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Efficient Routing and Wavelength Division Multiplexing Conversion With Different Link Capabilities and Optical Paths in Trans-Egypt Communication Networks

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Abstract- ***All optical networks using wavelength division multiplexing (WDM) technology are promising for serving as the backbone of next generation Internet, because optical WDM networks can provide huge bandwidth capacity effectively. In wavelength routed WDM networks, data are routed in optical channels called lightpaths. Given a set of connection requests, the routing and wavelength assignment (RWA) problem involves finding a route (routing) and assigning a wavelength to each request This paper has presented the WDM technology which is being extensively deployed on point to point links within transport networks in the Egypt. However, WDM promises advantages for switching and routing as well as for transmission. Optical cross connects are currently being developed which can switch an entire wavelength from an input fiber to an output fiber so that large bandwidth circuits can be routed through the network according to wavelength. High speed, fixed bandwidth, end to end connections called lightpaths can then be established between different nodes. Trans-Egypt network (TEGYNET) which uses optical cross connects to route lightpaths through the network are referred to as wavelength routing networks has deeply investigated based on routing and wavelength assignment algorithms such as first fit (FF), random, least used (LU), and most used (MU) to network management. The average setup time, average link utilization, traffic load, blocking probability, and achievable link utilization in the presence of both single path and multi math routing are the major interesting parameters in the design of TEGYNET topology for different optical link capability with OC-24 and OC-30.***

Index Terms— Traffic load, Average setup time, Blocking probability, Average link utilization, Single path, and Multi path.

I. INTRODUCTION

Wavelength division multiplexing (WDM) has significantly expanded the capacity of optical networks by allowing different wavelengths to be combined and transmitted simultaneously over the same optical fiber [1]. Synchronous optical network (SONET) is a successful standard for communicating digital information over optical fiber and it forms the basis of current high speed backbone networks [2]. The increasing bandwidth demands are placing a heavier load on the current network infrastructure. Deploying additional hardware equipment and laying extra optical fibers are expensive. Therefore, improving upon current technologies is a more feasible solution. Optical fiber has an extremely high theoretical bandwidth, approximately 25 terahertz in the 1.55 low attenuation band, which is equivalent to 1,000 times the total radio bandwidth on the Earth [6]. However, only transmission rates of a few gigabits per second (Gbps) are achieved in optical networks due to the limited electronic speed in which users can access the network. Thus, it is difficult to fully utilize the bandwidth offered by optical fiber using only a single wavelength channel. Wavelength division multiplexing (WDM) is a technology which can send multiple light beams of different wavelengths simultaneously through an optical fiber [3]. A WDM system uses a multiplexer to combine signals at the transmitter end. Once signals arrive at the receiver end, a demultiplexer is used to split them apart. WDM technique can increase optical fiber's usable bandwidth and expand network capacity without lay ignore optical fibers. Modern systems can support up to 160 signals per optical fiber [4]. With a basic transmission rate of 10 Gbps, WDM systems can theoretically have a capacity of 1.6 terabits per second per optical fiber. Wavelength routing in optical WDM networks allows network nodes to communicate with each other via all-optical lightpaths [5]. A typical wavelength routed optical WDM network where optical routing nodes are interconnected by fiber links. When a message is sent from the source node to the destination node using a lightpath, optical-electronic-optical conversion and buffering at the intermediate nodes are not required. Thus, a lightpath between two nodes is an all-optical communication path [6]. In wavelength-routed networks, two lightpaths can use the same wavelength if their underlying physical paths are link-disjoint. This wavelength reuse feature can increase the number of lightpaths established given a limited number of wavelengths.

Synchronous optical network (SONET) is a successful standard for communicating digital information over optical fiber [7]. It forms the basis of current high-speed backbone networks and allows transmission of data and voice up to 40 gigabits per second (Gbps). A standard frame consists of a header and a payload where the payload follows the header during the transmission process. A SONET frame also has two components: overhead and payload. The overhead in a SONET frame is the same as the header in a standard frame. However, overhead is not completely transmitted before the payload. The transmission of overhead and payload is interleaved, which implies part of the overhead is followed by part of the payload, then the next part of the overhead and next part of the payload, until the whole frame has been transmitted. SONET frames are 810 bytes in size and are transmitted in exactly 125 microseconds [8]. The bandwidth in SONET is represented by OC-n (Optical Carrier-n) where n typically starts at 3 and increases by multiples of 4. The basic unit is OC-1 and it specifies an approximate transmission rate of 51.84 megabits per second (Mbps) [9]. Thus, OC-192 and OC-768 correspond to approximate transmission rates of 10 Gbps and 40 Gbps respectively.

In the present study, The model has been investigated to enhance the performance characteristics of TEGYNET design parameters such as blocking probability, traffic load, link utilization, wavelength conversion benefit, routing lengths and average setup time in the presence and absence of wavelength conversion for different optical carriers (OC-24, and OC-30).

II. Different Topologies of Light Path Network

Although bursty Internet traffic has been increasing because of point to point (P2P) file sharing and voice communications, Internet backbone networks lack the capacity for this growing traffic. Presently, wavelength division multiplexing (WDM) provides multiplex wavelength channels on a single fiber, enables high capacity parallel transmission, and is expected to provide capacity for backbone networks [10].

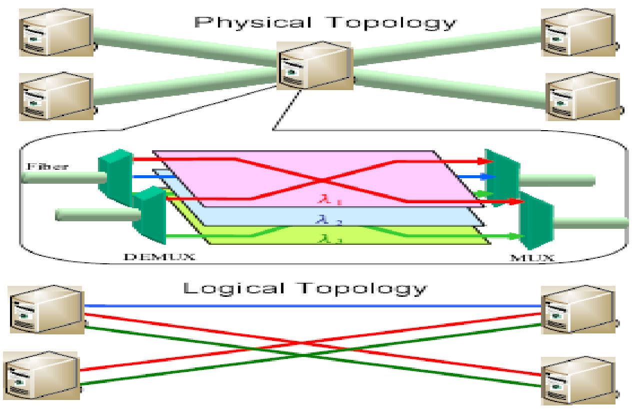

Fig. 1. light path network with different topologies.

One way of using WDM technology is to establish wavelength channels (called lightpaths) on a demand basis as shown in Fig. 1. A lightpath network consists of nodes with switching devices and links to optical fibers in a physical network. Optical cross connect (OXC) is a switching device that binds an input wavelength channel to a specified output wavelength channel on the same wavelength. Lightpaths are formed through this switching process in intermediate nodes [11].

III. Network System Model Analysis

A connection (lightpath) request sees a network in which a wavelength's usage on a fiber link is statistically independent of other fiber links and other wavelengths. However, this model generally tends to overestimate the blocking probability because it ignores the correlation of usage of wavelength in successive links, especially for a multi link lightpath. Let there be W wavelengths per fiber link, and let ρ be the probability that a wavelength is used on any fiber link. (Since ρW is the expected number of busy wavelengths on any fiber link, ρ is also the "fiber utilization" of any fiber.) We will consider an H link path for a connection from node one to any node that needs to be set up [8-10]. First, let us consider a network with wavelength converters. The probability $P_{B(wc)}$ that the connection request from node one to any node will be blocked equals the probability that, along this H link path, there exists a fiber link with all of its W wavelengths in use, so that [11, 24]:

$$P_{B(wc)} = 1-\left(1-\rho^{W}\right)^{H}, \qquad (1)$$

Defining q to be the achievable utilization for a given blocking probability in a wavelength convertible network, that yields:

$$q = \left[1-\left(1-P_{B(wc)}\right)^{1/H}\right]^{1/W} \approx \left(\frac{P_{B(wc)}}{H}\right)^{1/W}, \qquad (2)$$

Where the approximation holds for small values of $P_{B(wc)}/H$, when the correlation of successive link utilizations are small. Next, let us consider a network without wavelength converters. The probability $P_{B(nwc)}$ that the connection request from node one to any node will be blocked equals the probability that, along this H link path, each wavelength is used on at least one of the H links, so that [12]:

$$P_{B(nwc)} = \left[1-(1-\rho)^{H}\right]^{W}, \qquad (3)$$

Defining p to be the achievable utilization for a given blocking probability in a network without wavelength conversion, that can be expressed as the following formula:

$$p = 1-\left(1-P_{B(nwc)}^{1/H}\right) \approx -\frac{1}{H}\ln\left(1-P_{B(nwc)}^{1/H}\right), \qquad (4)$$

Where the approximation holds for large values of H, and for $P_{B(nwc)}^{1/H}$ not too close to unity. Observe that the achievable utilization is inversely proportional to the length of the lightpath connection H, as expected. Define G=q/p to be a measure of the benefit of wavelength conversion, which is the increase in (fiber or wavelength) utilization for the same blocking probability. From Eqs. (2) and (4), after setting $P_{B(wc)}=P_{B(nwc)}$, yields:

$$G \approx H^{1-\left(\frac{1}{W}\right)} \frac{P_{B(nwc)}^{1/H}}{-\ln\left(1-P_{B(nwc)}^{1/H}\right)}, \qquad (5)$$

Where the approximation holds for small $P_{B(nwc)}$, large H, and moderate W so that $P_{B(nwc)}^{1/H}$ is not too close to unity. Observe that, if H=1 or W=1, then G=1, i.e., there is no difference between networks with and without wavelength converters in these cases. Based on MATLAB curve fitting program, the fitting traffic load, TL in Erlangs, as a function of blocking probability in the absence of wavelength conversion, $P_{B(nwc)}$ for both single path (SP) and multi path (MP) routing with different optical carriers for high transmission rates can be given [13]:

$$TL = \frac{P_{B(nwc)} + 0.0456}{0.02196}, \text{ (SP) [OC-24]} \qquad (6)$$

$$TL = \frac{P_{B(nwc)} + 0.0055}{0.002265}, \text{ (MP) [OC-24]} \qquad (7)$$

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$$TL = \frac{P_{B(nwc)} + 0.06955}{0.04355}, \text{ (SP) [OC-30]} \quad (8)$$

$$TL = \frac{P_{B(nwc)} + 0.02775}{0.018721}, \text{ (MP) [OC-30]} \quad (9)$$

The root mean square errors for the previous fitting equations are 0.00256%, 0.00963%, 0.00232%, and 0.00654% respectively. Moreover based on MATLAB curve fitting program, the fitting traffic load (TL) in Erlangs, as a function of blocking probability in the presence of wavelength conversion, $P_{B(wc)}$ for both SP and MP routing with different optical carriers for high transmission rates can be expressed as [14]:

$$TL = \frac{P_{B(wc)} + 0.0077}{0.0035707}, \text{ (SP) [OC-24]} \quad (10)$$

$$TL = \frac{P_{B(wc)} + 0.00372}{0.0003742}, \text{ (MP) [OC-24]} \quad (11)$$

$$TL = \frac{P_{B(wc)} + 0.032625}{0.0217487}, \text{ (SP) [OC-30]} \quad (12)$$

$$TL = \frac{P_{B(wc)} + 0.04065}{0.027695}, \text{ (MP) [OC-30]} \quad (13)$$

The root mean square errors for the previous fitting equations are 0.00546%, 0.00765%, 0.00843%, and 0.00324% respectively [22]. As well as based on MATLAB curve fitting program, the fitting average setup time (T_S) in µs as a function of traffic load, TL in Erlangs, for both SP and MP routing can be given by [15, 16]:

$$T_S = 565 + 2.65\,TL - 0.012\,TL^2, \text{ (SP)[OC-24]} \quad (14)$$

$$T_S = 1150 + 6.82\,TL - 0.037\,TL^2, \text{ (MP)[OC-24]} \quad (15)$$

$$T_S = 1046.25 + 6.25\,TL - 0.034\,TL^2, \text{ (SP)[OC-30]} \quad (16)$$

$$T_S = 1150 + 6.82\,TL - 0.073\,TL^2, \text{ (MP)[OC-30]} \quad (17)$$

Also the root mean square errors for the previous fitting equations are 0.0.000987%, 0.000654%, 0.000396, and 0.00065432% respectively [23, 24]. As well as based on MATLAB curve fitting program, the fitting average link utilization (U_L) percentage as a function of traffic load, TL in Erlangs, for both SP and MP routing can be [17-19]:

$$U_L(\%) = 28.5 + 0.63\,TL + 0.59x10^{-3}\,TL^2, \text{ (SP)[OC-24]} \quad (18)$$

$$U_L(\%) = 43.44 + 0.02\,TL + 0.6x10^{-3}\,TL^2, \text{ (MP)[OC-24]} \quad (19)$$

$$U_L(\%) = 30 + 0.68\,TL + 0.73x10^{-3}\,TL^2, \text{ (SP) [OC-30]} \quad (20)$$

$$U_L(\%) = 44.97 + 0.026\,TL + 0.42x10^{-3}\,TL^2, \text{ (MP)[OC-30]} \quad (21)$$

In addition to the root mean square errors for the previous fitting equations are 0.0.000437%, 0.00112%, 0.00512%, and 0.0006987% respectively. The TEGYNET network is with the 6 nodes and 7 links with related states as shown in Figs. (2, 3), the versions of network capacity and connection arrival rate network dimensioning are used as shown in Table 1 which has a uniform load between each source/destination pair and uniform link capacity.

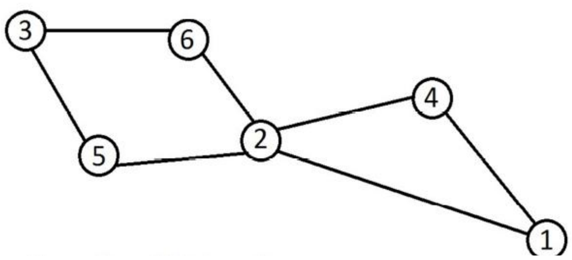


Fig. 2. Six nodes TEGYNET network topology.

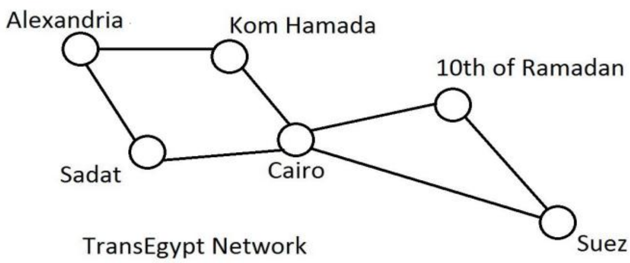


Fig. 3. States related to nodes in TEGYNET network topology.

Table 1: Network uniform capacity and connection arrival rate for TEGYNET network.

	Network uniform capacity						Connection arrival rate					
Node	1	2	3	4	5	6	1	2	3	4	5	6
1	0	75	0	75	0	0	0	10	10	10	10	10
2	75	0	0	75	75	75	10	0	10	10	10	10
3	0	0	0	0	75	75	10	10	0	10	10	10
4	75	75	0	0	0	0	10	10	10	0	10	10
5	0	75	75	0	0	0	10	10	10	10	0	10
6	0	75	75	0	0	0	10	10	10	10	10	0

IV. Simulation Results and Performance Analysis

We have established the research progress on algorithms based routing and wavelength assignment in optical trans-Egypt network management, these algorithms such as first fit (FF), random, least used (LM), and most used (MU) can be applied in our network topology for different optical carriers (OC-24, and OC-30) under study over wide range of simulation parameters listed in Table 2. Based on Simulator in Ref. [21], the blocking probabilities of the four algorithms based wavelength assignment and routing for TEGYNET network in the presence and absence of wavelength conversion are listed in Table 2.

Table 2: Simulation parameters used in TEGYNET network topology [14, 15, 20].

Simulation parameters		Values
Network topology		**TEGYNET**
Wavelengths per link, W		25-75
Link path, H		6
Fiber utilization, ρ		90%
Link bandwidth		OC-24, and OC-30
Number of nodes		6
Number of links		7
FF	$P_{B(wc)}$	0.010052-0.055845

	$P_{B(nwc)}$	0.009948-0.064371
Random	$P_{B(wc)}$	0.010244-0.053837
	$P_{B(nwc)}$	0.008380-0.056008
LU	$P_{B(wc)}$	0.010429-0.054995
	$P_{B(nwc)}$	0.007834-0.056042
MU	$P_{B(wc)}$	0.010429-0.054995
	$P_{B(nwc)}$	0.009105-0.057071

Based on the model equations analysis, the series of the operating parameters that are listed in Table 2, and the series of Figs. (4-37), the following features are assured:

i) Figs. (4-7) have assured that blocking probability with and without wavelength conversion decreases with increasing both wavelengths per link and light paths for different routing algorithms under study.

ii) As shown in Figs. (8, 9) have indicated that link utilization with wavelength conversion increases with increasing both wavelengths per link and light paths for different routing algorithms under considerations.

iii) Figs. (10, 11) have proved that link utilization without wavelength conversion decreases with increasing both wavelengths per link and light paths for different routing algorithms under study.

iv) Figs. (12, 13) have demonstrated that wavelength conversion benefit increases with increasing both wavelengths per link and light paths for different routing algorithms under considerations.

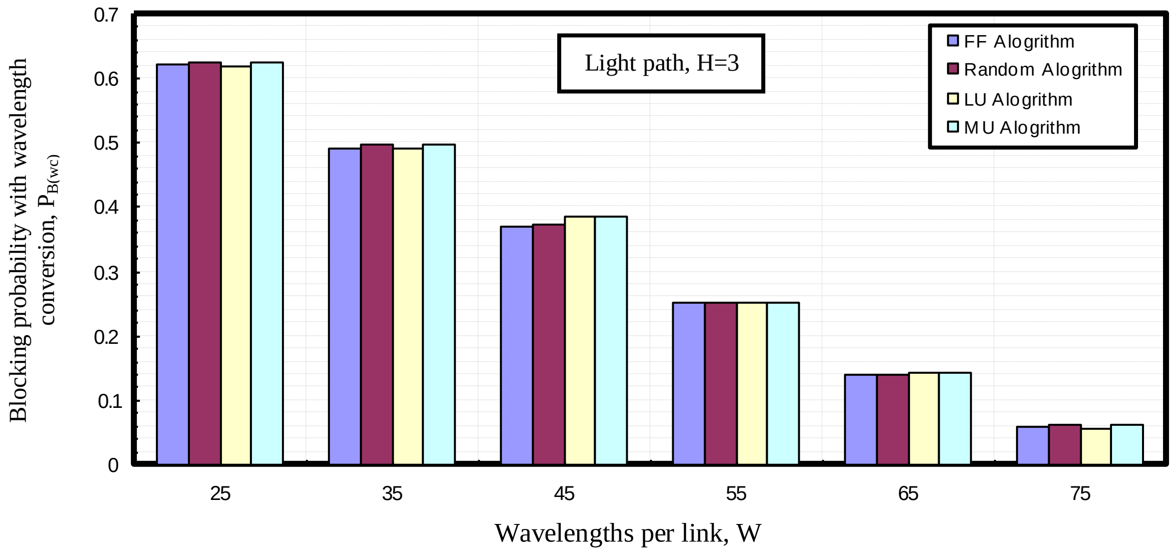


Fig. 4. Blocking probability with wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.

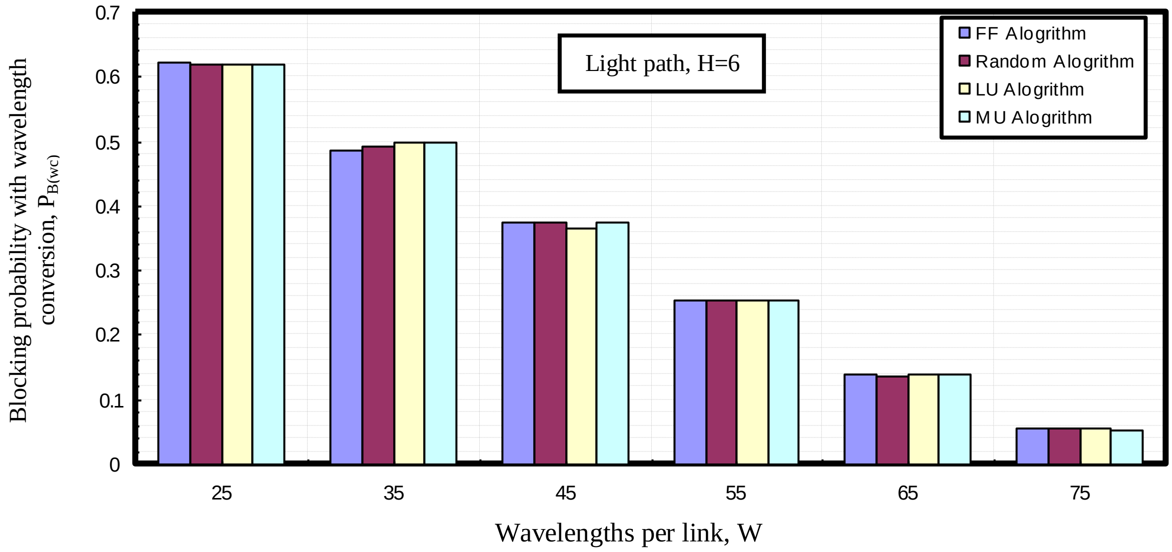


Fig. 5. Blocking probability with wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.

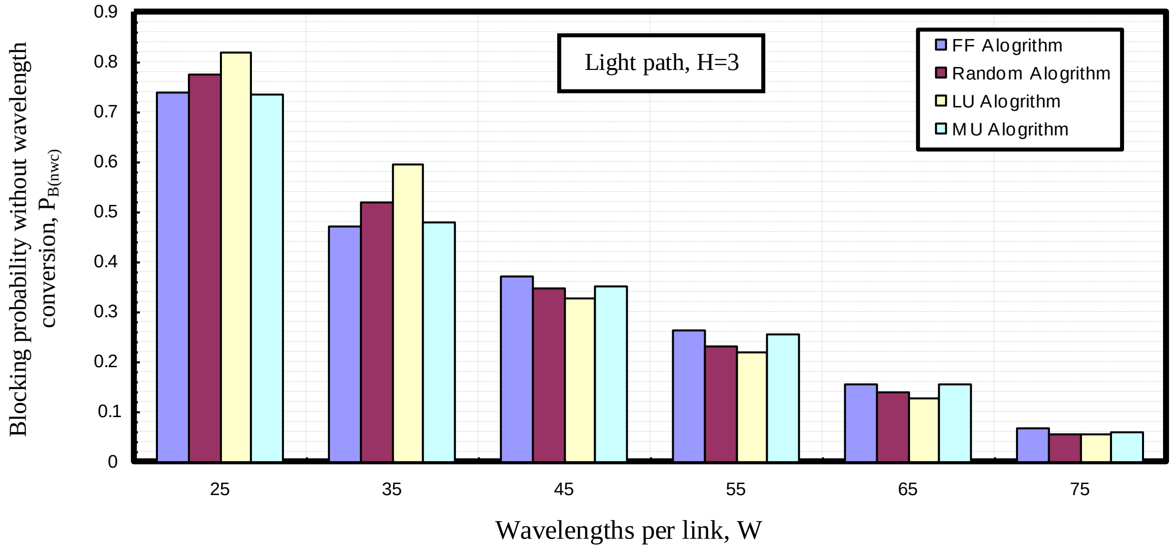


Fig. 6. Blocking probability without wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.

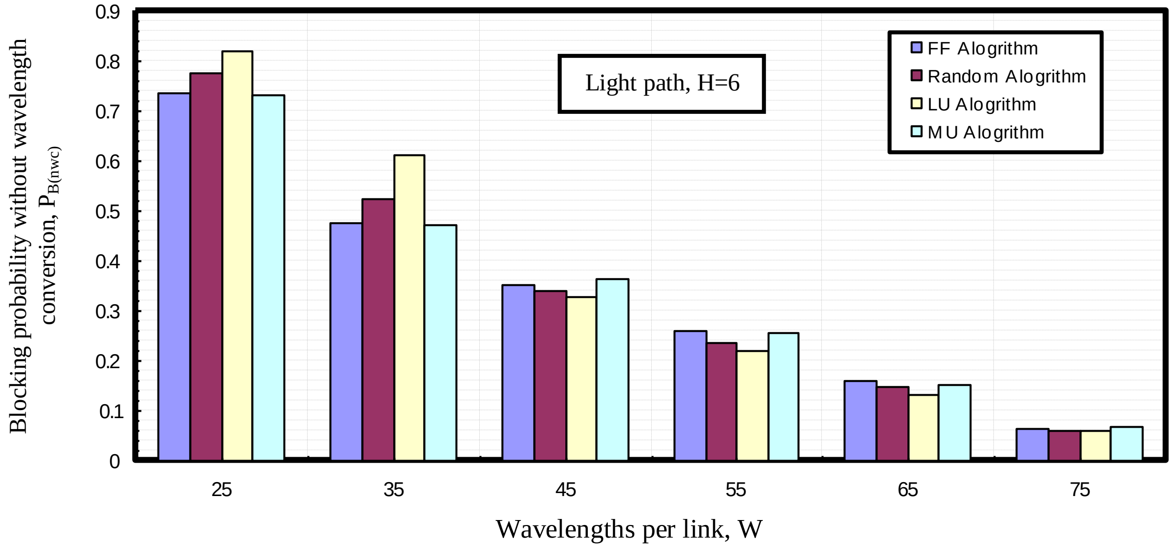


Fig. 7. Blocking probability without wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.

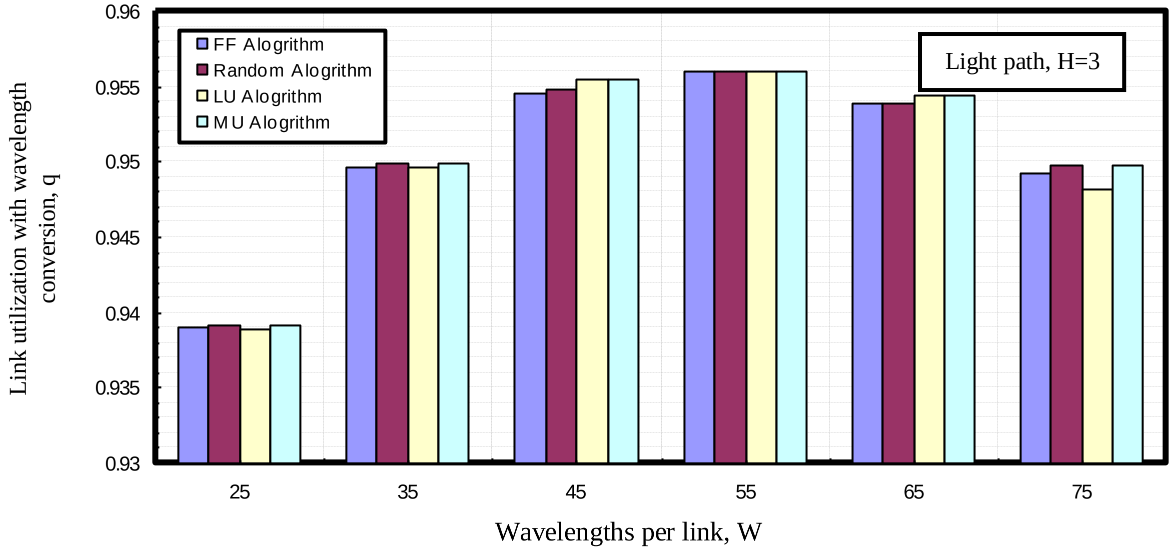


Fig. 8. Link utilization with wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.

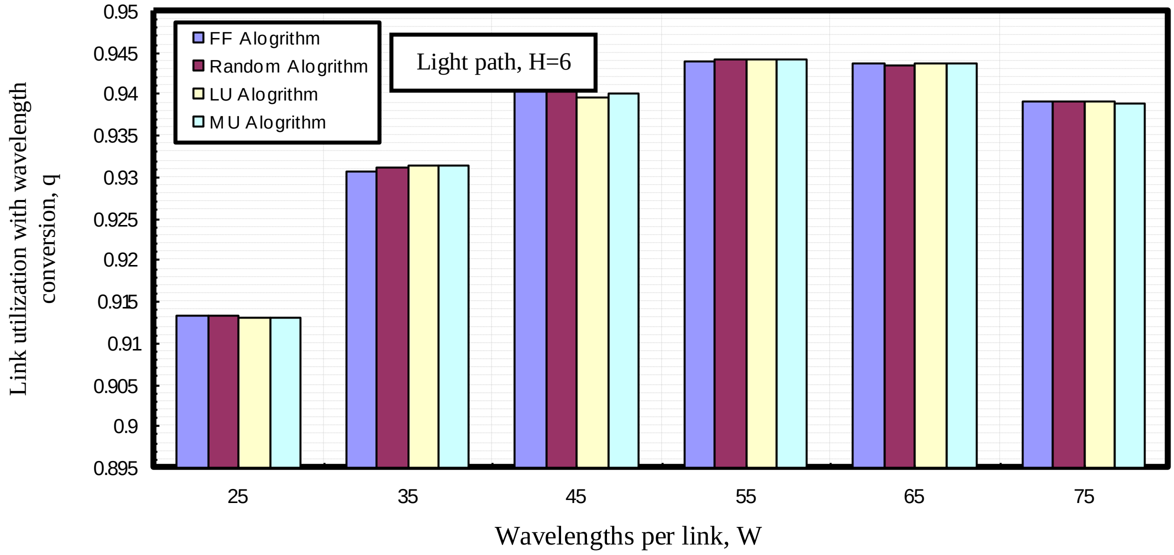


Fig. 9. Link utilization with wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.

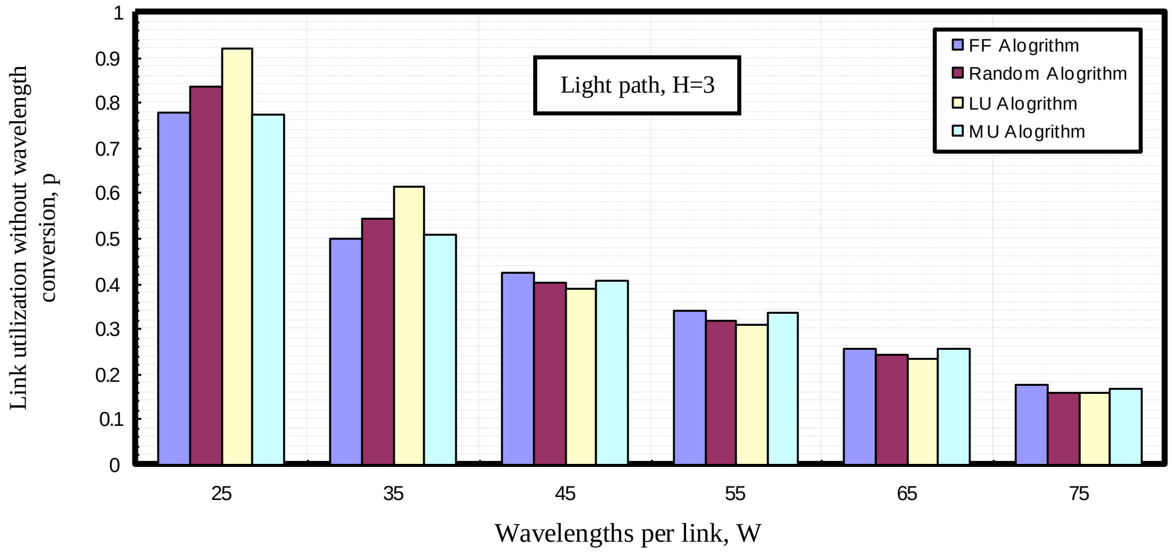
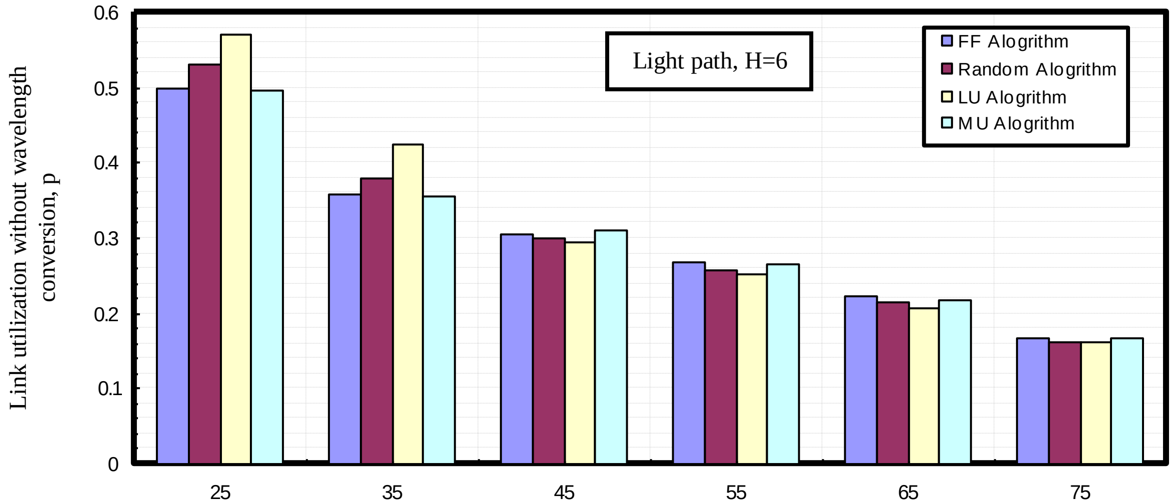
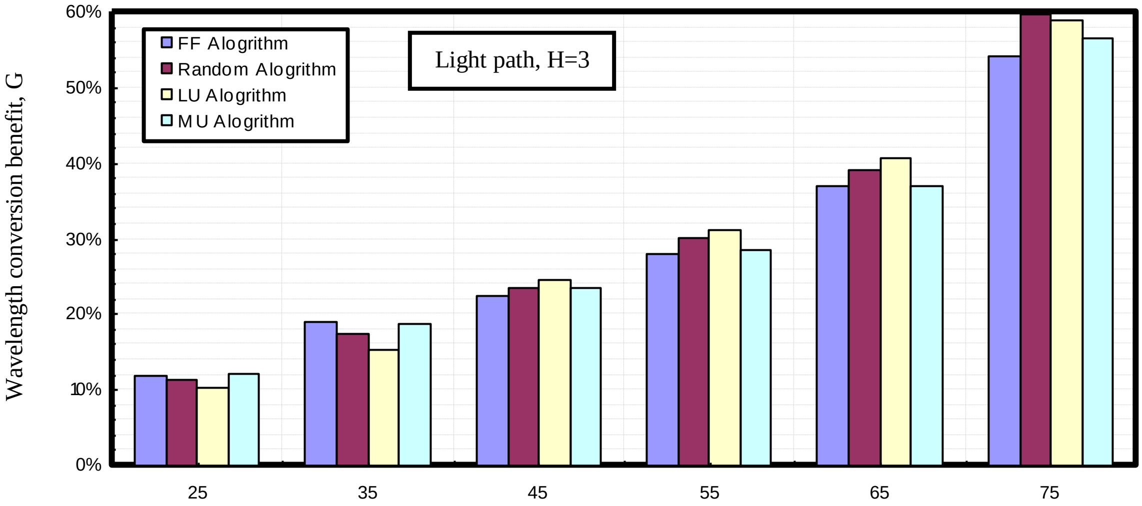


Fig. 10. Link utilization without wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.



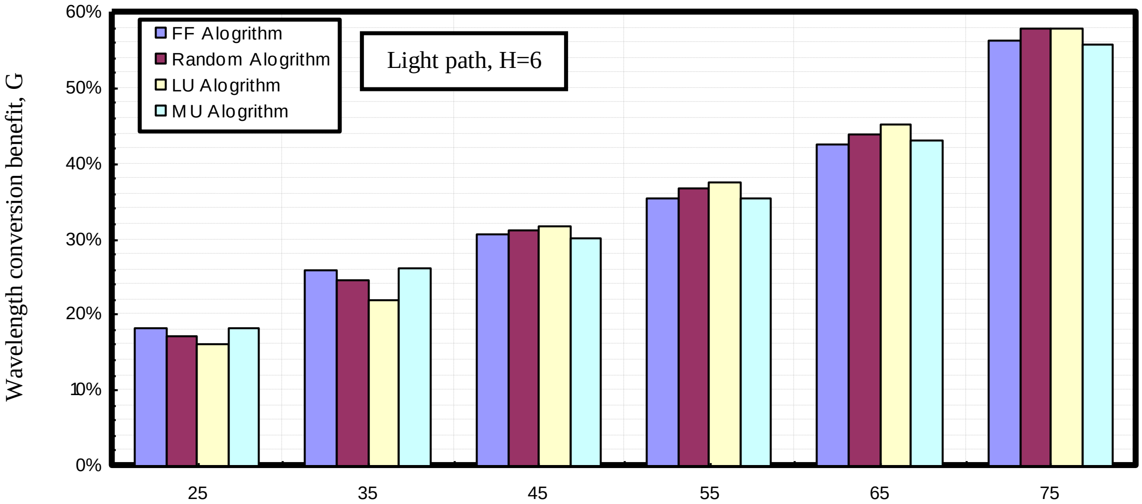
Wavelengths per link, W

Fig. 11. Link utilization without wavelength conversion in relation to wavelengths per link at the assumed set of the operating parameters.



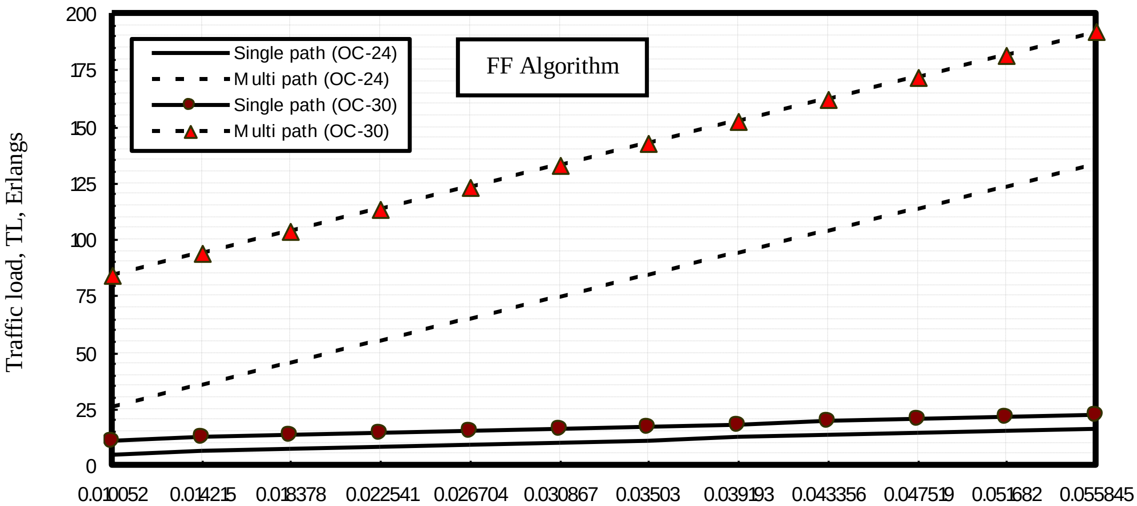
Wavelengths per link, W

Fig. 12. Wavelength conversion benefit in relation to wavelengths per link at the assumed set of the operating parameters.



Wavelengths per link, W

Fig. 13. Wavelength conversion benefit in relation to wavelengths per link at the assumed set of the operating parameters.



Blocking probability with wavelength conversion, $P_{B(wc)}$

Fig. 14. Traffic load in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.

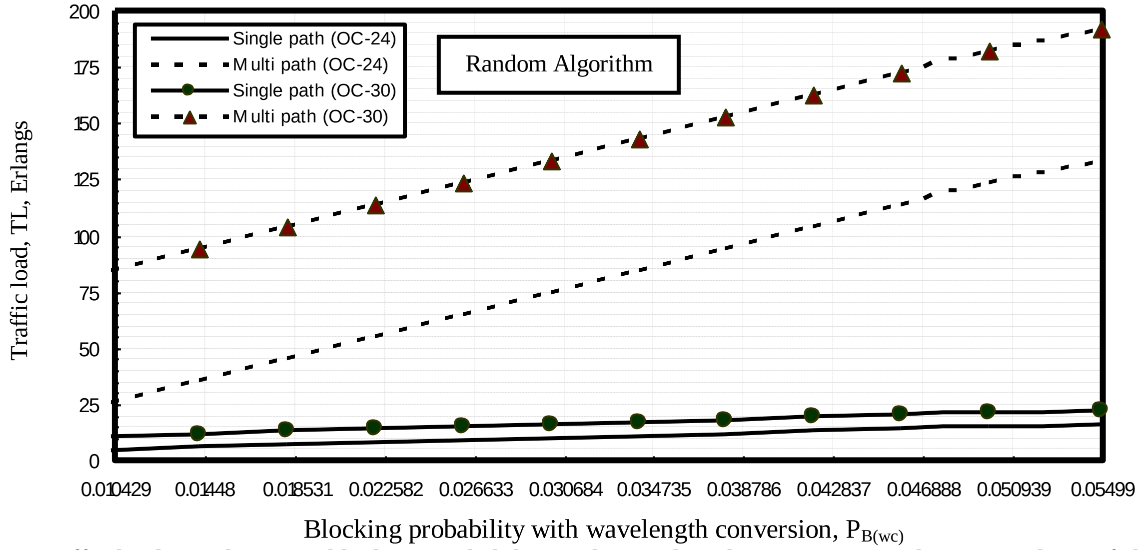


Fig. 15. Traffic load in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.

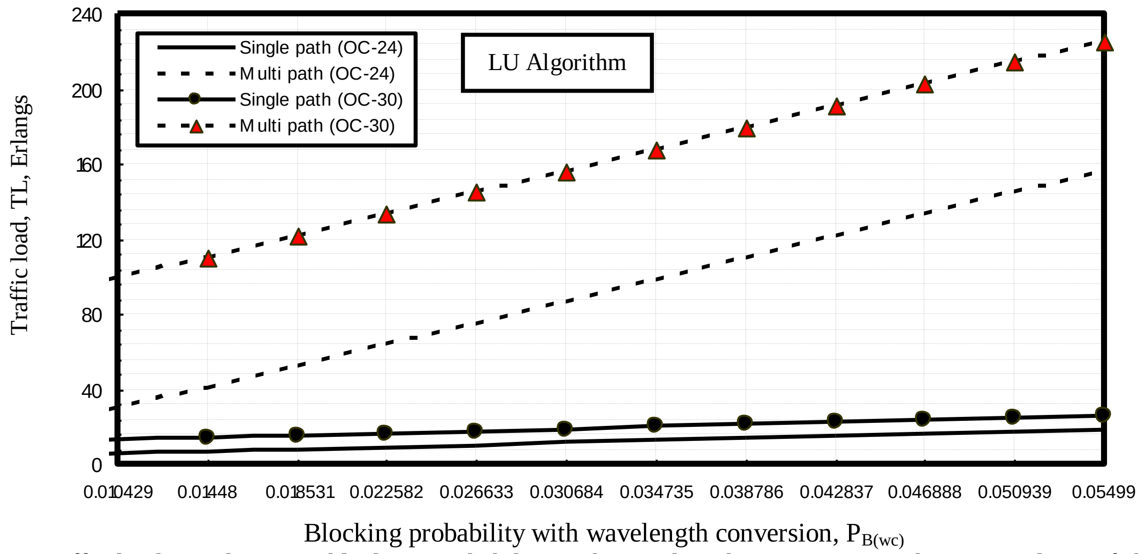
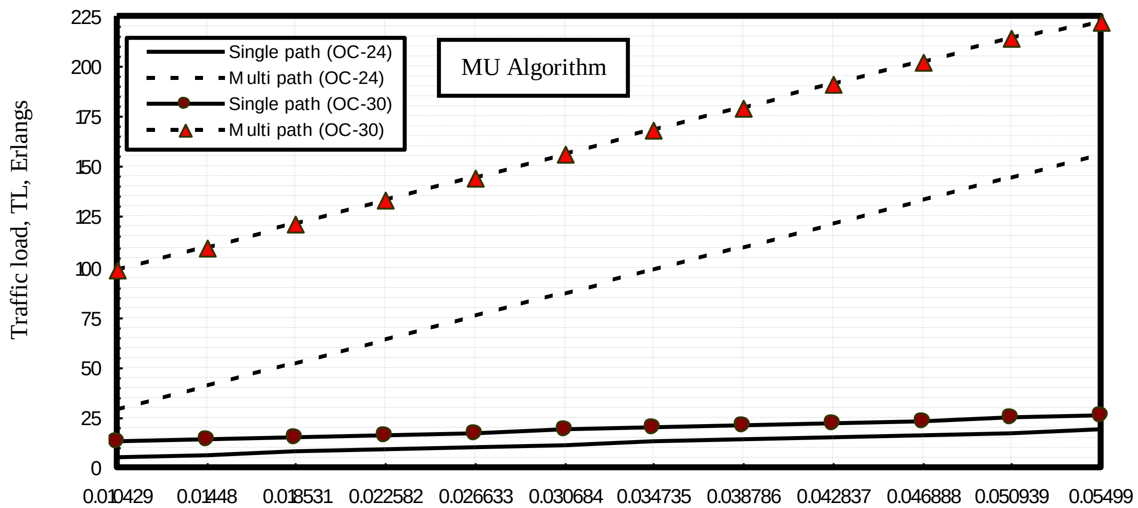


Fig. 16. Traffic load in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.



Blocking probability with wavelength conversion, $P_{B(wc)}$

Fig. 17. Traffic load in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.

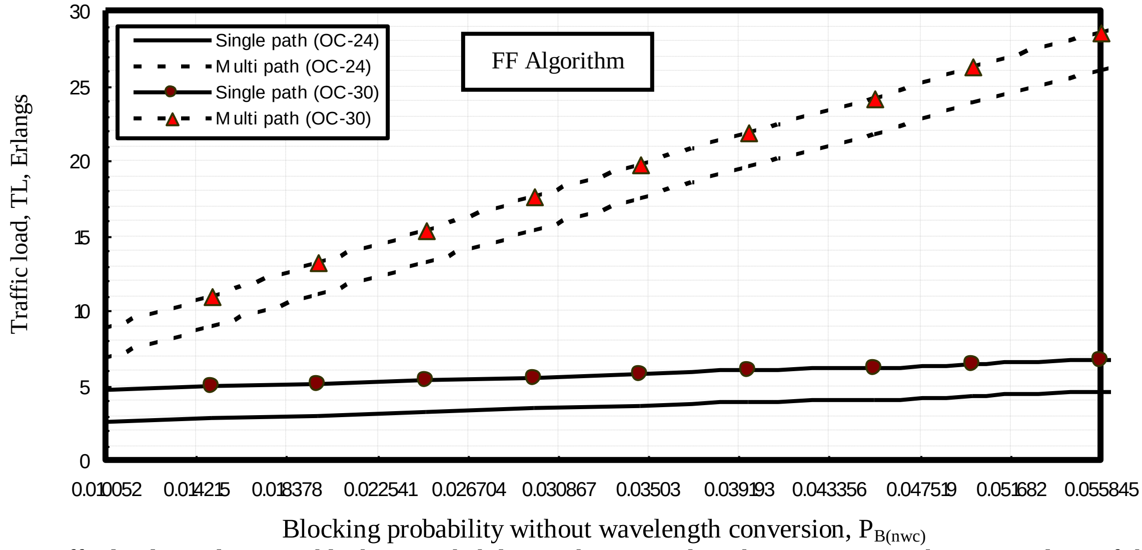


Fig. 18. Traffic load in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

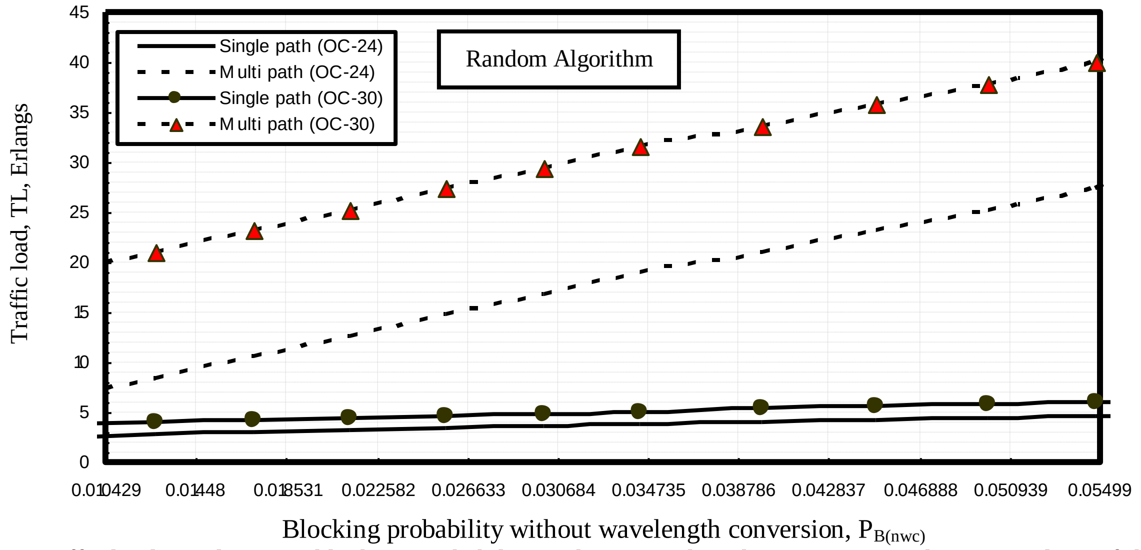


Fig. 19. Traffic load in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

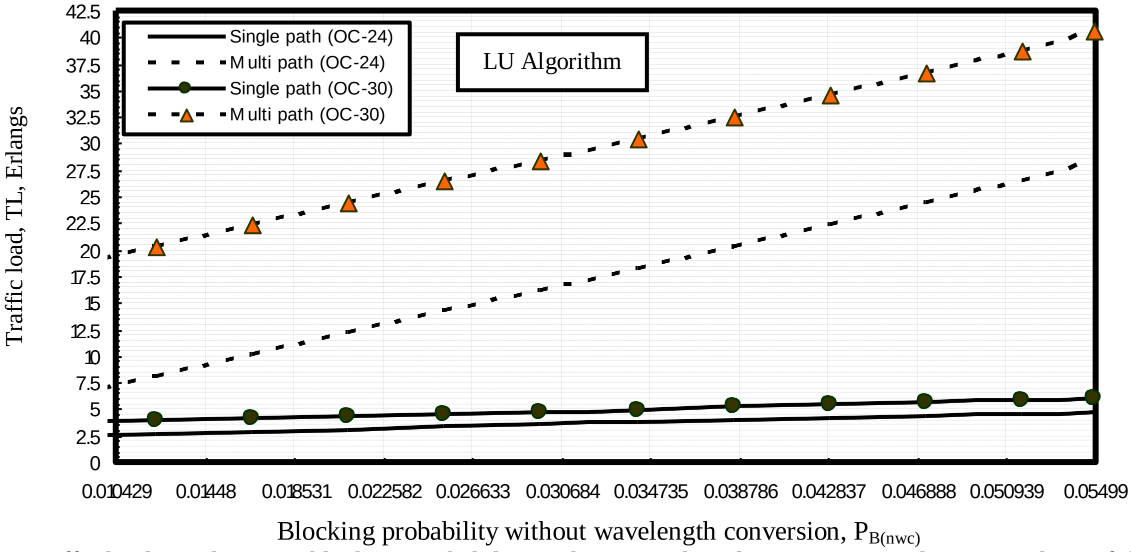


Fig. 20. Traffic load in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

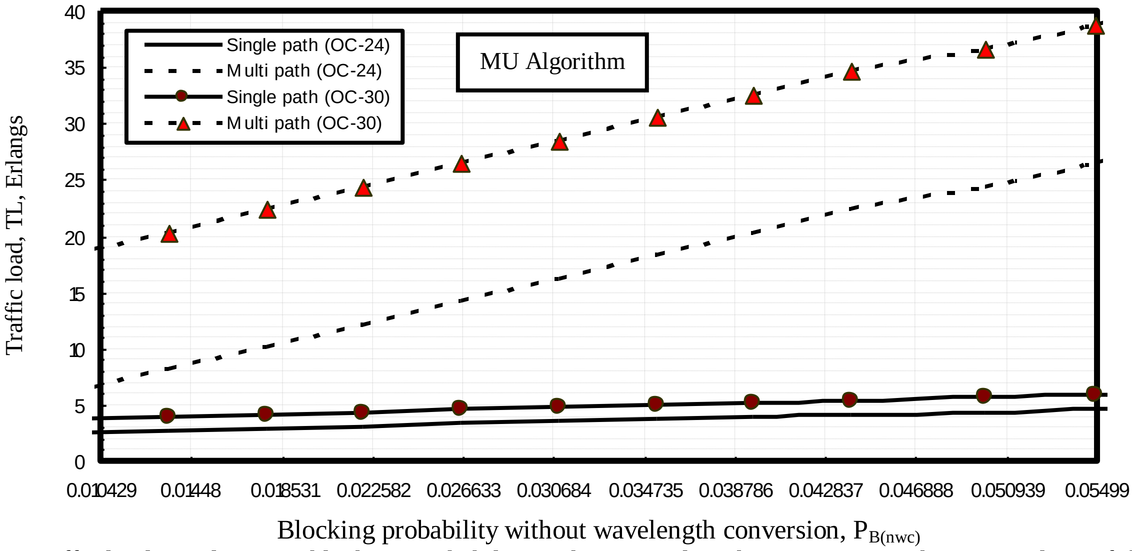


Fig. 21. Traffic load in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

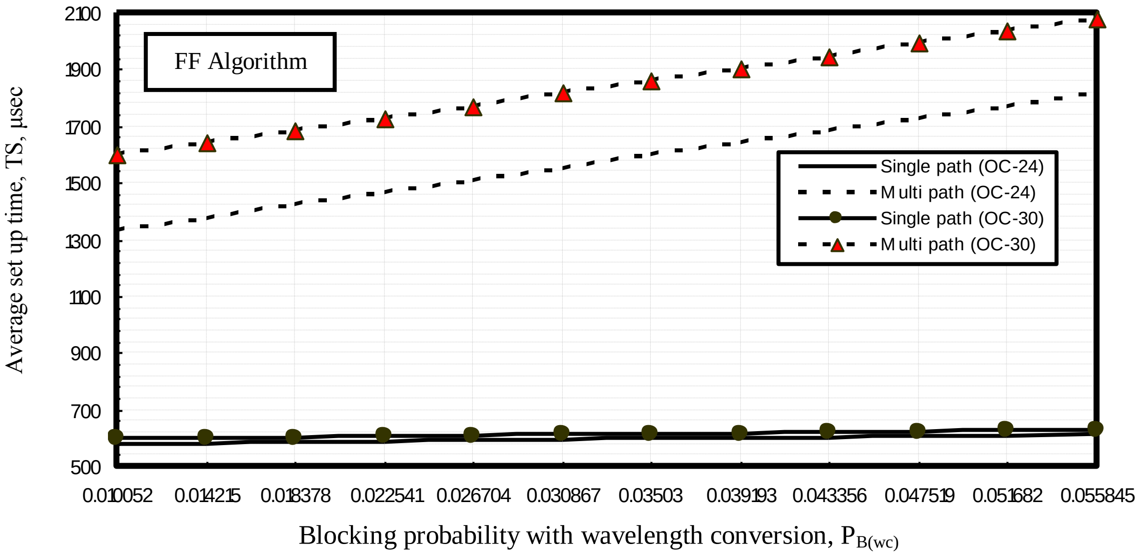


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Fig. 22. Average set up time in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.

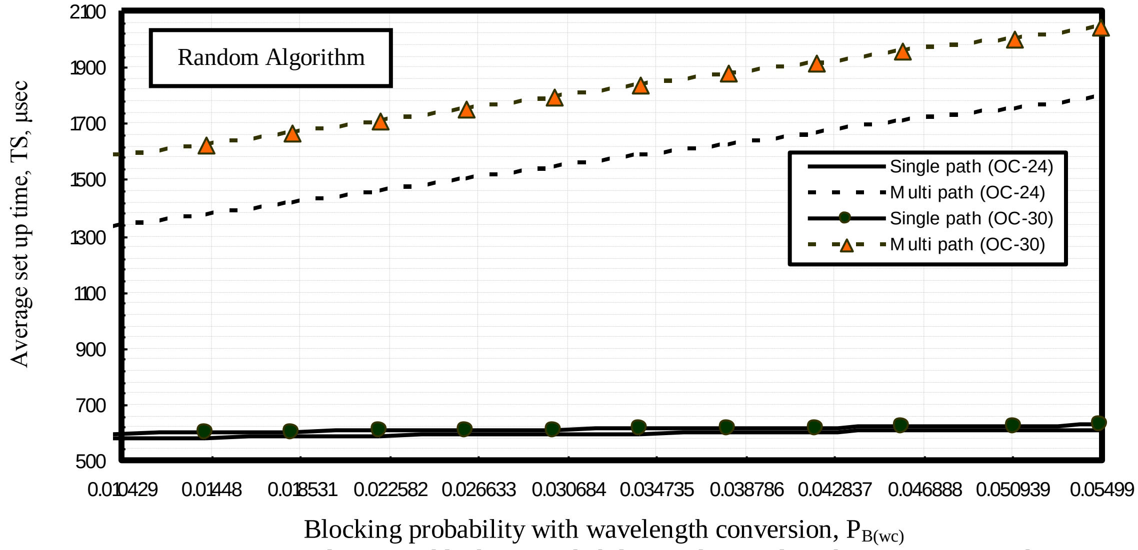


Fig. 23. Average set up time in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.

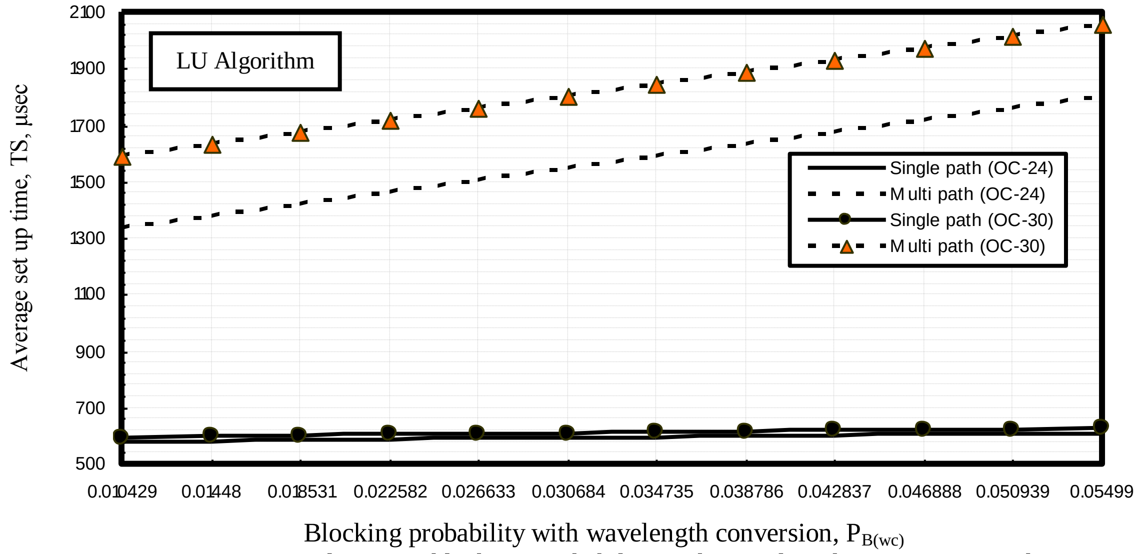
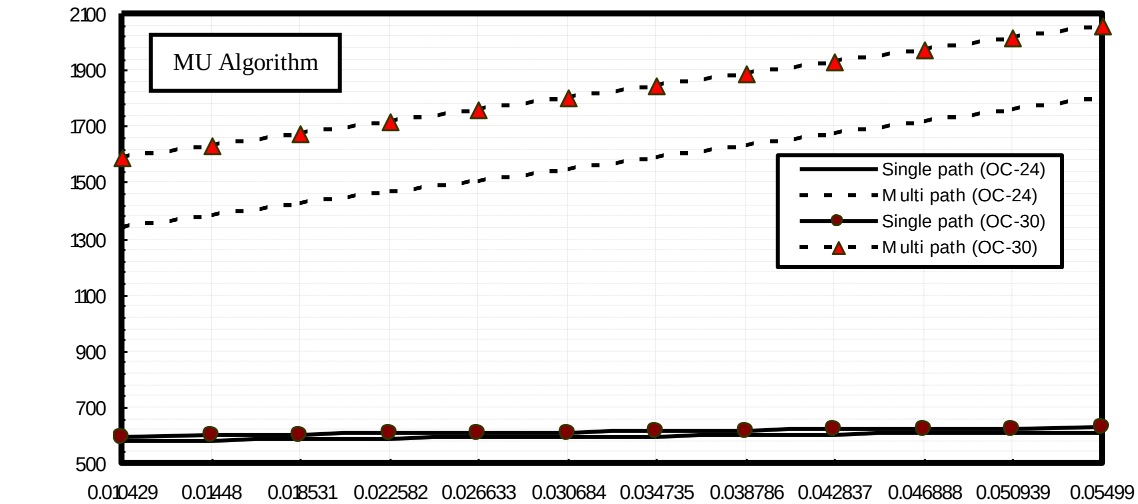
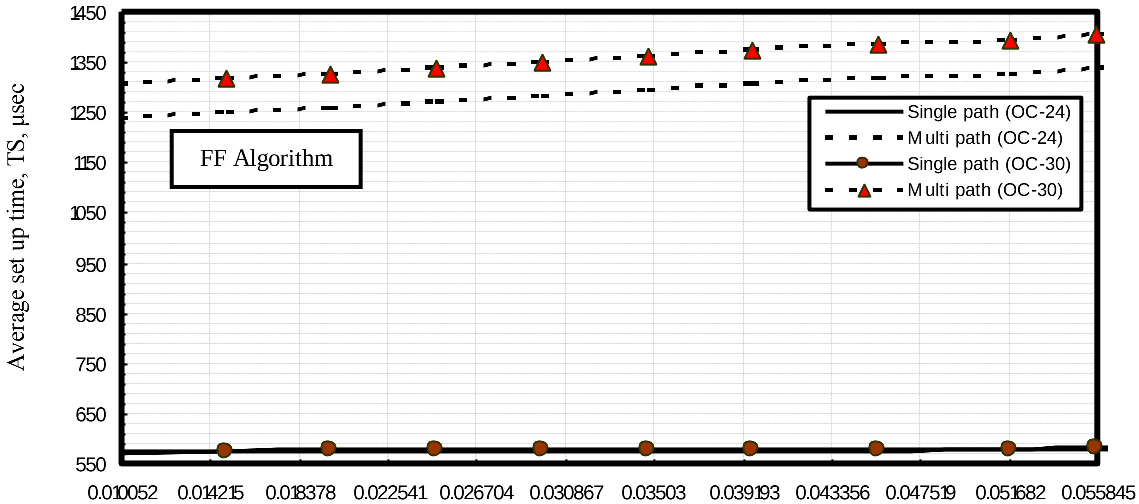


Fig. 24. Average set up time in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.



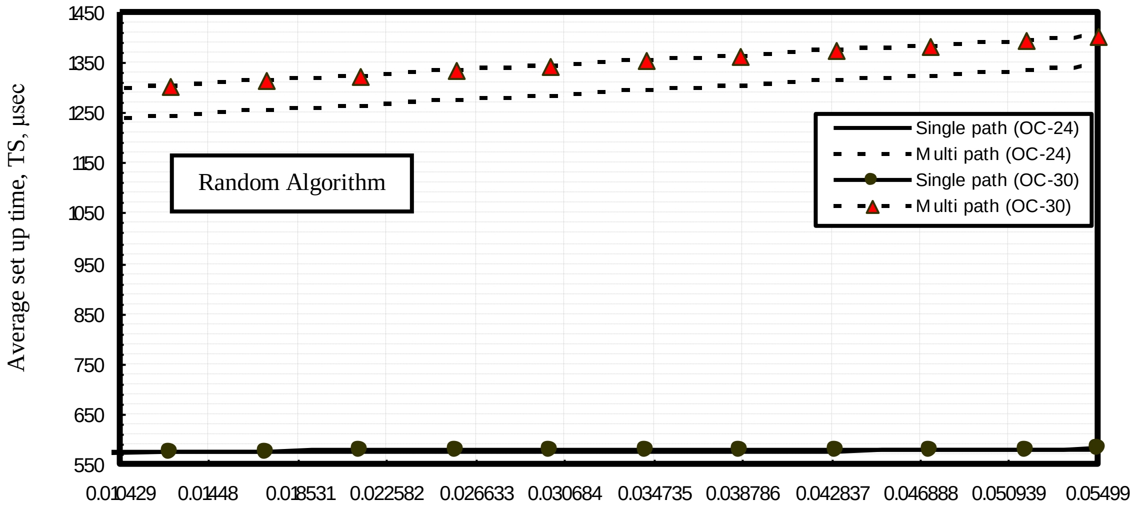
Blocking probability with wavelength conversion, $P_{B(wc)}$

Fig. 25. Average set up time in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.



Blocking probability without wavelength conversion, $P_{B(nwc)}$

Fig. 26. Average set up time in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.



Blocking probability without wavelength conversion, $P_{B(nwc)}$

Fig. 27. Average set up time in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

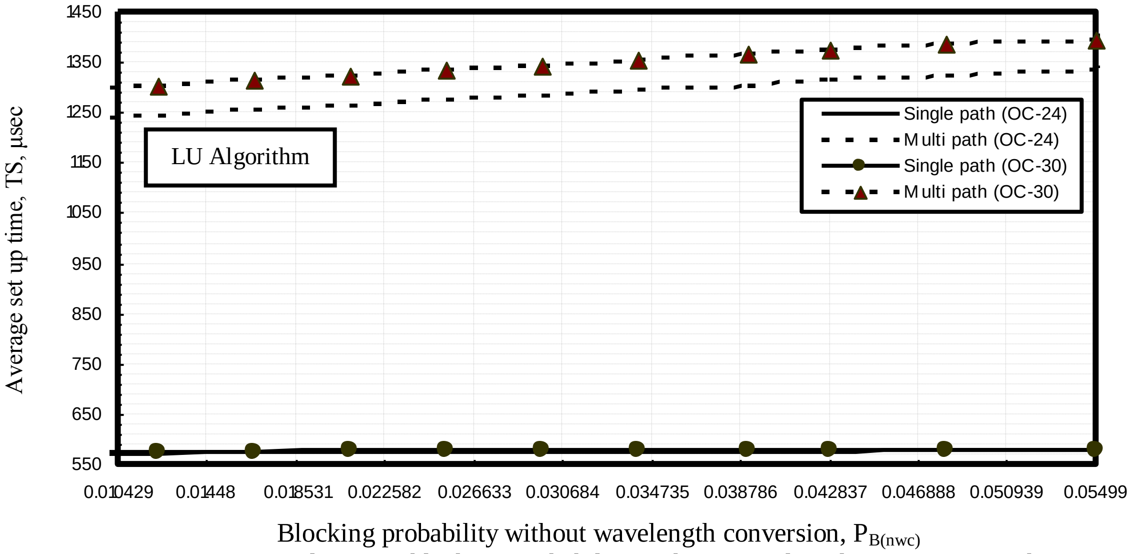


Fig. 28. Average set up time in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

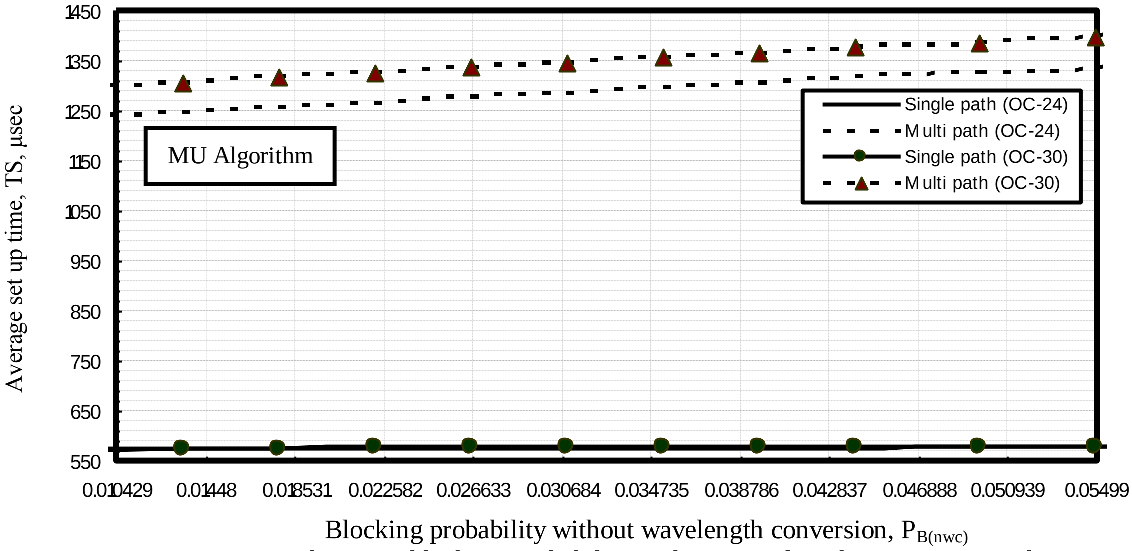


Fig. 29. Average set up time in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

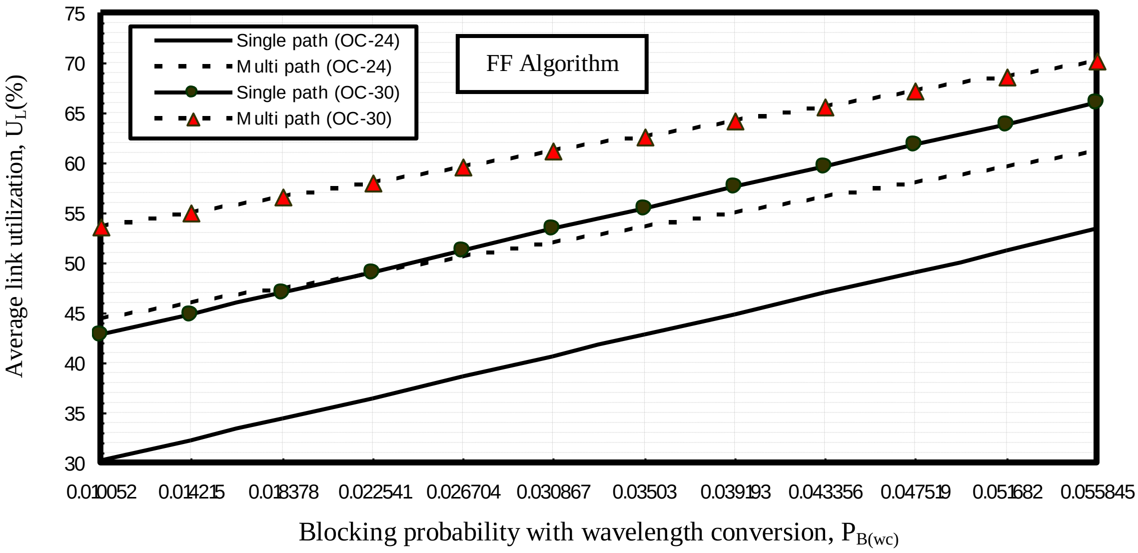


Fig. 30. Average link utilization in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.

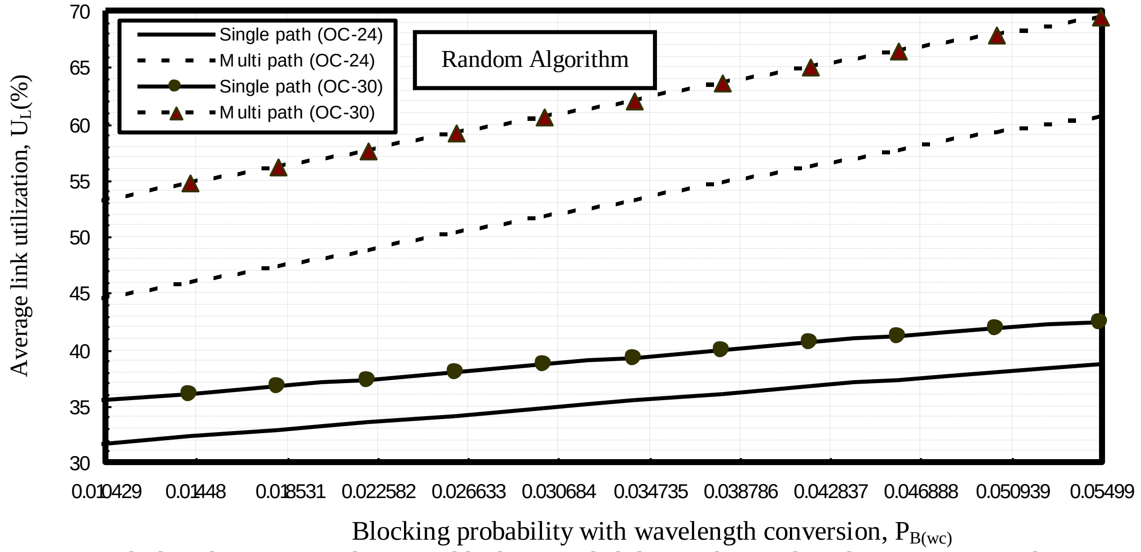


Fig. 31. Average link utilization in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.

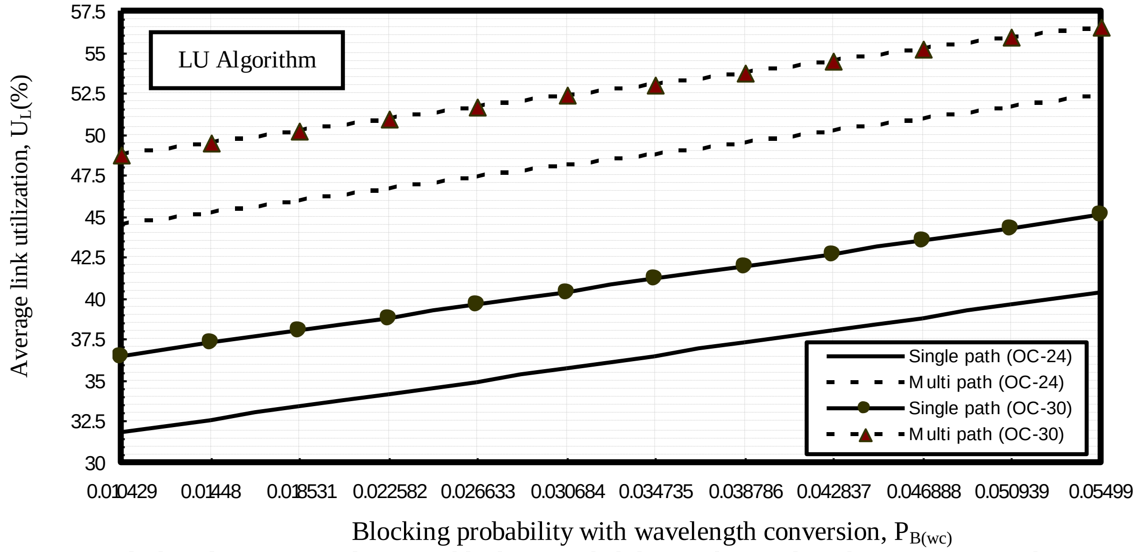
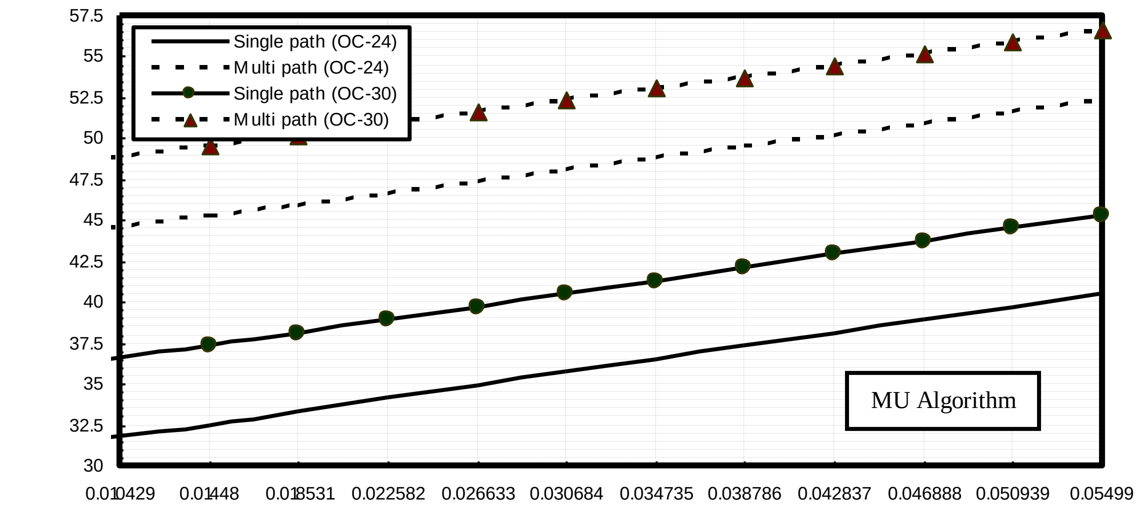


Fig. 32. Average link utilization in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.



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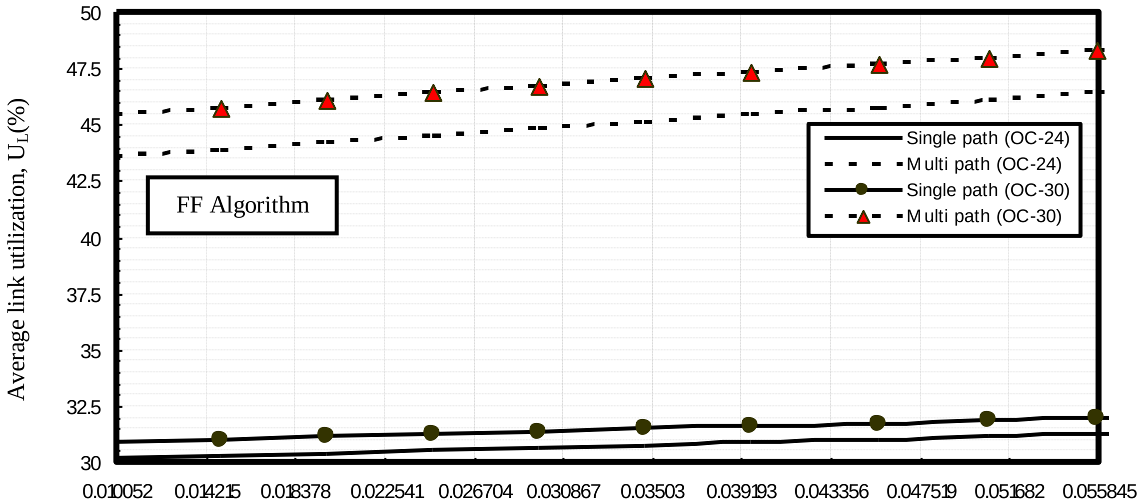
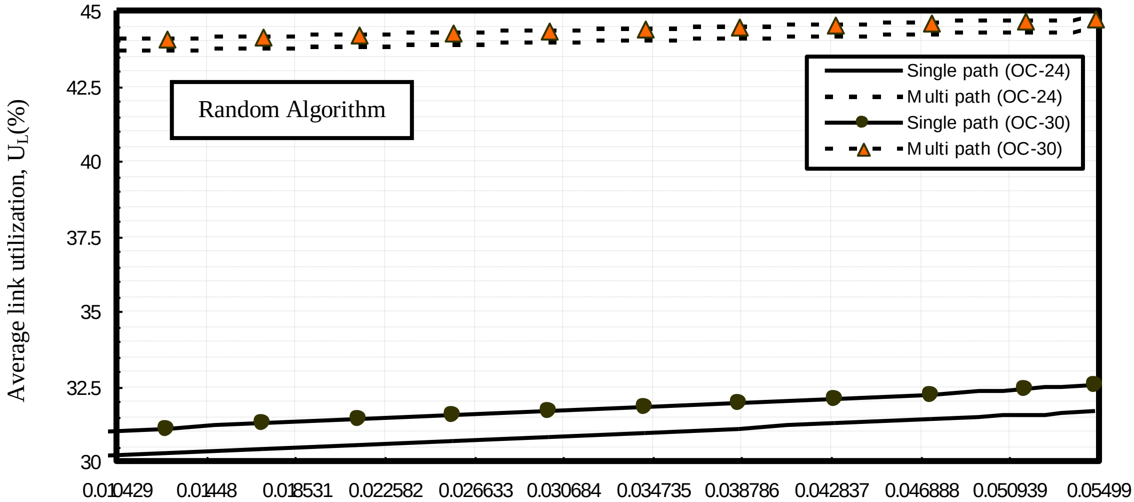
Blocking probability with wavelength conversion, $P_{B(wc)}$

Fig. 33. Average link utilization in relation to blocking probability with wavelength conversion at the assumed set of the operating parameters.



Blocking probability without wavelength conversion, $P_{B(nwc)}$

Fig. 34. Average link utilization in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.



Blocking probability without wavelength conversion, $P_{B(nwc)}$

Fig. 35. Average link utilization in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

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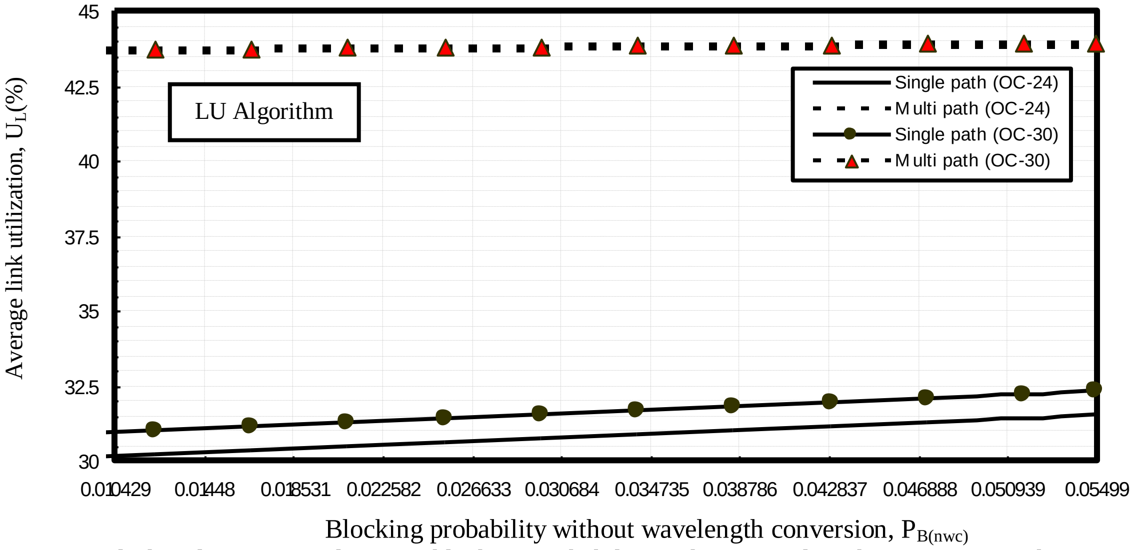

Fig. 36. Average link utilization in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

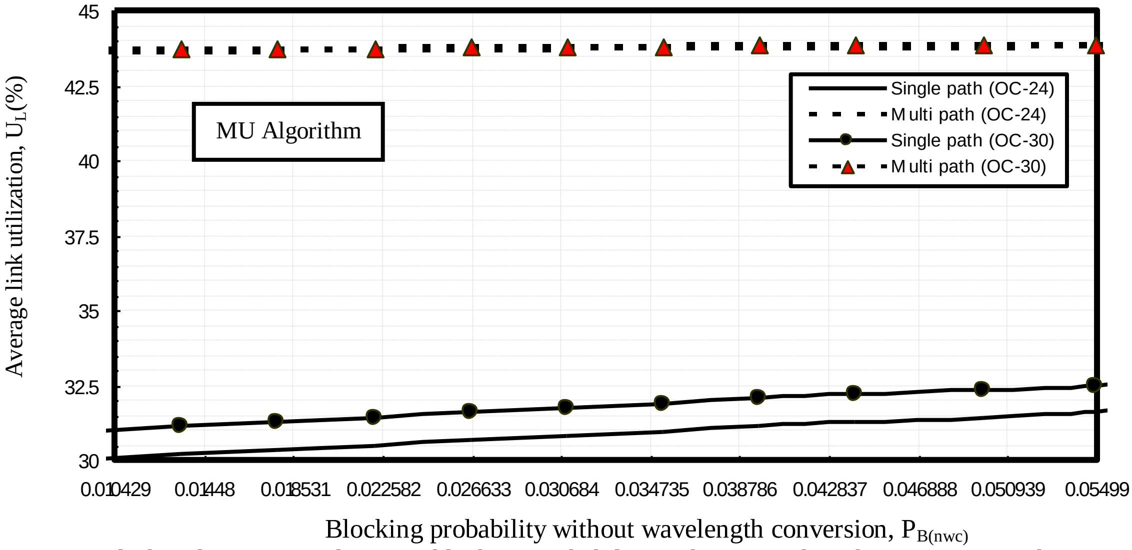

Fig. 37. Average link utilization in relation to blocking probability without wavelength conversion at the assumed set of the operating parameters.

v) As shown in Figs. (14-21) have indicated that traffic load increases with increasing both blocking probability with and without wavelength conversion for different both routing algorithms and link capabilities under study. It is observed that for multi path routing suffers from heavy traffic load compared to single path routing for different algorithms under the same conditions. Also it is found that with increasing link capability, resulting in increasing traffic load on the network. As well as traffic load is heavily with wavelength conversion compared to without wavelength conversion for different routing algorithms.

vi) Figs. (22-29) have indicated that average set up time increases with increasing both blocking probability with and without wavelength conversion for different both routing algorithms and link capabilities under study. It is observed that for multi path routing takes more average set up time compared to single path routing for different algorithms under the same conditions. Also it is found that with increasing link capability, resulting in increasing average set up time for the connection on the network. As well as average set up time is high with wavelength conversion compared to without wavelength conversion for different routing algorithms.

vii) As shown in Figs. (30-37) have indicated that average link utilization increases with increasing both blocking probability with and without wavelength conversion for different both routing algorithms and link capabilities under study. It is observed that for multi path routing suffers from higher average link utilization compared to single path routing for different algorithms under the same operating conditions. Also it is found that with increasing link capability, resulting in increasing average link utilization for the connection on the network. As well as average link utilization is high with wavelength conversion compared to without wavelength conversion for different routing algorithms.

V. Conclusions

This paper has examined the various facets of the wavelength conversion: from its incorporation in a wavelength routed trans-Egypt network design to its effect on efficient routing and management algorithms to a measurement of its potential benefits under various network conditions. Some of the important results that were highlighted by our simulation based case study of wavelength conversion as a network needs a mixing of traffic for wavelength converters to be beneficial (i.e., single rings benefit little from wavelength converters, while graphs with higher connectivity benefit more). A network with wavelength conversion can achieve almost the same benefit as a network that has "full" conversion capabilities and traffic load can influence the benefit of wavelength conversion. It is theoretically found that the increased wavelengths per link, resulting in the decreased blocking probability, and the increased link utilization with wavelength conversion, and the increased wavelength conversion benefit for different routing algorithms management. As well as it is observed that with wavelength conversion and the increased link capability, leads to that the traffic load, average set up time, and average link utilization are increased compared to without wavelength conversion.

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