RECEIVER COLLISION ANALYSIS FOR WDM NETWORKS USING A MULTICHANNEL CONTROL ARCHITECTURE

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Abstract: A single-hop WDM network is studied, for a passive star topology, based on a new network architecture which uses several wavelengths as control channels with an appropriate Network Interface Unit (NIU) at each station for coordination of packet transmissions on the data channels referred to as Multichannel Control Architecture (MCA). With the MCA, control information are distributed over the total control channels reducing the "electronic processing bottleneck" at one of end stations [1],[2]. We examine the receiver collision phenomenon and evaluate the performance reduction due to finite number of tunable receivers at each station. Receiver collision makes the performance analysis more realistic and expands the original analysis in a quantitative basis for comparison. Also the MCA is effective means of keeping the interface electronics in their bounds of achievable speed while providing good performance measures. CSCC'99 Proc.pp.5611-5614

Keywords: wavelength division multiple access WDMA, multichannel, electronic processing bottleneck, receiver collision, rejection probability, Multichannel Control Architecture MCA.

1 Model and Assumptions

The system under consideration as figure 1 shows is a passive star network. The system uses (v+N) wavelengths $\{\lambda_{c1,\ldots,}\ \lambda_{cv,},\ \lambda_{d1}\ldots\lambda_{dN}\}$ to serve a finite number M of stations. The multichannel system at wavelengths $\{\lambda_{c1,\ \ldots\ ,}\ \lambda_{cv}\}$ forms the MCA and operates as the control multichannel system while the remaining N channels at channels at wavelengths $\{\lambda_{d1}\ldots\lambda_{dN}\}$ constitute the data multichannel system. The Network interface unit (NIU) can be described as a CC^v-TT-FR^v-TR^F structure. It means that there are v control channels and each station has a tunable transmitter tuned at $\{\lambda_{C1},\ldots,\ \lambda_{CV,}\lambda_{d1,},\ldots,\lambda_{dN}\}$. The outcoming traffic from a station is connected to one input of the passive star coupler. Every station also uses v fixed tuned receivers one for each control channel and F(F≤N) tunable receivers to any of data channel $\{\lambda_{d1}\ldots\lambda_{dN}\}$. The incoming traffic to a user station is splitted into v+F portions by a 1x(v+F) WDMA splitter as Figure 1 indicates. In our analysis the access method to MCA and the data multichannel system is based to the ALOHA protocol. The transmission time of a fixed size control packet is used as time unit (control slot) and the data packet transmission time normalized in control slot time units is L (L>1) which is called data slot. Both control and data channels use the same time reference, which we call, cycle. We define as cycle, the time interval that includes one time unit for control packet transmission followed by a data packet transmission period. Thus the cycle time duration is L+1 time units. Time axis is divided into contiguous cycles of equal length and stations are synchronized for transmission on the control and data packet during a cycle. The packet transmission procedure is as follows:

A station generating or retransmitting a data packet, waits the beginning of the next cycle, selects randomly one of the v wavelengths $\lambda_{c1,\ \ldots,}\ \lambda_{cv}$ and sends a control packet over the control channel at the first time unit of the cycle. The control packet is consisting of the transmitter address, the receiver address and the wavelength, λ_{dk}, as is shown in Figure 1. Packets are collectively generated in a Poisson stream. If more than one control packets on a cycle use the same, a collision occurs and all overlapping control packets are destroyed (control channel collision). Here a data packet is transmitted only if the corresponding control packet is successful on one of the control channels. If more than one data packets select the same $\lambda_{df,}$ to be transmitted during a cycle, a collision occur (data channel collision). A

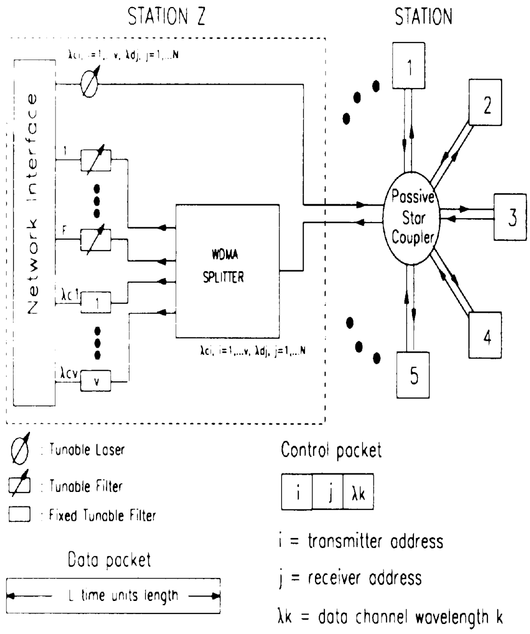

Figure 1:Passive star multiwavelength control architecture, and packets structure

station will hear the result of the transmission of its control and data packet by listening to the star coupler multichannel system since it is operating as broadcast operating system.

In the receiving mode if a station sees its address announced in a control packet, and the corresponding data packet is transmitted successfully, immediately adjust a receiver to the transmission wavelength channel which is specified in the control packet for packet reception.

We say that the tunable receiver of a station Z is active, if it is tuned receiving a data packet from a data channel of a λ_{di} (i=1,...N). It is possible more than F successfully transmitted data packets on different data channels to have as destination the same station during a given cycle. In this case the station tunable receivers are tuned to F data channels of the incoming successful transmissions and reject the others. This phenomenon is called receiver collision [3]. Depending on the examining protocol there are different policies to select which packet is received correctly at destination. As an example we can say that the data packets transmitted on the lower data channels win the competition. We consider that at any point in time each station is capable of transmitting at a particular wavelength λ_{dT} and simultaneously receiving at a wavelength λ_{dR}.

Stations participating in unsuccessful transmissions defer their retransmissions for a random time until successful retransmission. In addition tuning times and propagation delays are assumed negligible.

2 Analysis

Let

G= the mean offered traffic over (v-channel) control system in a cycle time that obeys to Poisson statistics.

G_n =G/v, the traffic to j_{th} control channel j $\in \{1,\ldots,v\}$ given that each control channel is chosen with equal and constant probability $P_j = 1/v$.

P_c= the probability of one Poisson arrival in a control channell during a multislot.

$$P_c = G/v \ e^{-G/v} \qquad (1)$$

A_w = random variable representing the number of control packets in a multislot time $0 \leq A_w \leq v$. Thus the probability of finding A_w = k, control packets every one with one Poisson arrival Let:

G = The mean offered traffic over (v-channel) control system in a multislot , that obeys to during a multislot obeys to binomial probability low.

$$Pr[A_w=k] = [\ v!/(v-k)!k!\ ]\ P_c^{\,k}\ (1-\ P_c)^{v-k} \qquad (2)$$

S_c = The average successful transmission rate of control packets in a multislot time in steady state.

$$S_c = E\ \{\ Pr[A_w = k]\ \} = \sum_{K=1}^{Min(M,v)} k\ \ Pr[A_w=k] = Ge^{-G/v} \qquad (3)$$

Consider that A_w = k, control packets, have successfully transmitted over the control multichannel system in the first part of a cycle. The examined problem corresponds to the occupancy problem of distribution indistinguishable balls to cells supposing that arrangements should have equal probabilities. We assume k indistinguishable data packets transmitted over to N indistinguishable channels using Maxwell-Boltzman statistics[4]. We assume that these packets have been uniformly distributed among N channels. The random distribution of k packets in N channels, gives N^k arrangements each with probability $(1/N)^k$.

We define $P_{suc}(k)$, as the conditional probability that only one from k data packets is destined to a data channel n, n$\in\{1,2,\ldots,N\}$, given that their corresponding control packets has been successfully transmitted in the first part of a cycle.

Thus the remaining k-1 packets are destined to the remaining (N-1) data channels in $(N-1)^{k-1}$ different ways. The $P_{suc}(k)$ can expressed as follows.

$$P_{suc}(k) = (k/N)\,[1-(1/N)]^{k-1} \quad (4)$$

Supposing that the output rate of successful transmitted control packets obeys to Poisson statistics in steady state, we take

$$E[A_w=k] = S_c \quad (5)$$

Using the approximation $(1-x)^y \approx e^{-xy}$, for small x, we get

$$P_{suc} = (S_c/N)\, e^{-Sc/N} \quad (6)$$

A_N = random variable representing the number of successfully transmitted data packets during a cycle. The probability of finding A_N = r, successfully transmitted data packets, can evaluated as follows:

$$P(A_N = r) = [\, N!/(N-r)!r!\,]\, P_{suc}^{\;r}\, (1- P_{suc})^{N-r} \quad (7)$$

S = the average number of successful transmissions during a cycle in steady state.

$$S = E[A_N = r] = \sum_{r=1}^{N} r\, P(A_N = r) = S_c\, e^{-Sc/N} \quad (8)$$

Let $U_v(r)$ = the number of transmissions with destination a given station let's say Z, conditional that r packets have been transmitted successfully. The examined problem corresponds to the occupancy problem. Let suppose that station Z does not transmit itself. The probability that station Z is also the source of one of the r transmitted packets is (r/M). In this case we assume the (r-1) packets have been uniformly distributed among (M-1) stations. The random distribution of (r-1) packets in (M-1) stations gives $(M-1)^{r-1}$ arrangements each with probability $[1/(M-1)]^{r-1}$. The probability that k packets are destined to station Z station can be found as follows:

$$P[U_v(r) = k\,] =$$

$$= (r/M)[(r-1)!/(r-1-k)!k!][1/(M-1)]^k[1- 1/(M-1)]^{r-k-1} +$$

$$+ (1-r/M)[r!/(r-k)!k!]\,[1/(M-1)]^k[1- 1/(M-1)]^{r-k} \quad (9)$$

Given that the number of tunable receivers of each station is F, we examine the rejection probability of a successful transmitted data packet destined to station Z, in steady state.

The probability $P_{col}(m)$, that m packets destined to station Z are aborted due to active tunable receivers is given by:

$$P_{col}(m) = \sum_{I=m}^{\min(M,N-F)} P[A_N = F+I\,]\; P\,[U_v(F+I) = F+m] \quad (10)$$

The mean probability a successful transmitted data packet to be aborted by a station Z in steady state, given that the number of tunable receivers of a station is F, is defined as

$$P_{col} = \sum_{I=m}^{\min(M,N-F)} m\, P_{col}(m) \quad (11)$$

So the total average rate of rejected data packets at destination due to active tunable receivers is given by

$$S_{rej} = M\, P_{col} \quad (12)$$

The throughput $S_{rc,}$ is defined as the average number of correctly received data packets at destination during a cycle in steady state.

$$S_{rc} = [L/(L+1)][S- S_{rej}] \quad (13)$$

The average rejection probability at destination of a packet, is evaluated as the ratio of the average number of packet rejection at destination in steady state due to active receivers, to the average number of successfully transmitted packets per cycle.

$$P_{rej} = S_{rej} / S \quad (14)$$

1.3 Numerical Results

Figure 2 depict the average rejection probabilities P_{rej}(Log.Scale) versus (control packets/cycle) for v=30 control channels, N=20 data channels, M=50 stations and for F=1,2,3 tunable receivers. It is obvious from the figure that for low values of G, the P_{rej} increases almost linearly with G(low values of S) for all values of tunable receivers. As G increases and S, S_{rc} approach their maximum value, P_{rej} begin to saturate increasing slowly towards its maximum value. As G increases, S is reduced due to data channel collision so P_{rej} decreases because the probability of collision at destination is lower. It can be observed that increasing the number of tuneable receivers by one, reduces the P_{rej} by many orders of magnitude.

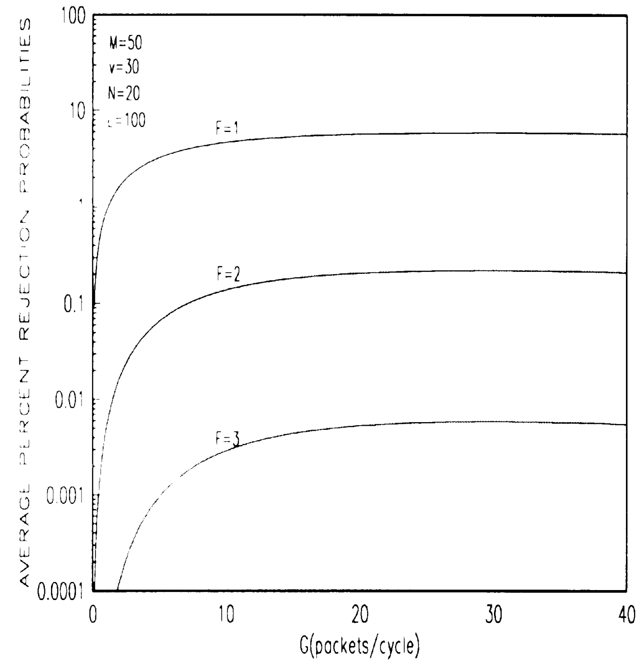

Figure 2:Average rejection probabilities Prej (Log. Scale) versus G(control packets/cycle

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