channels and there is no interference between transmissions on each wavelength. WDM optical networks support wavelength routing. These networks support lightpaths, which are end-to-end circuit-switched communication connections that traverse one or more links and use one WDM channel per link. A lightpath [1,2] is an optical connection from one end-node to another, that is used to carry data in the form of encoded optical signals at a data rate of 10 or even 40 giga-bits per second (Gbps) with no optoelectronic conversion at any intermediate node in the route from the source to the destination of the communication. The lightpaths may be viewed as the edges of a directed graph G (V, E), where the nodes of G in V are the end-nodes of the network. Such a graph is called the logical topology (also called the virtual topology) of an optical network and the edges of such a graph are called logical edges [1], [2]. The tremendous growth in the research of optical networks moves toward high-bandwidth and low-cost scalable communication networks [2].But, physical impairments damage the signal quality gradually after a certain range of transmission. To restore the unrecognizable signal, Optical-Electrical-Optical (O/E/O) conversion is essential at proper nodes. In optical network, a major cause of hampering scalability is consumption of power in nodes. This increases proportionally with the increasing number of nodes having O/E/O conversion capability in the network.

In opaque optical networks every node has the capability of O/E/O conversion. Request blocking is negligible here [3] due to O/E/O and available wavelength conversion. *In all-optical (also known as transparent) network* signals are transmitted through optical fiber in the optical domain, from source to the destination without any conversion at any intermediate node to the electrical domain. Physical impairments such as Optical noise, Polarization Mode Dispersion (PMD), Amplifier Spontaneous Emission (ASE), Polarization Dependent Loss (PDL), Chromatic Dispersion, Crosstalk, and Effective Pass band etc [4, 5-8] can produce bit-error-rate (BER) of the original optical signal which degrades quality gradually when it traverses a distance of fixed length through optical fiber without regeneration at any intermediate node. So, some requests may be blocked. Nodes with O/E/O interfaces are absent in transparent optical network [9] and all nodes are in the optical domain. *The translucent optical network* bridges the gap between opaque and transparent optical network. A translucent optical network is capable to reduce the network design cost as well as routing cost by dividing each light-path into one or limited number of segments. In translucent optical network an optical signal is permitted to stay in the optical domain for much of its path. This transmission limit in optical domain is termed as optical reach [10]. The length of an optical reach is typically 1500km. To keep the original optical signal quality, regeneration is essential at proper nodes. Basically each O/E/O interfaces is responsible for regeneration (3R: reamplification, reshaping and retiming) and wavelength conversion.

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All-optical 2R regeneration (2R: reamplification, reshaping) occurs in optical domain. So, all-optical 2R regeneration is less costly than 3R regeneration. Regeneration and O/E/O 3R regeneration are almost same except retiming functionality. Among these three regenerations, 3R regeneration is most expensive [11].

The 3R regenerations at intermediate nodes divide the light paths in translucent optical network from the source node to the destination node into several segments. Each segment is termed as a *regeneration segment* [1]. All lightpaths in translucent optical network may be broadly classified as (a) translucent lightpath and (b) transparent lightpath. Lightpaths with regeneration are known as translucent light paths. Transparent lightpaths do not contain any regenerator. Moreover, electronic processing is limited in translucent optical network. A request set in a particular translucent optical network cannot be blocked if at least one either transparent or translucent lightpath is found for each of the all requests of that request set. The number of blocked lightpaths is less in translucent optical network compared with all-optical networks due to regenerations and necessary wavelength conversion. Recent research [12] reveals that the performance of translucent optical network is very near to fully opaque network but much better than transparent network in terms of cost and overall blocking. So, translucent optical network is economical as well as reliable too with minimum required numbers of properly placed regenerators. Minimization of the total number of placed regenerators and selection of their best locations to establish a path between every pair of source-destination nodes in the network are the main objective of translucent optical network design. To design a cost-effective translucent optical network, allocation of minimum number of 3R regenerators at proper nodes is known as regenerator Placement Problem (RPP). RPP has been proved to be NP-complete [13, 14].

RPP can be optimized by fining at least one lightpath for each of the all possible request sets of a particular network with as few as possible number of nodes in that network having 3R regeneration capability. So, Routing with Regenerators Problem (RRP) is closely associated with RPP [13]. In RRP, locations of the regenerators are already selected and routing of a lightpath is computed for any request with smallest number of regenerations. So many research works were developed where RRP and RPP are solved simultaneously [15]. These methods generally find out a lightpath for any particular request and then place regenerators if necessary. After the completion of this process for all possible request set of any particular network, total number of placed regenerators of that network is significantly higher. Therefore, the main target of translucent optical network planning is to solve RPP satisfying RRP as a constraint.

Although various sophisticated works were done on RPP, still now creation of lightpaths with smallest no. of 3R regenerations is a major challenge in today's research issues. Various approaches have been put forward recently for the above mentioned scheme. However, our aim is to give an overview of the current research work in this field to investigate a charming balance between network construction-cost and cost of service providing activities of opaque and all-optical networks. This article reviews various research works developed on RPP in translucent optical network. This paper consists of the following sections. Section 2 represents the description of the review work on RPP in translucent optical network. Future work is depicted in section 3. Conclusion is drawn in section 4.

2. LITERATURE SURVEY

2.1Classification of translucent optical network based on RPP

Translucent Optical Network planning can be done into three different ways [3]. These are (a) Translucent networks with transparent islands, only border nodes are 3R regenerators (b) Translucent networks with sparsely placed 3R regenerators and (c) Translucent networks with Mixed Regenerators.

2.1.1 Translucent networks with transparent islands (TI)

A translucent optical network may be constructed by dividing the whole network into minimum number of non overlapping islands. The network design cost can be reduced by selecting fewer numbers of islands so that number of border nodes is also diminished. Inside each island all the nodes are in optical domain. Border nodes between two islands act as regenerators. All the lightpaths inside each island are transparent. For any particular request if it is necessary for any light path to cross the island's boundary, regeneration may occur at boundary nodes checking the optical reach constraint. This is a NP-complete K-cluster problem [3].

2.1.2 Translucent networks with sparsely placed 3R regenerators

A translucent optical network can also be formed by distributing minimum number of O/E/O interfaces strategically around the whole network. These opaque nodes are responsible for regeneration and wavelength conversion if necessary. All the remaining nodes of the network are all-optical. This is a NP-complete K-center problem [3, 16].

2.1.3 Translucent networks with Mixed Regenerators

Another approach can be taken into consideration by placing 1R, 2R and 3R regenerators instead of only 3R regenerators in the entire network. The network planning cost for this case can be lessened by diminishing total number of distributed 3R opaque nodes and replacing them by all-optical 2R nodes which guarantees that all node pairs can communicate with each other via transparent or translucent light paths. Each light-path through these switches can either stay at optical domain or become regenerated according to the optical reach limit of the network. In this strategy instead of the total number of reduction of regenerator placement in the whole network, less number of 3R regenerations for a particular request set is more important [11].

2.2 Research Works on RPP

Following are the details of the survey work on RPP discussed under three categories-

2.2.1 Translucent networks with transparent islands

In Clustered translucent approach in RPP [17, 18] a group of nodes from the whole network are selected as regenerators. Only these nodes can host 3R unit. All the remaining nodes are all-optical in nature. If two nodes from two different TI want to connect themselves then some boundary nodes are selected as regenerators. Total number of regenerators of the whole network is minimized [17] by considering only border nodes of islands that can only host 3R regenerators. The nodes of selected Islands of the network can be handled easily. Another advantage is that blocking probability is less compared to the static SHF (Shortest Hop First) algorithms in various large networks. Either failure or updating in the network may require a reconstruction of islands and a re-selection of the majority of the regenerators. This is the main disadvantage. In [19] a concept of hierarchical, optical backbone network is constructed. The main disadvantage of this method is its scalability in optical networking solution. In [18] the number of selected islands is also minimized by an ILP formulation as well as by a new heuristic which repeatedly combine graph faces to islands. The main advantage is that restoration with separate design is computationally more manageable since various smaller sized problems are solved separately instead of solving a single large sized problem. The main drawback is that the proposed heuristic for partitioning algorithm is only applicable for planar network topologies. In [20] connectivity graph is formed to solve the RPP. The formation of the connectivity graph is based upon the TI information of each node. A k-connected, k-dominating 3R-node set of any network can be constructed by achieving a desired level of network connectivity k. The proposed algorithm k-CD3S may be able to produce minimum number of 3R nodes. Performance of k-CD3S is compared with CNF [21]. k-CD3S shows significantly better result. The main drawback is that the regenerator placement strategy is totally dependent upon formation of k-connectivity graph by ILP formulation. In [22], an impairment-aware ILP (IA-ILP) formulation and a greedy heuristic are proposed to minimize the number of regenerating nodes in the network. IA-ILP takes the advantage of connectivity graph to minimize the computational complexity of RPP. Here all kinds of physical impairments are taken into consideration. The capital expenditure (CAPEX) for network planning as well as operational expenditure (OPEX) [33] is reduced here. But the main disadvantage of this paper is that physical model depicted here can site complication if further propagation effects are added to it. In [24] the basic connectivity graph is intensified to a "wavelength-aware" connectivity graph. The performance of the produced tool in designing translucent optical network has already shown better results. The drawback is that one mathematical ILP has been formulated for solution of RPP. ILP always produce optimum result in reasonable time for small optical networks. In [9] the concept of connectivity graph is extended for creation of k-path (k-p) connectivity graph. Using Yen's algorithm k no. of paths is selected first. Then the k-p IA-ILP is formulated that is able to plan a translucent optical network satisfying a static traffic. All operations are done on the k-p connectivity graph. The k-p IA-ILP is flexible in nature. The network designing procedure given by k-p IA-ILP can address both the TI and the sparse strategies. For a network operator the proposed method may produce the most cost-effective translucent network planning. Further research will reveal its correctness. The main drawback is that the mathematical k-p IA-ILP formulation is the input of hybrid method for the selection of regenerators.

2.2.2 Translucent networks with sparsely placed 3R regenerators

In sparse translucent approach of [2], any node in the network can be selected as regenerator during design of the translucent network as every node can host 3R units. In translucent network design, the sparse placement strategy generally places fewer regenerator nodes than the transparent islands approach [17, 18]. In NDF [21] all nodes of the network are manipulated in a list according to their decreasing order of nodal degrees. As the first node (highest nodal degree node) is deleted from the list, it is added in the regenerator-list and nodal degree of all the neighbors of the deleted nodes are decreased by one. So the original list of the nodal degree will be re-manipulated and above mentioned process will be repeated until a 1-connected and 1-dominating set of regenerators can be obtained. In CNF algorithm [21], all the nodes are arranged according to their decreasing order of topological centrality. To calculate this value for a node of the network, how many times that particular node is crossed by all-node-pairs shortest paths, is checked. Highest valued node is deleted from the list and added in the regenerator-list. Regenerator-list is constructed finally by adding other nodes sequentially according to their ranks in the list until a 1-connected and 1-dominating set of regenerators will be formed. The main advantage of these methods in [21] is their simplicity. The main drawback of these methods is that after the execution of each algorithm the selected regenerator nodes become significantly higher. A new heuristic algorithm based on calculation of transitional weight (TW) of each node is presented in [25] for sparse placement of 3R ESs (electronic switches) with minimum lightpath blocking. Here, TW of each node k is calculated by considering two important parameters. Those are λ_{sd} (the expected value of random traffic load in Erlangs between source-destination pair (s-d) of lightpath requests between nodes s and d) and T_k^{sd}, k € $\{0, 1, N-1\}$, N being the total number of nodes of the network. (T_k^{sd} is 1 if the route between s and d passes through the node k; otherwise, it is zero; T_k^{sd} is also 0 if k = s or d). Therefore, Transitional weight (TW_k) for each node k can be computed using the formula-$TW_k = \sum T_k^{sd} \lambda_{sd}$ *for all s, d and* s≠d, k € $\{0, 1..., N-1\}$. The nodes with high TWs are given higher priority in the given network. This heuristic then places electronic switches in nodes in order of decreasing TWs. The main advantage of this heuristic is its simplicity. The main drawback of this algorithm is that ranking of all nodes of the network are done by one-time calculation of TWs. Iterative computation for updating TWs of each node may produce better results. In [26] a new auxiliary graph model is invented to conquer the placement of regenerators and wavelength assignment problem jointly. Considering a request from the given request set, shortest path is selected for the request and then proper weights are allocated on every edges of the auxiliary graph in such a way that the total number of regenerators to be placed will be minimized considering optical reach constraint and wavelength continuity constraint. Here Regenerator Placement Problem and Wavelength Assignment Problem are solved simultaneously. Another advantage of this approach is that it can produce reduced number of wavelength change comparing with other two approaches in [26].The main drawback is that if number of nodes of the selected shortest path are high then auxiliary graph computation becomes complex. In [27] two major linear impairments PMD (Polarization Mode Dispersion) and ASE (Amplifier Spontaneous Emission) constraints [28] are considered. Both ASE and PMD costs are computed in every edge of the graph. RPP using REPARE approach in translucent network uses the graph transformation process to construct the neighborhood of each node and auxiliary graph. ILP formulation is simple, scalable, very fast and practical enough and can produce optimal solution (excluding large network). One innovative scheme TND [27] is proposed in REPARE which gives effective results ($K = |V|/4$, where K= no. of placed regenerators among the total V number of nodes of the network) for large networks. Here instead of optical reach (R), C_{ASE} (the ASE constraint which is the maximum number of hops a lightpath may have) and C_{PMD} (the PMD constraint which is the length of a lightpath with considerable BER) are considered. The other advantage of this heuristic is that it minimizes blocking probability. This proposed heuristic as well as ILP may collapse when optical communication operates at higher bitrates as effects of nonlinear impairments are not taken into consideration. Nonlinear effects may affect energy and shape of an optical signal which are not considered here. This is the main drawback of REPARE in translucent network. G. Shen and W.D. Grover have proposed a leading heuristic in [29] introducing Hub Node First (HNF) algorithm with lower number of regenerator placement notification. This is an exhaustive combinatorial search. At first, degree of each node of the network is counted in logical topology and higher degree node gets higher priority. Then the highest degree node is selected and the logical graph is reconstructed by connecting any two nodes from the neighbor list of the highest degree node. The above mentioned procedure is repeated for rest of the nodes until a fully connected logical graph is obtained. The main disadvantage of this algorithm is that it cannot consider any span-failure situation. To overcome this drawback of HNF, survivable HNF (SHNF) algorithm arises. Subir Bandyopadhyay et al., in [16] used heuristic to place 3R regenerators in translucent optical networks by forming Labeled minimum Connected Dominating Set problem in labeled graph. The proposed heuristic is complex in computation procedure. However this paper demands that near-optimal solution can be generated in a very small time. In [30] a new algorithm named MDORA based on fuzzy logic is proposed which has the capability of placement of optimum number of regenerators in appropriate places of the network. The fuzzy control system consists of Fuzzyfier, rule base and Defuzzyfier. In this case the input to the fuzzy system (fuzzy set) are the distance between two nodes and degree of each node. Gaussian membership function describes distance values of small, medium and large ranges. Triangular membership function is responsible for degree of each node in the network according to their ranges of small, medium and high. This fuzzy logic based regenerator placement algorithm is simple enough to implement even for large network. For 14-node NSFNET, MDORA algorithm places 2 nodes as regenerators. Two selected input parameters for the fuzzy system may not be always the sufficient inputs to the fuzzy system of Regenerator Placement Problem. In [14] a purely theoretical approach has been taken for placing minimum number of distributed regenerators. Here Approximation algorithms are used into consideration. The RPP reduces to a Minimum Vertex Cover problem. All lightpaths are classified into two distinct categories-(a) short lightpaths and (b) long lightpaths. Short lightpaths are of length 1. So it is the direct edge between two vertices of the network. Long lightpaths consist of one or more than one intermediate nodes. For short lightpaths any one end node may act as a regenerator. This paper reveals that at least $3*|E|+|X|$ (where E is the total number of edges of the network and set X represents a vertex cover of network G) regenerators are needed for any long lightpath. The main aim of this paper is to place minimum number of regenerators satisfying all possible request sets of a network. The main disadvantage of this paper is that experimental results for any large network are not shown. In [7] a mathematical ILP model (OPT-RPP) has been developed with physical-impairment constraints. Another game-theoretic approach (GT-RPP) where RPP is modeled as a non-cooperative game is implemented successfully too. In GT-RPP, players update their action in round robin fashion. GT-RPP can solve RPP much more quickly in approximated fashion. The performance of this method is good enough but worst than OPT-RPP in terms of regenerator selection in US national backbone network topology. However, the main drawback of this method is that this method is more weak compared with an IA-ILP design strategy demonstrated in [31]. RPP along with traffic grooming is solved in [32]. Proposed heuristic is based upon formation of auxiliary graph. Each auxiliary link of the auxiliary graph is constructed using shortest path routing. In the auxiliary graph if two nodes are connected by an auxiliary link then those nodes are reachable without any signal regeneration. To construct an auxiliary graph BFS algorithm is used to find out shortest paths between all pair of nodes. The drawback of this method is that it is assumed that all transponders and line interfaces operate at the same rate. Here lightpaths are hop-constrained by impairments. Costs have been reduced here by accumulating grooming with RPP jointly. Mixed-line-rate (MLR) optical networks with selected regenerations (translucent network planning) are modeled in [33]. MLR can increase flexibility of a next-generation optical network by assigning line rates to a particular demand. A cost-effective MLR network in translucent architecture is designed. A two step ILP is formulated. It can produce effective placements of 3R nodes for paths with high bit rates and cost optimization. It can further reduce overall cost in a translucent network compared to a transparent network. The main advantage of this method is that it is possible to enable as many high bit-rate paths as possible with placements of minimum number of regenerators. Construction of large translucent optical networks may not be possible as it is purely based upon ILP formulation. This is the main disadvantage. An effective heuristic method for selection of optimal number of regeneration sites has been depicted in [37]. This proposed heuristic is efficient enough for large network. The main disadvantage is that this framework is totally based upon creation of multiple paths.

2.2.3 Translucent networks with Mixed Regenerators

However, still now distributed 3R regeneration techniques is immature and highly-priced. The works depicted previously obey that O/E/O 3R regenerators are essential for BER restoration of an optical signal. But, it is already proven theoretically as well as experimentally that BER cannot be restored until FEC (forward-error-correction) functionality is available in 3R regenerators. 3R regenerators with FEC waste more power (approx. 20% of total energy) [11]. But all the 3R regenerators may not have FEC capability as budget cost and energy constraint is there. Recently many researchers think about the MRP (Mixed Regenerator Placement Problem) [34, 11] for further reduction of network planning cost as well as operation cost. Here it is assumed that FEC functionality is present only at end nodes of each lightpath for minimization of energy consumption. According to MRP [34, 11], taking the advantages of all-optical 2R regenerators, cost of a translucent network can be further minimized. This research is on MRP algorithms by moderately replacing O/E/O 3R regenerators by all-optical 2R regenerators. Periodic placement, GA (Genetic Algorithm) and ACO (Ant Colony Optimization)-these three methods are adopted for sketching three different MRP algorithms. BER_t and $BER_{s,d,l}$ (BER_t is the BER threshold and $BER_{s,\,d,\,l}$ is the end-to-end BER in the lth lightpath) are calculated using BER models depicted in [11, 38]. Link-based matrices of [35, 36] are used to model impairments. The proposed GA, ACO and Periodic placement for MRP problem has been applied for lightpaths of different hop count. Their performances are also measured in static network planning and GA produces best result in terms of number of 3R regenerator placement. The main drawback in [34, 11] is that simulation results for any particular large network are not shown at all.

3. FUTURE WORK

Selection of sufficient, as few as possible proper locations of 3-R nodes in a large network is the primary and essential necessity to develop a translucent optical network. A new algorithm on RPP can be developed remembering the above necessity. Route and Wavelength assignment problem (RWA) is the important problem of assigning a wavelength to each lightpath in a WDM network and finding out a route through the physical topology. A considerable amount of research has been done on RWA in opaque networks requiring wavelength continuity constraint, using graph-theoretic tools [10]. After the completion of RPP, a new algorithm on RWA may be generated for translucent optical network. In recent years, the design of robust, fault tolerant WDM networks has become a major topic. The problem becomes complex when implementing a protection scheme, since a backup path has to be determined. The problem becomes even more complicated when the logical topology and the routing scheme for a given traffic matrix have to be solved at the same time. In such a design, the characteristics of the WDM network are important. This includes whether or not wavelength converters are present, how many transmitters and receivers are available at each node and how many channels are supported on each fiber [10]. A research work on path protection & restoration in translucent optical network may be solved. Traffic Grooming in WDM networks can be defined as a family of techniques for combining a number of low-speed traffic streams from users so that the high capacity of each lightpath may be used as efficiently as possible. Traffic grooming minimizes the network cost in terms of the number of transmitters, receivers and optical switches. One important problem is to consider situations where the traffic is relatively stable over long periods of time [10]. In this scenario, it is important to think over in determining the most cost-effective approach for traffic grooming in translucent optical network.

4. CONCLUSION

This paper deals with various indispensable schemes regarding design of a translucent optical network especially RPP. Without violating the optical reach limit the most cost-effective design of a translucent optical network procedures have been discussed here. Numerous efficient heuristics are deliberated here for near-to-optimal solution as all optimization problems with constraints (which give optimal solution) are NP-complete. Many solutions regarding RPP have been explained here but we really realize that to blueprint a prudential translucent network further investigations are essential.

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