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Traffic Grooming with IA-RWA for Dynamic Optical WDM Networks

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Abstract: The Optical network is a field of transmitting data over light signals across various distances. An increasing number of users in Wavelength Division Multiplexing network increases the blocking probability and Physical layer impairments such as Amplifier Spontaneous Noise, Cross talk, Cross Phase Modulation and Four wave mixing. The proposed "Adaptive Most-Shared Impairment Aware Routing and Wavelength Assignment (AMSIR)" algorithm effectively utilizes bandwidth and reduces impairments. Simulation result demonstrates that the proposed algorithm reduces blocking probability, increases capacity utilization and minimizes the number of wavelength requirements when compared with First Fit (FF), Ant Colony (ACO) algorithm, Genetic Objective First (GOF) algorithms.

Key words: Wavelength Division Multiplexing (WDM) networks, physical layer impairments, Routing and Wavelength Assignment (RWA), priorityqueue, traffic grooming, quality of transmission

INTRODUCTION

Optical fibre communication technology has advanced tremendously due to increasing number of users and bandwidth requirements. Total capacity of optical fiber is of Tbps which is not utilized fully since user requirement ranges only up to Mbps. The concern of full bandwidth utilization lead to emergence of technique called Wavelength Division Multiplexing which multiplexes smaller bandwidth units explained in books (Mukherjee, 2006; Somani, 2006). Bandwidth utilization is improved by grooming low speed traffic streams into high speed light paths in optical network and dynamic traffic grooming analytical modelling was proposed by Xin (2007) and De *et al*. (2010). Control mechanisms were analyzed for updating wavelength utilization in link state and distance vector routing by Zang *et al*. (2001) proposed GOF algorithm to improve network performance for different RWA approaches. Bo *et al*. (2005) proposed Routing, Timeslot and Wavelength assignment algorithm for reducing the blocking probability using LRW (Least Resistance Weight) and LLT (Least Loaded Time-slot) technique. The blocking probability is reduced by wavelength re-usage and proper wavelength selection was explained by Zhang and Acampora (1995) and Zang *et al*. (2000). ACO (Ant Colony Optimization) algorithm is introduced which solves the intrinsic problem of RWA on WCC (Wavelength Continuity Constraint) (Triay and Pastor, 2010; Largo *et al*. (2012). Introduced multi objective algorithm to solve RWA problems in both static and dynamic optical WDM networks. Reduction of physical layer impairments is another challenging task in long haul optical networks. Quality factor evaluation and multi objective optimization strategies were introduced to solve physical impairments in static optical network (Monoyios and Vlachos, 2011). Direct and indirect modelling techniques were proposed to calculate the quality of light signal (Rahbar, 2012). A novel IA-RWA (Impairment Aware-Routing and Wavelength Assignment) algorithm considered the impact of physical layer impairments to reduce the blocking probability (Azodolmolky *et al*., 2011). This study proposes a new strategy of RWA with the consideration of priority and PLI (Physical Layer Impairments).

Literature review: The RWA problem is considered as challenging problem. For an optical WDM network,

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the dynamic requests arrive at a Poisson rate. Route selection, wavelength assignment and QoT estimation for impairment should be performed in the light path.

Physical topology of an optical network is a directed graph G (V, E, W), where V and E are a set of nodes and edges of the network respectively. Each link has a finite and equal number of Wavelengths (W) and all channels have the same Bandwidth (B). The numbers of requests counted in disjoint time intervals are independent of each other and there is no simultaneous arrival of requests. A connection request 'r_i' = Is represented by (S_i, D_i, λ_i, C_i, T_{Hi}), where: 'S_i' = Is the source, 'D_i' = Is the destination, 'λ_i' = Is the arriving time, 'C_i' = Is required capacity and 'T_{Hi}' = Is the unknown holding time of i^{th} request.

Adaptive routing routes a request, based on priority queue, shortest path and available wavelength capacity. Most-shared wavelength assigns the request on wavelength where more capacity is shared. In dynamic RWA, wavelengths are assigned as the request arrives and once the tear down takes place, the same path and wavelength can be re-used. The flow diagram of AMSIR algorithm is shown in Fig. 1.

MATERIALS AND METHODS

Adaptive Most-Shared Impairment Aware Routing and Wavelength Assignment (AMSIR) Algorithm:

Begin

Initialize No. of nodes 'N'; No of links 'P'; No. of wavelengths available per link '$\bar{e}_i$'; Time Slot 'T'; Sub time slot '$t_i \subset$ T'; request with source s and destination d 'r(s, d)'

```
 For an undirected graph G (V, E),
Start: Ti, i = 0 to ∞,
   Forti = 0 to ∞
         Receive requests rj(s, d), where j = 1-8
         for every rj,
Sub problem S1: Routing
       Shortest path selection-Dijkstra'sk shortest path Algorithm
        If path available,
       Sub problem S2: IA-RWA
       Check for impairments
       If Quality of Service assured, Sub problem S3: Wavelength
       Conversion
       Check for wavelength Constraint
       Check for Capacity
       If S1, S2, S3 solved,
                      rj⊂ Selected requests
             Else
                      Block
                             End
       end
             end
End: Ti+1
   Allocate the path for selected requests
End
```

Request are collected in time slots and verified with the wavelength availability. Grooming takes place in order to maximize the wavelength usage. Rest of t_i requests are carried to be added to the next processing slot.

Path computation: The shortest paths between nodes which are at a one hop distance are estimated directly. If the source and destination nodes are not neighbor nodes the shortest path is ascertained using Dijkstra's k shortest path algorithm.

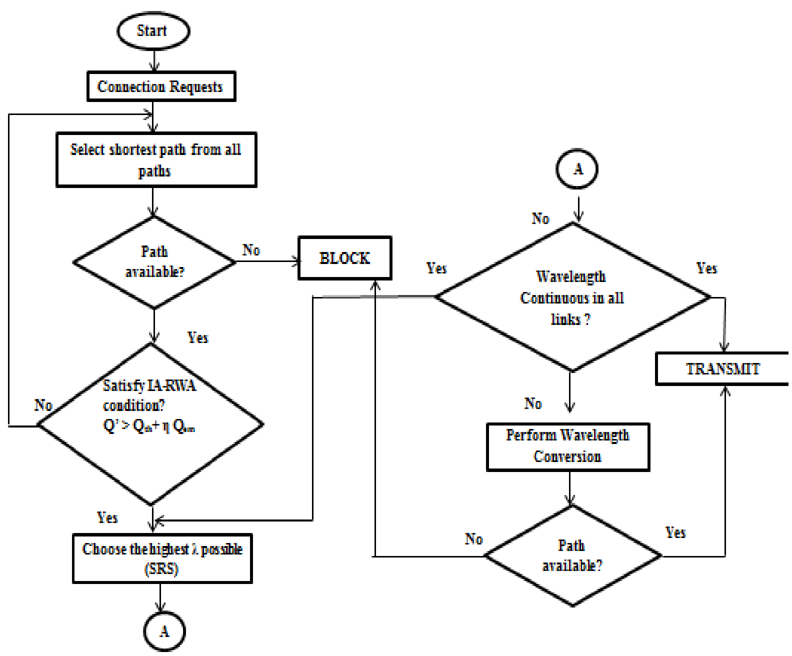

Fig. 1: Flow chart

Sub Problem S_1: /* Routing algorithm */

```
Begin
∀rj, Find all possible paths between s and d
Initialize K = 3 /* No. of paths between the source and destination of rj */
/* Dijkstra's Algorithm */
    For every rj(s, d),
            Select K-shortest paths having minimum hop count
            for every selected path i = 1-K
go to sub problem S2;
    end
End
```

QoT estimation: For the k-shortest path, the proposed algorithm selects the sub-problem S_2 where the QoT of the shortest route is determined using the Q-tool estimator. Quality factor ($\hat{Q}$) is found based on Linear impairments such as Amplifier Spontaneous Emission (ASE) noise and crosstalk (XT) and nonlinear impairments such as Cross Phase Modulation (XPM) and Four Wave Mixing (FWM). These factors play a pivotal role in determining the signal strength.In IA-RWA algorithm a factor 'σ' is used to estimate impairments present in WDM networks. This factor varies from 0-1 where 1 denotes there are no information of the impairments and 0 when information of all the impairments is available. The Erlang B equation which is given in Eq. 1 deals with calculation of blocking Probability (Pb) for a load (L) with arrival rate (λ):

$$P_b = \frac{\frac{L^\lambda}{\lambda!}}{\sum_{i=0}^{n}\frac{L^i}{i!}}. \quad (1)$$

The arrival of requests over time interval (Ti) is represented by Eq. 2:

$$R_T = \{r_1(s,d), r_2(s,d)......r_n(s,d)\} \quad (2)$$

Wavelength conversion factor (ε) focused in (3) where $P_B(\alpha)$, $P_B(\infty)$ and $P_B(0)$ represents blocking probability of wavelength converters used is minimum, maximum and none respectively:

$$e = \frac{P_B(a) - P_B(\infty)}{P_B(0) - P_B(\infty)} \quad (3)$$

Equation 4-6 deals with the QoT aware estimator tool value and effect on binary bits 1(on) and 0(off) and their variance change due to PLI effects:

$$\hat{Q} = \frac{P}{\sigma_{on} + \sigma_{off}} \quad (4)$$

$$\sigma_{on}^2 = \sigma^2_{on,ASE} + \sigma^2_{on,XT} + \sigma^2_{on,XPM} + \sigma^2_{on,FWM} \quad (5)$$

$$\sigma^2_{off} = \sigma^2_{off,ASE} + \sigma^2_{off,XT} \quad (6)$$

Algorithm; Sub Problem S2: /* IA-RWA and QoT inaccuracies */:

```
Q̂ = Quality tool;
Qth = Quality threshold;
Qem = maximum error during transmission;
η = inaccuracy factor
   Begin
  Calculate (Equation 4)
  Initialize Qth= 15.5 dB, Qem= 0.5 dB
  check η,   0 ≤η≤1
  if Q̂ >Qth+η×Qem
  go to sub problem S3;
  else
          Restart Dijkstra's k shortest path algorithm for rj
  end
  End
```

Capacity assignment: In case of WCC failures, constraint for limited full wavelength convertors is utilized. To efficiently utilize the bandwidth in a WDM system, more than one successful connection request is capable of sharing one wavelength. This algorithm fills the requests on wavelength with more capacity shared and it reserves resources for the new requests. New request can be accommodated when, wavelength is continuous, i.e., each link of the route should have a Capacity (C_{ri}):

$$C_{ri} = \text{Maximum capacity} - \sum \text{shared capacity on that link}$$

where, i = 1, 2, ..., etc. Once the request gets tear down, capacity utilized by that request is returned to the former wavelength.

Condition 1: Priority is assigned to a number of requests that collectively utilize a higher order wavelength capacity rather than individual high capacity requests which block the entire higher wavelength. This is given in order to ensure the number of requests suffer less from Stimulated Raman Scattering (SRS) effect, since at higher wavelengths the SRS effect is minimized.

Condition 2: Once condition one is checked, if there are requests which cannot conglomerate to collectively utilize the capacity then the request with higher capacity is given the highest possible wavelength.

Alogrithm; Sub Problem S_3: /* Wavelength constraint */:

```
Begin
∀rj, Choose highest wavelength available;  /* SRS */
Forrj> r1
```

```
        Check available capacity in λn
        Capacity of rj= available capacity
If λn? occupied
                n = n - 1;
                Check WCC;
        if true
                Transmit in λn-1
else
                        Convert to available λ
                    Check  Pb(Equation 1)
else
                    Check available capacity in λn-2
                Capacity of rj= available capacity
end
end
End
```

Illustration: A six node architecture is cited in Fig. 2 where connection requests arrive in three time intervals t_1, t_2 and t_3. For illustration, we consider two wavelengths for each link 'l' in a path. Let the maximum capacity of a wavelength in a link be 1. The time interval is divided into five time slots. '#'and '*' represent the symbolic representation of, holding time that exceeds five time slots and the impairment present.

Requests that arrive at t_1, t_2... start transmitting from T_1, T_2.., respectively. For every request the source-destination pair is determined by the shortest path algorithm and its capacity is assignedalong with holding time, impairment and WCC. The starting time and holding time of random requests are shown in Fig. 3.

RWA with dynamic reservation for requests in time interval T_1: For requests arriving at time interval t_1 and starting the transmission at T_1, route and wavelength assignment is shown in Table1. At time interval t_1, requests R_{11} and R_{12} are processed without any issues whereas request R_{13} fails due to IA-RWA condition. So, the next shortest route is assigned for request R_{13}which satisfies IA-RWA. At the same time, λ_2 is unavailable for the request R_{13} since it is already used by R_{11} and R_{12} Wavelength λ_2 is selected over λ_1 because at higher wavelength the SRS effect is minimized. Since λ_2 is available for R_{14}, it is utilized.

The RWA on the six node architecture and the capacity allocated in each link of a wavelength are shown in Fig. 4. Dashed lines represent wavelength λ_1 and solid lines represent wavelength λ_2. The shaded portion denotes the presence of physical layer impairments due to nonlinear effects. Capacity allocated on two wavelengths in each link is shown in Fig. 5.

RWA with dynamic reservation for requests in time interval T_2: For requests arriving at time interval t_2 and

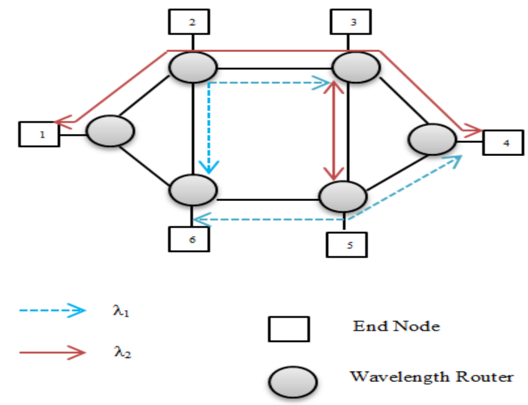

Fig. 2: Wavelength routed networks

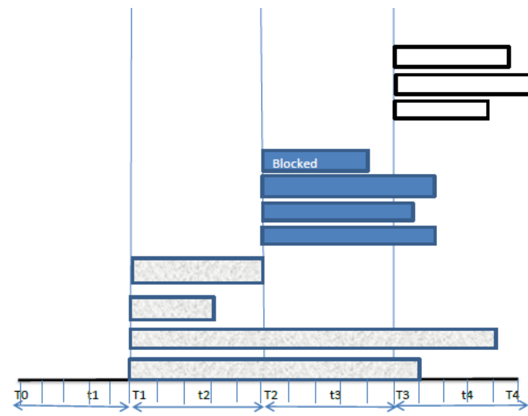

Fig. 3: Random start time and holding time of requests

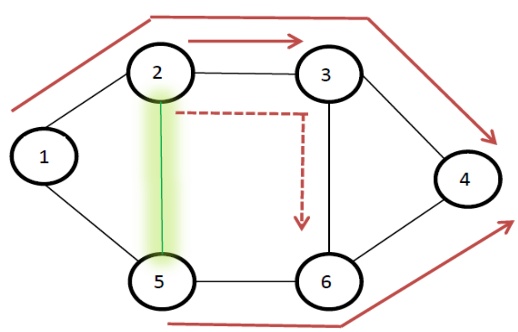

Fig. 4: Routing and wavelength assignment at T_1

starting the transmission at T_2, route and wavelength assignment is shown in Table 2. In the case of next time interval t_2, it not only includes its own requests but also includes requests from previous time slots which have an unknown (longer) holding time. Therefore, this leads to request R_{22} to change its original wavelength as it fails both IA-RWA and WCC condition. Request R_{21}, R_{23} are processed normally

Table 1: Routing and wavelength assignments for requests in time interval T_1

Time interval	R	S	D	C	T_H	IA-RWA	λ	Intermediate nodes	WCC λ path	Remark
t_1										
	R_{11}	1	4	0.4	11	True	λ_2	2,3	λ_{222}	
	R_{12}	2	3	0.4	14	True	λ_2	-	λ_2	
	R_{13}	2	6	0.7	3	False	-	5	-	
	R_{13}	2	6	0.7	3	True	λ_1	3	λ_{11}	Impairment
	R_{14}	5	4	0.5	5	True	λ_2	6	λ_{22}	

Table 2: Routing and wavelength assignments for requests in time interval t_2

Time interval	R	S	D	C	T_H	IA-RWA	λ	Intermediate nodes	WCCλ path	Remark
t_2										
	R_{21}	5	4	0.9	7	True	λ_2	6	λ_2	
	R_{22}	1	4	0.2	6	False	-	2,3	-	Impairment
	R_{22}	1	4	0.2	6	True	λ_2	2,3,6	λ_{2221}	WCC failed
	R_{23}	5	4	0.8	7	True	λ_1	6	λ_{11}	
	R_{24}	4	6	0.5	4	True	-	-	Blocked	Overload

Table 3. Routing and wavelength assignments for requests in time interval t_3

Time interval	R	S	D	C	T_H	IA-RWA	λ	Intermediate Nodes	WCCλ path	Remark
t_3										
	R_{31}	2	6	0.2	4	True	λ_1	5	λ_{11}	New λ
	R_{32}	1	2	0.4	6	True	λ_2	-	λ_{22}	
	R_{33}	5	1	0.7	5	True	λ_2	-	λ_{22}	

Fig. 5: Capacity allocations for requests at T_1

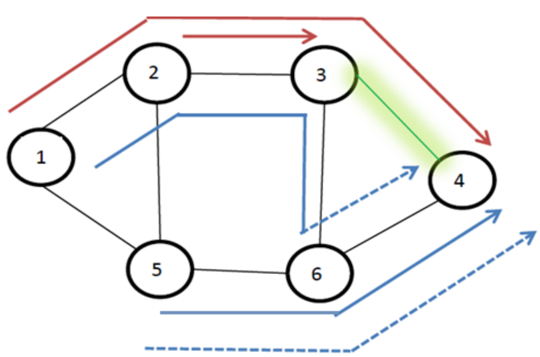

Fig. 6: Routing and wavelength assignment at T_2

in wavelength λ_2 based on availability. Request R_{24} gets blocked due to overload of request paths. Routing and wavelength assignment with capacity allocation at T_2 is shown in Fig. 6. The capacity allocated for each request in each link is given in Fig. 7 and capacity is allocated in the wavelength where more capacity is shared. If there is no wavelength available, it goes for next wavelength.

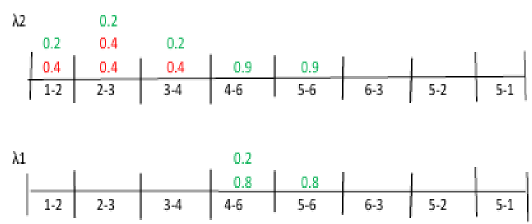

Fig. 7: Capacity allocations for requests at T_2

RWA with dynamic reservation for requests in time interval t_3: For requests arrived at time interval T_3 and starting transmission on T_3, route and wavelength assignment is shown in Table 3. The third case is a special scenario where request R_{31} utilizes an entirely smaller wavelength from the start even though initially λ_2 is available from node 2-5, since it fails to achieve the threshold condition (1 in this case. The request has 2 links and it changes its wavelength after first link which is not viable), a new wavelength is chosen which reduces unwanted wavelength conversions. The other two requests are processed as usual. In this case no physical layer impairment is present and so requests are sent without any blocking. Similarly for next time intervals, the routing is done and wavelength is assigned as mentioned. Figure 8 shows routing and wavelength assignment of requests that arrive in the time interval t_3. Figure 9 depicts the capacity allocations for the requests arrived at T_3. The capacities which have holding time extend till the time interval T_3 remains until they tear down.

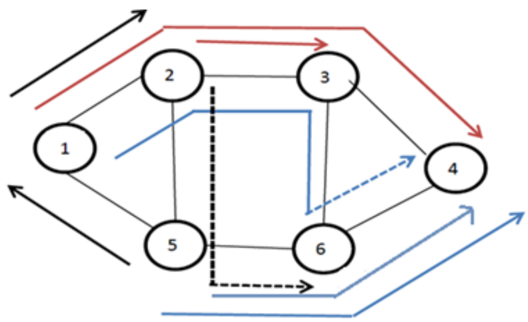

Fig. 8: Routing and wavelength assignment at T_3

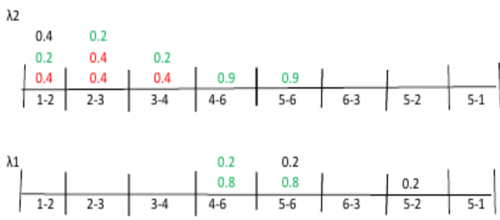

Fig. 9: Capacity allocations for the requests at T_3

Thus, by using AMSIR algorithm more than one successful connection request is capable of sharing one wavelength and also they will get decreased. This algorithm utilizes the wavelength capacity effectively by selecting the most shared wavelength which gives less blocking for future requests.

RESULTS AND DISCUSSION

Multiple simulations were executed to analyze the AMSIR algorithm's performance. The parameters used in this algorithm are Blocking Probability, Capacity Utilization and Number of wavelengths used have been compared with First Fit Wavelength assignment (FF), Genetic Objective Function (GOF) and Ant Colony Optimization (ACO) algorithms. Below are the considerations to be followed:

- All nodes have bidirectional links
- Requests are randomly generated at any source to any destination
- Received requests at Interval (T_1) are prioritized and processed before the time (T_2)
- Dijkstra's K shortest path algorithm is used to find more than one shortest path
- The request is blocked when the capacity availability of wavelength is less than the request capacity level
- Any request tearing down the capacity of wavelength is updated before the next time slot

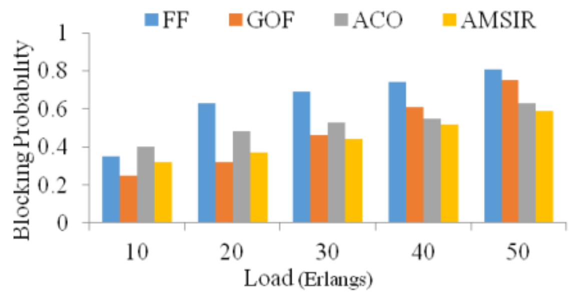

Fig. 10: Blocking Probability with various loads

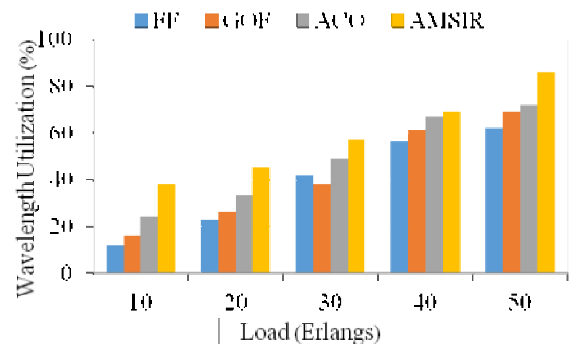

Fig. 11: Wavelength capacity utilization vs load

Blocking probability: For low traffic load, FF and GOF algorithms have less blocking probabilities because the number of requests is less than the available capacity. Since the same wavelengths are frequently used for the forthcoming requests, P_b increases with load for FF and GOF algorithm. Fig. 10 assures the P_b of AMSIR algorithm gets reduced for a large traffic load due to priority in random request queue.

Wavelength capacity utilization: Operational expenditure of WDM network directly depends on wavelength capacity utilization. The proposed algorithm utilizes the maximum wavelength capacity with minimum blocking probability. Figure 11 shows the capacity utilization of random requests. Queue (T_i) is assigned to random requests to choose a wavelength based on available capacity with affordable level. In FF and GOF no priorities are used for requests, therefore the request capacity which is greater than the available capacity is blocked and hence the wavelength capacity is not utilized effectively. Thus the simulation results conclude the overall capacity utilization rate is increased in AMSIR algorithm.

Number of wavelengths used: The number of wavelengths used in the dynamic optical WDM network is one of the important factors. Requests may arrive at random time with dynamic capacity and unknown holding time. To

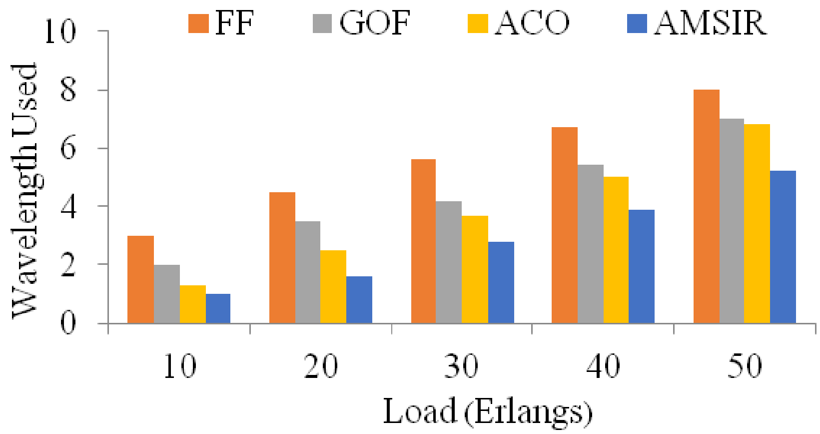

Fig. 12: Number of wavelengths used for dynamic requests

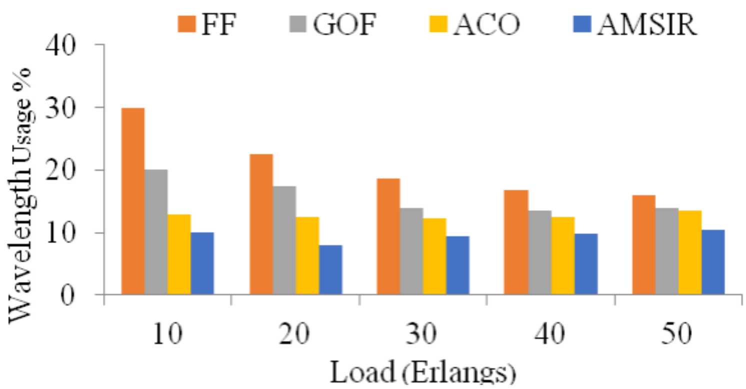

Fig. 13: Wavelength usage vs load

provide the link and assign the capacity of requests effectively, network provider must have a free wavelength with large capacity. The power consumption of the network increases when the new wavelength is allocated for every request. The proposed algorithm efficiently utilizes the maximum capacity of single wavelength, so that it reduces the number of wavelengths used in optical networks as plotted in Fig. 12. From Fig. 13 it is proved, for the same traffic load the number of wavelengths used is minimized in AMSIR algorithm.

CONCLUSION

In this study, we proposed the novel algorithm (AMSIR) for an RWA problem with the consideration of physical layer impairments. The proposed algorithm performs significantly better in terms of blocking probability, capacity utilization and number of wavelengths used. From exhaustive simulation, we conclude that the average reduction rate of blocking probability is 19.5% higher than FF, GOF and ACO for the same traffic load. In other aspects capacity utilization is increased by 27.59% in ASMIR when compared with the above mentioned algorithms. Also the number of wavelengths used is reduced to 23.53 % for the same traffic. In future AMSIR algorithm has to be applied in elastic optical networks to reduce blocking probability of dynamic traffic and to achieve energy efficiency.

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