Abstract — Blocking probability has been one of the significant parameters in the design of WDM optical networks. In most of the network topologies the probability for each link to be occupied is different. There are always some links which are more likely to be used than others which can be denoted as key links. The existing routing algorithms do not take this important factor into account significantly. The network performance deterioration is more likely caused by certain key links of the network, which is related to static factor such as particular network topology, and dynamic factors such as wavelength exhausted rate as well as the number of free wavelengths available on a link. In the proposed approach, the key links are identified based on the link usage factor of a link to minimize the capacity exhaustive blocking in WDM networks. The concept of key links is incorporated in wavelength converter placement strategies for performance optimization in WDM networks. For sparse wavelength conversion the wavelength converters are placed in the nodes that connect the key links with higher normalized frequency of usage. The performance of the proposed approach is studied for various set of wavelengths and compared over full wavelength conversion and no wavelength conversion conditions in terms of blocking probability and link utilization. The proposed approach closely tracks the performance of full wavelength conversion.

Keywords: Link Utilization, Blocking probabilities, Routing and wavelength Assignment (RWA), Wavelength Division Multiplexing (WDM)

I INTRODUCTION

Optical networks with wavelength routing are expected to form the backbone in the next generation wide area networks [1]. The RWA problem is to establish a light path for each connection request and assign a wavelength to each light path such that no two light paths share a same wavelength and that the number of wavelengths used is minimized. A related optimization problem of RWA is throughput maximization problem. Performance evaluation of online algorithms for RWA was studied in [2]. The issues in wavelength routed networks include routing and wavelength assignment, minimizing the effect due to wavelength continuity constraints, design reconfiguration, Survivability of virtual topology, optical multicasting, control and management, traffic grooming, and IP over-WDM [3]. The connection requests can be either static or dynamic. The shortest-paths for each source destination pair is computed using Dijkstra’s algorithm. In Dijkstra’s algorithm, every link in the network is associated with a weight, for example, the propagation delay of the link. In addition to it the WDM specific information may be incorporated in the weight functions to improve the performance [4].

II SHORTEST PATH ROUTING

Here, each router periodically broadcasts its neighboring link information to all other routers. This information is used to construct the network topology with the associated link cost functions. Each router then independently computes the shortest paths from itself to every destination. When a new session request arrives, the router uses the routing table to determine the entire path from source to destination. It then attempts to assign a wavelength along this path by propagating a wavelength request to all the routers along the path. The initial wavelength may be selected randomly from one of the available wavelengths or based on other information as in [5]. If wavelength conversion is available in the network, then a light-path can be established using different wavelengths on different links. If this request fails, a different wavelength is chosen, which can be based on the feedback from the closest node on the shortest path. This process may be repeated till there is at least one wavelength available. If this fails, then the request is blocked, i.e. the light path cannot be set up. The concept of Dijkstra’s algorithm may be found in [6]

A. Routing Algorithm

The network topology is represented as a graph G(V, E), where V denotes the set of vertices (network nodes) and E the set of edges (links). Each link (i, j) E E is associated with
a weight function $W_{ij}$ which denotes the cost of using the link. At the end of executing a shortest path algorithm such as Dijkstra’s algorithm, each router has a routing table with complete path information to every destination. In WDM networks, link state information will also include WDM specific status such as number of available wavelengths, and total wavelengths. In addition, links on which all wavelengths are presently utilized may be marked as unavailable until the next routing update. Previous research has shown that weighting of links affects the blocking performance of optical networks [7].

The routes are usually considered with minimum hop counts because more scope is available for future connection requests (higher number of links are free implies higher degree of freedom). Taking the square root values offers the best performance in terms of blocking probabilities compared to other weighted functions [8]. Hsu et al. proposed a weighted-shortest path strategy, which looks for the path that minimizes the resource cost while maintaining the traffic load among the links as balanced as possible [9]. However, only the case of full wavelength conversion has been investigated.

### III LINK USAGE FACTOR

Most network topologies in actual use are irregular, so the probability for each link to be occupied is different. There are always some links are more likely to be used, which can be denoted as more “important”, and at the same time some others are not. This inherent unbalance does exist but still unfortunately the existing routing algorithms do not take this important factor into account enough [10]. The concept of link usage intensity is used in [10] but it is used to check whether any key links exists before a decision on removing a route from the candidate route table is made. In the network with dynamically changing traffic pattern it is better to pick a route that has a minimum effect for other future connection requests even the distance is longer. Obviously, once the wavelength resource is rapidly exhausted on such links that will lead to network congestion. Similar conditions are caused by not only the static network topology, but also dynamic network traffic. Due to the traffic among the node pairs is not uniformly distributed, the number of connection requests between node pairs may be much more than that between other node pairs. This implies that there may be a significant number of identical connection requests between certain node pairs that need to be satisfied concurrently passing through certain important links denoted as “Key Links”. The statistical characteristics for arrival rate of connection request are difficult to define in realistic network, thus lead to the inaccurate predication for link occupation probability. Hence to decrease the network congestion and improve the network resource utilization, the effective strategy is to find out the usage factor of each link and normalizing it with the usage factor of most congested link in the network. At least one of most congested or near-most congested links (generally links with congestion level above 90%) are involved in the capacity exhaustion blocking of the network [11]. In practical scenario, the connection requests from different nodes are correlated sometimes [12]. When designing the routing algorithm, the information of network topology (static) and link’s usage frequency (dynamic) as well as the computing complexity should be taken into account.

### IV THE PROPOSED SCHEME

When designing the routing algorithm, the information of network topology (static) and link’s usage frequency (dynamic) as well as the computing complexity is considered. When the weight function solely based on hop count (HOP) is considered, the effect of frequency of usage of a link on blocking probability and link utilization is ignored. The design of weight function is based on the following observations: When selecting a route, two important factors should be considered: (1) the number of free wavelengths; (2) the hop length of each route. The route with more free wavelengths should be preferred, and at the same time the hop length of that route should not be very long. If there is no wavelength conversion, these two factors are correlated, i.e., a route with shorter length is likely to have more free wavelengths than the routes with longer length. Therefore conventional dynamic RWA algorithms work very well by selecting the route with more free wavelengths if there is no wavelength conversion. However, if the network has the capability of wavelength conversion, the correlation between the number of free wavelengths and the route hop length is weakened, in the sense that a route with longer length is possible to have more free wavelengths than the routes with shorter length. Thus if we always select the route with more free wavelengths, it is possible that such routes have longer route lengths, which can result in a low wavelength utilization and high blocking probability. In the proposed approach apart from minimizing blocking probability the objective of maximizing resource utilization is also taken into account. The routes with minimum hop counts are usually considered because more scope is available for future connection requests (higher number of links are free implies higher degree of freedom). The proposed approach uses link usage factor to assign weights to each link. It tries to balance the traffic load in the network and considers the Key Links which are usually more likely to cause network congestion and performance deterioration faster. The link usage factor which specifies the dependency of a specific node pair relative to the particular link is calculated which can be summed up with that of other source destination pairs to find out the frequency of usage a link relative to the entire network. The frequency of usage is assigned as the weight for each link (FR). Since the route is selected based on the minimum weight the advantages of minimum hop count are incorporated in this approach. In addition to that the performance degradation due to capacity exhaustion is reduced by assigning more weights to the links with high frequency of usage. Through the concept of Key Links, we can adopt proper measures to reduce traveling through these links that contribute significantly to traffic congestion.
A System Parameters, Notations

1. The network consists of N nodes and L links.
2. The wavelength channels are labeled as 1 to λ. A route R is a subset of link set \{1,2,...,L\}.
3. The hop length of route is h(R).
4. The physical distance between the nodes on a link is D_{ij}.

B. Frequency of usage of a link

Capacity Exhaustion Blocking occurs both for networks with wavelength conversion as well as networks without wavelength conversion. The frequency of usage of any link is the number of routes traversing through link in a network. The link with the highest frequency of usage, has the maximum carried traffic and gets congested before any other link in the network and, therefore, is the most congested link of the network. The normalization of frequency of usage of any link can be done by dividing the frequency of usage of a link by the frequency of usage of most congested link.

A. Link Usage Index (LUI)

\[ LUI \] denote the dependency of specific node pair relative to link L. If certain candidate route passes Link \( L_{ij} \) if \( i, j \) are disparate nodes, then mark \[ L_{ij}^{LUI} = 1 \]

\[ L_{ij}^{LUI} = 0 \quad \text{otherwise} \]

Then \[ LUI_{IJ} = \sum L_{ij}^{LUI} \] where \( (i,j) \) and \( (I,J) \) represent link and s-d node pair respectively.

Frequency of usage of a link \( FR \) relates the link’s importance relative to whole network. Let \( FR_{(i,j)} = \sum L_{ij}^{LUI} \) \( (i,j) \in N \)

\[ FR_{max} \] is the maximum value of \( FR \) which denotes the most congested link.

D. Key Link Concept

This section describes the concept of key links in optical networks. The links with \( FR/FRmax > 0.8 \) influence significantly in traffic congestion and eventually the network performance are designated as key links.

E. Algorithm Description

1) Find k routes for each s-d node pair according to k shortest algorithm
2) Calculate \( LUI_{IJ} = \sum L_{ij}^{LUI} \) for each candidate route for a s-d pair
3) Calculate FR for each link.
4) Assign the weight \( LUI=FR \) to each link.
5) When connection request arrives for a s-d node pair assign the route which has the least weight
6) After completing route selection, the wavelengths are assigned on this route according to First-Fit algorithm.
8) If the constraints on wavelengths are not satisfied block the request

In honoring the connection request only the shortest route is selected and no additional candidate route is considered.

V Results and Discussion

In our paper we have applied the weight functions to a realistic example of backbone network, namely the NFSNET irregular topology in Fig.1. Permutation routing has been taken for finding out the sample source destination pairs. The number of wavelengths varied are 16, 24 and 32.
A. Performance Evaluation

The performance of the dynamic weights based on the proposed approach (LUI) was evaluated and the outputs are compared through simulation with the blocking performance of routing based on hop count (HOP). Simulations were carried out for 16, 24 and 32 wavelengths per links under no wavelength conversion, full wavelength conversion and sparse wavelength conversion conditions. Fig 2 shows the blocking probability versus connection requests for 16, 24 and 32 wavelengths. The results show that there is a remarkable improvement in blocking probability performance for LUI. It compares the performance of full wavelength conversion LUI (FC), no wavelength conversion LUI (NC) and hop count HOP with the performance of sparse wavelength conversion where wavelength converters are placed only in 8 nodes (LUI(8)). It can be observed that LUI(8) closely follows the LUI(FC). There is only a marginal difference in performance when wavelength converters are placed only in the 8 nodes which connect the key links over the performance when wavelength converters are placed in all the nodes in the
Network. Thus the concept of key links may be incorporated in wavelength converters placement strategies for performance optimization in WDM networks. Fig 3 shows the link utilization versus connection requests for 16,24 and 32 wavelengths for hop count and LUI under no wavelength conversion, full wavelength conversion and sparse wavelength conversion conditions. In all set of wavelengths the link utilization is better in LUI than the hop count. The results show that the network with full wavelength conversion provides better link utilization compared to network with no wavelength conversion. Overall link utilization decreases as total wavelengths increases, adding extra capacity to the network.

VI. CONCLUSION

This paper studied frequency of usage of a link and their impact on the blocking performance and link utilization in optical networks. Corresponding to varying number of connection requests and set of wavelengths, the blocking probability and link utilization are calculated. An irregular topology network was taken where sessions are assigned light paths for the session duration. The characteristics are investigated for no wavelength conversion, full wavelength conversion and sparse wavelength conversion conditions. Simulation results show that the dynamic weight based on link utilization index yields considerable performance improvement on blocking probability and link utilization with reduced computational complexity. The proposed approach of placing the wavelength converters in the nodes that connect the key links closely track the performance of full wavelength conversion. Thus improved functioning results by placing the wavelength converters over specific nodes rather than in all the nodes in the network.

VIII. REFERENCES

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