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MODIFIED DYNAMIC ONLINE ROUTING ALGORITHM AND REGENERATOR PLACEMENT IN WDM NETWORKS

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Abstract
Dynamic Online Routing Algorithm (DORA) has been already proposed for conventional networks to distribute load evenly across the network. However, the exponential growth of the internet has placed heavy burdens on network management and control application when the existing protocols are used. Adding more resources to the network may temporarily remove congestion conditions. However, it is not a cost-effective solution in solving resource contention problems in the long run. The network providers are facing problems in setting up on-demand network tunnels in backbone or transport networks. The MDORA proposed in this work is useful to decide the optimum number of regenerators to be placed on each node. Placement of regenerator in all the nodes is not cost effective and hence in this work, techniques have been proposed to place the regenerators only in selected nodes. Node selection for regenerator placement is performed using fuzzy logic.

Keywords:
DORA, MDORA, Fuzzy Logic, Conventional Network

1. INTRODUCTION

The key concepts and protocols used in the Internet Protocol-Multi Protocol Label Switching (IP-MPLS) framework can be extended easily to WDM based optical networks. With the current technology, the WDM networks provide circuit-switched light path services to the IP layer through other layers [5]. This increases network operating and management cost to a large extent. The use of an MPLS approach in optical networks helps to minimize the cost of transition from the present circuit switched technology to the burst switching or packet switching technology. The IP-MPLS framework enables direct integration of IP and WDM without any intermediate layer between the IP layer and WDM layer. The IP-WDM framework can be used in all kinds of optical networks-circuit switching burst switching, and packet switching networks.

Depending on the switching technique employed, a WDM network using the MPLS approach is classified as a Labeled Optical Circuit Switching (LOCS), Labeled Optical Burst Switching (LOBS) network, or Labeled Optical Packet Switching (LOPS) network [6]. The labeled optical circuit switching is also known as Lambda-labeling or multi-protocol lambda switching (MPλS). The advantages of label switching are:

1. Optimized network resource usage.
2. Fast forwarding due to label switched paths (LSPs) can be specified explicitly. The traffic can be measured on every LSP. Moreover,
3. Backup LSPs can be used to ensure survivability.

In LOCS networks, only a subset of the label operations can be performed. In these networks, the wavelength cross connects (or the wavelength routers) are the Label Switched Routers (LSR). Here, an LSP is nothing but a light path. Therefore, the granularity of an LSP is much larger (on the order of gigabits per second) when compared to that seen in the traditional electronic IP-MPLS networks. The label associated with an LSP is the wavelength of the corresponding light path. The label-add and label-drop operations are done in a similar way as in electronic networks. Since the LOCS is a circuit-switched network and the messages are optically switched in an LSP (light path), the label swap operation is performed only at the time of establishing the LSP. Even then, the labels can be changed at a node only if it has wavelength conversion capability, otherwise the label remains unchanged. It is to be noted that no label processing is performed at the nodes traversed by an LSP (light path) during message transfer.

In a wavelength-routed optical network, the failure of a network element (e.g., fiber) can cause the failure of several light paths, thereby leading to large data loss. Ensuring network survivability in WDM network using MPLS approach (Labeled Optical circuit switching network) is an important problem.

The exponential growth of the internet has placed heavy burden on network management and control operations. The addition of more resources to the network may provisionally relieve congestion conditions, but it is not a cost-effective solution for resource contention problems in the long run. Furthermore, the trend is towards providing differentiated classes of service and another level of complexity to network management and operations. Hence the service providers need mechanisms to coordinate, control and efficiently utilize existing resources to satisfy customer demand. The on line routing can be used to alleviate resource contentions and improve overall network utilization.

RWA algorithms discussed in the literature [3, 7, 9, and 10] find the path for sending traffic from source to destination. The calls may be blocked due to the non - availability of resources due to repeated usage of the same light path. Sometimes it is under - utilized. Hence, a new algorithm is required to solve this kind of problem. Moreover, for differentiated services, the required constraints and quality of service must be satisfied. But a single algorithm cannot solve all the problems at the same time. Hence, different algorithms are required to meet the present demands.

Secondly, a majority of the RWA algorithms consider the physical layer of the network to be ideal. The impairments introduced by the physical layer are not considered. The devices, optical fiber and the components used in the network, can introduce several impairments to a transmitted signal and can affect its quality. The significant transmission impairments are: cross talk, amplifier noise, dispersion and non-linear effects [12, 13]. This will result in increased BER in the network. Nodes in the network use optical cross - connect to connect the input signal from one part to another part. In addition to the fiber loss, switches also introduce insertion loss, cross talk and polarization dependent loss. The RWA algorithm should also consider the above mentioned physical layer impairments [14, 15].

While the signal propagates through channel, the signal quality will be degraded by impairments. The proposed RWA algorithm automatically considers the effects of impairments when setting up light path.

This paper proposes new algorithm to distribute the traffic evenly across the network in order to reduce the amount of recovery request under multiple failure scenario protection as its resource efficiency is due to the fact that back up paths can share wavelength links when their corresponding working paths are mutually diverse.

To maintain the signal quality, regenerators are placed and the optimum number of regenerators to be placed in a node is found using fuzzy logic in order to reduce the cost.

This paper is organized as follows:

Section 2 presents the Issues pertaining to path selection algorithms. Section 3 describes the MDORA. Section 4 presents the simulation results of DORA and MDORA. Section 5 gives the design details of regenerator placement using fuzzy logic.

2. ISSUES PERTAINING TO PATH SELECTION ALGORITHMS

The following are the issues pertaining to path selection algorithms.

Routing Constraints: Routing constraints include delay, signal degradation, loss ratio and administrative constraints to mention a few. It has been proved that finding the optimal route subjected to two or more additive and/or multiplicative metrics is NP-complete. In addition, it is generally difficult to obtain accurate values for certain metrics such as delay and jitter.

Online/Offline Routing: Offline constraint-based routing requires a demand matrix as input. A demand matrix describes the expected amount of data to be transmitted between a source-destination pair in the network at different times. In contrast, online constraint-based routing does not require a priori knowledge of the size and arrival time of each individual path setup request. This research work focuses on online constraint-based routing, as it is the appropriate approach to solving the dynamic path setup problem in MPLS networks.

Computational Complexity: Online routing algorithm computes paths as setup requests arrive at the network. In the case where the ingress node is operating in demand-driven mode, the path computation time is added to the overall response time that the user perceives. Therefore, it is necessary for path computations to be as fast and as efficient as possible. Each incoming request is processed at the ingress router that typically operates at very high load. The time it takes for a path to be established in the network should be short.

Re-routing Performance: During link or node failures, re-routing can induce service interruption or delay for the end-users. Routing algorithm must map traffic trunks onto the network in such a way that the number of paths affected by link or node failures is minimized.

Link State Distribution: To compute paths with specific requirements, the node(s) that executes the routing algorithm should have correct topology and resource information.

The issues related to constraints for the routing and wavelength assignment problem are as follows:

Wavelength continuity constraint: A light path should use the same wavelength on all the links along its path from source to destination edge node.

Distinct wavelength constraint: All light paths using the same link (fiber) should be allocated distinct wavelengths. One of the better performing on line routing schemes, called Minimum Interference Routing Algorithm (MIRA) [2, 6] is based on a heuristic dynamic online path selection algorithm. The key idea and but also the intrinsic limitation of the algorithm, is to exploit the a priori knowledge of ingress-egress pairs to avoid routing over links that could “interfere” with potential future paths set-up. These “critical” links are identified by MIRA as links are heavily loaded, that would make it impossible to satisfy future demands between some ingress-egress pairs. The drawbacks are:

(i) The identification of the “critical” links leads to a severe computation complexity caused by the maximum flow calculation performed each time a new Light Switched Path or light path is established

(ii) The algorithm cannot estimate bottlenecks on links that are “critical” for clusters of nodes

(iii) MIRA [11] can lead to unbalanced network utilization because it does not take into account the current traffic load in routing decisions. The Min Hop algorithm routes an incoming connection along the path which reaches the destination node using the minimum number of feasible links. The scheme, based on the Dijkstra algorithm, simple and computationally efficient. However, the use of Min Hop can result in heavily loaded bottleneck links in the network, as it tends to overload some links leaving others underutilized. The cost given to each link, in fact, remains constant and independent of the current link and, therefore, Min Hop tends to use the same paths until saturation is reached before switching to other paths with underutilized links. Hence, the Dynamic Online Routing Algorithm is proposed to distribute load evenly across the network. Adding more resource to the network may temporarily relieve congestion conditions but it is not a cost-effective solution for solving resource contention problems in the long run. The network providers are facing problems in setting up on-demand network tunnels in backbone or transport networks. So Boutaba [4] addressed this issue by proposing a new routing algorithm called Dynamic on line Routing Algorithm (DORA) for circuit switched networks.

3. MODIFIED DYNAMIC ON LINE ROUTING ALGORITHM

In this work, the DORA has been modified for wavelength routed networks. The performance analysis of the algorithm has been carried out for NSFNET with different link length networks that are considered in this work. Each link in the Fig. 1 has a number of wavelength channels. This algorithm is divided into two stages. In this proposed algorithm, Link Potential Value (LPV) for each link is computed.

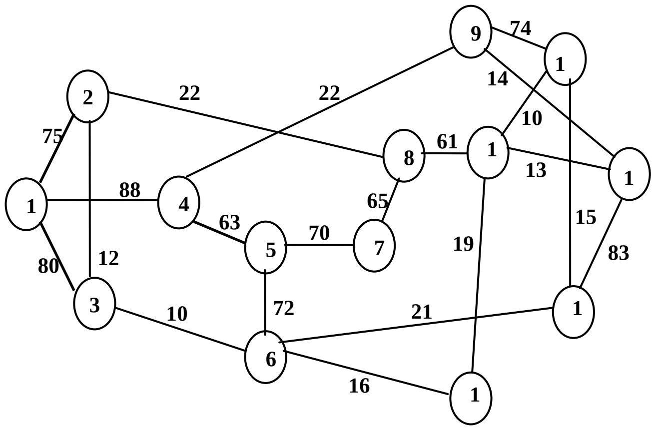


Fig.1. 14-NODE NSFNET

The performance of the modified DORA has been enhanced by considering optical switching technology using Micro-Electro-Mechanical System (MEMS) at the node level. This algorithm automatically checks the signal quality and regenerates the signal if required. Currently, the optical switches in each node in the network consist of regenerator and transceivers. This increases the operational cost [1]. Hence, the regenerator is placed in few nodes to reduce the cost of the system. A fuzzy logic method is adopted to find the suitable position to place the regenerative node.

The operation of DORA is divided into two stages. The first stage calculates the path potential value (PPV) array associated with a source–destination pair and the second stage combines PPV with residual link bandwidth to form a weight value for each link, which is then used to compute a weight-optimized network path. The design of the first stage is based on the following observation:

1. There are many paths that data could take to flow between a given source and destination nodes, and some links are more likely to be included in these paths than are others.
2. The potential of a link being more likely to be included in a path than other links is characterized by an associated PPV. Each source–destination pair (S, D) is associated with an array, PPV(S*;* D).

The working of the DORA algorithm to find critical links is explained as follows:

1. For each source–destination pair (S, D), determine the set of all disjointed paths DP(S*;* D).
2. For each source–destination pair (S, D), construct the PPV(S*;* D) array and initialize all entries to zero. The size of the array is equal to the number of network links.
3. For the source–destination pair (S_1, D_1), for each link L in the network, if L is part of any path in DP (S_1*;* D_1), subtract 1 from PPV (S_1*;* D_1) (L).
4. For all the source–destination pairs other than (S_1, D_1), inspect each link L and determine the number of times z that L appears in DP(S*;* D) where (S, D) is not equal to (S_1, D_1). Increment PPV (S_1*;* D_1) (L) by *z*.
5. Repeat Step 3 for all the other source–destination pairs.

In the second stage of DORA, the residual bandwidth is found and then it is normalized it. The final step is to find the link weight where Dijsktra's algorithm is used to compute a weight-optimized path from the source node to the destination node.

3.1 MDORA WITH LINK POTENTIAL VALUE

This algorithm is divided into two stages. It is analyzed into three methods namely DORA, DORA-second stage modified and MDORA. A study is carried out with DORA as given in Boutaba et al [4] for 14-Node NSFNET in the first case. In the second method, the second stage of DORA is modified and proposed for a wavelength routed circuit switched networks. The blocking performance is compared with first case (DORA). In order to maintain signal quality, the optical switching technology is used [8]. In this work, Micro-Electro-Mechanical System (MEMS) is considered at the node level. The main types of switches are LiNbO3 switches, SOA-based switches, liquid crystal switches, electro holographic (EH) and electronically switchable waveguide Bragg grating switches. The main drawbacks of LiNbO3 switch are high insertion loss and high crosstalk.

In the final stage, the link weight is computed by using link potential value (LPV) meant for wavelength routed networks. This algorithm automatically checks the signal quality and regenerates the signal if required.

MDORA presents a reduced computation complexity while identifying the critical links in a network where the ingress-egress pairs are known in advance. The idea is to associate a Link potential value (LPV) to each link in the network, and, using this information, the available free wavelength is used to compute a link weight-optimized path. LPV values indicate the potential of a link to be included in many paths than other links. This scheme allows furthermore balancing the load in the network, reducing the congestion probability.

3.2 MATHEMATICAL MODEL TO FIND LPV

The LPV is obtained by combining PPV values (used in DORA) of all S, D pairs. The source nodes can be represented as $\{S_1, S_2, \ldots S_i\}$ and destination can be represented as $\{D_1, D_2, \ldots D_j\}$. Number of all possible source and destination pairs n=i*j and they can be represented as

$$
\begin{aligned}
\{ & \\
& \{(S_1, D_1), (S_1, D_2) \ldots (S_1, D_j)\}, \\
& \{(S_2, D_1), (S_2, D_2) \ldots (S_2, D_j)\} \\
& \ldots \\
& \ldots \\
& \{(S_i,D_1),(S_i,D_2) \ldots (S_i,D_j)\} \\
\} &
\end{aligned}
$$

For each S, D pair all possible disjoint paths are computed in terms of the minimum number of hops.

To find a Link Potential Value for a particular link, say L, the number of times the link L is present in any of the disjoint path in all S, D pair is calculated and it is represented by a letter 'k', LPV array is initialized to zero, where (n-k) is equal to the number of times the link is not present in any of the disjoint path in all S, D pairs.

Consider only the S, D (S_1,D_1) pairs which contain the link L in any of the disjoint path i.e only 'k' number of S, D pairs are considered to combine. As per DORA, for the (S, D) pair if the link L is present in any of the disjoint path of (S, D) pair then subtract 1 from the PPV value and increment the PPV by the value equal to the number of times the link L is present in all other ingress egress pairs other than S_1, D_1 and repeat this step for all other ingress- egress pair. Here in MDORA, only those 'k' (S, D) pairs are considered which contain the link L in its disjoint path set. So the LPV is decremented once and incremented by (k-1) and it is repeated for 'k' (S, D) pairs (adding LPV of the link L corresponding to k number of S, D pairs) which contain the link L in the disjoint path set.

$$LPV = ((-1 + k - 1) + (-1 + k - 1)\ldots\text{k times}) + x \quad (1)$$

x is the value obtained when (n-k) other S,D pairs are considered.

Now consider the remaining 'n-k' (S, D) pairs which do not contain the link L in any of the disjoint path. So PPV is incremented by k (as per DORA) and this step is repeated n-k times.

From Eq. (1)

$$LPV= ((-1+k-1) + (-1+k-1) +...\text{k times}) +(k+k+\ldots \text{(n-k) times}) \quad (2)$$

Eq. (3.2) is simplified to

$$LPV = k\,(n - 2) \quad (3)$$

The minimum value for LPV is zero. i.e. The link is not used by any S, D pair in its disjoint path set. The Maximum Value for LPV is n (n-2) i.e. the link is used by all S, D pair in its disjoint path set.

Thus the range of PPV is given by:

$0 \le LPV \le n\,(n-2)$.

3.3 PROCEDURE TO FIND LINK WEIGHT USING LPV

Setting up of the topology for the network and identification of the critical links i.e. those likely to be congested in future are found out.

Stage 1

Find the source-destination pairs.

For each source-destination pairs(S, D), determine the set of all disjoint paths (DP).

Construct The Link Potential Value (LPV) Array, using the relation.

$$LPV\ (L\ (S_i, D_j) = k\ (n-2) \quad (4)$$

Find the normalized LPV.

This is done by (i) first finding the set of all disjoint paths between all possible ingress and egress pair. (ii) Then the Link potential value (LPV) for each of the links is found out. This is computed using the formula (LPV value of the link between nodes 'a' and 'b' from Eq. (2)

$$LPV\ (L\ (a, b)) = k\ (n-2) \quad (5)$$

where,

k=number of times the link is used in any of the disjoint paths of all ingress and egress pairs,

n=number of all possible ingress and egress pairs and LPV values are normalized between 0 -100.

After this, the LPV proportion value is set by analyzing the LPV value of all the links.

Stage 2

1. Remove the links which have no free channels.
2. Find the available number of free wavelength channels in a link.
3. Take the inverse of the available free wavelengths and let it be AW and the link weight is computed using LPV.
4. Path selection using Dijsktra algorithm.
5. Link weight is calculated using the following equation

   Link Weight=NLPV*(WP) +AW (1-WP) (6)

   where,

   NLPV - Normalized link potential value and

   WP - Wavelength proportion parameter
6. Run the shortest path algorithm to compute a link weight optimized path between (S_1, D_1).

Stage 1 is executed only once. When there is a topology change, it has to be executed again. Stage 2 is executed when there is a request.

3.3.1 Constraint Based Routing (Stage 2):

When there is a request to set up a path between particular ingress and egress with some constraints (delay, signal degradation), then link weights of the network links are computed as follows:

1. Delay and signal degradation values of the links are considered, if required.
2. The delay and signal degradation proportion values depending on the type of data transmitted through the network are set.
3. The link weight of link 'l' is found as follows:

LW (l) = NLPV (l)*(1-DSP) +DSP*DSC (l) (7)

DSC (l) = (DP*DV) + (SP* SD),

where,

(1-DSP) - LPV proportion

DSP - Delay and Signal degradation proportion

DP - Delay proportion

SP- Signal degradation proportion

DV- Delay Value

DC- Delay value in the link

SD - Signal degradation along the link.

NLPV - Normalized LPV value of the link.

After computing link weight using Eq. (6), the shortest path algorithm is run and the optimized link weight path is calculated between source and destination.

3.4 IMPORTANCE OF LPV

Stage one is executed whenever a topology change has occurred, and stage two is executed whenever a path setup request arrives to the network. In the first stage, the key operation is to assign Link potential value (LPV) to each link.

LPV reflects how likely a particular link will be part of some potential paths between some source-destination pairs in the network. A large LPV link value implies that this link is likely to be part of many potential paths and thus routing over this link should be avoided whenever possible. A small LPV link value means that there are less potential paths using this link and, therefore, it is more desirable to use this link than others with larger LPV value.

If the LPV proportion equals 0.7, this implies that 70% of the link weight is contributed by the associated LPV and 30% of the link weight is contributed by the other parameters like delay, signal degradation

3.5 COMPLEXITY ANALYSIS

N=number of nodes

M=number of edges for the average case:

For DORA:

Stage 1: O $(N*M^2*P^2)$

Stage 2: O (N*M)

Where P=no of edge nodes and P<=N.

For Modified DORA:

Stage 1: O $(N*M^2)$

Stage 2: O (N*M).

For the worst case

For DORA:

Stage 1: O (N^3*M^2)

Stage 2: O (N*M)

For MDORA:

Stage 1: O $(N*M^2)$

Stage 2: O (N*M)

Thus the complexity of the algorithm is reduced by a factor of P^2 (average case) and N^2 (worst case) when compared to DORA.

Comparison: The Modified DORA is better than the existing dynamic online routing algorithm in the following ways:

1. The number of steps used to compute the PPV array is replaced by a simple formula to find LPV.
2. In DORA, every time a request is made, it is necessary to map the PPV array corresponding to the S, D pair. This is actually an added delay to set up a path. But, considering the case of MDORA based on LPV, there is no need for mapping.
3. Considering 100 nodes in a network, under the worst case, it requires 10000 PPV arrays as per DORA. The size of each PPV array is the number of nodes present in the network. So the memory required to store all the entries is large. But in the modified algorithm, only a single LPV array is maintained for the entire network. So, the size of the LPV array depends only on the number of links in the network and not on the number of nodes (i.e. there is no need to have an array for every (S, D) pair).

In DORA algorithm, the PPV for all SD pairs are computed individually. Hence the array size is equal to the number of links in the network leading to increase in computation time. In MDORA, for all links, only one LPV is computed using Eq.5. Therefore the computation time is much less even though it is done at the time of light path establishment.

The proposed algorithm provides a good solution for both critical path determination and also congestion control. The importance of LPV is also stressed here which has greater significance and greater priority than the number of hops in many network topologies.

4. SIMULATION MODEL

NSFNET with 14 nodes and 21 links is considered as shown in Fig. 1. Each edge actually consists of two standard single modes fibers carrying bidirectional traffic. The call arrives at the network as a Poisson process. The source and destination of the incoming call is determined using a uniform distribution. The call duration is exponentially distributed with the mean of unity. The number of wavelength (W) on each link is eight and they are: [1546.99, 1547.80, 1548.60, 1549.40, 1550.20, 1551.00, 1551.80 and 1552.60] nm.

External intensity modulation is assumed at the transmitter, the bit rate channel is 2.5 Gbps under this condition, assuming a standard single mode fiber operating at 1.5 μm region, the chirping of the transmitted signal and chromatic dispersion can be neglected.

For each dynamically arriving call request, a route and free wavelength are determined using MDORA and the blocking occurs only due to the non availability of free wavelength. In the second case, it is assumed that the receiver Bit Error Rate (BER) associated with this connection request is equal to 10^{-12}. The light path is established, if the required BER is satisfied; otherwise the call is blocked. It may be noted that calls may be blocked for non- availability of free wavelengths.

Fig.2. shows the performance comparison of various modifications of the DORA algorithm. In one method, the first stage of DORA is unchanged and the second stage of DORA is modified for wavelength routed networks. In this modification, the link weight is calculated using the available wavelengths. In the next variant, in the first stage, PPV array used by DORA is replaced with LPV array. In the second stage, the link weight is calculated using available wavelengths as in the earlier case. It is observed that the blocking probability of modified Dora is reduced significantly. This is due to distribute the load evenly across the network and finding the link weight using link potential value.

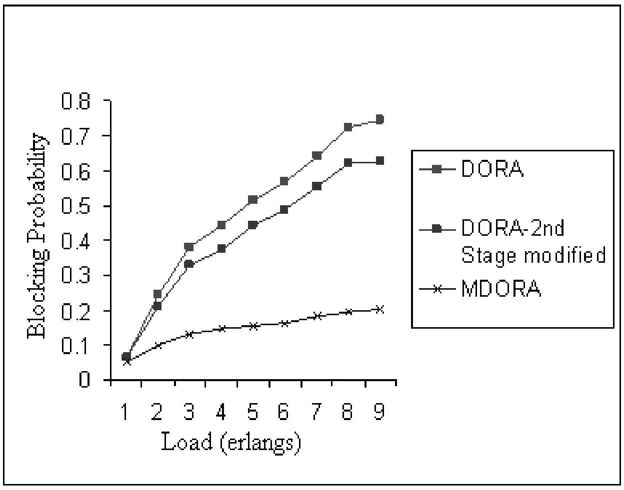


Fig.2. Performance comparison of DORA and MDORA related to modification at different stages of algorithm

5. REGENERATOR PLACEMENT USING FUZZY LOGIC

The WDM optical network is likely to be the backbone of future communication network. Although most people are optimistic about the emergence of an all-optical global-scale optical network, they addressed the technical difficulties of overcoming the signal degradation introduced by the physical impairments such as amplified spontaneous emission noise, dispersion, optical fiber nonlinearities, etc. In reality, there is no satisfactory method to overcome these impairments without Optical-Electrical-Optical (OEO) conversion. Therefore, regeneration is required if the transmission path length exceeds the available transparency length. Placement of regenerators in all the nodes is not cost-effective.

The components of conventional systems and fuzzy systems are quite a like differing mainly in the fuzzyfier part. The three main parts of the fuzzy logic control system are Fuzzyfier, Rule base (Knowledge base) and Defuzzyfier. The fuzzyfier converts the crisp values into fuzzy representations. The rules in the knowledge base are all executed based on the fuzzyfier input. These rules generate a new fuzzy set representing the output. The Defuzzyfier converts the output of the fuzzy system into a crisp value is shown in Fig.3.

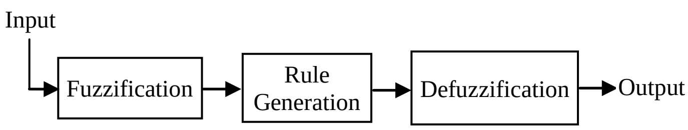


Fig.3. Fuzzy logic control

5.1 FUZZIFICATION

Fuzzification can be considered as a mapping from an observed input space to fuzzy sets. It performs the following functions:

1. Measuring the value of the input variable at every sampling instant
2. Normalization of the input variables.
3. Conversion of the input data into linguistic variables.

5.1.1 Knowledge Base:

The knowledge base of fuzzy logic controller consists of two components which are rule base and data base. The rule base characterizes the control goals and the control policy by means of a set of linguistic controls. The data base provides necessary definitions that are used to define linguistic variables and fuzzy data computation.

5.1.2 De-fuzzification:

The Defuzzyfier converts the output fuzzy set into a crisp variable. It produces a non-fuzzy control that best represents the possible value of an inferred relation.

5.1.3 Implementation:

The node selection for regenerator placement is performed using fuzzy logic. The input to the fuzzy system is the distance between the two nodes and the number of fiber ports attached to each node. The distance between two nodes and the number of links attached with a node are formed into a fuzzy set. The fuzzy set includes small, medium and large values. The three steps of fuzzy logic are fuzzification, rule generation and defuzzification. Gaussian membership function is generated for the distance values with small, medium and large ranges. Similarly, triangular membership function is created for the numbers of links connected to each node. To generate membership function for each set, we need mean and standard deviations of that set. Hence mean and standard deviations are calculated and based on which the Gaussian membership function is created. The Gaussian function is generated by the below given formula,

$$F(X) = \text{Exp}\left(-(X - \mu)^2 / (2*\sigma^2)\right) \quad (8)$$

where μ is mean and σ is standard deviation.

The triangular curve is a function of a vector, x, and depends on three scalar parameters A, B and C, and is given by the equation

$$F(X, A, B, C) = \begin{cases} 0 & X \le A \\ (X-A)/(B-A) & A \le X \le B \\ (C-X)/(C-B) & B \le X \le C \end{cases} \quad (9)$$

The deviation from the input and the values available in the fuzzy set are calculated with the mean values. The deviation is calculated by using the formula

$$P = (p_1, p_2, ..., p_n) \quad (10)$$

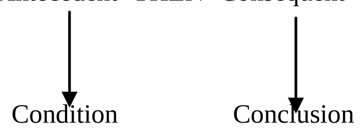
$$Q = (q_1, q_2, ..., q_n) \quad (11)$$

$$\sqrt{(p_1-q_1)^2+(p_2-q_2)^2+...+(p_n-q_n)^2} = \sqrt{\sum_{i=1}^{n}(p_i-q_i)^2} \quad (12)$$

where P and Q are the input variable and the mean.

To find the utilization range, Fuzzy MIN reasoning rule was applied. The general syntax for the IF-THEN rule is given by

IF<Antecedent>THEN<Consequent>



The threshold values are calculated by the defuzzification procedure, using the centroid method. The simulated Gaussian and triangular membership functions are shown in Fig. 4 and 5 respectively. The link length ranges are classified into three groups namely small, medium and high and they are shown in Fig.4.

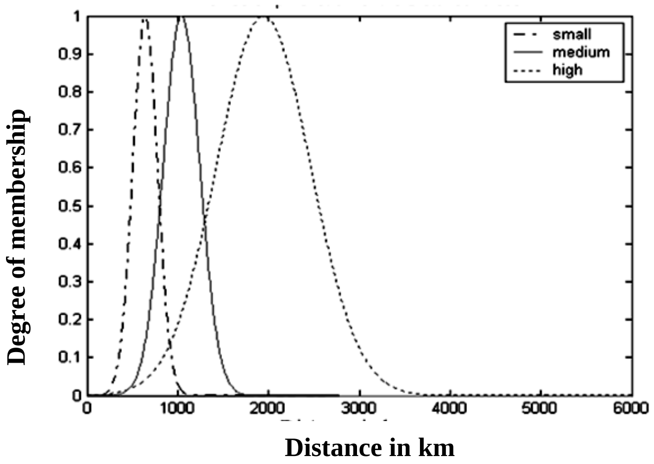


Fig.4. Gaussian membership function

The number of fiber ports attached to each node is summed up, and, according to the ranges, it is classified into small, medium and high and their corresponding membership values are shown in Fig. 5. The network is considered to find the regenerative node is given in Fig. 6. It is of 14-node NSFNET. The link length between two nodes given in kilometers.

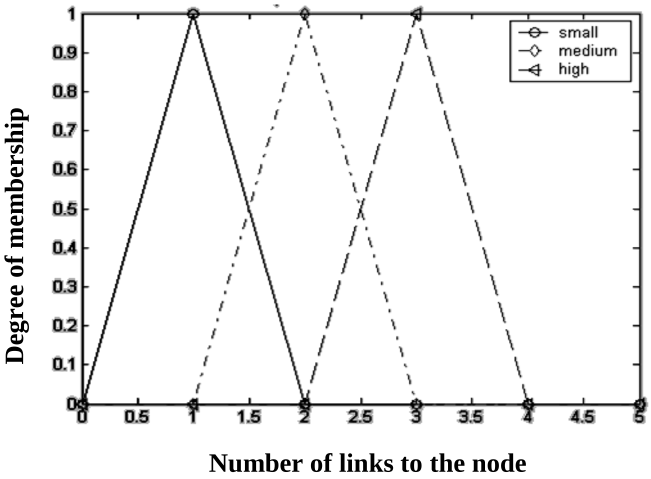


Fig.5. Triangular membership function

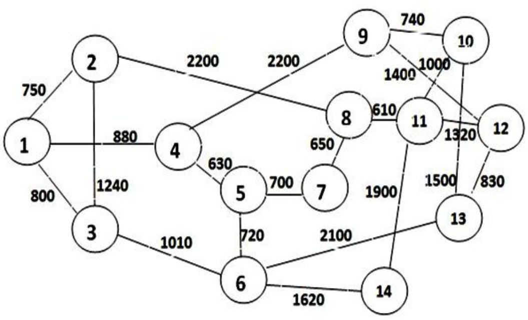


Fig.6. 14-node NSFNET

6. REGENERATOR PLACEMENT ISSUE

Optical switches constitute an essential ingredient in the optical networks to perform the switching functionalities. One application of optical switches is in the provisioning of light paths. In this application, the switches are used inside wavelength cross connects to configure them to support new light paths. Another application is to switch the traffic stream from the primary fiber on to another fiber in case the primary fiber fails. Currently, optical switches in each node in the network consist of regenerator and transceivers.

A number of switching technologies are currently available. Electro-optical switches realize optical switching functions by using electro-optic effects, which offer a relatively fast switching speed. Main types are $LiNbO_3$ switches, SOA-based switches, liquid crystal switches, electro holographic (EH) optical switches, electronically switchable waveguides, Bragg gratings switches and Optical MEMS. The main weak points of LiNbO3 switch are high insertion loss and high crosstalk (Xiahia Ma and Kuo 2003). PLZT (Polarized Lead Zirconium Titanate) is a material with a higher electro optic coefficient than LiNbO3. Hence, PLZT electro optic switch improves the overall switch performance. The SOA-based switches refer to current-controlled optical switches, where some SOAs used as gates are turned OFF/ON by controlling the bias currents. The SOA-based switches refer to current-controlled optical switches, where some SOAs used as gates are turned OFF/ON by controlling the bias current. These switches introduce various losses and crosstalk which degrades the signal to noise ratio. In this work MEMS switches are used .The losses are listed below in Table.1.

Table.1. OMEMs switching characteristics

Optical MEMs		
Insertion loss (dB)	Switching speed (ms)	Polarization Dependent Loss (dB)
1.7	7	0.25

Optical MEMS are miniature devices with optical, electrical, and mechanical functionalities at the same time, fabricated using batch process techniques derived from microelectronic fabrication. Optical MEMS provide intrinsic characteristics for very low crosstalk, wavelength insensitivity, polarization insensitivity, and scalability. Optical MEMS-based switches are distinguished based on mirrors, membranes, and planar moving waveguides. The former two are free-space switches; the latter are waveguide switches.

Signal quality is given by SNR=signal power/noise power where noise power comprises of factors like crosstalk, losses

$$\frac{P_{output\ signal}}{P_{crosstalk} + P_{noise}} \geq SNR_{min} \qquad (13)$$

where SNR min is the minimum allowable SNR value for the signal to pass without regeneration.

The bit error rate (BER) is given by

$$BER = Q\left(\sqrt{\frac{M}{2}}\right) \qquad (14)$$

where Q(x) denotes the probability that a zero mean, unit variance Gaussian random variable exceeds the value x and the receiver sensitivity is expressed by M. To obtain a BER of 10^{-12} the argument to the Q(.) function must be 7. Let the argument to the Q(.) function be γ.

$$\gamma = \frac{2\times \mathrm{OSNR}\sqrt{\frac{B_0}{B_e}}}{1+\sqrt{1+4\times \mathrm{OSNR}}} \quad (15)$$

The SNR value calculated is related to the bit error rate. The SNR of 20 dB corresponds to a bit error rate of 10^{-12}. In this work optical MEMs switch is considered, the dimension of the switch is assumed to be N×N. In this case the switch has N bidirectional fiber ports. The number of possible input/output port pair is NC_2 = N (N- 1)/2. In the following analysis, the switch has four fiber ports, which gives us six possible (input port, output port) combinations. It is assumed that an equal number of regenerators are assigned to each of the NC_2 input/output port pairs. If the total number of regenerators in the switch is c, then the number regenerator is found by c' which is given by

$$c' = 2c/(N^2-N) \quad (16)$$

The above equation gives the number of regenerators available to each port pair, which receives connection requests at a rate of

$$\lambda' = 2\lambda/(N^2-N) \quad (17)$$

The blocking probability for connections requiring the use of any given input/output port pair is $B(c',\rho')$ where

$$\rho' = \frac{\lambda'}{\mu} \quad (18)$$

is the directional regenerator load, measured in erlangs. Then the blocking probability is given by,

$$B(c',\rho') = \frac{(\rho')^{c'}/c'!}{\sum_{k=0}^{c'} (\rho')^k/k!} \quad (19)$$

Using the above analysis for a optical MEMS switch, the blocking probability for a network can be computed. The number of regenerators required in each node is shown in Fig.7.

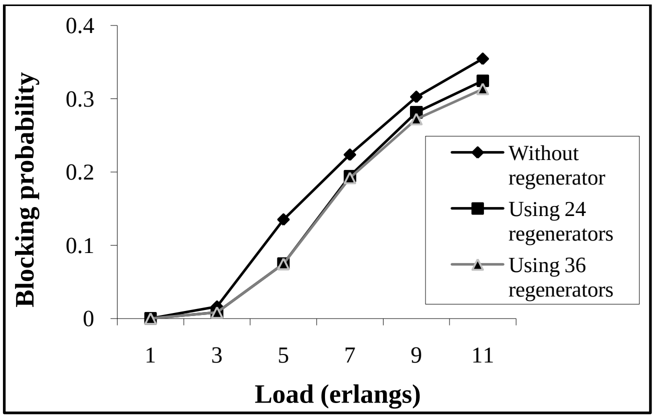


Fig.7. Blocking probability comparison related to optimum number of regenerators required at each node using OMEMs

In this work, MDORA has been proposed by extending the DORA algorithm to reduce the time complexity and to reduce blocking probability. On the other hand, fuzzy logic is used for effective regenerator placement which is a different contribution. The MDORA proposed for 14-Node NSFNET provides a reduced computational complexity while identifying the critical links in a network where the ingress-egress pairs are known in advance. As this algorithm uses LPV for the computation of a link weight, the blocking probability and computational complexity are further reduced when compared DORA with PPV. Moreover, the presence of regenerators improves the blocking performance in a network. However, it is sufficient to place the regenerators at a few nodes to achieve better performance. It is concluded in this work that regenerator placement using fuzzy logic is simple to implement by using the number of ports attached to each node and the length of a link between two nodes. In this algorithm, only two nodes such as node 6 and node 11 are found to be regenerative nodes; thereby the cost of the system is reduced. To find the number of regenerators required in each node, OMEMS with 2 × 2 switches is considered and it is found that 24 regenerators are enough to be placed in a node, instead of 36 regenerators without compromising the blocking probability. However, both the techniques are aiming at the reduction of blocking probability.

In optical Wavelength Division Multiplexing networks, effective routing and wavelength assignment are the two important criteria that are used for improving the blocking performance. In the past, a number of researchers have proposed solutions and techniques for effective wavelength assignment and routing. However, due to the increase in data traffic in the internet scenario, the existing algorithms are not adequate to provide an optimal level of performance. Hence, the need arises to propose separate routing and wavelength assignment algorithm to meet the requirements of different types of networks that are part of the internet. In this work, Modified Dynamic Online Routing Algorithm (MDORA), have been proposed.

7. CONCLUSION

The MDORA proposed for 14-Node NSFNET provides a reduced computational complexity while identifying the critical links in a network where the ingress-egress pairs are known in advance. As this algorithm uses LPV for the computation of a link weight, the blocking probability and computational complexity are further reduced when compared DORA with PPV. Moreover, the presence of regenerators improves the blocking performance in a network. However, it is sufficient to place the regenerators at a few nodes to achieve better performance. It is concluded in this work that regenerator placement using fuzzy logic is simple to implement by using the number of ports attached to each node and the length of a link between two nodes. In this algorithm, only two nodes such as node 6 and node 11 are found to be regenerative nodes; thereby the cost of the system is reduced. To find the number of regenerators required in each node, OMEMS with 2 × 2 switches is considered and it is found that 24 regenerators are enough to be placed in a node, instead of 36 regenerators without compromising the blocking probability.

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