หอสมุดกลาง สถาบันวิทยบริการ จุฬาลงกรณ์มหาวิทยาลัย

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ภาคผนวก

บทความทางวิชาการที่ได้รับการเผยแพร่

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A NEW ACCESS CONTROL TECHNIQUE FOR CHANNEL REQUEST IN WIRELESS COMMUNICATIONS

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ABSTRACT--Medium access control protocols are at the core of many wireless communication systems with shared channel resources. Newly MAC protocols tend to divide bandwidth into 2 parts. The first part is used to contend among all users for channel reservation and the second part used for actual data transmission for users who succeed in reservation. From the significant role of the first part, the access probability used by all users for determining whether or not to access the request slot for channel reservation, is an important factor effecting on the system performance. Therefore, this paper presents a full analysis for deriving a new access technique that an appropriate access probability used in the system is selected in accordance with the present system condition taking the number of users and number of request slots into consideration. It is shown by the simulation that in the system which each user has only a single access per frame the new technique outperforms all conventional techniques in all tested traffic and system environments.

KEYWORDS--Access Probability, Slotted-ALOHA, MAC, and Wireless Communication

I. INTRODUCTION

Due to the mobility and access flexibility features in wireless communications, the demands for wireless communication services are growing at rapid pace. A wireless access system consists of one base station and several wireless users. The base station is part of a fixed backbone network and the wireless users are mobile users or computerized devices. The base station uses the downward channel to broadcast control traffic and/or information traffic to users, while users use the upward channel to transmit their traffic to the base station. Since the base station is a unique transmitter using the downward channel, the base station can appropriately schedule the transmission of its traffic. On the other hand, the upward channel is shared among all users, who are usually distributed over the service area. It is not possible for these users to synchronize their transmission. Therefore, some means of multiple access control (MAC) protocols are needed.

A number of distinct MAC protocols have been developed over the past years. For early or conventional MAC protocols, they can be classified into two categories, namely contention-free and contention-based. In contention-free protocols, each user has its own dedicated slot for sending their traffic. Therefore, packet collision never occurs and access delay is basically deterministic. Although no collision is encountered in the information transmission, these techniques are inefficient when user is in the silent phase as this portion of unused channel capacity cannot be transferred to or utilized by other users. Examples of these protocols are FDMA and TDMA. Conversely in the contention-based scheme, such as random access protocols, all users have to make its own decision regarding when to access the channel. The contention-based scheme is rather simple to implement and can be adaptive to varying traffic demand characteristics. Therefore this scheme is suitable for multiplexing many burst data sources with a light traffic load. However, at high traffic load the channel bandwidth utilization is wasteful due to frequent and excessive collisions. In addition, the unpredictable delays encountered in packet transmission make packet contention appear unattractive for voice transmission, which is a delay-sensitive service. Examples of these protocols are Pure-ALOHA [1], Slotted-ALOHA [1], Selective-Reject ALOHA [1], CSMA [1]. To overcome the limitation of these conventional MAC protocols, newly developed protocols tend to take advantages of each scheme by organizing the channel bandwidth into a frame structure that is composed of two parts, reservation part and information part, see Figure 1. The reservation part consists of a number of request slots, which is used by all users on a contention basis for channel reservation. A user that succeeds in the reservation process will be assigned data slot within the information part for its data transmission. These protocols derive their improved efficiency from the fact that reservation periods are shorter than transmission periods by several orders of magnitude. Examples for this type of protocol are ALOHA Reservation [2], Round-Robin Reservation [3], PDAMA [4], DQRUMA [5], PRMA [6].

Figure 1 Frame Structure

In order to achieve the maximum throughput of the system, it is found that the vital part effecting the system performance is the reservation part. In the reservation process, each user accesses the request slots with a certain probability. In this paper, we propose a new access technique use to select an appropriate access probability for channel reservation considering both the number of active users and the number of available request slots in the reservation part. It is also assumed that all users in the system are allowed only one single access per frame.

The paper is organized as follow. Section 2 presents the variation of the access techniques used for selecting the access probability. In Section 3, we analyze the new access technique proposed to improve the throughput of the system. Next, in section 4, the performance of various techniques will be predicted and compared. Finally, conclusions are given in section 5.

2. CONVENTIONAL TECHNIQUE

There are many access techniques for selecting an access probability of users. With the original scheme, all users use a constant access probability for request channel. But it is very difficult to choose an appropriate value of access probability that can achieve a good system performance under dynamic load conditions. Therefore various techniques have been developed to improve the system performance. An interesting one is an exponential backoff-scheme [7]. In this technique, we assume that each user can know the outcome of their request within the same slot. Also it is supposed that there is a ternary feedback (idle when there is no user access in that request slot, success when only one user access, and collision when there is more than one user access in the same slot) for a slot. When traffic load is low, the request slots are mainly idle. In such a situation, each user increases an access probability, by q, contributing to increase in channel utilization. Conversely, under high load conditions, most of the request slots are occupied. Thus, it is better to reduce the access probability, by 1/q, in order to decrease the chance of packet collision. In addition, if there is a successful user in the previous contention, it means that an access probability is suitable. Another technique is to use a fixed access probability equal to $1/N_u$ (N_u = total number of users in the system). It is found that the use of access probability equal to $1/N_u$ for each user is much appropriate since the total access probability of all users equal to 1. The modified scheme of this technique use a dynamically adjusted access probability according to the number of active users in contention at that time. With the adaptive access probability, all users in contention use the access probability equal $1/N'_u$ (N'_u = number of users contend in that request slot). This technique is true from the fact that if the number of users in contention is large, each user should access with lower access probability. Theoretically, this scheme is always better than the previous one because it concerns only active users, not all users. However, in reality, we can not estimate the number of users in contention at each access slot.

All these techniques described above are only suitable for the system that users can know the outcome of their request within the same slot and can access immediately in the following slot if it is not successful owing to collision. This assumption may not be realistic for some practical system where the forward and backward propagation delay between base station and users are relatively much larger than the request slot length. This is partially the case with high bitrate system when users maybe obtain the outcome of their request after the end of the request slot. It is not clear whether these known techniques are effective when apply to the system which allows all users to access only once in the frame. Therefore, we propose a new algorithm using for selection an appropriate access probability for channel request which concerns both the number of active users and the number of request slots which are available. In the next section, we shall derive an appropriate access probability from a simple system when there are only one and two users. Then we continue to derive this technique into general cases.

3. APPROPRIATE ACCESS PROBABILITY FOR REQUEST CHANNEL

It is assumed in this study that all users in the system are allowed to access only once per frame and they all use the same access probability for request. If more than one user accesses at the same time in any request slot, collisions will result and none of these users succeed in reservation. We shall first give definitions of all terms used in the access probability derivation.

p : Access probability that each user uses for all request slots

N_u : Total number of users in the system

N_{su} : Total number of successful users in the system

N_{au} : Number of active users that access simultaneously in the same request slot (this is defined for use in the first request slot that contains access)

N_s : Total number of request slots in the reservation part

N_{as} : Total number of slots that receive accesses from users

$P[N_u, N_{su}, N_{as}, N_{au}, N_s]$: Probability that the system with N_u users has N_{su} users succeed in reservation by using N_{as} request slots and there are N_{au} users accessing at the same time

and $\begin{pmatrix} N_u \\ N_{au} \end{pmatrix} = \frac{N_u!}{(N_u - N_{au})!(N_{au})!}$

Where $n! = n(n-1)(n-2)\ldots(1) \quad , n \in I^+$

3.1 Only one user in the system

- Probability that the user will not access in any request slots of N_S slots in each frame is $P[N_u = 1, N_{su} = 0]$

  $= (1-p)^{N_s}$

- Probability that the user will access only once in one of the request slots is $P[N_u = 1, N_{su} = 1]$

  $= p + (1-p) \times p + (1-p)^2 \times p + \ldots + (1-p)^{N_s - 1} \times p$

  $= \sum_{i=0}^{N_s - 1} (1-p)^i \times p$

Thus the average number of successful users is
$0 \times P\,[N_u = 1, N_{su} = 0] + 1 \times P\,[N_u = 1, N_{su} = 1]$

3.2 System with 2 users

In the system with 2 users, there are 3 situations that can happen. First, one user accesses at the first slot, so no collision occurs and another user remains in the system. The remaining user may or may not access in remaining slots of the frame. If that user accesses immediately in the next request slot, that user will succeed and the number of request slots required for reservation is only two. But if that user does not access in the next slot, the number of request slots used for reservation will increase until that user access or until the end of the reservation period. Second, both users access simultaneously in the same request slot, causing collision and no one will ever succeed. Third, no one accesses in the first request slot. For the following slots, similar situations will repeated as stated above. We summarize all possible situations that may arise and their corresponding probability in Table1

From Table 1, we can now calculate the probability of different number of successful accesses as follows.

- Probability that no user succeeds in the reservation in all request slots of the frame is $P\,[N_u = 2, N_{su} = 0]$

= probability that no user accesses in all request slots ($P\,[N_u = 2, N_{su} = 0, N_{au} = 0]$)
+ probability that 2 users access at the same time in a slot ($P\,[N_u = 2, N_{su} = 0, N_{au} = 2]$)

$$= (1-p)^{2N_s} + [p^2 + (1-p)^2 p^2 + (1-p)^4 p^2 + \ldots + (1-p)^{2\times(N_s-1)} p^2]$$

$$= (1-p)^{2N_s} + \sum_{i=0}^{N_s-1} (1-p)^{2i} p^2$$

- Probability that only one user succeeds in the reservation is $P\,[N_u = 2, N_{su} = 1]$

= probability that only one user succeeds in the reservation ($P\,[N_{su} = 2, N_{su} = 1, N_{au} = 1]$)

$$= 2p(1-p)\times(1-p)^{N_s-1} + (1-p)^2 \times 2p(1-p)\times(1-p)^{N_s-2}$$
$$+ (1-p)^4 \times 2p(1-p)\times(1-p)^{N_s-3} + \ldots + (1-p)^{2\times(N_s-1)} \times 2p(1-p)$$

$$= \sum_{i=0}^{N_s-1} (1-p)^{2i} \times 2p(1-p)\times(1-p)^{N_s-i}$$

- Probability that there are 2 users successful in the reservation is $P\,[N_u = 2, N_{su} = 2]$

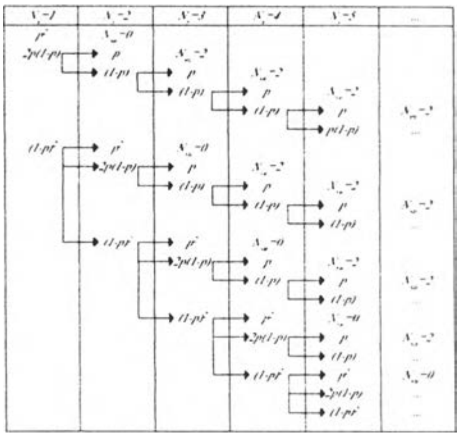
= probability that both users succeed in the reservation because they do not access at the same time slot ($P\,[N_u = 2, N_{su} = 2, N_{au} = 1]$)

$$= 2p(1-p)\times P[N'_u = 1, N'_{su} = 1, N'_s = N_s - 1]$$
$$+ (1-p)^2 \times 2p(1-p)\times P[N'_u = 1, N'_{su} = 1, N'_s = N_s - 2]$$
$$+ (1-p)^4 \times 2p(1-p)\times P[N'_u = 1, N'_{su} = 1, N'_s = N_s - 3]$$
$$+ \ldots$$
$$+ (1-p)^{2\times(N_s-2)} \times 2p(1-p)\times P[N'_u = 1, N'_{su} = 1, N'_s = 1]$$

$$= \sum_{i=0}^{N_s-2} (1-p)^{2i} \times 2p(1-p)\times P[N'_u = 1, N'_{su} = 1, N'_s = N_s - 1 - i]$$

Hence the average number of successful users of the system can be calculated from $0\times P\,[N_u = 2, N_{su} = 0] + 1\times P\,[N_u = 2, N_{su} = 1] + 2\times P\,[N_u = 2, N_{su} = 1]$. The appropriate access probability can now be determined by choosing the value of p that gives maximum number of successful users.

Table 1



3.3 Systems with more than 2 users

For the system with more than 2 users, the access probability can be calculated in a similar fashion as the previous two cases. Steps for calculation the value of $P\,[N_u, N_{su}, N_{as}, N_{au}, N_s]$ are as follows.

1) If no users access in any reservation slots ($N_{su} = 0$, $N_{as} = 0$ *and* $N_{au} = 0$) then probability of this event is $P[N_u, N_{su} = 0, N_{as} = 0, N_{au} = 0, N_s] = (1-p)^{N_u \times N_s}$

2) Otherwise, there is one or more users attempting access. To derive the probability of this event, consider Figure 2. The reservation part is divided into 3 sections: first, second and third sections.

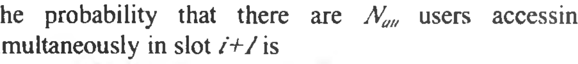


Figure 2 Reservation part

First Section: represents the period that no users begin to access. The probability that no users commence accessing in the first i slots is

$$(1-p)^{N_u \times i}$$

Second Section: represents the first slot that at least one user starts to access the request slot, *i.e.* slot number $i+1$. The probability that there are N_{au} users accessing simultaneously in slot $i+1$ is

$$\binom{N_u}{N_{au}} \times p^{N_{au}} \times (1-p)^{N_u - N_{au}}$$

Third Section: represents the period after the second section. Consider slot number $i+2$ until the end of the reservation part, the probability that there are N'_u left in the system with N'_s remaining slots and N'_{as} slots being accessed in the third section and there are N'_{su} users successful in the third section is expressed as

$$\sum_{N'_{au}} P\,[N'_u, N'_{su}, N'_{as}, N'_{au}, N'_s]$$

Where,

N'_u : Number of users left in the system after the first access

N'_{su} : Number of users that succeeds in during the third section

N'_{as} : Number of request slots that are accessed in the third section

N'_s : Number of request slots available in the third section

$$N'_u = N_u - N_{au}$$

$$N'_{su} = \begin{cases} N_{su} & , if\ N_{au} \neq 1 \\ N_{su} - 1 & , if\ N_{au} = 1 \end{cases}$$

$$N'_{as} = \begin{cases} N_{as} & , if\ N_{au} = 0 \\ N_{as} - 1 & , if\ N_{au} \geq 1 \end{cases}$$

$$N'_s = N_s - i - 1$$

$$N'_{au} = I'_{au}, I'_{au} + 1, I'_{au} + 2 \ldots, E'_{au} - 1, E'_{au}$$

$$\left.\begin{aligned} I'_{au} &= 0 \\ E'_{au} &= 0 \end{aligned}\right\} if\ N'_{as} = 0$$

$$\left.\begin{aligned} I'_{au} &= 2 \\ E'_{au} &= N'_u - 2 \times (N'_{as} - 1) \end{aligned}\right\} if\ N'_{as} \neq 0\ and\ N'_{su} = 0$$

$$\left.\begin{aligned} I'_{au} &= 1 \\ E'_{au} &= 1 \end{aligned}\right\} if\ N'_{as} \neq 0, N'_{su} \neq 0\ and\ N'_{as} = N'_{su}$$

$$\left.\begin{aligned} I'_{au} &= 1 \\ E'_{au} &= (N'_u - N'_{su}) - 2 \times (N'_{as} - N'_{su} - 1) \end{aligned}\right\} if\ N'_{as} \neq 0, N'_{su} \neq 0\ and\ N'_{as} \neq N'_{su}$$

Thus,

$$P[N_u, N_{su}, N_{as}, N_{au}, N_s] = \sum_{i=0}^{N_s - N_{as}} (1-p)^{N_u \times i} \times \left[\binom{N_u}{N_{au}} \times P^{N_{au}} \times (1-p)^{N_u - N_{au}} \right] \times \left[\sum_{N_{au}} P[N'_u, N'_{su}, N'_{as}, N'_{au}, N'_s] \right]$$

The initial condition of $P[N_u = 0]$ is defined from

$$P[N_u = 0, N_{su}, N_{as}, N_{au}, N_s] = 1$$

We can now calculate the term $P[N_u, N_{su}, N_s]$ from

$$P[N_u, N_{su}, N_s] = \sum_{N_{as}} \sum_{N_{au}} P[N_u, N_{su}, N_{as}, N_{au}, N_s]$$

Finally the average number of successful users is given by

$$\sum_{N_{su}=1}^{N_u} N_{su} \times P[N_u, N_{su}, N_s]$$

4. RESULTS AND DISCUSSION

We shall first illustrate how the access probability has an effect on the system performance, which is measured in terms of the average number of successful users in each frame. By using the last equation previously derived in section 3, it is possible to obtain a relation between the average number of successful users and the access probability; this is depicted in Figure 3. In this Figure, the number of slots (N_s) is fixed at 50 and the number of users (N_u) varied from 1 to 10. As we can see, at small values of access probability the average number of successful users increases with the access probability. This is simply because under this condition users do not access the request slots frequently enough; a lot of time these slots are idle. Therefore, an increase in the access probability will reduce the number of idle slots and thus improving the system throughput. When increasing the access probability up to a certain value, the number of successful users begins to decline. This performance degradation is due to an increase in the number of collisions caused by too many access attempts. A further increment of the access probability beyond this will only generate more collisions and results in the reduction of the number of successful users. For example, the maximum number of successful users for the system of 5 users occurs at the access probability of 0.06. Approximately 4.2 users on average succeed in accessing the request slots, an equivalence of 84% throughput.

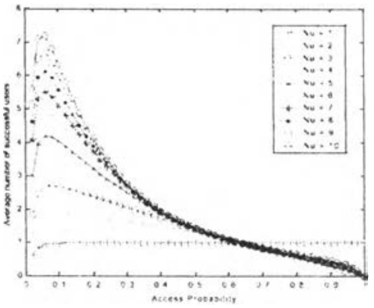


Figure 3 The average number of successful users vs the access probability with the number of users varied from 1 to 10 andthe number of request slots fixed at 50

Consider Figure 4 that shows the relation between the average number of successful users and the access probability for the system of 10 users using different number of slots, *i.e.* 5, 10, 15, 20, 25 and 30. It is apparent that the average number of successful users rises as the number of request slots increases. An interesting point to highlight here is that the maximum number of successful users for different number of available slots occurs at different value of access probability. The maximum number of successful users for large number of slots appears at lower access probability than the system with smaller number of slots. This is because when there are larger number of request slots, the users can lower the risk of collision by reducing the access probability. On the contrary, when there are few slots available, all users should attempt access at greater probability.

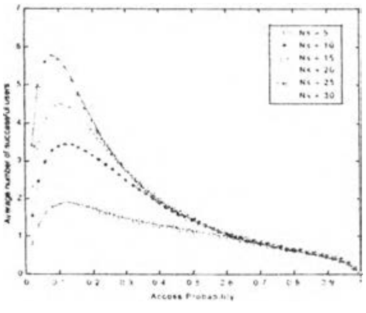


Figure 4 The average number of successful users vs the access probability with various number of request slots from 5, 10, 15, 20, 25 and 30 for a system of 10 users

All the above investigations indicate that the access probability is a key factor to the system performance and to determine an appropriate access probability it is essential to take account of both the number of users and the number of slots available into consideration. Figure 5 summarizes an appropriate access probability for a various number of users and request slots. This graph is derived directly from last equation by taking the access probability that give the maximum throughput for a given number of users and request slots. Notice that when number of request slots is large, the appropriate access probability tends to be small and will approach zero in the extreme case where the number of slots is infinite. This is because when there are increased number of request slots, users gain greater opportunity for access. Therefore, they can access using the lower access probability to avoid collision. In other word, in the system which has a little number of request slots the users must attempt to increase their success opportunity by increasing their access probability.

Using the appropriate access probability in Figure 5, we can now obtain the maximum system performance for systems with different number of users and request slots and this is depicted in Figure 6. As we can see, the number of successful users clearly increases with the number of slots.

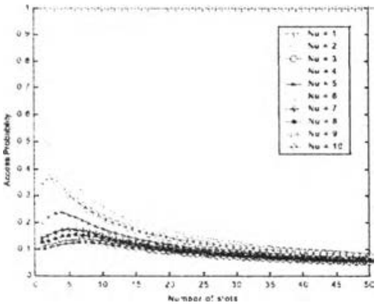


Figure 5 Appropriate access probability with the number of request slots varied from 1 to 50 and the number of users varied from 1 to 10

For a given number of slots, the more the users access the system the greater the number of successful users. However, its corresponding system throughput which is defined as the average number of successful users divided by the total number of users becomes degraded.

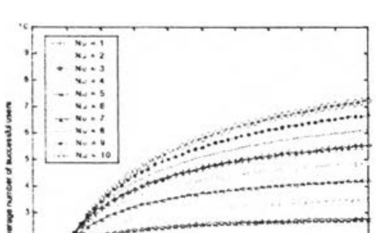


Figure 6 The number of successful users vs the number of request slots using the access probability from Figure 5

Although we have completely analyzed and obtained the appropriate access probability when given both the total number of users and request slots, it is intuitive to further develop a more effective access system that can dynamically adjust the access probability in each slot based on the present system condition. Instead of using a fixed access probability for all the request slots, the remaining active users change their access probability in each slot according to the number of remaining request slots and the number of active users using the appropriate access probability in Figure 5. For comparison purpose, the fixed access probability and the dynamic schemes will be referred to as Method 1 and Method 2 respectively. Note that Method 2 is not fully applicable to our system assumption, as it requires the system to know the number of active users in all slots.

The remainder of this section will compare the system performance of these two proposed access schemes with three other known techniques. The other techniques considered are as follows:

1. $1/N_u'$ technique: this technique changes the access probability in according with the number of remaining users, *i.e.* using the access probability of $1/N_u'$ where N_u' is the number of remaining users.
2. $1/N_u$ technique: this technique uses a fixed access probability of $1/N_u$ for all request slots.
3. Exponential Backoff technique (EB): this is a technique that dynamically adapts the access probability in each request slot based on the access outcome of the previous slot. If the previous request slot is idle, success or collision then the access probability used is made double, kept the same, or reduced by half, respectively. In this simulation the initial value of the access probability in the slot is set to $1/N_u$ (N_u = the total number of users in the system) and q is set to 2.

Figure 7 illustrates the throughput performance of all access techniques as a function of the number of users in the system using 15 request slots. It appears that among these five techniques the EB technique offers the lowest throughput, despite this technique is found effective and widely adopted for many studies on MAC protocols that users can access more than once in each frame. When the access attempts are limited to only once per frame, the performance becomes rather poor. This is because users that encounter collisions in their access attempts will no longer take part in the remaining slots. Consequently, the access probability that has been consecutively updated to fit the channel condition will affect only users that remain. This means that if a lot of users crease their access attempts before the appropriate probability is acquired through the dynamic adjustment of access probability, such an access mechanism will no longer be effective or useful.

For the $1/N_u'$ technique, the throughput performance of is slightly better than the EB technique, whereas the $1/N_u$ technique offers further increase in throughput. This implies that the $1/N_u$ technique can determine a more proper access probability than the $1/N_u'$ technique.

For the proposed technique, Method 1, the simulation results illustrate that the performance of this scheme is better than all above access techniques. With closer examination, it is observed that in all previous schemes frequent collisions occur at early few request slots and no active users are left in the system at later slots. As opposed to this behavior, Method 1 chooses access probability by considering both the number of users and the number request slots. As a consequence, the protocol uses relatively low access probability to avoid early collisions and tends to distribute the access attempts equally over the available slots.

Consider the throughput of Method 2, which dynamically adjust the access probability in every request slots based on the number of remaining request slots and active users. It is apparent that Method 2 gives the highest throughput among all techniques.

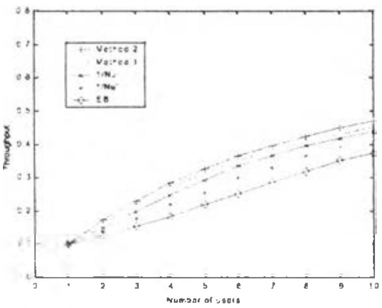


Figure 7 Throughput vs the number of users with N_s=15 slots

To further highlight some key points of these various system performances, the results of similar systems with increased request slots to 50 are depicted in Figure 8. It can be seen that no significant improvement of system throughput is observed for the EB and the $1/N_u'$ techniques when compared to the system with 15 request slots. These results indicate that these two protocols are unable to utilize the additional request slots. This is as expected because a large portion of users end their accesses in early few request slots due to collision or success as mentioned before. Therefore, the remaining slots are mostly left unused. On the contrary, the system throughputs of Method 1 and Method 2 are increased noticeably, meaning that these proposed schemes are able to make effective use of these extra request slots. The performance improvement is achieved by lowering the access probability of users and hence in effect distributing the access attempt over a larger number of request slots and reducing the chance of collision. For the $1/N_u$ technique, the system throughput improves with the number of slots available, but the amount of improvement is relatively less at high number of users. This is to say that this technique may appear effective but good performances may not always be achieved.

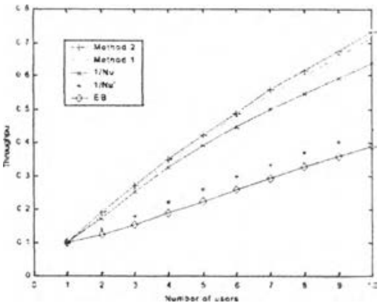


Figure 8 Throughput vs the number of users with N_s=50 slots

5. CONCLUSIONS

This paper has introduced a new access protocol for channel reservation in wireless communications and provided a full analysis of its throughput performance. It is revealed that the system throughput depends largely on the access probability used by each user. Simulation results show that the proposed schemes, Method 1 and Method 2, offer much higher level of throughput in comparison to the other three known techniques, the EB, the $1/N_u'$ and $1/N_u$. This is because appropriate access probability is determined by taking both the number of users and the number of slots into consideration and thus these two techniques can distribute the access attempts properly over the entire request slots whereas the other three techniques do not pose such a feature.

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New Channel Reservation Techniques for Media Access Control Protocol in High Bit-Rate Wireless Communication Systems

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Abstract – This paper presents a new class of channel reservation techniques for medium access control protocols suitable for high bit-rate wireless communication systems. Seven distinct channel reservation schemes are proposed, namely *CFP, CAP, COP, COP+SPL, CFP+SPL, UNI* and *UNI+LA* and their performance are analytically evaluated and compared with the existing known techniques. In the high-speed environment, transmission time is comparatively shorter than the propagation delay so that the user request outcome can not be acquire within the same reservation period. Consequently users will request only once in each reservation period. Under such an environment, it is shown that conventional reservation techniques become less effective and the proposed schemes are superior as they take both the number of active users and available slots simultaneously into their consideration while accessing the request slots.

I. INTRODUCTION

A number of distinct media access control (MAC) protocols have been developed over the past years. For early or conventional MAC protocols, they can be classified into two categories, namely contention-free and contention-based [1]. More recently developed protocols tend to organize the channel bandwidth of the upward channel into a frame structure that is composed of two parts, reservation and information transfer, see Fig. 1. The reservation part consists of a number of request slots, which is used by all users on a contention basis for channel reservation. A user that succeeds in the reservation process will be assigned data slots within the information part for its information transmission. These protocols derive their improved efficiency from the fact that reservation periods are shorter than transmission periods by several orders of magnitude. Examples for this type of protocol are ALOHA Reservation [2], DQRUMA [3], PRMA [4] and other more recent proposed protocol [5].

In this paper, we propose seven new channel reservation techniques suitable for high-speed wireless communication systems where all users in the system are allowed only one access per frame. We will show that the transmission probability is a key factor to the system performance and it must be properly selected by considering both the number of active users and the number of available request slots simultaneously. A complete performance analysis of all proposed schemes will be derived and numerically presented and compared.

II. CONVENTIONAL TECHNIQUES

There are many access techniques for selecting a transmission probability of users. An interesting one is an exponential backoff scheme [6]. In this technique, it is assumed that each user can know the outcome of their request within the same slot. Also it is supposed that there is a ternary feedback (*idle* when no user accesses that request slot, *success* when only one user accesses, and *collision* when more than one user accesses in the same slot) for a slot. If the previous frame is idle, each user increases a transmission probability, by q. Conversely, if a collision occurs, each user decreases the transmission probability, by $1/q$, in order to decrease the chance of packet collision. In addition, if there is a successful user in the previous contention, it means that a transmission probability is suitable. Another technique is to use a transmission probability equal to $1/M$ (M = total number of active users in the system) [1,4,7]. It is found that the use of transmission probability equal to $1/M$ is appropriate because the effective transmission probability of all users equal to 1. Since the number of active users keeps changing as they progress the slots, it is useful to dynamically adjust the transmission probability according to the number of remaining users in each successive slot. This technique will be referred to as $1/m$ where m is the number of users contending in a slot.

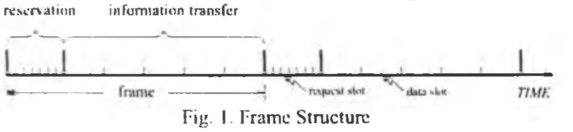

Fig. 1. Frame Structure

All these techniques described above are only suitable for the system that users can know the outcome of their request within the same slot and can access immediately in the following slot if it is not successful owing to collision. This assumption may no longer be the case for future high-speed system. In these systems, a round trip propagation delay between the base station and users can be relatively larger than the request slot period. This means that users may not be able to obtain the outcome of their request right after the end of the request slot. For the extreme case, each user may in fact receive the reservation result after the end of current reservation period. If not successful, the next reservation attempt will have to be made in the following frame, not the following request slot. This implies that each user has only a single reservation attempt in each reservation period. Under these new system conditions, it is not clear whether presently known reservation techniques are effective when applied to the system that allows all users to access only once in the frame.

III. PROPOSED CHANNEL RESERVATION SCHEMES

In this section, we shall describe the details of all proposed schemes and their average number of successful users performance derivation. For all the access schemes investigated here, it is assumed that all mobile users can acquire the total number of users attempting to gain access at the beginning of each frame and the total number of request slots available.

A. Cascade Fixed Prob (CFP)

In the first scheme, each user will attempt to make reservation on each request slot in sequence from the first slot to the last. In each slot, the user will decide whether it will access the present slot with a certain probability (p) and the value of this probability is the same for all users and fixed throughout all request slots. As a result, this scheme will be referred to as *Cascade Fixed Prob (CFP)*. It is apparent that the value of probability p is the key parameter to the system performance, hence must be chosen with care. We shall now derive an appropriate value of p that results in the maximum average number of successful users as a function of the number of active users and the number of available slots.

Let $T[m,n]$ be the average number of successful users of the system with m users and n request slots and $b[m,i,p]$ the binomial probability that i out of m users access a particular request slot with transmission probability p, which is expressed as:

$$b[m,i,p] = \binom{m}{i} p^i (1-p)^{m-i}, \text{ Where } \binom{m}{i} = \frac{m!}{i!(m-i)!}$$

In each request slot, only a single user can succeed in reservation and this occurs when no other users except that user makes access to the slot. We can formulate $T[m,n]$ in a recursive form as follows.

$$\begin{aligned} T[m,n] &= b[m,0,p]\, T[m,n-1] \\ &+ b[m,1,p]\,(1+T[m-1,n-1]) \\ &+ \sum_{i=2}^{m} b[m,i,p]\, T[m-i,n-1] \end{aligned} \tag{1}$$

where $m \geq 0, n \geq 0$.

The boundary conditions of (1) are $T[a,0] = T[0,b] = 0$ where $a = 0,1,\dots,m$ and $b = 0,1,\dots,n$.

We can then find an appropriate transmission probability $p_{CFP}[m,n]$ of each frame by differentiating (1) with respect to p, setting it to 0, *i.e.* $\frac{\partial}{\partial p} T[m,n] = 0$ and determining p that gives the maximum average number of successful users $T_{CFP}[m,n]$.

B. Cascade Adaptive Prob (CAP)

In the *CFP* scheme, it is seen that an appropriate value of p exists and can be formulated as function of the number of active users at the start of each frame (M) and the number of slots in each frame (N). It is interesting to further explore this finding to improve the system performance by introducing an idea of adaptive probability. Like the *CFP* scheme, all users still use the same value of probability at each slot, but the transmission probability may change from one slot to another by considering the current number of remaining users and slots. At the beginning of each request slot, each user must somehow acquire the present system conditions *i.e.* the current number of remaining users and slots. Note that this requirement contradicts with the fundamental system assumption made here. Nevertheless, its analysis provides an interesting new aspect to this study. Once the user knows both parameters the user will choose the value of p based these values using the formulation derived in the *CFP* scheme. Since the transmission probability is properly selected in response to the current system scenarios, intuitively an improved system performance can be expected. This scheme will be known as *Cascade Adaptive Prob (CAP)*. The model for average number of successful users analysis of this scheme is similar to that of the *CFP* scheme, though they differ in details.

Let $T_{CAP}[m,n]$ be the average number of successful users of the *CAP* system with m users and n request slots and $p_{CFP}[m,n]$ is the optimal transmission probability derived form the *CFP* system with m users and n request slots. $T_{CAP}[m,n]$ is computed as a recursive formula.

$$\begin{aligned} T_{CAP}[m,n] &= b[m,0,p_{CFP}[m,n]]\, T_{CAP}[m,n-1] \\ &+ b[m,1,p_{CFP}[m,n]]\,(1+T_{CAP}[m-1,n-1]) \\ &+ \sum_{i=2}^{m} b[m,i,p_{CFP}[m,n]]\, T_{CAP}[m-i,n-1] \end{aligned} \tag{2}$$

The same boundary conditions as in the *CFP* system are applied.

C. Cascade Optimal Prob (COP)

The adaptive scheme described above can indeed enhance the system performance, see the comparative results in the next section. Nevertheless, if the system assumption is to be violated, there exists a more effective way to adapt the transmission probability in accordance with the present system status and it in fact offers truly optimal system performance. This better scheme is referred to as *Cascade Optimal Prob (COP)* and its full analysis will be given below.

Let $p[m,n]$ be the transmission probability as a function of the number of available request n and remaining users m.

$$\begin{aligned} T[m,n] &= b[m,0,p[m,n]]\, T[m,n-1] \\ &+ b[m,1,p[m,n]]\,(1+T[m-1,n-1]) \\ &+ \sum_{i=2}^{m} b[m,i,p[m,n]]\, T[m-i,n-1] \end{aligned} \tag{3}$$

The boundary conditions of (3) are the same as in the *CFP* system. We can now find the appropriate transmission probability $p_{COP}[m,n]$ of each frame by differentiating (3) with respect to $p[m,n]$, setting it to 0, and determining $p[m,n]$ that gives the maximum average number of successful users $T_{COP}[m,n]$.

D. Cascade Optimal Prob + Split (COP+SPL)

This scheme is further developed from the *COP* scheme. The concept of this scheme initially arises from the observations that the average number of successful users of the system with small number of users and slots tends to be superior to the system with increased number of users and slots proportionally. As a result, we felt it may be useful and effective to split the number of slots into half and divide users into two groups on a random basis. Users in one group will make reservation in the first half of request slots and users in the other group utilize the second half. Each user determines which group it belongs to by simply flipping a coin. Note that the number of groups can be an arbitrary number. If users can be grouped perfectly, *i.e.* equally split between the two groups, improvement of the overall system performance will result. However, since users are split in a random manner, it is not known what pattern of grouping will appear. In the worse case half of the slots are heavily loaded with all users while the other half are left totally unused. Under this condition, the overall performance will clearly be degraded. The uncertainty in various grouping possibilities raises the concern whether such an idea will really offer benefit or it may actually make things even worse. To answer this problem, we shall derive its performance analytically as follows.

Let g be the number of groups and n/g is the number request slots in each group which must be an integer number. The average number of successful users of the *COP+SPL* system can be expressed as follows:

$$T_{COP+SPL}[m,n] = g \sum_{i=0}^{m} b[m,i,\tfrac{1}{g}]\, T_{COP}[i,\tfrac{n}{g}] \tag{4}$$

E. Cascade Fixed Prob + Split (CFP+SPL)

This scheme can be considered as a simplified version of the previously described *COP+SPL* scheme. It functions in the same manner as the *COP+SPL* except for the transmission probability used in each group split. The transmission probability for this new scheme is set to a fixed value for all the groups, not optimized for individual group separately as in the *COP+SPL* scheme. We shall call this technique as the *Cascade Fixed Prob + Split (CFP+SPL)* scheme. The average number of successful users of the *CFP+SPL* scheme can be expressed as follows:

$$T[m,n] = g\sum_{i=0}^{m} b[m,i,\frac{1}{g}]\,T[i,\frac{n}{g}] \tag{5}$$

where $T[i,\frac{n}{g}]$ is the recursive formula as in (1).

The maximum system average number of successful users $T_{CFP+SPL}[m,n]$ of the *CFP+SPL* scheme can be determined in a similar fashion as in the *CFP* scheme. The same boundary conditions as in (1) can be applied here.

F. Uniform (UNI)

All five previous schemes have one feature in common: users consider reservation on each request slot in sequence. This is a common method adopted in most well-known access control algorithms, as it fits well with the conventional system environment where users can repeatedly make reservation attempts on consecutive request slots. In high-speed situation, users will not receive such a chance, *i.e.* only a single attempt is possible at each frame. Under this system condition, the order of request slots becomes irrelevant. Users need not consider each slot in sequence. They may simply select one slot for reservation out of the available slots uniformly. Therefore this new technique will be called the *Uniform (UNI)* scheme. This *UNI* scheme poses some interesting property. First, the system no longer needs to know the number of active users at the start of each frame, making this scheme more practical. Second, unlike the previous schemes where early slots tends to support greater reservation demands than later slots, all request slots can now be uniformly loaded and thus better utilized. The system average number of successful users can be computed as follow:

$$\begin{aligned} T_{UNI}[m,n] &= b[m,0,\frac{1}{n}]\,T_{UNI}[m,n-1] \\ &+ b[m,1,\frac{1}{n}](1+T_{UNI}[m-1,n-1]) \\ &+ \sum_{i=2}^{m} b[m,i,\frac{1}{n}]T_{UNI}[m-i,n-1] \end{aligned} \tag{6}$$

The boundary conditions of (6) are the same as in the *CFP*.

G. Uniform + Limited Access (UNI+LA)

One problem associated with the *Uniform* scheme is that it does not take the number of users into account. Accordingly, its performance can be significantly deteriorated when the number of users is relatively much higher than the number of slots available. This is because all users will definitely place a reservation in one of the slots, collision will most likely be hard to avoid. For example if only two slots are available for ten active users. It is better for most users not to make request. Otherwise, collisions will inevitably take place in both slots. As all users will access the slots, the maximum number of successful users is one and this occurs with a very small chance, *i.e.* nine users access one slot and one of them accesses the other slot. Clearly the *UNI* scheme is not at all effective in this situation. To eliminate such shortcomings, it is essential to find some means to limit the user attempts in accordance with the number of users and available slots. This is achieved by introducing a probability (p) that assists each user to decide whether it will request the slot. Users that find themselves not to access the request slots will do nothing and wait till the next reservation period whereas other users will follow exactly the same step as the Uniform scheme. We shall refer to this scheme as *Uniform + Limited Access (UNI+LA)*. The value of p certainly plays an important role to the system performance and we will now illustrate how the optimal value of p can be analytically determined.

$$T_{UNI+LA}[m,n] = \sum_{i=0}^{m} b[m,i,p]\,T_{UNI}[i,n] \tag{7}$$

We can identify the appropriate transmission probability $p_{UNI-LA}[m,n]$ of the *UNI+LA* scheme by differentiating (7) with respect to p, setting it to 0, and finding p that gives maximum average number of successful users $T_{UNI+LA}[m,n]$. The boundary conditions of (7) is the same as in the *CFP* system.

IV. NUMERICAL RESULTS AND DISCUSSION

A. Performance of the CFP, CAP and COP schemes

Fig. 2. shows the appropriate transmission probability of the CFP scheme as a function of the number of request slots, we can now obtain the maximum system performance for the *CFP* scheme under different total number of users and request slots and this is depicted in Fig. 3. As we can see, the number of successful users clearly increases with the number of slots. For a given number of slots, the more the users access the system the greater the number of successful users. However, its corresponding success rate which is defined as the average number of successful users divided by the total number of users becomes degraded.

Fig. 4 shows the optimal transmission probability derived from the *COP* scheme in (3) for various values of the number of users (M) and slots (N). Using the optimal transmission probability in Fig. 4, we can obtain the system performance for the *COP* scheme under different total number of users and request slots and this is depicted in Fig. 5. As we can see, the *COP* scheme can improve the number of successful users in comparison to the *CFP* scheme. This is as expected, because of two reasons. Firstly, the *COP* scheme can dynamically adjust their transmission probability at each slot in response to the actual system condition. Secondly, the transmission probability is optimally calculated for each system state.

When comparing these two schemes with the *CAP* scheme, it is found that the number of successful users lies between the *CFP* and *COP* schemes. Note that no results of *CAP* are given here at this stage. This behavior can be explained as follows. The *CAP* scheme poses the same feature as the COP scheme in that the transmission probability can be dynamically adjusted at each slot, but the transmission probability is not optimal as it adopts from the *CFP* scheme. Therefore its performance is still below the *COP* scheme but is better than the *CFP* scheme.

B. Performance of the COP+SPL and CFP+SPL schemes

We shall first examine the performance of the *COP+SPL* and then the *CFP+SPL* schemes. The numerical results of the

COP+SPL scheme summarized in Fig. 6 are obtained from the derivation in (4). In the Figure, the number of slots is fixed at 16 while the number of users is varied from 1 to 32. It is very interesting to see that the introduction of split mechanism can substantially increase the average number of successful users and the improvement is increased with the number of groups split. For example, in the case of 32 users with no split only 6 users on average succeed in reservation. When users are split into 2, 4, 8, 16 groups the average number of successful users increases to 6.2, 6.6, 7.4 and 8.8, an equivalence of 3%, 10%, 23% and 47% improvement respectively.

While the results of COP+SPL scheme are found that spilt mechanism is very encouraging, but the results of the CFP+SPL scheme is not as effective, see Fig. 7. As can be seen no difference in performance is observed for different values of group (g = 2, 4, and 8). This is because of all users from different groups much using the same transmission probability. It is certainly not possible chosen probability to be appropriate for groups. Nevertheless at g = 16, there is a slight improvement.

C. Performance of the UNI and UNI+LA schemes

Fig. 8 illustrates the performance comparison of the *UNI* and *UNI+LA* schemes; these numerical results are obtained from (6) and (7). For a given number of slots (*N*), the average number of successful users of both schemes are identical in the area where the number of users (*M*) is less than the number of slots available. However, when the number of users becomes greater than the number of slots, the *UNI+LA* scheme still performs consistently well no increase of average number of successful users though whereas the number of successful users of the *UNI* declines continuously and eventually approaches zero. This is not surprising, as already discussed earlier that when too many users accessing a few number of slots collision is inevitable some means of limiting access would be advantageous and desirable. Nevertheless, in practical system one may wish to ensure that the number of slots is sufficiently provided and hence the *Limited Access (LA)* mechanism may not be needed. If this is the case, we think that the *UNI* scheme is practical and interesting because it is very simple and to implement and yet effective.

D. Performance Comparison with Known Techniques

We shall devote the final part of this section to the performance comparison of all proposed schemes and the existing known techniques namely the *1/m* and exponential backoff schemes; this is depicted in Fig. 11. In this example, the number of slots is set to 16 and the number of users varied from 1 to 32. As we can see, the *COP+SPL* scheme with 16 groups clearly outperforms all other schemes. To explain why, we shall identify two useful guidelines for effective reservation protocol design. Firstly all slots should be uniformly accessed loaded and utilized. Secondly the transmission probability must be truly optimized to accomplish the maximum average number of successful users. It is not difficult to see that the *COP+SPL* scheme poses both properties. For the *CFP, CAP* and *COP* schemes, none of them have the first property. However, they are all designed to meet the second property with the *COP* scheme being the best among them. In contrast, the *CFP+SPL, UNI* and *UNI+LA* schemes fully conform with the first guideline, but they do not satisfy the second guideline. In fact, the *CFP+SPL* scheme with users split into the same number of groups as the number slots is completely identical to the *UNI+LA* scheme.

When comparing all the proposed schemes with the existing known techniques, it is clear that our proposed schemes generally perform better than the existing techniques particularly at small number of users. This is as expected because the existing techniques do not include the number of available slots into consideration. When there are relatively larger number of slots than users, the existing techniques are unable to make use of these additional slots. They keep accessing the request slots at the same rate regardless of how many slots available, leading to low system average number of successful users. At larger number of users, the known techniques begin to offer comparable performance. In summary, the performance of the existing techniques is sensitive to the number of users and slots, whereas the proposed schemes perform consistently well for all system conditions, except for the *UNI* scheme.

V. CONCLUSION

This paper has introduced a new class of channel reservation for media access protocols in high bit-rate wireless systems. Seven new reservation schemes are presented and analytically evaluated. It appears that only the *CFP, UNI* and *UNI+LA* schemes are practically applicable to the system assumption that the base station can obtain the number of active users at the start of each reservation period. Other schemes *CAP, COP, COP+SPL* and *CAP+SPL* require additional information, *i.e.* the number of remaining users at each request slot or the number of users in each split group. Such information is hard to acquire instantly in high-speed environment. Therefore, these schemes will not be practical in high-speed systems. Nevertheless, the performance of *COP+SPL* is the maximum achievable for the access system with a single attempt transmission per frame. Its analysis also provides an interesting aspect to the overall system protocol design. Finally, based on the numerical results it is clear that the *UNI+LA* scheme offers relatively superior performance and practically realizable, hence highly recommended. However, the *UNI* scheme can also be attractive as it offers comparative performance to the *UNI+LA* scheme and is yet very simple to implement but the system must ensure the condition that the number of active users does not exceed the number of slots.

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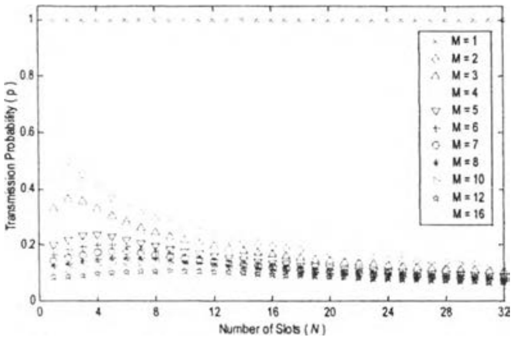

Fig. 2. Appropriate transmission probability with the number of request slots varied from 1-32 and the total number of users varied from 1-16.

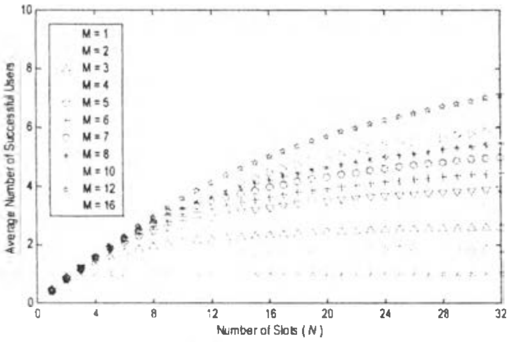

Fig. 3. The number of successful users vs the number of request slots using the transmission probability from Fig. 2 (the *CFP* scheme).

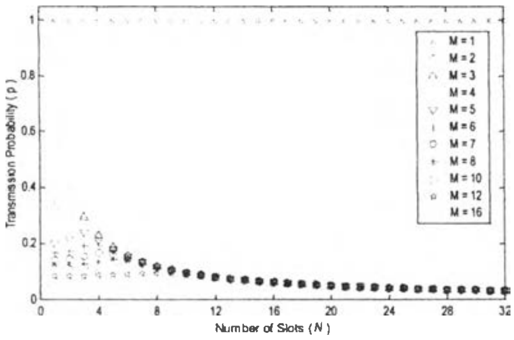

Fig. 4. Transmission probability for the *COP* scheme

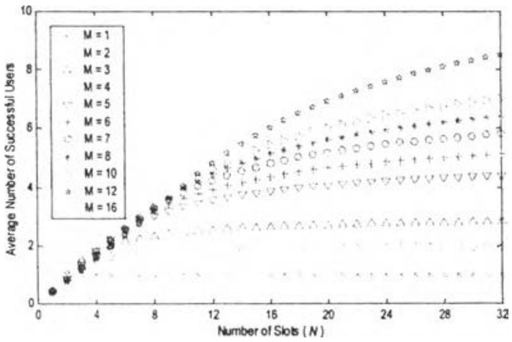

Fig. 5. The number of successful users vs the number of request slots using the transmission probability from Fig. 4 (the *COP* scheme).

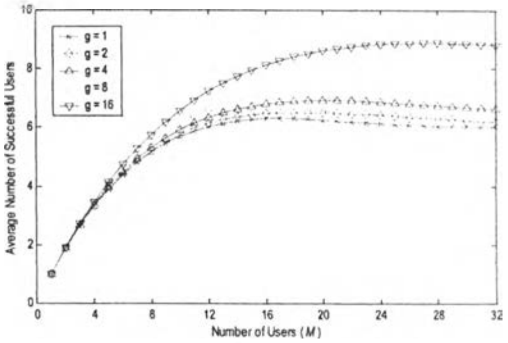

Fig. 6. The number of successful users vs the number of users given a fixed number of 16 slots (the *COP+SPL* scheme).

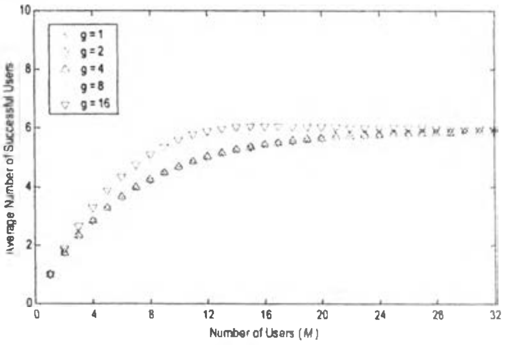

Fig. 7. The number of successful users vs the number of users given a fixed number of 16 slots (the *CFP+SPL* scheme).

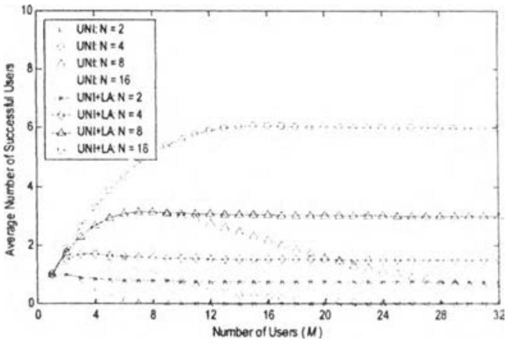

Fig. 8. The number of successful users vs the number of users with varied number of 2, 4, 8 and 16 slots for the *UNI* and *UNI+LA* schemes.

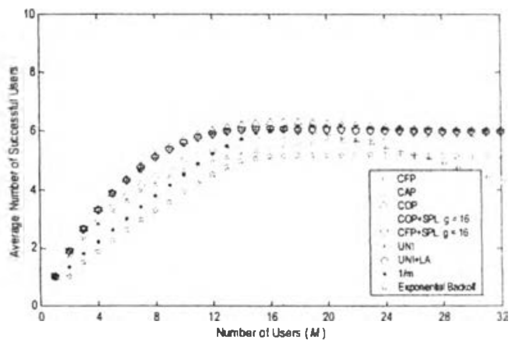

Fig. 11. The number of successful users vs the number of users with 16 slots for all proposed schemes and known techniques.

ประวัติผู้เขียนวิทยานิพนธ์

นายณัฐพล ศิวาโมกข์ เกิดเมื่อวันที่ 25 กรกฎาคม พ.ศ. 2520 ที่อำเภอหาดใหญ่ จังหวัดสงขลา สำเร็จการศึกษาปริญญาตรีวิศวกรรมศาสตรบัณฑิต ภาควิชาวิศวกรรมไฟฟ้า คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย ในปีการศึกษา 2540 จากนั้นได้ศึกษาต่อในหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต สาขาวิศวกรรมไฟฟ้า ภาควิชาวิศวกรรมไฟฟ้า ที่จุฬาลงกรณ์มหาวิทยาลัย เมื่อ พ.ศ. 2541