Performance of a Symmetric Robust WDM Network when the Channel Access Pattern at Nodes is Known[1]

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Abstract

Many WDM architectures are based on fixed wavelength channels which require the lasers to be tuned to their channels accurately. Achieving this task is difficult and costly especially in the distributed environments. Robust WDM is an approach that tolerates large laser wavelength variations, due to temperature drifts and manufacturing tolerances. A reservation-based medium access protocol is used to dynamically select the laser for communication. A token-passing based control channel assigns a reservation interval to one of the waiting stations. The performance of a circuit-switched Robust WDM network is considered when each node has only a limited number of lasers. The model evaluates the performance of a network for a given access pattern, specifying the channels accessible to each station. Simulation results are used to verify the analytic results.

1. Introduction

Wavelength division multiplexing (WDM) [4,5,11,12] is an option to utilize the potential bandwidth of a fiber. A WDM network exploits the tremendous bandwidth of the optical fiber to realize several independent channels, each on a different wavelength. Recent major contributions toward the realization of WDM networks include Rainbow-I&-II [12] and STARNET [5].

Current WDM implementations rely on fixed wavelength channels and hence stable lasers with tight wavelength tolerances are needed to build WDM networks especially in a distributed environment, resulting in high hardware complexity and cost. Robust WDM network [13,14,16], a project being carried out jointly by Colorado State University and University of Colorado, aims at relaxing manufacturing and operating wavelength tolerances, leading to a cost-effective network implementation. The network differs from other networks in that the wavelength at a station may drift slowly with time, and even overlap with those of another station at a given time.

The approach of the Robust WDM network is to use an access protocol that can tolerate large variations of wavelengths of lasers over both limited and extended period of time. The medium access protocol does not depend on fixed wavelength channels, but dynamically adapts to the variations of the signal wavelengths. The protocol is based on the use of reservation intervals during which a waiting station seeks an available channel and establishes a connection with its intended destination. The network can also be implemented based on several different medium access protocols [7,8].

In [1], we analyzed the performance of a symmetric circuit-switched Robust WDM network where each station has a sufficient number of lasers to cover all the network channels. Another Robust WDM network configuration is considered in [2] where each station has a limited number of lasers and accordingly has access only to the corresponding number of channels that are randomly selected from the entire

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network channels. In this paper, a more realistic scenario that corresponds to an already established WDM network is investigated, where the limited channels that a station has access to are specified by a given access pattern. This pattern is determined by the wavelengths of the transmitter array at each station. The example, shown in Figure 1 is for a network with five channels and ten stations with station 1 having access to channels 1,2,3, station 2 to channels 2,3,4, etc. The access pattern specifies which channels are accessible by each station.

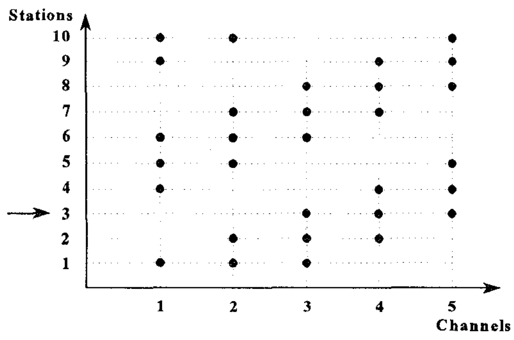

Figure 1: An example of an access pattern of a symmetric WDM network with N=10, c=5, and c_s=3.

Though the analysis in this paper is demonstrated by the access pattern in Figure 1, it is also applicable to any other pattern as well, as long as the number of lasers per station is the same for all the stations. In this work, we investigated circuit-switched connections whereas packet-switched connections for WDM networks are addressed in [3,10].

The paper is organized as follows. In the following section, the Robust WDM network is briefly described. In section 2, the assumptions are stated. The performance is modeled and analyzed in section 4. Section 5 discusses the analytic results which are verified by the simulation results. The paper is concluded in section 6.

2. Robust WDM network

The architecture of the Robust WDM network is based on a broadcast-and-select star topology with a passive star in the hub. The available bandwidth of the optical fiber is divided into multiple high speed, all-optical data channels, and one low speed control channel. Each station in the network has an array of lasers from which the station dynamically selects one of its lasers at the transmission time. Circuit switched simplex/duplex connections are developed for data transfer between any two stations.

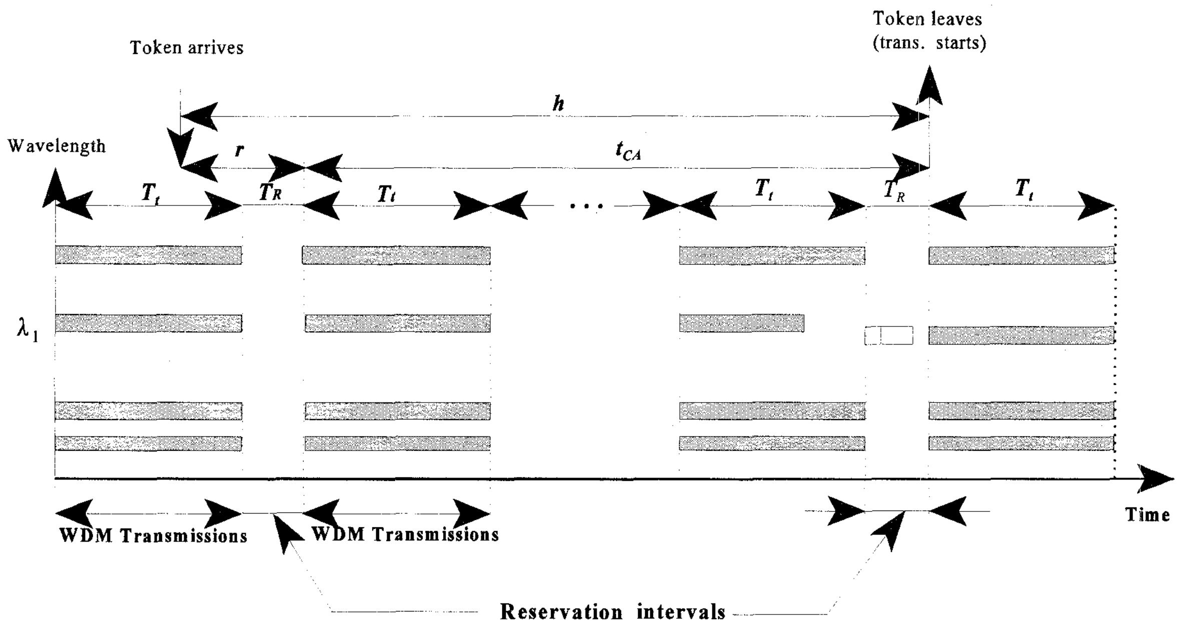

Figure 2: The interlaced WDM transmissions and reservation intervals.

The time axis is divided into slots, with each slot consisting of two subslots (intervals): a reservation interval with (T_R) and a transmission interval (T_t). The WDM transmissions are interlaced with the reservation intervals as illustrated in Figure 2. High-speed WDM transmissions are allowed only during the transmission intervals to allow a new transmission to be initiated. Using WDM, several stations, up to the total number of channels (c), may transmit during a transmission interval, as long as they are on different channels (wavelengths). During a reservation interval, all the stations have to pause their high-speed WDM transmissions. A waiting station which is assigned to use that reservation interval gets an available channel, if one exists, corresponding to a wavelength that is not used by any other station. Only the station that acquires the reservation interval can get an available channel even if there are more than one channel available and more than one station requiring a channel at that moment. Once an unused wavelength is found, the station establishes a link with the intended destination at the beginning of the next transmission interval. Each reservation interval is followed by a transmission interval in which all the WDM links resume their operation. The reservation interval may also be used to acknowledge whether or not the receiver was able to lock-on to the signal as well as to establish a reverse link if needed. The allocation of the reservation interval among stations may be done using the control channel. Although the requirement that all stations ceasing transmission during the reservation interval degrades the performance, it has a significant impact on the cost and the implementability of the network. The reasoning for having a reservation interval and how it enhances robustness is addressed elsewhere [13,14]. Note that the term available channel refers to a wavelength that is not used by any other station, rather than a predefined wavelength. As a result, the spacing between adjacent channels need not be constant and may vary with time.

2.1. The MAC protocol

The network has a control channel, in which a token is passed among stations in a cyclic order. Only a station that is idle (not transmitting) and has a connection-request pending is allowed to hold the token. Thus, an active (transmitting) station with incompleted transmission or a station with no connection-request is not allowed to hold the token. The station that holds the token seeks an available channel (wavelength) during the reservation interval that is next to the token arrival. If no available channel is found during this reservation interval, it waits until the next one to reseek an available channel, and so forth. Once an available (unused) channel is found, the station starts its WDM transmission at the beginning of the next transmission interval and only then does the station transmit the token to the next station in sequence.

3. Assumptions

* A symmetric network that consists of (N) stations and (c) transmission channels is considered where arrival rate, service time distribution as well as the node characteristics are the same for all the stations.
* Connection requests arrive at stations according to independent Poisson processes (mean λ_s arrivals per sec per station); while the service times of connections are independent, independent of the arrival process, and are geometrically distributed, with parameter p; where p is the probability that the transmission continues in the next slot.
* Only one connection request can be handled by a station at a time; hence new requests arriving before the station completes a prior request are lost.
* The token changeover time (e), from a station to another, is constant. However, the model can be easily extended to cover the case where e is varying.

Unlike in traditional token-passing networks where the token and the data transmissions occur in the same channel, the token is passed on a separate control channel. As long as the change over time is significantly less than T_t, the distribution or the value of e will have a negligible effect on the performance.

* No receiver blocking, i.e., the receiver is always available and the need for retransmitting due to receiver unavailability is discarded to simplify the analysis.
* Only simplex WDM transmissions are considered.
* Each station has c_s lasers ($c_s \leq c$), and hence has access only to a similar limited number of channels (c_s), the wavelengths of which are non-overlapping according to a given access pattern, e.g., Figure 1.

The difference between the networks modeled in this paper and the one in [2] is represented by the last assumption in the above list, which can be considered as a further step towards reality.

4. Analysis

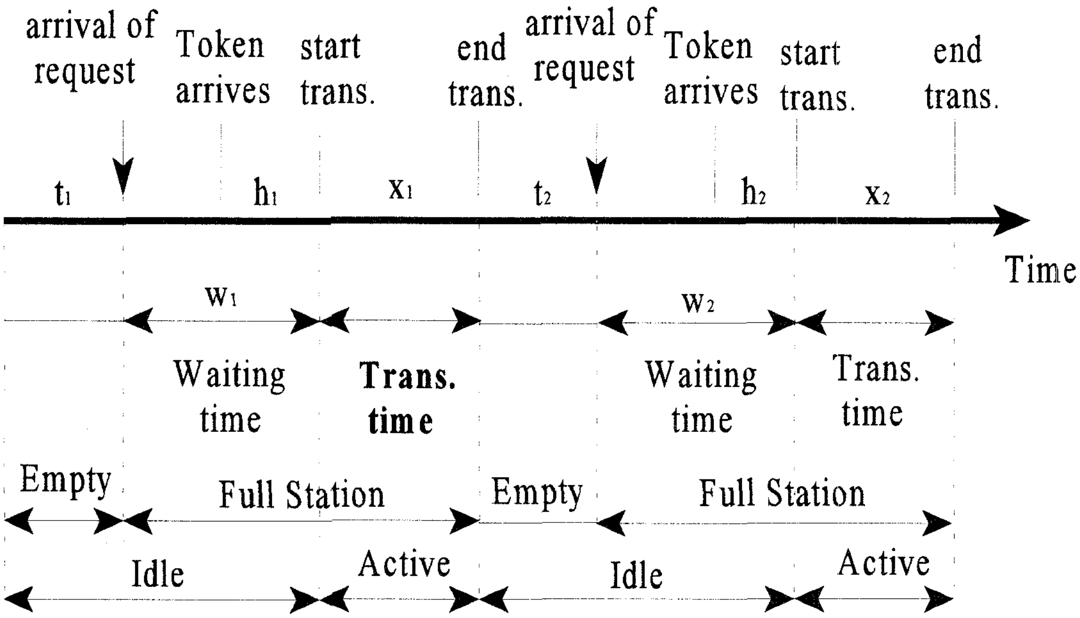

Figure 3: The different events that take place at a station.

t_i .... time between the end of transmission of request (i-1) and the instant of next connection request (i) arrival. E[t_i] = $1/\lambda_s$, assuming Poisson arrival process.

h_i ... token holding time until the WDM transmission of the connection request i is started. E[h_i] = H.

x_i ... transmission time of request i ; E[x_i] = X.

w_i ...waiting time of connection request i ; E[w_i] = W_Q.

λ_s ... arrival rate to a station.

Figure 3 illustrates the sequence of events that take place at a station. At the beginning, the station is assumed empty (***ES***). After time t_1, it receives a request for a circuit-switched connection and hence becomes full (***FS***). The station waits until it is visited by the token and holds it for time h_1 until the station gets an available channel (free wavelength) to establish link with its intended destination. Only then, does the station transmit the token, on the control channel, to the next station in sequence as well as start the WDM transmission corresponding to the request. By the end of the WDM transmission, i.e., after x_1 time units, the station becomes ready for the next request arrival, and the pattern repeats. Thus, the token can be considered as a server that serves a station for a time h as shown in Figure 2. h is the time from the token arrival at a station till the connection is established. Since the token serves a station for only one request at a time, the serve-at-most-one discipline can be considered.

Assuming constant token changeover times (e) and Poisson arrivals to each station, and using the results given in [6,9], the waiting time (W_Q) can be expressed as follows

$$W_Q = [\frac{1-\rho}{1-\rho-\lambda e}]\,[\frac{(N-1)e}{2(1-\rho)} + \frac{\lambda H^{(2)}}{2(1-\rho)} + \frac{e}{2} + H] \qquad (1)$$

where

W_Q .... mean of the total waiting time, measured from the moment of a connection request arrival to that of the connection set-up.

N .... number of stations in the network.

H, $H^{(2)}$ first and second moments of the service time (visit period of the token).

e .... mean token changeover time.

λ .... total effective arrival rate to the network [arrivals/sec].

ρ .... total token (server) utilization.

λ_s .... arrival rate of connection requests to a station.

$$\lambda = N\lambda_s P_{ES} \quad (2)$$

$$\rho = \lambda H \quad (3)$$

P_{ES} = Prob {the station under consideration is empty}

4.1. Evaluation of P_{ES}, λ and ρ

In Figure 3, consider the station is initially empty. Assuming Poisson arrivals, the mean time until the next connection request arrival is $(1/\lambda_s)$. After a random waiting time with mean value W_Q, the corresponding transmission starts. The transmission time is an independent random variable and independent of the arrival process, with mean value X. Then, the next connection request arrival occurs after a time whose mean is $(1/\lambda_s)$, and so forth.

Considering a cycle of events in Figure 3, we get P_{ES} as follows

$$P_{ES} = \frac{1/\lambda_s}{(1/\lambda_s)+W_Q+X} = \frac{1}{1+\lambda_s(W_Q+X)} \quad (4)$$

Using equations (2), (3) and (4),

$$\lambda = \frac{N\lambda_s}{1+\lambda_s(W_Q+X)} \quad (5)$$

$$\rho = \frac{N\lambda_s H}{1+\lambda_s(W_Q+X)} \quad (6)$$

Substituting for λ and ρ in equation (1) and rearranging, W_Q is given by

$$AW_Q^2 + BW_Q + D = 0 \quad (7)$$

where

$$A = 2\lambda_s \quad (8)$$

$$B = 2+[2X-2(N+1)H-3Ne]\lambda_s \quad (9)$$

$$D = -\{Ne+2H+ [(X-H)Ne+NH^{(2)}+2H(X-NH)]\lambda_s\} \quad (10)$$

4.2. Evaluation of H and $H^{(2)}$

Assuming that r and t_{CA}, in Figure 2, are independent, H and $H^{(2)}$ can be evaluated as follows

$$H = E[r + t_{CA}] = R + T_{CA} \quad (11)$$

$$H^{(2)} = E[(r + t_{CA})^2] = R^{(2)} + 2RT_{CA} + (T_{CA})^{(2)} \quad (12)$$

$$T_{CA} = \sum_{i=0}^{\infty} i.S.P_{CA}(i) \quad (13)$$

$$(T_{CA})^{(2)} = \sum_{i=0}^{\infty} (i.S)^2 P_{CA}(i) \quad (14)$$

R, $R^{(2)}$ .... first and second moments of the residual time (r), where r is measured from the instant of the token arrival to a station till the beginning of the next transmission interval. Expressions for R and $R^{(2)}$ are in [4].

T_{CA}, $(T_{CA})^{(2)}$ first and second moments of the time t_{CA}, measured from the beginning of the transmission interval next to the token arrival to the moment when the token leaves the station.

S $= (T_t + T_R)$ .... slot time.

$P_{CA}(i)$ = Prob {there is a channel available, exactly at $t=i$ **and** not before that}

In the following analysis, a station is considered 'active' if it starts or continue its WDM transmission in the current slot; otherwise, it is 'idle'. Also, a station is 'full' if it has an incomplete, pending or being served, connection request; otherwise it is 'empty'.

4.2.1. Evaluation of $P_{CA}(i)$

Assuming that request transmission time, i.e., the duration of a connection, is geometrically distributed with a mean value L slots/connection, thus,

q = Prob {at the beginning of a slot, the station under consideration gives up the channel, i.e., the station becomes 'idle'} $= 1/(L+1)$

p = Prob {at the beginning of a slot, the station under consideration keeps the channel for another slot} $= 1 - q$

Consider only the simplex WDM transmissions and let (t=0) represents the beginning instant of the first transmission interval after the token arrival, where (t) is a time expressed in slots. Thus, **for $N>c_s$ and $i>0$,**

$P_{CA}(i)$ = Prob {there is a channel available, exactly at $t=i$ **and** not before that}

$P_{CA}(i) = P(E \cap F) = P(E/F).P(F)$

$P(E/F)$ = Prob {exactly at $t=i$, a channel or more of the c_s busy channels become(s) free | all the c_s channels were busy for i successive slots from t=0}

Assuming geometrically distributed service times, a busy channel may keep busy, with an active station, or become free, in the next slot, with probabilities (p) and ($1-p$), respectively, **independent** of how long it was busy. Thus,

$P(E/F)$ = Prob {a channel or more of the c_s busy channels become(s) free | all the c_s channels were busy during the previous slot}

= 1 - Prob {none of the c_s busy channels becomes free | all the c_s channels were busy during the previous slot}

$$= 1 - p^{c_s}$$

$P(F)$ = Prob {no channel is available before $t=i$}

Considering c_s busy channels at $t=0$ may include a new one that became busy right at that moment. This case needs to be excluded because we are interested only in the case where all the c_s channels are busy at $t=-1$ and have continued for another slot. Hence,

$P(F)$ = Prob {all the c_s channels of the station under consideration are busy at $t=-1$ **and** all of them keep busy for $(i+1)$ successive slots}

= Prob {all the c_s busy channels keep busy for $(i+1)$ successive slots | all of them were a $t=-1$}

. Prob {all the c_s channels are busy at $t=-1$}

$$P(F) = p^{c_s(i+1)} P_{CSB}$$

P_{CSB} = Prob {all the c_s channels, accessible by the station under consideration, are busy at the beginning of a transmission interval}

Hence, for $N>c_s$ and $i>0$:

$$P_{CA}(i) = (1-p^{c_s})\, p^{c_s(i+1)} P_{CSB} \qquad \textbf{(15)}$$

Substituting from equation (15) into equations (13) and (14), we get T_{CA} and $(T_{CA})^{(2)}$, respectively, as follows

$$T_{CA} = \frac{(p^{c_s})^2}{1-p^{c_s}}\, S\, P_{CSB} \qquad \textbf{(16)}$$

$$(T_{CA})^{(2)} = \frac{(p^{c_s})^2(1+p^{c_s})}{(1-p^{c_s})^2}\, S^2 P_{CSB} \qquad \textbf{(17)}$$

For $N \le c_s$:

$P_{CA}(i) = 1$; for i=0

$= 0$; otherwise

From equations (13) and (14), for $N \le c_s$:

$$T_{CA} = (T_{CA})^{(2)} = 0 \qquad \textbf{(18)}$$

4.2.2. Evaluation of P_{CSB}

P_{CSB} can be considered as the transmission blocking probability. Figure 1 illustrates an example of an access pattern of a network that consists of N=10 stations and c=5 channels, where each station has access only to c_s=3 channels. The access pattern illustrates which channels are accessible by each station in the network. Assuming c_s is the same for all stations, the probability (P_{CSB}) will be the same for all stations in the network and hence any station can be considered to evaluate P_{CSB}. Considering station "3", for example, as the idle station that is holding the token and attempting to use one of its c_s accessible channels, P_{CSB} can be evaluated using Figure 1 as follows

P_{CSB} = Prob. {all the c_s channels accessible to station "3" are busy | station "3" is idle}

P_{CSB} = Prob. {there 3(=c_s) stations, excluding station "3", out of the ones that have access to the c_s channels of station "3", are active and using these c_s channels}

Let **ch**, **st**, **B**, and **I** stand for channel, station, busy, and idle, respectively; hence,

P_{CSB} = Prob. {**(ch3B ∩ ch4B ∩ ch5B)** | **st3I**}

Evaluating this probability is equivalent to adding the probabilities of all the possible combinations of having 3 (=c_s) stations in the network that are active and using these channels. To evaluate these probabilities, the access matrix (P_{acc}), equation 19, is built-up from the given access pattern, e.g., Figure 1.

$$P_{acc} = \begin{array}{c} \\ st1 \\ st2 \\ st4 \\ st5 \\ st6 \\ st7 \\ st8 \\ st9 \\ st10 \end{array} \begin{array}{c} \begin{array}{ccc} ch3 & ch4 & ch5 \end{array} \\ \left[\begin{array}{ccc} P_A/3 & 0 & 0 \\ P_A/3 & P_A/2 & 0 \\ 0 & P_A/3 & P_A/2 \\ 0 & 0 & P_A/3 \\ P_A/3 & 0 & 0 \\ P_A/3 & P_A/2 & 0 \\ P_A/3 & P_A/2 & P_A \\ 0 & P_A/3 & P_A/2 \\ 0 & 0 & P_A/3 \end{array} \right] \end{array} \qquad (19)$$

In this matrix, the rows represent the stations in the network, excluding the one under investigation (in our example, station 3), and the columns represent the channels accessible by that station, in sequence. Thus using Figure 1, columns 1, 2, and 3 represent channels 3, 4, and 5, respectively.

Let p_{ij} be the element in row i and column j. Thus, the elements of the matrix can be evaluated as follows

p_{i1} = Prob. {station i is active using the first one of the considered c_s channels}

p_{i2}= Prob. {station i is active using the second one of the considered c_s channels | the first one is busy}

p_{i3} = Prob. {station i is active using the third one of the considered c_s channels | the first and second ones are busy}

and so forth.

Assuming a symmetric network, in the sense that all stations have similar characteristics, the probability "P_A" that a station is active (transmitting) is similar for all stations in the network.

Consider station 2, for example, which has access only to channels 3 and 4 of the c_s channels accessible by station "3". At the beginning, station 2 being active has three equal possibilities, either using channel 2, 3, or 4, with each has an equal probability (=P_A/3). Thus, p_{21} =P_A /3. To evaluate the second element of the corresponding row (2) of the matrix, knowing that channel 3 is busy will leave station 2, when it is active, with only two equal possibilities, using either channel 2 or 4, with each has the same probability (=P_A/2). Hence, p_{22}=P_A /2. Since station 2 has no access to the third channel under consideration (5), p_{23}=0. Similarly, all the other elements of the matrix can be evaluated. The probability of a possible combination of having 3 active stations using the specified c_s channels, can be evaluated as follows. Multiply an element of row (l) of the first column by an element of a row u ($\neq l$) of the second column and an element of row v ($\neq l \neq u$) of the third column. Thus, P_{CSB} can be represented as follows:

$$P_{CSB} = \sum_{\substack{l=1:N\neq z \\ u=1:N\neq z,\, l \\ v=1:N\neq z,\, l,\, v}} p_{l1} \cdot p_{u2} \cdot p_{v3} \qquad (20)$$

where z is the number that corresponds to the station under investigation, in our example station 3.

To evaluate P_A, consider a cycle of events in Figure 2; thus,

P_A= Prob. {a station is active (transmitting)}

$$P_A = \frac{X}{\frac{1}{\lambda_s} + W_Q + X} = \frac{\lambda_s X}{1 + \lambda_s (W_Q + X)} \qquad (21)$$

This technique of evaluating the transmission blocking probability is valid for any predefined access pattern that has the same number of channels accessible to each station; however Figure 1 is used as an example for demonstrating the analysis.

Solving equations (19), (20), and (21), we get the probability P_{CSB}. Substituting for P_{CSB} in equations (6) and (7), together with equation (18), we get T_{CA} and $(T_{CA})^{(2)}$. Using their values , together with R which is evaluated as in [3], in equations (11) and (12), we get H and $H^{(2)}$, respectively. Then, from equations (8), (9), and (10), we get A, B, and D, respectively. Substituting in equation (7) and solving it by iteration we get W_Q.

5. Results

The network configuration which is used in the following analysis consists of ten stations (N=10) and five fixed non-overlapping WDM transmission channels (c=5) where each station having access only to three transmission channels (c_s) according to a given access pattern, Figure 1. The reservation intervals (T_R) and the token changeover time (e) are chosen to be 1 μsec and 0.1 μsec, respectively, taking into account the propagation delay and device tuning times. The transmission intervals (T_t) and the mean connection duration (***L***) are kept constant at 100 μsec and 100 slots, respectively. Moreover, the mean arrival rate per station (λ_s) is changed to keep constant normalized network load (***G***) for each curve. The normalized network load (***G***) is given by $G=N\ \lambda_s\ X/c$, where $X=L(T_R+T_t)$ is the mean connection (transmission) duration.

To investigate the effect of the different network parameters on the network performance, in this analysis on the mean waiting time (W_Q), only one parameter is changed in each curve while keeping the others constant. Since the network prototype is still under implementation, no measurement is available and hence the analytical results of the model are compared with the simulation [15] results to verify the accuracy. The simulation was of a network using the MAC protocol described here, and based on the same traffic characteristics used in this paper. In the following figures, the solid or solid with circles lines represent the analytic results while the *'s and +'s represent the simulation values.

Assumption such as no receiver blocking made it possible to develop this model. The simulator, however, considers a realistic network where blocking occurs. Discrepancy between the analytic model's and the simulation's results are due to such simplifying assumptions in the model.

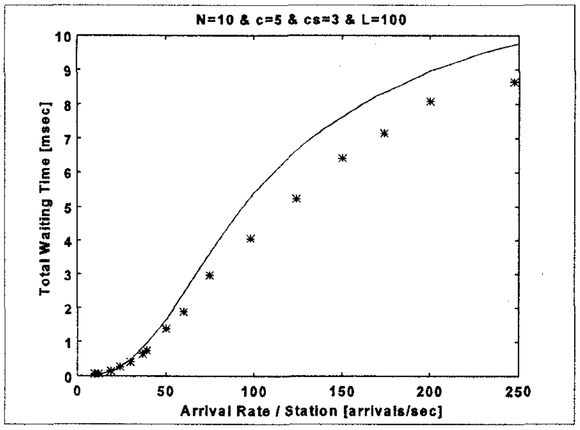

Figure 4: Mean waiting time (W_Q) vs arrival rate per station (λ_s).

Figure 4. illustrates the behavior of the mean waiting time (W_Q) with the arrival rate per station (λ_s). Increasing λ_s, increases the network load (***G***) and the number of full stations that utilizes the network WDM transmission channels as well. Thus, a larger number of stations hold the token when it visits them and hence the token rotation time increases, i.e., a full station waits for a longer time till it is visited by the token. In addition, the probability of having an available WDM transmission channel decreases, i.e., the station holding the token waits for a longer time before it finds an available channel. As a result, the mean waiting time of a connection (W_Q) increases with increasing λ_s.

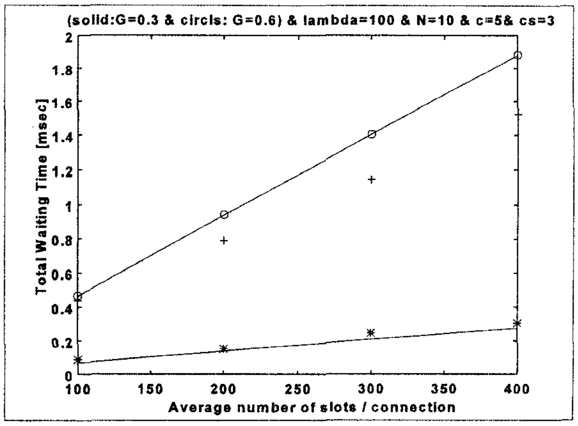

Figure 5: Mean waiting time (W_Q) vs number of slots / connection (*L*).

The changes of the mean waiting time (W_Q) with the average length of a connection (***L***) is shown in Figure 5. In the figure two sets of curves are illustrated at different values of network loads (***G***), the lower set represents the results at G=30% while the upper one at G=60%. The network load (***G***) is kept constant for each curve by changing the value of the arrival rate per station (λ_s) at each point.

As ***L*** increases, the connection (transmission) duration, $X=L(T_R+T_t)$, increases and hence a transmitting station uses a WDM transmission channel for a longer time. Thus, a station holding the token waits for a longer time before it gets an available WDM transmission channel. Also, expanding the connection duration (***L***) increases the number of arrivals within that time and hence increases the number of full stations that are either waiting for the token or using the WDM transmission channels. As a result, increasing ***L*** increases W_Q, almost linearly. In addition, increasing ***G***, by increasing λ_s, increases W_Q as it is explained in Figure 4.

In Figure 6., the relation between the mean waiting time (W_Q) and the number of stations in the network (***N***) is illustrated at different values of the network load (***G***), namely G=30% and G=60%. Also, ***G*** is kept constant by changing the value of the arrival rate per station(λ_s).

Increasing ***N***, increases the number of full stations that hold the token during its rotation and hence increases the token rotation time. Also, increasing ***N***, increases the number of stations that utilize the WDM transmission channels and thus a station holding the token waits for a longer time before it gets an available channel. Accordingly, increasing $\boldsymbol{G}$, by increasing λ_s, increases W_Q as described before.

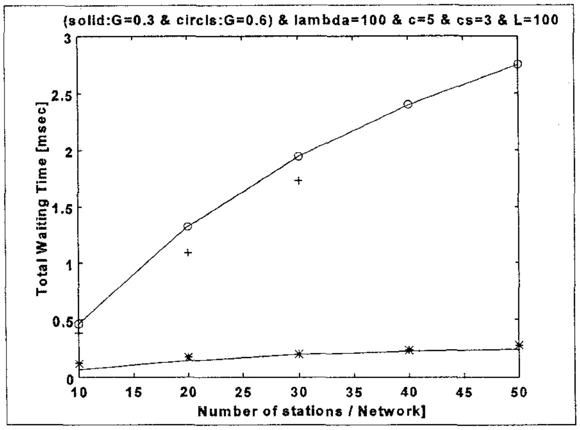

Figure 6: Mean waiting time (W_Q) vs number of stations in the network (N).

Figure 7. illustrates the effect of changing the duration of the transmission interval per slot (T_t) on the mean waiting time (W_Q) at different network loads ($\boldsymbol{G}$), namely $\boldsymbol{G}$=30% and $\boldsymbol{G}$=60%. Increasing T_t, increases the mean connection (transmission) duration, $X=L(T_R+T_t)$. Thus, a transmitting station holds a WDM transmission channel for a longer time and meanwhile the number of full stations waiting for the token increases. Hence, the token rotation time and the waiting time of a full station that holds the token for an available channel increase. As a result, increasing T_t, increases W_Q. Also, increasing $\boldsymbol{G}$, by increasing the arrival rate per station (λ_s), increases W_Q as it is mentioned before.

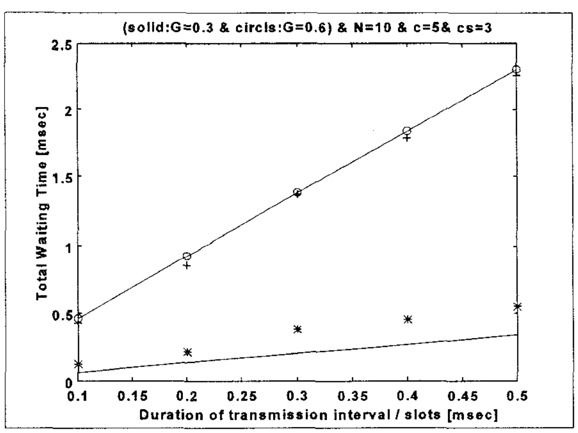

Figure 7: Mean waiting time (W_Q) vs transmission interval (T_t).

6. Conclusion

A circuit-switched Robust WDM network is modeled where each station has access only to a limited number of channels as in [2]. However here, these accessible channels are assumed to be defined according to a given access pattern that specifies which channels are accessible by each station. This can be considered as a further step towards reality where a pre-established network can be investigated. Also, a general approach is proposed for evaluating the transmission blocking probability which is valid for any MAC protocol.

The following assumptions are considered in the proposed model: a symmetric network, a fixed set of available channels, each station accesses only a limited number of these channels according to a given access pattern, Poisson arrivals, constant token changeover times, simplex circuit-switched WDM transmissions, and geometrically distributed connection (transmission) times.

A token-passing scheme is utilized on a low-speed control channel to assign a reservation interval to one of the waiting stations. During that interval, the station that is assigned to it seeks an available WDM transmission channel to establish a circuit-switched connection with its desired destination.

The influences of changing the different network parameters on the network performance, namely the mean waiting time, is investigated and the results are compared with the corresponding simulation for the model's verification. The comparison assures the accuracy of the model in predicting the network's performance.

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