Generalized Modified Accelerative Pre-allocation WDMA MAC Protocol for WDMA Networks

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Abstract

For wavelength division multiple access (WDMA) networks, various media access control (MAC) protocols have been proposed. In this paper, generalized modified accelerative pre-allocation WDMA (GMAP-WDMA) is proposed, which is based on MAP-WDMA considering channel sharing at channel limited conditions. The network performance of channel utilization, throughput, and latency is analyzed under balanced traffic loads and uniform traffic distribution by employing neighboring channel sharing. As a result, the performance of GMAP-WDMA mainly depends on the number of channels at given number of stations, and their behaviors can be applied to practically design the network.

1. Introduction

A WDMA network with a single hop passive star coupled topology can be a good access network since concurrent packet transmission is reliably executed [1], [2]. Further, as higher layer services are built on the fundamental packet transfer service provided by media access control (MAC) sub-layer, the advance of MAC protocols improves performance, and guarantees diverse applications [3].

Several MAC protocols have been proposed for the WDMA network [3]-[5]. In particular, to overcome the drawbacks of pre-allocation based WDMA and reservation based WDMA MAC protocols, accelerative pre-allocation WDMA (AP-WDMA) has been proposed [4]. Through the early transmission (ET), the SDP, which is a source (i.e., the station sending packet) destination (i.e., the station receiving packet) pair scheduled a few time slots later, is shifted in advance to replace with presently idle SDP. However, as the source trying the ET can not know the buffer status of the destination, the trial of ET can result in collision. To reduce this, a modified AP-WDMA (MAP-WDMA) has been devised by checking the idle sources and recoupling them through the modified ET (MET). Especially, MAP-WDMA is more proper than AP-WDMA at uniform traffic distribution and several traffic delay environments [5].

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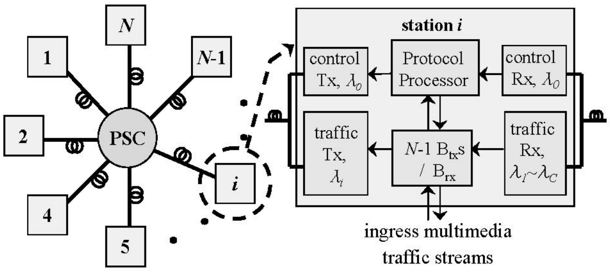

Figure 1. Architecture of the WDMA network.

However, [5] is simply confined to non-channel sharing case. There are more practical design issues when the number of channels is limited at given number of stations such as grouping stations or allocating their priorities for packet transmission. Thus, in this paper, GMAP-WDMA which is the generalized MAP-WDMA under channel limited condition is introduced by expanding the MET idea equally conceptualized as [5]. Further, the network performance in terms of channel utilization, throughput, and latency is investigated so as to provide an engineering table upon designing the WDMA network by applying GMAP-WDMA.

2 Network Architecture

With a single hop passive star coupled topology, N stations are deployed around a passive star coupler (PSC) and

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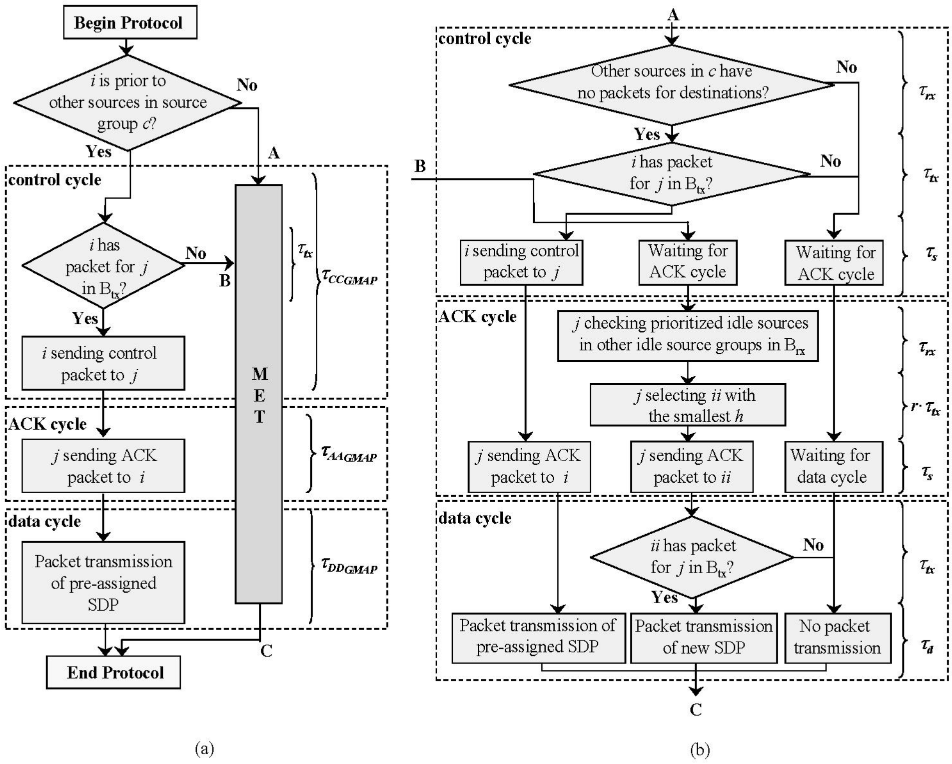

Figure 2. Flow chart of GMAP-WDMA. (a) Overall flow chart. (b) MET flow chart.

connected by optical fibers as shown in Fig. 1. C wavelengths are dedicated to N stations as channels, and channel sharing is inevitable when $N > C$. Due to broadcast and select mechanism, one station broadcasts packet to all stations which determine to receive or discard it according to GMAP-WDMA. Every station has a fixed wavelength transmitter and a fixed wavelength receiver (FTFR) for control signaling, as well as a fixed wavelength transmitter and a tunable wavelength receiver (FTTR) to transceive traffic stream. There are $N-1$ buffers, B_{tx}s, which correspond to other $N-1$ stations for packet transmission and one buffer B_{rx} for packet reception per a station. B_{tx} and B_{rx} burst out the packet without fragmentation [4].

3 GMAP-WDMA MAC Protocol

In this section, GMAP-WDMA is detailed, and its processing time is also investigated.

3.1 Control cycle

To begin with, GMAP-WDMA entails the priority of the sources in the source group, c which is the identification number of the source group ($1 \leq c \leq C$). s, the number of the sources in c, can be determined as $s = \lceil \frac{N}{C} \rceil$. The identification number of the source in c is denoted as a where $(c-1)s+1 \leq a \leq cs$.

The control cycle is time-interleaved and executed with an increasing order of a and c. The priority of a in c is continued during one cycle. The priority is repeated per s cycles, and the sources have their priorities in turn as the increasing order of a. If a has the priority during a cycle as well as packet for its destination j, it can transmit control packet to j. If a has the priority but have no packets for j, it should wait for the ACK cycle, and the chance is passed to the second prioritized source. When a is the most prioritized for a cycle, the priority can be transferred as $a+1$, $a+2$, ... , $a-2$, and $a-1$. Thus, if at least a source in c has packet to its destination, the source can send control packet for its destination. Otherwise, all sources of c wait for the ACK cycle. The control cycle processing time (CPT) of GMAP-WDMA per a station, $\tau_{CC_{GMAP}}$, can be obtained as

$$\tau_{CC_{GMAP}} = \tau_{rx} + \tau_{tx} + \tau_s \quad (1)$$

where τ_{rx} is the time to check B_{rx}, τ_{tx} is time to check B_{tx} and τ_s is time to send control packet.

3.2 ACK cycle

The ACK cycle is also implemented as the increasing order of j. If the destination j has received control packet from the pre-allocated source a in c, it can send ACK packet to a. When j did not receive any control packet from a, j can try the MET in [5] so as to send ACK packet to another source in another source group providing that a is the most prioritized in c. Otherwise, j cannot transmit any ACK packet, and it should just wait for the data cycle. The MET can be different according to the number of idle source groups, r ($1 \leq r \leq C$). When r is 1 or 2, the MET can be executed by moving the SDP N time slots forwards. When $r \geq 3$, the corresponding h, the number of time shifted forward due to the MET, is in the range of $1 \leq h \leq N$. The ACK CPT of GMAP-WDMA, $\tau_{AA_{GMAP}}$, can be expressed as

$$\tau_{AA_{GMAP}} = \tau_{rx} + r \cdot \tau_{tx} + \tau_s \qquad (2)$$

where $r \cdot \tau_{tx}$ is the time to investigate B_{tx}s of r idle sources in r idle source groups.

3.3 Data cycle

The data cycle of GMAP-WDMA is equivalently processed as that of MAP-WDMA. Therefore, the data CPT of GMAP-WDMA, $\tau_{DD_{GMAP}}$ is $\tau_{tx} + \tau_d$ as $\tau_{DD_{MAP}}$ in [5] where τ_d is the time to send packet. The total control and ACK CPTs of GMAP-WDMA, $\tau_{C_{GMAP}}$ and $\tau_{A_{GMAP}}$, can be obtained by multiplying $\tau_{CC_{GMAP}}$ and $\tau_{AA_{GMAP}}$by N. Thus, similarly in [5], the total processing time of GMAP-WDMA, τ_{GAP} under channel limited condition, can be represented as

$$\tau_{GMAP} = (NC + N + 1) \cdot \tau_{tx} + 2N\tau_s + 2N\tau_{rx} + \tau_d \qquad (3)$$

where r should be fixed as C to match the synchronization of the time slots.

4 Performance Analysis of GMAP-WDMA

In this Section, the network performance of GMAP-WDMA is analyzed. First, the latency of GMAP-WDMA, L_{GMAP}, is defined as the amount of time when one specific SDP waits for its next turn for packet transmission. Since the time for a cycle is $N \cdot \tau_{GMAP}$, and one of sources in one source group should wait other s cycles for packet transmission, L_{GMAP} can be represented as

$$L_{GMAP} = s \cdot N \cdot \tau_{GMAP}. \qquad (4)$$

In Fig. 3, L_{GMAP} is illustrated according to increasing N where τ_{tx} and τ_{rx} are 5 ns, as well as τ_s and τ_d are individually 1 μs and 100 μs [5], [6]. It is shown that greater C at fixed N guarantees shorter L_{GMAP}, and this situation becomes significant with respect to the increment of N.

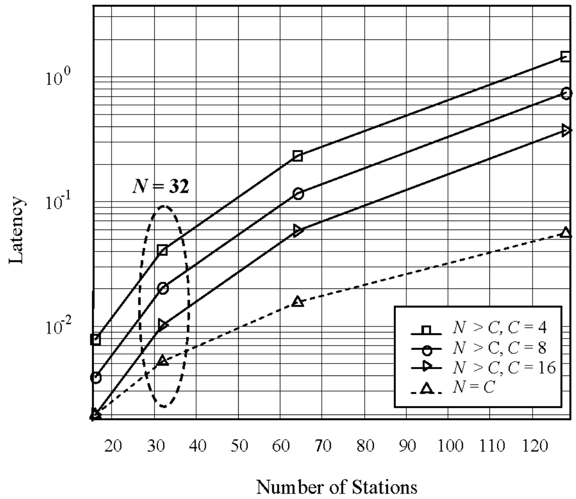

Figure 3. Latency vs. the number of stations.

The channel utilization of GMAP-WDMA, U_{GMAP}, can be obtained from the passive star coupled blocking probability [4]. The probability where at least a packet is available for the SDP (c, j) till the pre-allocated time slot considering MET, $R_{cjGMAP}(h)$, can be derived as

$$R_{cjGMAP}(h) = \begin{cases} 1 - \prod_{a=(c-1)s+1}^{cs} \left(1 - \sigma_a p_{aj}\right)^N, h = 0 \\ \frac{C-3}{2CN} \prod_{a=(c-1)s+1}^{cs} \left(1 - \sigma_a p_{aj}\right)^N \\ \qquad , 1 \leq h \leq N-1 \\ \frac{3N+C-3}{2CN} \prod_{a=(c-1)s+1}^{cs} \left(1 - \sigma_a p_{aj}\right)^N \\ \qquad , h = N \end{cases} \qquad (5)$$

where σ_a is the traffic loads to a, and p_{aj} is the probability that the traffic arriving at a is scheduled for j. In Eq. (5), the first term is the probability that at least a source of the source group has packet for its destination during N time slots. The second term is the probability where no packets are buffered for all sources in c, and $r \geq 3$. The last term shows the sum of the probabilities for the cases of $r = 1$, $r = 2$ and $r \geq 3$ where the MET is implemented only at $h = N$. By summing $R_{cjGMAP}(h)$ according to h, and averaging it with respect to c and j, U_{MAP} can be represented as

$$U_{GMAP} = \frac{1}{C} \sum_{c=1}^{C} \frac{1}{N} \sum_{\substack{j=1,\\ a \neq j}}^{N} \sum_{h=0}^{N} R_{cjGMAP}(h). \qquad (6)$$

Further, the throughput of GMAP-WDMA, T_{GMAP}, is obtained as $U_{GMAP} \cdot C$ [4], [6].

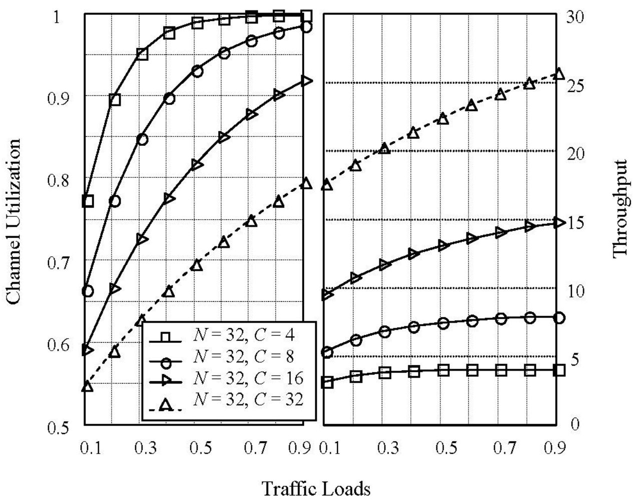

Figure 4. Channel utilization and throughput of GMAP-WDMA vs. traffic loads at $N = 32$.

The behaviors of U_{GMAP} and T_{GMAP} are investigated with respect to traffic loads as shown in Fig. 4. The traffics are assumed to be balanced to all stations, the traffic flow of a station is uniformly distributed as in [7]. Additionally, neighboring channel sharing is employed [4]. N is determined as 32. Throughout this analysis, it is checked that the more stations share channels, the better the channel utilization can be achieved. Further, as C becomes small, U_{GMAP} is saturated to 1 according to traffic loads contrary to large C at which U_{GMAP} monotonously increases. On the other hand, the performance of T_{GMAP} performance in Fig. 4 shows reversed situation compared with that of U_{GMAP}. While the throughput increment at greater C according to traffic loads is high, the throughput at smaller C provides insignificant improvement in spite of the increase of traffic loads.

5 Conclusions

For the WDMA network, GMAP-WDMA MAC protocol has been introduced considering priority issue and channel sharing under channel limited condition. The behaviors of channel utilization, throughput, and latency of GMAP-WDMA are also investigated under balanced traffic loads and uniform traffic distribution pattern. By applying those analysis, an engineering table as Table I for designing the WDMA network employing GMAP-WDMA can be provided. Therefore, to select the number of wavelengths at given number of stations can be determined according to the network performance parameters which the network designer regards as important. Moreover, since this analysis is generalized to theoretically calculate the network parameters of GMAP-WDMA under channel limited condition, the analysis can be further specified considering other environments such as asymmetric and unbalanced traffic loads or specific channel sharing methods. This remains as the sequel of this paper.

Table 1. Engineering table of GMAP-WDMA.

Contents	The number of channels			
	32	16	8	4
Channel utilization	4	3	2	1
Throughput	1	2	3	4
Latency	4	3	2	1
Cost	4	3	2	1

* **Rating** (1 : best performance , 4 : worst performance, 1 >> 2 > 3 >> 4)

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