JEATSA JOURNAL
JOURNAL OF ENGINEERING ADVANCES AND TECHNOLOGIES FOR SUSTAINABLE APPLICATIONS
Volume 1, Issue 3 (July, 2025)
Print ISSN: 3062-5629 Online ISSN: 3062-5637
Open Access
https://jeatsa.journals.ekb.eg/

A WDM Ring Network Based on Integrated Reconfigurable Optical Wavelength Add/Drop Multiplexers

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Received 29-09-2024
Revised 16-10-2024
Accepted: 1-11-2024
Published: July-2025

Print ISSN: 3062-5629
Online ISSN: 3062-5637

Abstract- A novel architectural design for an optical wavelength division multiplexed (WDM) ring network is presented and analyzed. The topology for the proposed network is based on a double fiber ring. The stations are connected to the ring through an Integrated Reconfigurable Optical Wavelength Search Add/Drop Multiplexers (IROWSADM). This device is used for inserting the transmission of each station at a certain selected free wavelength from the wavelength pool used. Also, the add-drop multiplexer has the ability to drop the incoming acknowledgment signals on the node wavelength from the destination node. A protocol for fast circuit switched applications is proposed for use with the proposed architecture and its performance evaluated.

Keywords- WDM ring network, Add/Drop Multiplexers,

I. INTRODUCTION

Wavelength division multiplexing is a technique that harnesses the extensive bandwidth capabilities of optical fibers, alongside the characteristics of Lightwave technology, to facilitate the creation of terabit-per-second networks [1]. Ring network architectures employing WDM transmission offer an effective method for establishing high-speed optical communication within both local and metropolitan areas. Ring topologies have demonstrated efficiency and resilience as network structures. They provide fault tolerance by incorporating an additional counter-rotating ring, which is utilized to reconfigure the logical ring during faulty conditions [2]. Furthermore, they enable a straightforward acknowledgment mechanism by routing the signal back to the requesting node through the ring.
The viability of optical WDM networks is largely contingent upon the accessibility of optical components. A reconfigurable wavelength add-drop multiplexer (ADM) constitutes a crucial network element employed for the selective insertion and removal of optical signals within a WDM network.
The ability to incorporate, remove, or pass wavelengths is essential for managing data flow within the network and ensuring effective wavelength routing. Also, reconfigurable ADM's offer great flexibility in the design of new network architectures [3],[4],[5].

This paper proposes an optical multi-channel ring network architecture which exploits the WDM technique and the ADM's. The key element in the proposed network architecture is the Integrated Reconfigurable Optical Wavelength Search Add/Drop Multiplexer (IROWSADM) which used mainly for inserting the transmission of each node after sensing the transmission wavelengths of the other nodes.
The structure of this paper is delineated as follows. Section II provides an overview of the network description. Section III elaborates on the medium access protocol. Section IV delves into the network performance analysis and discusses the simulation outcomes. Lastly, Section V concludes the paper.

II. NETWORK DESCRIPTION

A. Network Architecture

The proposed architecture for the WDM ring network is depicted in Figure 1. This system comprises N nodes linked by two fibers that create a ring. The transmission direction of one fiber is reverse to that of the other fiber. Each node is connected to the ring via an Integrated Reconfigurable Optical Wavelength Search Add/Drop Multiplexer (IROWSADM)[7].
Each node possesses a single tunable transmitter

designated for the transmission of connection requests, messages, and acknowledgment signals to other nodes. Additionally, it contains a single fixed-tuned receiver dedicated to receiving connection requests, messages, and acknowledgment signals originating from other nodes.

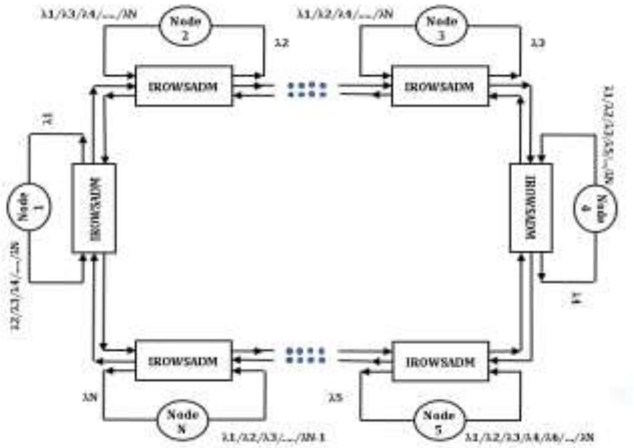

Figure 1: The proposed WDM Ring network using IROWSADM

Every node is allocated a specific reserved wavelength for receiving signals. The total number of wavelengths (W) corresponds to the total number of nodes (N). Each node possesses the capability to transmit via any available wavelength based on the intended recipient. A transmitting node adjusts its tunable transmitter to match the wavelength of the target node's receiver and then proceeds to send its message.

B. Integrated Reconfigurable Optical Wavelength Search Add/Drop Multiplexer (IROWSADM)

A fundamental component within the suggested network framework is the Integrated Reconfigurable Optical Wavelength Search Add/Drop Multiplexer (IROWSADM). Figure 2 illustrates the configuration of the IROWSADM, which supports the implementation of four wavelength channels. For N wavelengths, the configuration comprises a pair of (1 x N) wavelength routers, a singular 99:1 splitter, a duo of (N x 1) combiners, and a reconfigurable add/drop module. Within this setup, a single 99:1 splitter unit is required, which is interfaced with fiber 1. The primary role of the 99:1 splitter is to extract 1% of the signal's power, thus facilitating the monitoring of a specific wavelength's presence.

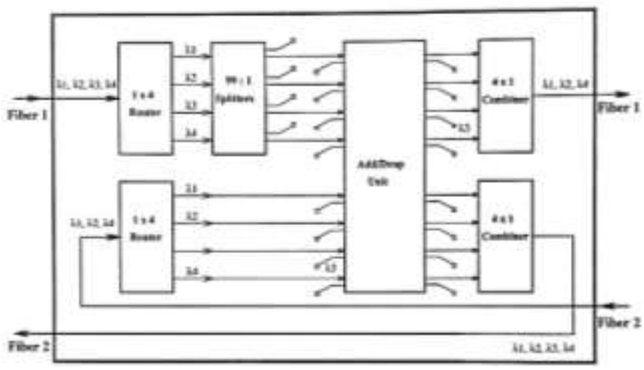

Figure 2: Schematic diagram of the Integrated Reconfigurable Optical Wavelength Search Add/Drop Multiplexer IROWSADM

Any node can be in one mode at a time, either transmission or reception. In addition, the add/drop unit has a fixed configuration to drop the incoming acknowledgment signals on the node wavelength from the destination node on fiber 2. Each node needs to sense only the traffic on fiber 1. The tunable transmitter will be connected to fiber 1 when transmitting connection requests and messages, and to fiber 2 when transmitting acknowledgments.

By detecting the traffic on fiber 1, each node can observe the presence of a specific wavelength. When a node intends to establish communication with another node, it initially detects the presence of the wavelength associated with the target destination. If this wavelength is free (not used by any other node), the node will configure its IROWSADM add/drop unit to add a connection request signal on this free wavelength and to drop any signal that will come later from the preceding nodes on this wavelength. At the same time, the requesting node is configured to drop the incoming acknowledgment on its wavelength.

For example, in a network consisting of 6 nodes, when node 2 wants to setup connection with node 5, it first senses the output of the splitter for the desired destination wavelength ($\lambda 5$). If $\lambda 5$ exist, this mean that another node is already transmitting a message or a connection request to node 5. In this case, node 2 will wait till that connection is finished and $\lambda 5$ becomes free. When node 2 senses that $\lambda 5$ is free, it configures its add/drop unit to drop any signal that will arrive later on $\lambda 5$ from any preceding node, and insert its connection request on $\lambda 5$ into the traffic to node 5. Also, it waits to drop the incoming acknowledgment from node 5 on $\lambda 2$.

III. MEDIUM ACCESS PROTOCOL

Figure 3 shows the flow chart of the medium access control protocol (MAC) for setting up a connection between any two nodes, for example i and j, as follows: Upon the arrival of a message at node i destined to node j, node i first checks its receiver status. If its receiver is busy, it waits till it finishes reception then reserves it for receiving the incoming acknowledgment. Next, it ignores any incoming connection request directed to it from other nodes. Then, node i senses the wavelength (λ_j) of the desired destination

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(node j). If λ_j is free (not used by any preceding node in transmission to node j), node i send a connection request (CR) signal to node j on wavelength λ_j. This CR signal is a periodically repeated special message that contains the addresses of the sender and the destination. In ideal case, this CR signal will propagate on the ring and go through the intervening nodes to the destination. Upon receiving the connection request of node i, node j will send out an acknowledgment on the wavelength of the requesting node i (λ_i) on fiber 2 to propagate back to node i. Node i's receiver which is fixed tuned to λ_i will receive the acknowledgment signal and will learn that node j is ready to receive its message. Node i will begin transmitting its message on wavelength λ_j. When transmission is completed, node i will release its receiver for receiving any waiting connection request directed to it from other nodes.

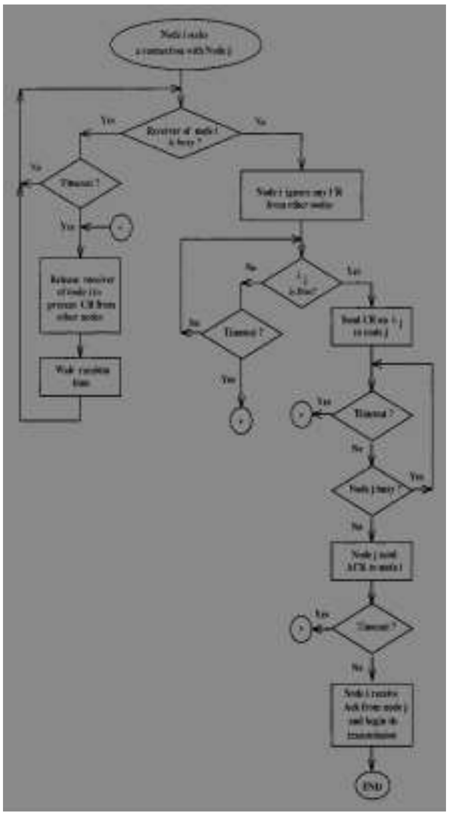
With this protocol, there is a possibility that when a message arrives at node i, the node may sense the destination wavelength busy (in use) for a long time. Also, it may happen that the CR signal does not get through an intermediate node for a long time. In addition, when a CR signal reaches its destination, it may find the destination busy. A deadlock may also happen, if two nodes begin sending connection requests to each other nearly at the same time. They will both reserve their receivers for the incoming acknowledgments, but since they will not receive the connection request of each other, the acknowledgments will never be sent. To overcome all these problems, the protocol includes a timeout mechanism. If an acknowledgment is not received within certain timeout duration measured from message arrival instant, the connection setup is aborted. The requesting node releases its receiver to receive any connection request directed to it, and waits for a random time after which it tries to set up the same connection again.

Figure 3: Flow chart for the medium access protocol used to setup a connection between network nodes

IV. NETWORK PERFORMANCE

To evaluate the performance of the proposed ring architecture and to investigate the effects of the network parameters, the following assumption are used:

- The network consists of N nodes
- Each node is assigned a reserved wavelength for reception. The number of wavelengths (W) is equal to the number of nodes
- There is no queuing. Each node has a single buffer for a message storage. New arrivals are permitted only when the existing message transmission is completed and the buffer becomes empty.
- Messages arrive at each node according to Poisson processes.
- Message lengths are geometrically distributed with an average message length is *ml* seconds.



- The propagation delay between neighboring nodes is constant (i.e, nodes are equally separated) and is equal τ microseconds.
- Uniform traffic distribution among nodes is considered. Transmission of each message is equally likely to any one of the other nodes.
- The transfer time of a message is a function of the source and destination positions on the network.
- Signal sensing times and processing times at each node are neglected
- Various timeout durations are considered.

In the simulation program, the following default values are considered:

- The ring network consists of N=6 nodes
- There are W=6 transmission channels
- The mean message lengths considered are 10 ms, 50 ms, and 100 ms.
- The mean arrival rate per node is varying between 10 and 1000 arrivals/second

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- The propagation delay τ is 10 μs corresponding to 2600 meters and network span of 15600 meters. In some cases propagation delay τ is varied between 10 μs and 400 μs.
- Timeout periods are varying between 0.1 ms and 2000 ms.

The effect of some of these parameters on the network performance is studied by varying them around the default values.

In Figure 4, the behavior of the normalized throughput versus message arrival rates is illustrated. In this study, the timeout duration is equal 1 ms and the propagation delay τ is 10 μs. The throughput values are plotted versus arrival rate values for different message lengths (ml).

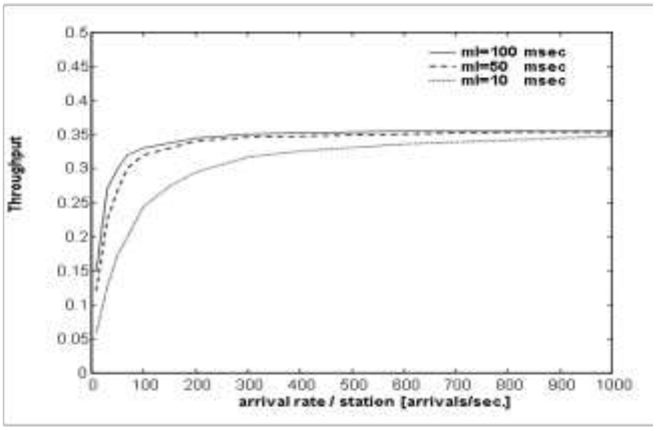

Figure 4. Throughput versus arrival rate for different message lengths

As the arrival rate increases, more messages become available for transmission, throughput increases till it reaches certain saturation level where the network reaches its full capacity. Figure 4 does not show the effect of the timeout duration on the throughput values. This is because the selected timeout duration (1 ms) was reasonable to let the system achieves its maximum throughput and stay at the same saturation level for long range of arrival rates. The effect of timeout on the network performance is shown in the next studies.

Figure 5 illustrates the behavior of the throughput versus timeout durations for different arrival rates, considering mean message length equal 100 ms and propagation delay τ equal 10 μs.

For all the considered arrival rates, as timeout duration increases, throughput first increases and then decreases.

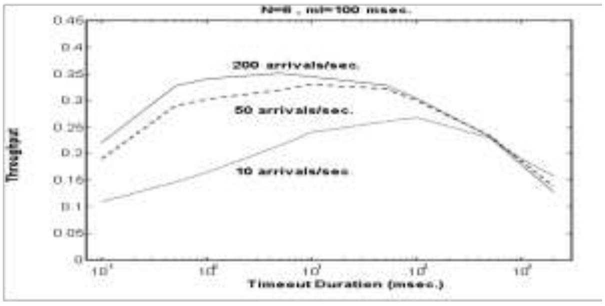

Figure 5: Throughput vs. timeout durations for different arrival rates

As shown in Figure 5, at low timeout durations, throughput values are small. This is because connection requests are timing out quickly, before they get the chance to be acknowledged. By increasing timeout duration, throughput values increase because more connection requests will be acknowledged. Increasing timeout duration even further, network nodes will spend longer amounts of time in the requesting mode and more nodes waiting for each other. As a result, fewer nodes will be available for acknowledging connection requests and throughput values decrease. An important result noticed, is that for a given arrival rate, there is an optimum timeout value at which the network reaches its maximum throughput. For 10 arrivals per second, the network achieves its maximum throughput of 0.268 at a timeout duration equal 100 ms. For 50 arrivals per second, the network achieves a maximum throughput of 0.33 at timeout duration equal 10 ms. For 200 arrivals per second, the maximum throughput equal 0.351 at a timeout duration equal 5 ms. This leads to an important conclusion that the function of the medium access control protocol can be improved by applying dynamic timeout duration. By changing the values of the timeout based on the arrival rate values at each node, it may be possible to get maximum throughput for certain arrival rates. Also, it is shown that the throughput reaches higher values for higher arrival rates, and reaches its maximum point faster than that in case of lower arrival rates.

Figure 6 shows the behavior of the throughput versus timeout duration for various message lengths. In this study the arrival rate of 200 arrivals per second is considered and the propagation delay τ is equal 10 μs. For all the considered message lengths, as timeout duration increases, throughput first increases and then decreases. As shown, at low timeout durations, connection requests are timing out quickly before being acknowledged, resulting in a low throughput. As timeout duration increases, more connection

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requests will be acknowledged, resulting in a higher throughput. As timeout increases even further, number of requesting nodes begins to be more than number of nodes that are available to acknowledge connection requests. This decreases throughput. An important result noticed is that the network achieves its maximum throughput at the same optimal timeout duration (5ms) for the different message lengths. This leads to conclusion that, this optimal timeout is not significantly affected by the message length. Throughput reaches higher values for long message lengths. Maximum throughput is 0.352 for message length =100 ms, 0.347 for message length =50 ms, and 0.311 for message length =10 ms.

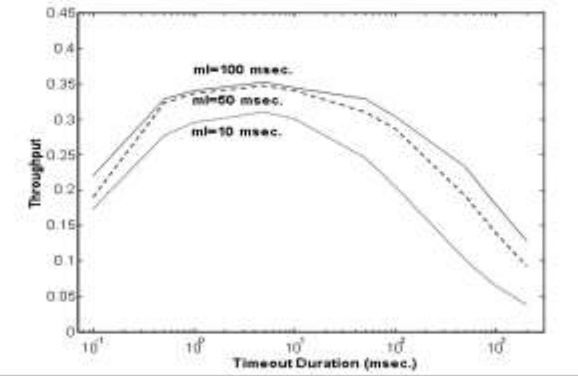

Figure 6: Throughput vs. timeout durations for different message lengths

Figure 7 shows the behavior of the network throughput versus the propagation delay between neighboring nodes, τ, for different arrival rates. In this study, the timeout duration is kept fixed at 10 ms, and a message length of 100 ms is considered.

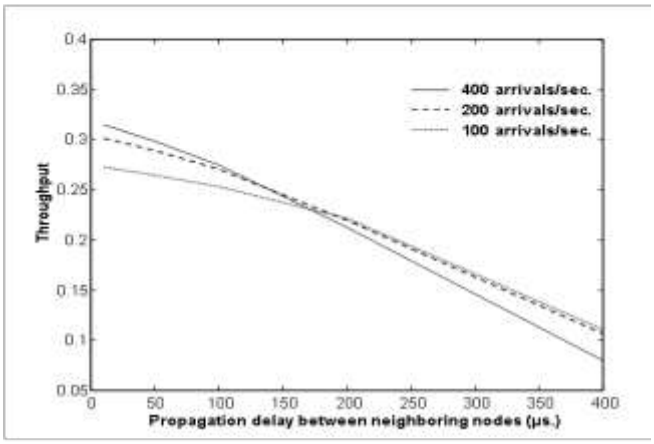

Figure 7: Throughput vs. propagation delay between neighboring nodes for different arrival rates

As shown in Figure 7, at all the arrival rates, increasing the propagation delay between nodes, by increasing the fixed distance between neighboring nodes, will cause a decrease in network throughput. This is because, the messages will spend long times on the network till reach their destinations. Also, as the arrival rate increases, increasing the propagation delay will cause the decrease of network throughput quickly.

V. CONCLUSION

This paper proposed a new ring architecture based on WDM technique and add-drop multiplexers. The key element in this architecture was the Integrated Reconfigurable Optical Wavelength Search Add/Drop Multiplexer device that used for sensing and inserting the transmissions of network nodes. In this network, each network node is equipped with only one transmitter and only one receiver. This node architecture affects the performance of the network, since there is a need for a timeout mechanism to overcome deadlocks during network operation. A medium access protocol considering timeout mechanism is presented. The limitations on the ability of each node to access the network are considered. Each node is involved in only one transmission or one reception at a time. A simulation study was carried out to investigate the effects of the different network parameters such as message arrival rate and timeout duration, on the network performance. The results show that, there is a great effect of selecting the suitable timeout duration for each arrival rate in each node. There is an optimal timeout duration for each arrival rate which lets the network achieve its maximum throughput. This leads to a conclusion that the function of the medium access protocol can be improved by the dynamic selection of the timeout duration. It is further shown that, the optimal timeout duration is not affected by the message lengths. The network throughput increases with increasing arrival rates and then decreases depending on the considered timeout duration. The network achieves higher performance for long message lengths.

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