A TOKEN-PASSING VARIABLE BUFFER MODEL FOR A DOUBLE-LAYERED HIERARCHICAL WDM ALL-OPTICAL NETWORK

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ABSTRACT

Presents a hierarchical all-optical network, employing wavelength division multiplexing for multiple channel transmission. A double-layered network with multiple sub-network implementation which provides for spatial wavelength reuse is considered. The piggybacked token-passing medium access protocol as a fair and non-contentious access scheme is studied for performance. The average delay in getting access to the network medium is determined from the semi-Markov process. The performance of the protocol model design with variable buffer sizes of the transmitter is analysed. It is shown from the double-layered hierarchical network that alternative route for data transmission can be implemented to improve on performance.

Keywords: ***semi-Markov process, All optical network, Piggybacked token-passing, Performance evaluation, Wait time, Queue length***

1.0 INTRODUCTION

Optical fiber networks are gaining popularity due to the salubrious nature of the transmission medium. Optical fiber transmission offers low error bit rates over longer distances, immunity to electromagnetism and cross lights; high speeds and high parallelism capability; no electrostatic emissions, non-sparking medium and lightweight compatibility with solid-state devices. Its distinction being the low cost on investment. [1, 2, 3].

All-optical network (AON) which supports end-to-end lightwave transmission is possible [4, 5]. In such AON, transmission is in lightform from source to destination. Wavelength division multiplexing (WDM) allows vast amounts of data to be transmitted using a single optical medium. It also minimises the speed mismatch between the transmission medium and processing devices [6]. The medium access control (MAC) protocol regulates the bid for transmission rights with arbitration schemes such as distributed control, centralised control or random control. A suitable MAC protocol for an AON would ensure among other considerations, acceptable bounded access delay, conformation to transmission requirements (e.g. bursty data, block transfers); and the application of the protocol design with an AON design.

The semi-Markov process (SMP) is used to obtain the performance metric of the mean delay [7] and other parameters [8]. SMP approximation is used because of its significant reduction in state space, and modelling of arbitrary holding times while in a particular state.

1.1 A Hierarchical Optical Network

In an all-optical local area network with C WDM channels where $C=\{\lambda_1+\lambda_2+\lambda_2+ ...+\lambda_n\}$, a certain number of channels may be isolated for use only within a local cluster of nodes forming a sub-network (subnet) such that $C_L=\{\lambda_1+\lambda_2+\lambda_3+ ...+\lambda_m\}$. The number of WDM channels that may be allotted to the subnet being $\{1 \leq m \leq (n-1)\}$. The remaining WDM channels $C_G=\{\lambda_{m+1}+\lambda_{m+2}+\lambda_{m+3}+ ...+\lambda_n\}$ are used for data transmission between networks and subnets [9, 10]. An optical filter for wavelength partition can be used to create a double-layer hierarchical optical network of $C=C_L+C_G$ channels. Multiple subnets can be created to maximise the use of the optical spectrum through spatial WDM channel reuse [10, 11]. For the purpose of this study each subnet is allocated the same number of C_L channels. Since each node has access to the same C_G channels, transmission between two nodes of the same subnet can be made using either the allotted local (i.e. subnet private) channels, or transmit over the global channels. A condition can be imposed for using the global channels such as when the local channels are busy or unavailable after an acceptable wait duration.

The wavelength partitioner (WP) allocates different wavelength channels to nodes or network devices [11]. The number of WDM channels allocated to each node or subnet may be the same (symmetrical), or may be varied according to channel resource requirements of the different nodes (asymmetrical).

At least a single channel must be reserved for global level transmission. Unlike the control channel in [12], the reserved global channel provides for transmission between subnets. The maximum number of local channels permitted is therefore C_L=C-1 since the minimum global channel requirement is C_G=1.

Multiple-layered hierarchical AON can be implemented by further partitioning at the subnet level, the WDM channels allotted to the subnet. A hierarchical approach is applied, i.e. for fault-tolerance, to isolate busy system resources and provide effective system control.

This paper is organised as follows: in Section 2, the system and the operating assumptions are presented. The SMP model and its transition states for global level and local level transmission are described in Section 3. State diagrams are used throughout the text to illustrate the SMP. The performance metrics of the hierarchical AON are presented in Section 4. The results from the SMP model is discussed in Section 5. Suggestions for further study are also presented.

2.0 SYSTEM DESCRIPTION

The system is considered for *Sg* number of subnets. Each subnet with *M* number of nodes. *C* number of WDM channels is assumed for a physically configured star-coupled network [13, 14]. WPs are suited at the branches of the network, forming a snowflake network topology as depicted in Fig. 1. As provision for channel reallocation is made, every node has access to the global channels, and also access to the remaining partitioned channels that are designated as local channels. Each node has access to all WDM channels available from its fiber transmission medium. Each node on the network requires a tuneable transmitter with a tuneable receiver [15]. The protocol that is presented enables each of the WDM channel to be used for token, data and acknowledgement transmission.

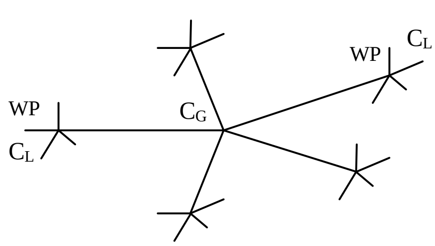

Fig. 1: Snowflake network topology

The token is used to grant access to the network [16]. A modified token-passing access protocol proposed by Ryley [17] is adopted. Known as *piggybacked token-passing*, the protocol utilises a single token to access multiple WDM channels with arbitrary channel selection to overcome channels that are busy, i.e. not available. The piggybacked token-passing operation focuses on the node status which may be active or inactive. The active node with data to transmit will sense all available WDM channels.

1. If two or more channels are sensed idle, the token and data will be transmitted on separate channels.
2. If only one channel is sensed idle, the data is piggybacked onto the token and transmitted on the only free channel.
3. If no channels are available, the node will wait until a channel is free.

The inactive node will sense all available channels.

1. If two or more channels are sensed idle, the token is transmitted over an idle channel.
2. If no channels are available, the node will wait until a channel becomes idle.

The acknowledgement token (ACK) is returned on the same data channel to the source node. The piggybacked token-passing protocol employs transmission of the token and data on separate channels, and transmission of token with data on the same channel. The data transmission mode is dependent on channel availability. Fair access to the medium is achieved in token-passing with each node having to wait for the token and having access in a logical round-robin manner. Once the token is released, the next node waiting in turn will be able to transmit a new token and data (on receiving the token) according to the protocol as described. Each subnet has its own local token, while a global token is circulated for intercommunications between subnets. The total number of tokens for a network with *Sg* subnets being *Sg*+1 global token.

2.1 Operating Assumptions

The receiver and transmitter of each node change states along the course of the protocol operation. The receiver remains inactive unless it receives a packet. It does not initiate any activity. The transmitter is considered for the SMP as it changes states often when a packet is generated at the node. The possible states are defined as:

1. IDLE - when the node has no packet to transmit
2. RESIDUAL WAIT - is the residual time of token arrival at the node after a packet is generated
3. TRANSMIT - where the token and data packet is transmitted together
4. FULL WAIT - for the token to return on leaving the node when there is another packet in buffer to be transmitted

The following operating assumptions are made for the piggybacked token-passing MAC protocol that is adopted for the double-layered hierarchical model:

1. All the network nodes have independent and identically distributed behaviour.
2. Packet arrival process is Poisson with λ packet generation rate per unit time for all nodes.
3. The packet generation rate is the same for all nodes of every subnets.
4. At most only one packet can arrive at each node per slot time.
5. Each node has the same number of buffers.
6. Each segment has the same number of nodes.
7. At each token inter-arrival time, only a single packet is transmitted.
8. Global channels are accessible by all the nodes.
9. Local channels are a subset of global channels, and are restricted for subnet access only.
10. The transmitter can access both the global and local channels.

The semi-Markov model, taking into consideration the above assumptions, is described in the following section.

3.0 SYSTEM MODEL

The present study analyses the system with variable buffer size at the transmitter. At any given time the transmitter can hold at most an active packet, and other packets in the buffer. The active packet and the first buffered packet at the transmitter is denoted as (x,y) where x denotes the active packet that will be transmitted and y denotes the first buffered packet. e.g. (0,0) denotes the idle state S_0 where there is no active packet in the transmitter and the buffer is empty, B=0.

Transition probability from the current state S_i to another S_j is denoted as p[i,j]. The parameter ρ denotes the probability that the packet generated is global bound, i.e. meant for global transmission. While (1-ρ) denotes a local bound packet. The probability where the node generates no packet during the sojourn time is $p[0,0] = e^{-\lambda}$. The probability when a packet is generated is $\beta = (1-e^{-\lambda})$.

Fig. 2 depicts the behaviour of a typical node on the network. Global transition states are shown from the initial idle state S_0. In its one slot time, a single packet may be generated with the probability $p[0,1]=\beta\rho$ and $p[0,(4B+3)]=\beta(1-\rho)$.

Only the global transition states are depicted as the local transitions can be similarly explained.

The residual wait (RW) state determines average time the token takes to arrive at the node when a new packet us generated. The probability of generating n global bound packets in tr time slots ($n \leq$ tr) is given by $pr(n) = {}^{tr}C_n (\beta)^n(1-\beta)^{tr-n}$. The onward transitions from the RW state is determined by the first buffered packet, i.e. whether the

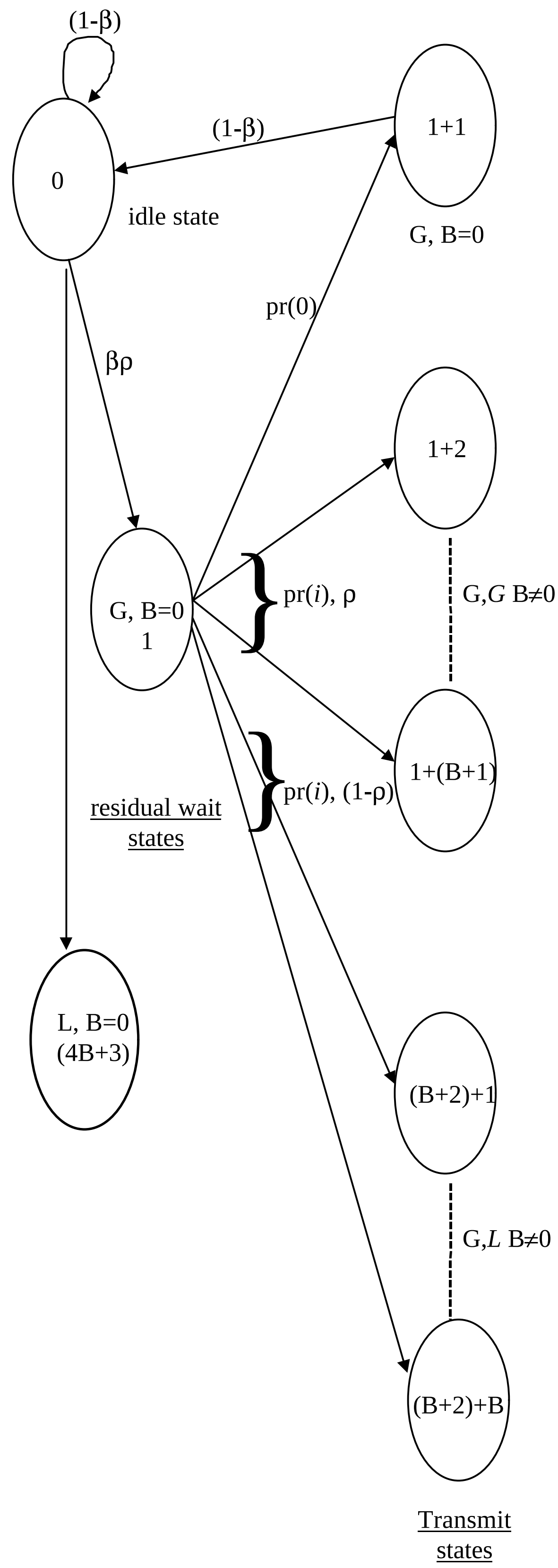

Fig. 2: Transitions from idle state S_0

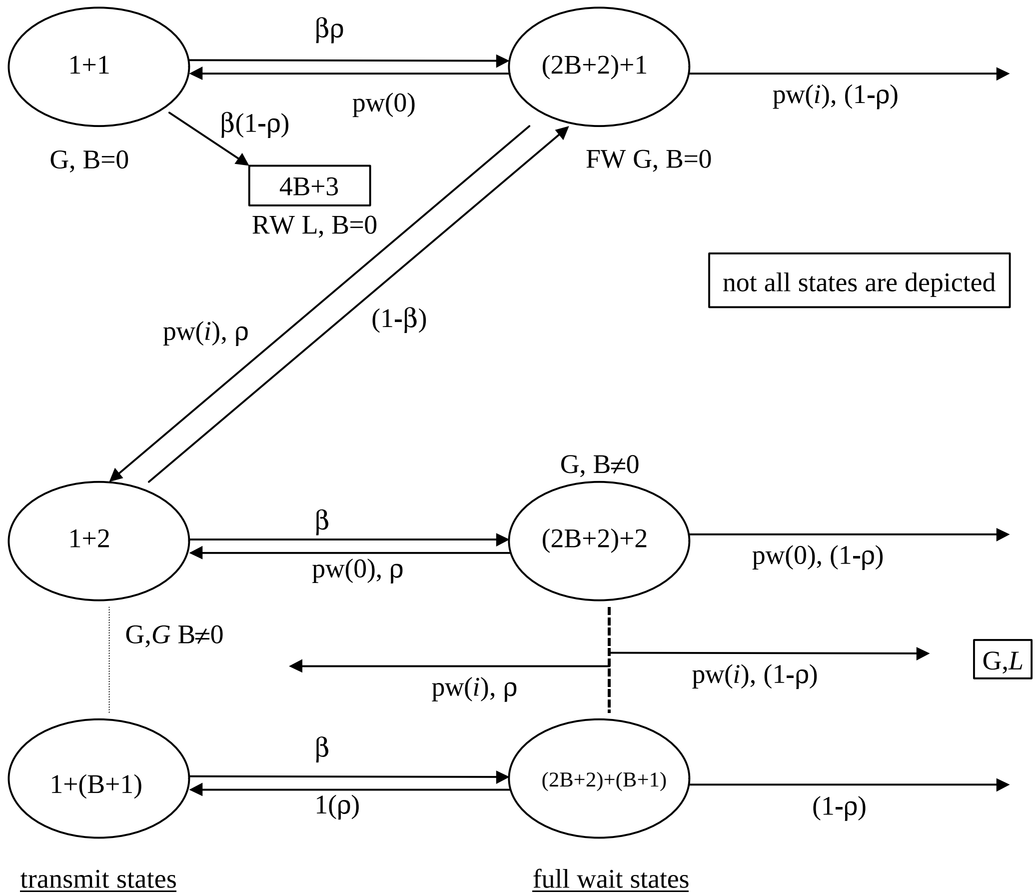

Fig. 3: Transitions from transmit states to full wait

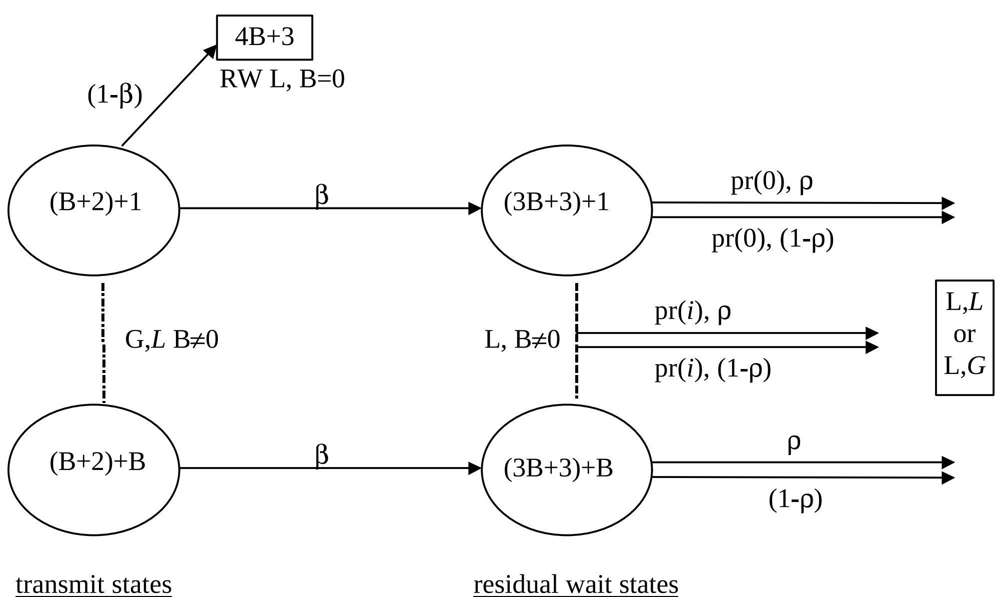

Fig. 4: Transitions from transmit states to residual wait

buffered packet is global bound or local bound, or if the buffer is empty. The transition probabilities from the RW state with B=0 to the global transmit states are:

p[1, 2] = pr(0) indicates no packet is generated in S_1
p[1,2+i] = pr(i)ρ head buffer is a global bound packet
p[1, (B+2)+i] = pr(i)(1-ρ) head buffer is local bound
i denotes {i=1 and i≤B}.

From the transmit states, the transition will enter into one of the full wait (FW) states. Here the node waits for the token to circle the network upon leaving it. Only one packet may be generated during the one slot time of the transmit states. In S_{1+1}, with only an active packet and B=0, the transmitter will return to idle if no new packet is generated, p[(1+1),0]=1-β. If a new packet is generated β and the new packet is global bound ρ, the transmitter will enter the FW state, p[2,(2B+2)+1]=βρ. If the new packet generated is local bound, then the transmitter will enter the RW state to wait for the subnet local token, p[2,(4B+3)]=β(1-ρ) as depicted in Fig. 3.

The transitions from the transmit states depend on the first buffered packet. If the first buffered packet is a global bound packet, then the transmitter will enter the FW states as in Fig. 3. Otherwise if the first buffered packet is local bound, the transmitter will enter the RW states as depicted in Fig. 4. The transitions from the global transmit states with a global bound first buffered packet is p[(1+1)+i,(2B+2)+(1+i)]=β, i={1≤i≤B}. Similarly, from Fig. 4, the transitions from the global transmit states with a local bound first buffered packet is p[(B+2)+i,(3B+3)+i]=β, i={1≤i≤B}.

During full wait, a certain *n* number of packets may be generated in tw time slots ($n \le$ tw) and is given by pw(*n*) = $^{tw}C_n\ (\beta)^n(1-\beta)^{tw-n}$. Depending on pw(*n*) and the probability of the first buffered packet, the transmitter will return to the global transmit states of either (1+1)+i or (B+2)+i. If the first buffered packet is ρ:

p[(2B+2)+1, (1+1)]=pw(0)
p[(2B+2)+1, (1+1)+i]=pw(i)ρ
p[(2B+2)+(1+i), (1+1)+i]=pw(i)ρ

If the first buffered packet is 1-ρ:

p[(2B+2)+1, (B+2)+i]=pw(i)(1-ρ)
p[(2B+2)+(1+i), (B+2)+i]=pw(i)(1-ρ)

for all i={1≤i≤B}. Transitions from the global FW state when B=0 is depicted as Fig. 5.

The global transmit states enter the local bound RW states (similarly the global bound RW states) when the first buffered packet is a local bound packet (Fig. 2 and 4). The transitions from the local RW states are to local bound transmit states, if the first buffered packet is 1-ρ:

p[(4B+3), (4B+3)+1] = pr(0)
p[(4B+3), (4B+3)+(1+i)] = pr(i)(1-ρ)
p[(3B+3)+i, (4B+3)+(1+i)] = pr(i)(1-ρ)

If the first buffered packet is ρ:

p[(4B+3), (5B+4)+i] = pr(i)ρ
p[(3B+3)+i, (5B+4)+i] = pr(i)ρ

for all i={1≤i≤B}.

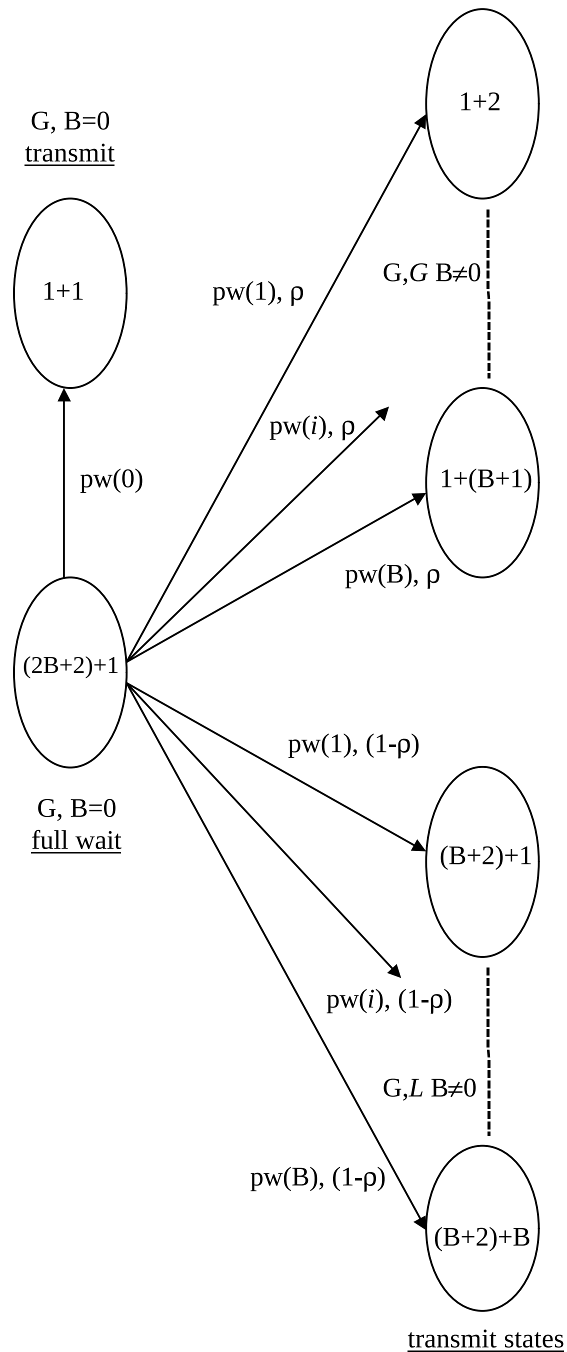

Fig. 5: Transitions from full wait state with B=0

The SMP input parameters are summarised below:

M	number of nodes in a subnet
B	buffer size of each node
Sg	number of subnets in the system
C	number of channels
C_G	number of global channels
C_L	number of local channels
β	probability of generating a packet
ρ	indicates a global bound packet
tr	average time spent in RW state, in slot time
tw	average time spent in FW state, in slot time

Transitions from local transmit states to idle state:
$p[(4B+3)+1, 0] = 1-\beta$, when no packet is generated

Transitions from local transmit states to local FW:
$p[(4B+3)+1, (6B+4)+1] = \beta(1-\rho)$
$p[(4B+3)+(1+i), (6B+4)+(1+i)] = \beta$
for all $i=\{1\le i\le B\}$.

Transitions from local transmit states to global RW if the head buffer is global bound:
$p[(5B+4)+1, 1] = 1-\beta$
$p[(5B+4)+i, (7B+5)+i] = \beta$
for all $i=\{1\le i\le B\}$.

The transition probabilities of the global RW states (7B+5)+i are similar to the local RW states transitions. To recap, when a packet is first generated in the idle state, the transition enters the RW state. In this state, new packets may be generated. The transition then enters the transmit state depending on the first buffered packet type. If the buffered packet is the same as the active packet, the transition enters the FW state. Otherwise the transition enters the RW state of the other hierarchy level. The process repeats. New packets may be generated while in the FW state, and one packet in the one slot time of the transmit state.

It is observed from the model that local transmission within a subnet can also be made via the global bound channels. A local bound packet may be transmitted over global channels when the local channels are not available or busy, provided the global token arrives during local wait. As such, in the event when a transmitter is holding an active global packet and the first buffered packet is local bound, the protocol may consider swapping the active global packet with the buffered local packet. The local packet may be associated priority depending on its attributes [18, 19].

The token-passing MAC protocol can dispense with the need to maintain clock synchronisation as required by non-contentious time division access protocols [11].

3.1 Limiting Probabilities

The average sojourn time for each state i, $(8B+5 \ge i \ge 0)$ assuming E{W} as the average wait time in the queue: τ_i is defined:

$$\tau_i \begin{cases} 1 & i = 0,\ 1+(1+j),\ (B+2)+j,\ (4B+3)+(1+j),\ (5B+4)+j \\ E\{W\}/2 & i = 1,\ (4B+3),\ (7B+5)+j,\ (3B+3)+j, \\ E\{W\} & i = (2B+2)+(1+j),\ (6B+4)+(1+j) \end{cases}$$

for all $j=\{1\le j\le B\}$. The steady state equations of the embedded Markov Chain of the variable buffer size model are derived as follows:

idle state

$$V_0 = (1-\beta)(V_0 + V_{1+1} + V_{4B+3+1}) \quad (1)$$

The steady state equations of the global bound states by status, i.e. residual wait, full wait and transmit.

residual wait states

$$V_1 = \beta\rho(V_0 + V_{4B+3+1}) + (1-\beta)V_{5B+4+1} \quad (2)$$
$$V_{7B+5+i} = \beta V_{5B+4+i} + (1-\beta)V_{5B+4+(i+1)} \quad (3)$$
$$V_{7B+5+B} = \beta V_{5B+4+B} \quad (4)$$

full wait states

$$V_{2B+2+1} = \beta\rho V_{1+1} + (1-\beta)V_{1+2} \quad (5)$$
$$V_{2B+2+(1+i)} = \beta V_{1+1+i} + (1-\beta)V_{1+1+(i+1)} \quad (6)$$
$$V_{2B+2+(1+B)} = \beta V_{1+B+1} \quad (7)$$

transmit states

$$V_{1+1} = pr(0)V_1 + pw(0)V_{2B+2+1} \quad (8)$$
$$V_{1+1+i} = \rho\,[pr(i)\,V_1 + pw(i)V_{2B+2+1} + {}_{j=1\to i}\Sigma\, pw(i-j)\,V_{2B+2+(j+1)} + {}_{j=1\to i}\Sigma\, pr(i-j)\,V_{7B+5+j}\,] \quad (9)$$
$$V_{1+B+1} = \rho\,[pr(B)\,V_1 + pw(B)V_{2B+2+1} + {}_{j=1\to i}\Sigma\, pw(B-j)\,V_{2B+2+(j+1)} + {}_{j=1\to i}\Sigma\, pr(B-j)\,V_{7B+5+B}\,] \quad (10)$$
$$V_{B+2+i} = (1-\rho)\,[pr(i)\,V_1 + pw(i)V_{2B+2+1} + {}_{j=1\to i}\Sigma\, pw(i-j)\,V_{2B+2+(j+1)} + {}_{j=1\to i}\Sigma\, pr(i-j)V_{7B+5+j}\,] \quad (11)$$
$$V_{B+2+B} = (1-\rho)\,[pr(B)\,V_1 + pw(B)V_{2B+2+1} + {}_{j=1\to i}\Sigma\, pw(B-j)\,V_{2B+2+(j+1)} + {}_{j=1\to i}\Sigma\, pr(B-j)\,V_{7B+5+B}\,] \quad (12)$$

The steady state equations of the local bound states:

residual wait states

$$V_{4B+3} = \beta(1-\rho)(V_0 + V_{1+1}) + (1-\beta)V_{B+2+1} \quad (13)$$
$$V_{3B+3+i} = \beta V_{B+2+i} + (1-\beta)V_{B+2+(i+1)} \quad (14)$$
$$V_{3B+3+B} = \beta V_{B+2+B} \quad (15)$$

full wait states

$$V_{6B+4+1} = \beta(1-\rho)V_{4B+3+1} + (1-\beta)V_{4B+3+2} \quad (16)$$
$$V_{6B+4+(1+i)} = \beta V_{4B+3+(i+1)} + (1-\beta)V_{4B+3+(i+1)} \quad (17)$$
$$V_{6B+4+(1+B)} = \beta V_{4B+3+(B+1)} \quad (18)$$

transmit states

$V_{4B+3+1} = pr(0)V_{4B+3} + pw(0)V_{6B+4+1}$ (19)

$V_{4B+3+(i+1)} = (1-\rho)\ [pr(i)\ V_{4B+3} + pw(i)V_{6B+4+1} + {}_{j=1\rightarrow i}\Sigma\ pw(i-j)\ V_{6B+4+(j+1)} + {}_{j=1\rightarrow i}\Sigma\ pr(i-j)V_{3B+3+j}\ ]$ (20)

$V_{4B+3+(B+1)} = (1-\rho)\ [pr(B)\ V_{4B+3} + pw(B)V_{6B+4+1} + {}_{j=1\rightarrow i}\Sigma\ pw(B-j)\ V_{6B+4+(j+1)} + {}_{j=1\rightarrow i}\Sigma\ pr(B-j)\ V_{3B+3+B}\ ]$ (21)

$V_{5B+4+i} = \rho\ [pr(i)\ V_{4B+3} + pw(i)V_{6B+4+1} + {}_{j=1\rightarrow i}\Sigma\ pw(i-j)\ V_{6B+4+(j+1)} + {}_{j=1\rightarrow i}\Sigma\ pr(i-j)V_{3B+3+j}\ ]$ (22)

$V_{5B+4+B} = \rho\ [pr(B)\ V_{4B+3} + pw(B)V_{6B+4+1} + {}_{j=1\rightarrow i}\Sigma\ pw(B-j)\ V_{6B+4+(j+1)} + {}_{j=1\rightarrow i}\Sigma\ pr(B-j)\ V_{3B+3+B}\ ]$ (23)

The limiting probability of being in state S_i in terms of P_i are used to derive the performance measures for the model (24). The equations are solved iteratively to compute the average delay and the mean queue length.

$$P_i = \frac{V_i\ \tau_i}{\sum_{j=0}^{(8B+5)} V_j\ \tau_j} \quad (24)$$

4.0 PERFORMANCE METRICS

The average delay D is derived using Little's Law [20] from the probability P_i of being in state S_i where $D=N/T$. N is the average number of packets in a node and T is the throughput. The average delay for global and local bound packets are denoted as D_G and D_L respectively. The average number of packets generated are denoted as N_G and N_L respectively. The delay includes the waiting time in the queue, packet transmission time and acknowledgement.

$N_G = P_1 + {}_{1\rightarrow j=B}\Sigma\ P_{1+(j+1)} + {}_{1\rightarrow j=B}\Sigma\ P_{(B+2)+j} + {}_{1\rightarrow j=B}\Sigma\ P_{(2B+2)+(j+1)} + {}_{1\rightarrow j=B}\Sigma\ P_{(7B+5)+j}$ (25)

$D_G = N_G / P_2 + {}_{1\rightarrow j=B}\Sigma\ P_{(j+2)} + {}_{1\rightarrow j=B}\Sigma\ P_{(B+2)+j}$ (26)

$N_L = P_{(4B+3)} + {}_{1\rightarrow j=B}\Sigma\ P_{(4B+3)+(j+1)} + {}_{1\rightarrow j=B}\Sigma\ P_{(5B+4)+j} + {}_{1\rightarrow j=B}\Sigma\ P_{(6B+4)+(j+1)} + {}_{1\rightarrow j\text{-}B}\Sigma\ P_{(3B+3)+j}$ (27)

$D_L = N_L / P_{(4B+3)+1} + {}_{1\rightarrow j=B}\Sigma\ P_{(4B+3)+(j+1)} + {}_{1\rightarrow j=B}\Sigma\ P_{(5B+4)+j}$ (28)

The mean queue length [21] taken as a snapshot while in the transmit states of (G,G), is the expected number of packets waiting to access the media for B>1 is given as:
$L = {}_{1\rightarrow j=B}\Sigma\ [(1+1)+i]\ P[i]$

Results obtained from evaluating the model are presented in the following section.

5.0 RESULTS AND DISCUSSION

Input parameters for the model are the number of nodes of a subnet M, buffer size B for each node, the number of subnets on the network Sg, the number of global channels C_G, and the number of local channels C_L for each subnet. The token, data and acknowledgement packet sizes are assumed to be 20, 5000 and 50 bits. Channel transmission rate is taken as 100 Mbps. The model is evaluated for a system size of 4 nodes for each subnet with a total of 6 subnets. The number of channels are fixed at half the number of nodes, at optimum with the shortest delay reported [18], C_G=MxSg/2=12 and C_L=M/2=2.

The average delay in slot time is plotted against the packet generation rates as Fig. 6. The average delay of the global bound transmission is compared with the local bound transmission for $B\in\{5,10,15,20,25\}$. ρ is set at 0.5. The buffer size is used as a comparative indicator together with the delay in the measure of performance. In a model where local transmission over global channels is possible, and swapping occurs in favour of a prioritised local packet, the mean queue length would indicate the service performance of the queues. For this model, the mean queue length presents the common queue that is utilised by both the global and local bound packet types.

From Fig. 6, as the packet generate rate increases, it can be seen that at lower loads the average delay varied slightly at λ=0.35 for B=5. As the buffer size is incremented, the average delay though increased and shifted upwards, also experienced a greater delay above λ=0.3 comparing all B>5.

The global average delay (with 24 nodes accessing) shows a steady increase after λ=0.2 for all B. More significant delay differences at higher loads λ=0.4 are registered as the buffer size is increased. The increase (shift up) in average delay as B is increased is caused by additional packets being generated (not blocked), and waiting to be transmitted.

Fig. 7 plots the mean queue length against the packet generation rate and shows its increase along with λ and B. The results for B>15 appeared to be less realistic as reflected by the probabilistic model. It is likely that the packets generated are mainly global bound as reflected by the increase in global delay (Fig. 6), and also additional packet generation being blocked during wait. A 2-buffer model can be used that may present a more realistic implementation. However, the cost of an additional buffer system would be greater and may add to the complexity of the protocol.

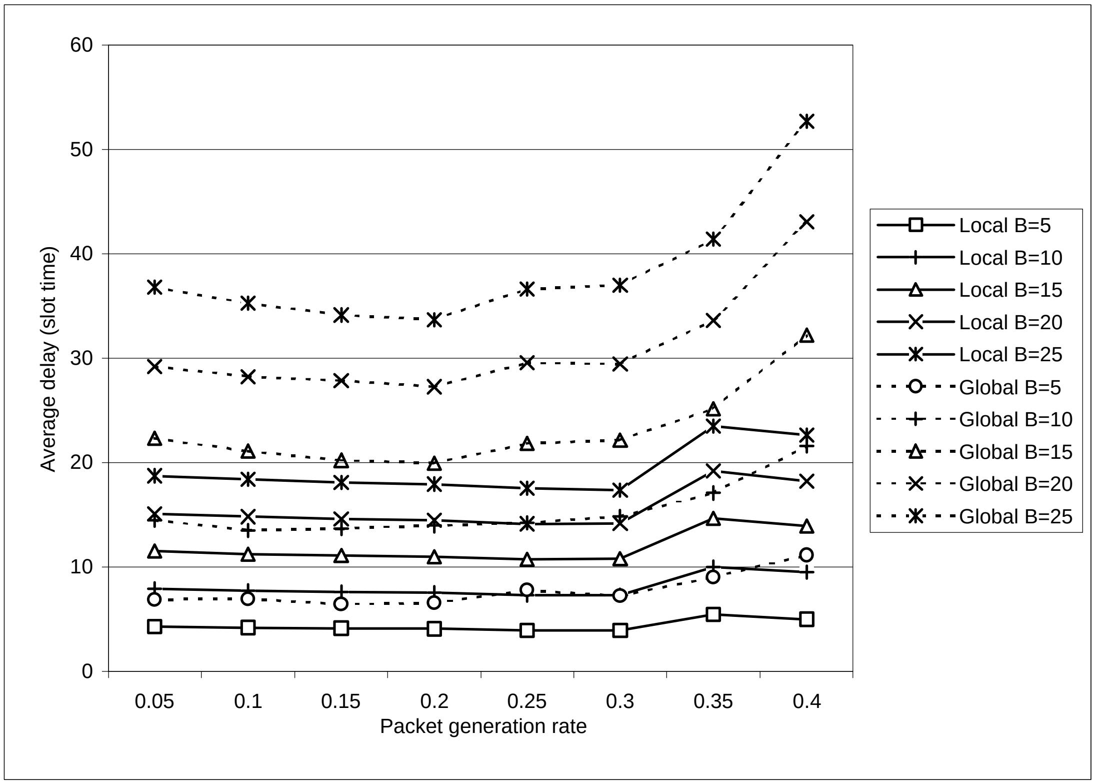

Fig. 6: Average delay vs. packet generation rate for M=4 Sg=16 Cg=12 Cl=2 B∈{5,10,15,20,25}

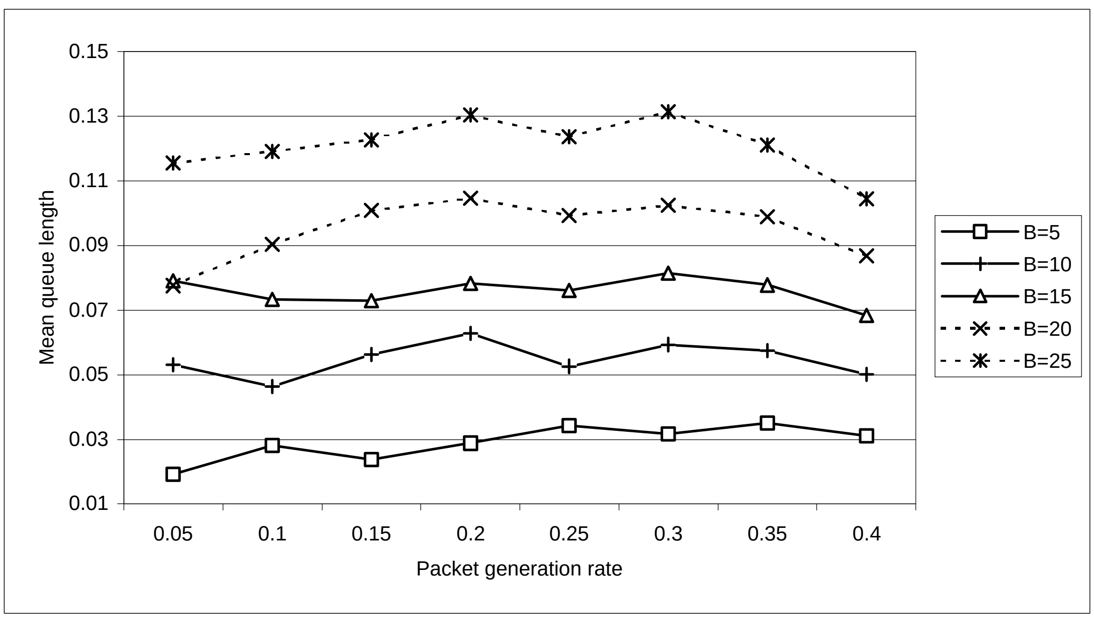

Fig. 7: Mean buffer length vs. packet generation rate for M=4 Sg=16 Cg=12 Cl=2 B∈{5,10,15,20,25}

The SMP model as presented is developed as a general hierarchical AON model to study the performance of the piggybacked token-passing MAC protocol [17], and to serve as a general model structure for modification for protocol improvement. Additional hierarchy layers can be added at each subnet level, and with each lower layer the number of alternative routes to overcome congestion at the level increases; (the first-subnet layer has 1 alternative route, subnets on the first-subnet layer will have 2 alternative routes). The hierarchical AON model can be adopted to provide cross bar connectivity for fault tolerant systems [19] and the MAC protocol designed to provide reconfiguration for balancing channel resources [22, 23]. Among the current work include the development of a dynamic channel allocation scheme to provide different number of channels to every subnet on the network.

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