A WDMA protocol for a New Control Architecture with Propagation Delay Analysis

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Abstract: - In this paper, we study the effect of the round trip propagation delay on performance measures of WDM networks and adopt a dynamic policy and a synchronous transmission procedure to access data channels. Also we propose a new control architecture for WDM star-coupled networks, to overcome the electronic processing bottleneck that the single control channel architecture introduces.

Key-Words: - Wavelength Division Multiplexing (WDM), round trip propagation delay, electronic processing bottleneck, Multichannel Control Architecture (MCA).

1 Introduction

A class of WDMA protocols based on pretransmission coordination employs a single separate common shared channel to exchange control information and the remainder channels are used as data channels. Thus for each packet on a data channel, a control packet is transmitted on the shared control channel, and each station is required to process all the control packets on the control channel. A fundamental problem in this protocol class is the ability of a station to receive and process all control packets that are transmitted over the single control channel. The maximum processing rate is limited to the speed of electronic interface of a station. This creates the electronic processing bottleneck [1].

This major obstacle gives rise to the need to develop efficient network architecture and medium access techniques to overcome this problem [2-4].

Another attribute of WDM networks is the large propagation delay as it compared with the data packet transmission time and plays a key role in the performance evaluation of the WDMA protocols. For example, let us consider a small network spread across 5 Km and assuming ATM-like cells with data packets ≈1000 bits. In case of a channel with capacity 10 Mbits/s and propagation speed of 2×10^{8} km/s, the propagation delay is 25 μsec while the data transmission time is 100 μsecs that is 4 times greater than propagation delay. In case of a wavelength with capacity of 1 Gbits/s the data transmission time is 1 μsec that is 25 times smaller than the propagation delay. Most of the studies ignore the impact of propagation delays to the networks efficiency. The large normalized propagation delay (the ratio of propagation delay to data packets transmission time) is a useful attribute to develop suitable multiple access algorithms based on the knowledge about the status of the data channels (idle or busy).

In this paper, the proposed architecture is a Passive Star network and the transmission access scheme belongs to the synchronous transmission protocols. The proposed network architecture suggests several control channels with appropriate multiple access technique in order to overcome the electronic processing bottleneck. The number of control channels and the proper structure of the station interface are related to the speed of interface electronics of a station. In this way a station is able to receive the entire incoming control information as it is distributed amongst all control channels at a lower rate compatible with the feasible electronic speed. Also in our analysis we exploit the propagation delay latency to introduce an access method based on the decision of a station for transmission or not at the end of the propagation delay after a successful transmission on the control channel

Our investigation is carried as follows: Section 2 describes the network architecture model and assumptions. Section 3, introduces the basic assumptions for proposed protocol. Analysis of performance measures is presented. In section 4 numerical results are provided and comments on numerical results and explanation of the behavior are presented. Finally some concluding remarks are made in section 5.

2 Network Architecture

The system under consideration as Figure 1 shows is a passive star network. The bandwidth is divided into $v+N$ WDM channels each operating with a different wavelength from the set $\{\lambda_{c1},...,\lambda_{cv},\lambda_{d1},...,\lambda_{dN}\}$.

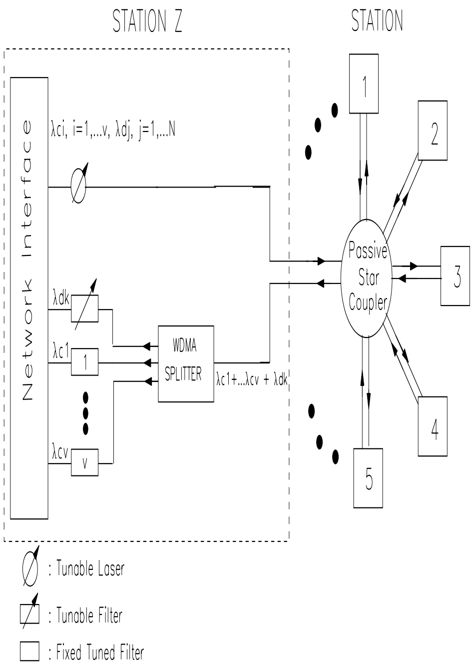

Figure 1: Passive star multiwavelength architecture

The multichannel system at wavelengths $\lambda_{c1},...,\lambda_{cv}$ forms the Multichannel Control Architecture (MCA) and operates as the control multichannel system for coordination of access among stations.

The remaining N channels at wavelengths $\lambda_{d1},...,\lambda_{dN}$ constitute the data multichannel system and are used for data packets transmission. We assume infinite population. The network model with the MCA is described as $[CC]^v - TT - [FR]^v - [TR]$. It means that there are v control channels and each station has a tunable transmitter tuned at $\lambda_{c1},...,\lambda_{cv},\lambda_{d1},...,\lambda_{dN}$. The outcoming traffic from a station is connected to one input of the passive star coupler. Stations are connected to input and output ports of a central passive star coupler. The star coupler acts as broadcast medium. Every station also uses v fixed tuned receivers FR one for each control channel and a tunable receiver to any of data channel $\lambda_{d1},...,\lambda_{dN}$ indicated by TR. The incoming traffic to a user station is splitted into $v+N$ wavelengths by a WDMA splitter from which one of N wavelengths can be selected by the tunable receiver as Figure 1 indicates. The transmission time of a fixed size control packet is used as minislot. The control packet consists of the transmitter address, the receiver address and the wavelength λ_{dk} as is shown in Figure 2.

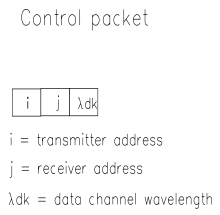

Figure 2: Control packet structure

We assume the existence of a common clock, obtained by distributing a clock to all stations. All data packets are of the same length and time axis is divided into slots equal to a data packet transmission time. Slots on the data channels are called data slots and contain actually data packets. Slots on the control channels are called control slots. The control slot for each control channel is divided into F minislots to be used on a contention basis for control packets transmission. The normalized roundtrip propagation time between any station to the hub of the star coupler and to any other station is assumed to be equal to R data slots and assume that is the same for all stations.

3 Analysis

Control slots are synchronized in a parallel system constituting the control multislot. As a result, each control multislot is subdivided into a system of F multiminislots. Each multiminislot contains v minislots one for each control channel as Figure 3 indicates. Stations are synchronized to transmit control packets at the beginning of each control multiminislot of the control multislot.

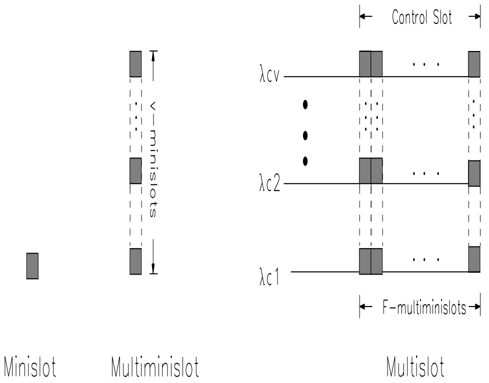

Figure 3: Control mulislot and multiminislot system

3.1 Transmission Part

If a station has to send a data packet to another, first chooses randomly a wavelength λ_{dk} on which data packet will be transmitted. Then, informs the other stations by selecting randomly one of the F contiguous multiminislots in the next control slot, lets say the j_{th} multislot, and transmits a control packet selecting one $\lambda_c (c = 1...v)$ of the control channels to compete according to the Slotted Aloha protocol to gain access. The outcome of the control packet transmission is known R slots later by all stations because of the broadcast nature of the control channels system. So after the R slots expiration time, all stations with successful transmissions on j_{th} control multislot are ready to transmit on the $j_{th} + R + 1$ data slot. It is possible more than one successfully transmitted control packets during the same control multislot on different multiminislots or on the same multiminislot but on different control channels to denote the same wavelength λ_{dk}, for (re) transmission. In this case only one of them is permitted to transmit according to certain arbitration rules and the others postpone the transmission according to adopting retransmission policy. As an example we may decide that the packet with transmission on the earliest multiminislot and on the lower control channel number on the control multiminslot slot win the right for (re) transmission.

3.2 Reception Part

In the receiving part a station's fixed tuned receivers monitor the control channels examining all minislots. A station upon identified its address announced in a control packet, first applies the arbitration rules to examine whether the intended transmitter authorized to transmit. If the transmitter wins the right to transmit, the receiver station waits R slots and then adjusts its tunable receiver to the channel specified in the control packet for data packet reception. If two or more successfully transmitted packets from different data channels are addressed to the same destination only one of them is correctly received and the others are aborted causing receiver collision [5] that we don't take into account in this study.

We adopt the Bertsekas's [6] for Poisson approximations of the overall traffic G and use the following steady state notations:

G = mean offered traffic per multiminislot on the control channels system. We use the slotted Aloha protocol to access to control channel system.

v = Number of control channels in the system.

N = Number of data channels in the system.

F = Number of minislots per control slot per control channel.

vF =Number of minislots per control multislot

s_c = Mean rate of successful transmitted control packets during a control multislot

S_d =Average rate of successfully transmitted data packets through one of the data channels per data slot.

S_T = Total throughput of the system, defined as the average number of successfully transmitted data packets during a data slot time without the effect of receiver collision.

Let’s say a communication system with finite M of stations and the probability that a given station $Z(Z \in 1...M)$ (re) transmit during a control multiminislot is p and obeys to binomial probability law.

The probability P_{suc} that station Z (re) transmit successfully in given control channel $\lambda_c (c = 1...v)$ during a multiminislot is given by

$$P_{suc} = M \frac{p}{v}(1 - \frac{p}{v})^{M-1} \quad (1)$$

For $M \to \infty$ and $p \to 0$ we get $Mp = G$ and then

$$P_{suc} = \frac{G}{v}(1 - \frac{G}{Mv})^{M-1} \approx \frac{G}{v} G e^{-\frac{G}{v}\frac{(M-1)}{M}} \approx \frac{G}{v} e^{-\frac{G}{v}} \quad (2)$$

S_v = Random variable representing the successfully transmitted control packets on the control channel system during a given control multislot $0 \le S_v \le vF$.

For every $S_v > 0$ the probability $S_v = k$, of finding k successfully transmitted control packets on a control multislot is evaluated by:

$$\Pr[S_v = k] = \binom{vF}{k} P_{suc}^{k} (1 - P_{suc})^{v-k} \quad (3)$$

And

$$S_c = E[S_v = k] = FGe^{-\frac{G}{v}} \quad (4)$$

Now we seek the probability $P[A_v(k) = r]$ of finding r correctly transmitted data packets when k control packets have been successfully transmitted during a control multislot. It is obvious that $k - r$ packets are aborted due to the adopting policy for transmission, while $N - r$ channels remain without any reception, then.

$P[A_v(k) = r] =$ {Probability of distribution k packets to r channels} × {Probability that r channels have received at least one packet}.

It is supposed that each station can transmit to every N channel and according to Maxwell-Boltzman statistics there are N^k possible arrangements of the k packets to N channels, each one with probability N^{-k}. Also the k packets can be distributed among the $r(r \le k)$ channels in r^k different ways. The ratio of favourable to possible arrangements gives the probability P_{kr} of distribution k packets to r channels. So

$$P_{kr} = \frac{\binom{N}{r}}{N^k} \quad (5)$$

Let $U(k,r)$ be the probability that r channels have been selected for (re) transmission from at least one data packet during the data slot. Thus according to inclusion - exclusion method we take:

$$U(k,r) = \frac{1}{r^k} \sum_{i=0}^{r} (-1)^i \binom{r}{i} (r-i)^k \quad (6)$$

The probability that exactly r among k successfully transmitted control packets transmit correctly their corresponding data packets during a data slot time is given by:

$$P[A_v(k) = r] = P_{rk} U(k,r) = \binom{N}{r} \sum_{i=0}^{r} (-1)^i \binom{r}{i} (\frac{r-i}{N})^k \quad (7)$$

The probability $S_T(r)$ of finding r correctly transmitted data packets in steady state during a data slot is given as follows.

$$S_T(r) = \sum_{k=r}^{\min(N,vF)} \Pr[S_v = k] \Pr[A_v(k) = r] \quad (8)$$

Then

$$S_T = E[S_T(r)] = \sum_{r=1}^{\min(N,vF)} r S_T(r) \quad (9)$$

And

$$S_d = \frac{S_T}{N} \quad (10)$$

An approximate analysis

Consider that $S_v = k$, control packets are successfully transmitted over the control channel system in the j_{th} control multislot. We assume that corresponding data packets are uniformly distributed among N channels in the $j_{th} + R + 1$ data slot.

Let $P_0(k)$ is the conditional probability that no one from the k corresponding data packets is destined to a given data channel $n, \in \{1,...,N\}$. Thus the k packets should be destined to the remaining $(N-1)$ channels in $(N-1)^k$ different ways. Then

$P_0(k)$ can be written as,

$$P_0(k) = \frac{1}{N^k}(N-1)^k = (1-\frac{1}{N})^k \quad (11)$$

If we approximate this equation taking into account the steady state conditions from Eq. 4, we take

$$P_0 = E[P_0(k)] \approx e^{-S_c/N} \quad (12)$$

We define P_f as the probability that a data packet is transmitted without collision over the channel n. In other words P_f implies that at least one data packet has as destination the channel n.
So we get,

$$P_f = 1 - P_0 = 1 - e^{-S_c/N} \quad (13)$$

Let $H_v(S_c)$ be the random variable representing the number of different channels selected as destination, given that S_c is the output rate of successfully transmitted control packets in steady state.

$$\Pr\{H_v(S_c) = m\} = \binom{N}{m} P_f^m P_0^{N-m} \quad (14)$$

The expectation value is given by:

$$S_T = E\{\Pr\{H_v(S_c)\}\} = \sum_{m=1}^{N} m \Pr[H_v(S_c) = m] = NP_f \quad (15)$$

And

$$S_d = 1 - e^{-Sc/N} = 1 - e^{-\frac{FG\exp(-G/v)}{N}} \quad (16)$$

If we set the first derivative of the above equation with respect to G equal to zero we can find the optimal value G_{opt} that maximize the throughput per data channel. We can find that that

$S_d(\max) = 1 - e^{-\frac{v}{N}\frac{F}{e}}$ Corresponds to the value of

$$G_{opt} = v \quad (17)$$

4 Numerical Results

The results from the above analysis are illustrated in Figures 4 and 5. Figure 4 depicts S_d versus G for v=5 control channels, $N = 10$ data channels and F =10,20,80 minislots. For fixed values of N and v, as traffic increases approaching G_{opt}, the throughput per data channel approaches $S_d(\max)$. For higher values $G(G > G_{opt})$, S_c is reduced due collisions on control multichannel system which consequently decreases S_d. So in case of F =10, $S_d(\max)$=0.3126, for F =20, $S_d(\max)$=0.5274, and for F =80, $S_d(\max)$=0.95014.

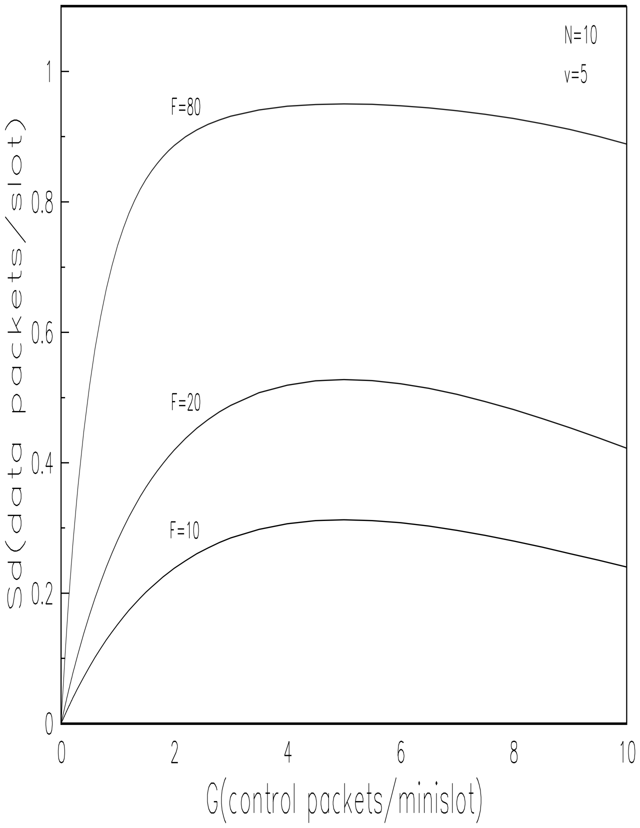

Figure 4 : The throughput per data channel S_d (packets/slot) versus G (control packets/minislot) for N =10 (data channels), v=5(control channels) and F =10,20,80 minislots.

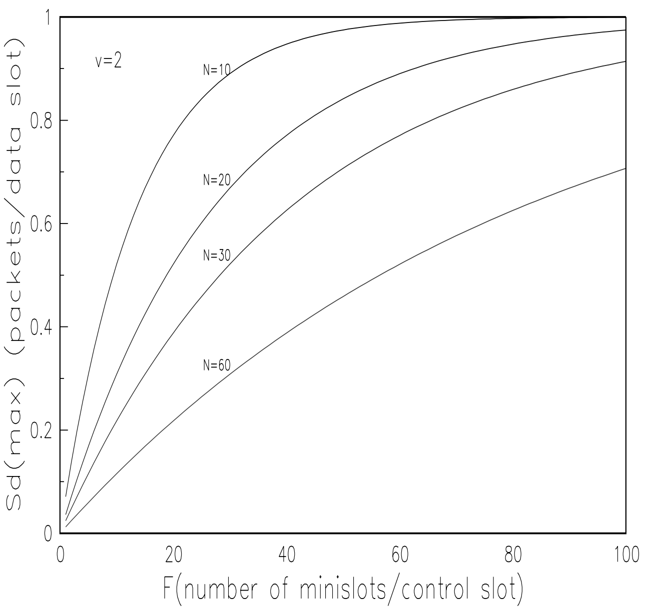

Figure-5: The maximum throughput per data channel $S_d(\max)$ (packets/slot) versus F (number of minislots /control slot) for N =10,20,30,60 (data channels) and v =2(control channels).

Figure 5 illustrates $S_d(\max)$ versus F for N =10,20,30,60 data channels. It is evident from the Figure that as N increases $S_d(\max)$ is shifted in higher values of F. This Figure shows that for every fixed value of N and at small values of F, $S_d(\max)$ is an increasing function of F. But at higher values of F, $S_d(\max)$ increases slightly approaching saturation. The explanation comes the equation of $S_d(\max)$ of Eq. 17, which says that for fixed values of v and N, as F increases the ratio vF/N tends to infinity and $S_d(\max) \to 1$.

4 Conclusion

The round trip propagation delay plays a key role in single-hop WDM Passive star technology networks and our objective is to exploit the normalized propagation delay feature to introduce suitable access algorithms. The proposed algorithm achieves collision avoidance with maximum achievable throughput in heavy load. The analysis demonstrated that utilization improvement is a function of the number of the minislots per control slot. We proved that we could attain 100% throughput per data channel. On the other hand, the novel concept of the Multichannel Control Architecture and the distribution of control information over a number of control channels, in conjunction with the fixed tuned receivers, minimize the headers processing requirement at each station. The proposed Multichannel Control Architecture is a solution to the problem of the electronic processing bottleneck that the single common shared control channel for pretransmission coordination introduces in WDM networks.

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