Performance Evaluation of Channel Reservation Schemes for Reservation-based MAC Protocols with Different Priorities

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***Abstract*—This paper considers the problem of channel reservation schemes for reservation-based MAC protocols with different priorities in wireless communication networks. A framework for designing such channel reservation protocols based on p-persistent is introduced. This framework allows us to explore several different prioritization mechanisms which are devised to serve different prioritization policies or requirements. This leads to the development of five channel reservation schemes, namely, *FPT+MP, FPT+MLT, FPT+SCS, FPT+PCP* and *FPT+HFF*.**

The average number of successful reservations for users of different priorities is evaluated as a primary performance measure. Unlike other previous works where different priorities exhibit strict differentiation, our success ratio (γ) is defined to illustrate how much different priorities are differentiated. In doing so, we seek for a channel reservation scheme that can satisfy the required γ, while maximizing the channel utilization. Numerical results show that the combined scheme of FPT+MP and FPT+SCS schemes is the most effective scheme, possessing all desirable key features.

I. Introduction

In wireless communication networks, a Medium Access Control (MAC) protocol is required to allow a number of mobile users to share a common wireless channel. Since in general mobile users are randomly distributed across the service area, they must compete against each other for a chance to transmit their packets. In conventional random access protocols, such as ALOHA, the channel access is quite flexible: each mobile user is permitted to send its packet whenever it has a packet ready for transmission. However, packet collisions among different mobile users are common and cause low throughput. In contrast, contention-free MAC protocols, such as TDMA, provide much higher throughput but they are not so flexible, as each mobile user is pre-allocated an exclusive portion of channel bandwidth, known as a timeslot, and it must transmit packets only on the assigned timeslot.

Over the past decades, MAC protocols that can combine two aforementioned key advantageous features, i.e., flexibility and efficiency, have been proposed, such as TDD ALOHA Reservation [1], DR-TDMA [2], RAMA [3], R-ALOHA [4], PRMA [5], and DRMA [6]. They are commonly classified as reservation-based MAC protocols. In these protocols, a mobile user first sends a request packet (usually on a contention basis) to the base station for channel reservation. Upon successful reservation, the mobile user is then assigned a data slot by the base station for its data packet transmission on a contention-free basis. Since collisions only occur during the reservation periods, in principle significant channel bandwidth efficiency can be achieved by making reservation slots much shorter than data slots.

Since multimedia services have become so commonplace nowadays, it is important for MAC protocols to provide different quality of services (QoS) for different classes of traffic. For reservation-based MAC protocols, different priorities of traffic can be effectively differentiated during reservation periods and several interesting priority mechanisms have been proposed. Some protocols adopt the policy that all low priority users are required to refrain from transmission until all higher priority users have already successfully accessed the channel [7], [8]. Other protocols suggest policies that are less discriminatory towards low priority users [9], [10]. That is, low priority users are allowed to compete against high priority users, but on average they experience longer delay than those high priority users.

In this paper, we consider prioritization mechanisms for reservation-based MAC protocols, in which the commonly known p-persistent algorithm [11] is applied during the channel reservation period. Mobile users are classified into high and low priority, and referred in this paper as class-1 and class-2 users, respectively. To differentiate between the two classes of users, we propose five different prioritization schemes, namely *FPT with Multiple Probability (FPT+MP), FPT with Multiple Limited Token (FPT+MLT), FPT with Partitioned Contention Period (FPT+PCP), FPT with Shifted Contention Slots (FPT+SCS), and FPT with High-priority Finished First (FPT+HFF).*

For the first three schemes, class-1 and class-2 users are allowed to directly compete against each other to access a channel, using different prioritization mechanisms. These mechanisms are setting higher probability of accessing the channel (FPT+MP), permitting more tokens (FPT+MLT) and allocating more slots (FPT+SCS) for class-1 users, in order to ensure that class-1 users always have a higher chance of successful reservations than class-2 users. For the forth scheme, the available contention slots are partitioned into two groups, each assigned to class-1 and class-2 users separately, such that they do not compete against each other. For the last scheme, the contention slots are always reserved for class-1 users first, and only made available to class-2 users if and only if class-1 users are all resolved.

In order to evaluate the performance of different schemes, we use a success ratio (γ) as our key performance metric. Specifically, γ is defined as a ratio between the success rates of a user from class-1 and class-2 and used to indicate the degree of differentiation in performance between the class-1 and class-2 users. This performance measurement framework is useful as it enables the system to vary the levels of differentiation in performance to any desired value that satisfies a specific priority policy or QoS requirement. Ideally, an efficient channel reservation scheme should not only provide a wide range of priority control (wide range of γ) but also maximize the channel utilization. Thus, we also use throughput as another performance metric.

The rest of this paper is organized as follows. In Section II, we propose channel reservation schemes for two-class traffic. Next, performance evaluation and numerical results are presented and discussed in Section III. Finally, the conclusion are given in Section IV.

II. Proposed Channel Reservation Schemes for Two-Class Traffic

In this section, we propose five channel reservation schemes for serving multi-class traffic of multimedia sources. These include FPT+MP, FPT+MLT, FPT+SCS, FPT+PCP and FPT+HFF. These schemes are extended from the FPT that is concisely described below to support multimedia traffic such as voice, video and data that require different quality of services (QoS). However, in this paper we concentrate on the case of two-class traffic for illustration purpose, although this framework can be extended to multi-class user scenarios. The purpose of these schemes is to allow different classes of traffic to gain access to the channel with different priorities.

In our notation system, we assign the subscript for class-1 users to be “1” and for class-2 users the subscript “2”, where the priority of class-1 users is higher than that of class-2 users. Let M and N be the total number of active users and available contention slots, respectively. S_1 and S_2 are the average number of successful reservations for class-1 and class-2 users, respectively. M_1 and M_2 denote the number of class-1 users and class-2 users, respectively, given that $M_1 + M_2 = M$. Also, let p_1 and p_2 denote the permission probabilities for the class-1 and class-2 users, respectively.

A. Fixed Probability Technique (FPT) for Single-Class Traffic

For FPT, each user will request a reservation with each contention slot in sequence from the first slot to the last, which is fundamentally the same as in p-persistent. In each slot, the user will request access to the current slot with a certain probability, referred to here as the permission probability (p). It is assumed that the value of p is the same for all users and it is fixed throughout for all contention slots. Users also know the outcome of their requests at the end of the slot and can immediately access the consecutive slot in case they did not succeed in the previous slot. A successful user will not be allowed to make another reservation until the end of the frame. It is clear that p is a key parameter to achieve system efficiency, and hence it must be optimally selected according to the traffic and the available system resources. Here, we will determine the appropriate value of p that maximizes the average number of successful reservations, as a function of the number of users and the number of available contention slots.

B. Fixed Probability Technique with Multiple Probability (FPT+MP)

In order to meet different QoS requirements of various traffic types, FPT+MP assigns different permission probabilities to each class of users, such that the high priority (class-1) user has a higher probability of making successful channel reservations than the low priority (class-2) user.

C. Fixed Probability Technique with Multiple Limited Token (FPT+MLT)

FPT+MLT is essentially the same as FPT, except that the lower priority users are allowed to access the contention slots with only a limited number of attempts, which is referred as the number of tokens. Users of the same traffic class are assigned the same number of tokens and it is different from that of another traffic class. Since we assign a larger number of tokens to the high priority users than to low priority users, the high priority users would have a higher chance to obtain a successful reservation, resulting in a negative effect for the low priority users.

D. Fixed Probability Technique with Partitioned Contention Period (FPT+PCP)

FPT+PCP separates the contention slots for the low and high priority users. The high priority users will contend in their own portion and so will the low priority users. Note that the high priority users will never have to compete against the low priority ones. Assigning proper portion of the contention

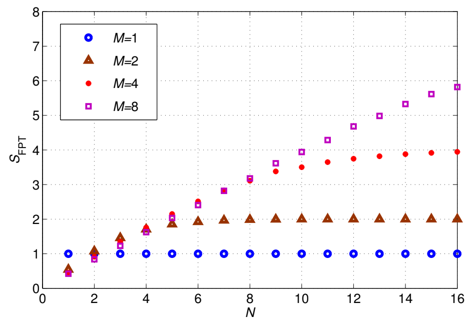


Fig. 1. Average number of successful reservations vs. number of contention slots for FPT.

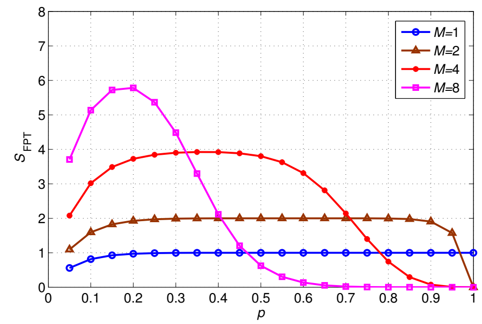


Fig. 2. Average number of successful reservations vs. permission probability of FPT.

slots for these two different classes of users is a key to achieve appropriate prioritization.

E. Fixed Probability Technique with Shifted Contention Slots (FPT+SCS)

In FPT+SCS, the high priority users are entitled to contend in all available slots while the low priority users are required to delay or shift their first attempt till later slots. This mechanism ensures that the high priority users will always have greater advantage.

F. Fixed Probability Technique with High-priority Finished First (FPT+HFF)

In FPT+HFF, the high priority users are entitled to access each available slot in sequence right from the start, while the low priority users are allowed to contend for the channel if and only if all high priority users have successfully completed their reservations. This means that the high priority users will never have to contend against the low priority users and vice versa. Obviously, this scheme adopts a prioritization policy that discriminates much against those low priority users, while offering great benefit to those high priority users.

III. Numerical Results and Discussion

In this section, we evaluate and compare the performance of the proposed schemes, with respect to the average number of successful reservations for both single-class and two-class traffic. For the two-class traffic, we examine the controllable range of γ for various mixtures of the two traffic classes, where

$$\gamma = \frac{(S_1)/(M_1)}{(S_2)/(M_2)}. \tag{1}$$

In addition, the overall average number of successful reservations per frame in a reservation period is calculated as follows:

$$S_{\mathrm{T}} = S_1 + S_2. \tag{2}$$

A. Performance of the Proposed Channel Reservation Techniques for Single-Class Traffic Scenario

Fig. 1 depicts the average number of successful reservations for FPT system as a function of the number of contention slots with different number of users (M = 1, 2, 4 and 8). It can be seen that as the number of available contention slots (N) increases, the average number of successful reservations (S) increases accordingly until reaching the saturation point, except for a trivial case where M = 1. The increases become less significant at higher values of N. However, at sufficiently large values of N, all users will eventually be able to have their requests transmitted successfully. It must be noted that all results are obtained with the optimal probability of success using an appropriate value of permission probability (this issue is discussed in the sequel).

Fig. 2 shows the performance of FPT as a function of the permission probability (p), with the number of contention slots (N) set at 16 and the number of users (M) varied between 1, 2, 4 and 8. For small values of p, the average number of successful reservations (S) clearly increases with p. When p increases up to a certain value, the maximum value of S is reached, and the value of p at this point is defined as the appropriate permission probability. When p further increases S begins to decline and eventually reaches zero when $p = 1$ (there is always collision, except for the case of $M = 1$). It can be seen that the maximum values of S for the systems with M = 1, 2, 4, and 8 are 1, 2, 3.92, and 5.81 which occur with the permission probability of 1, 0.54, 0.37, and 0.18 respectively. This suggests that if there are more users in the system, each user should access the slot with lower permission probability in order to obtain the maximum average number of success reservations.

B. Performance of the Proposed Channel Reservation Techniques for Two-Class Traffic

In this section, the performance of the proposed schemes which can satisfy different γ requirements for different traffic classes is evaluated in terms of the average number of successful class-1, class-2 and overall users, denoted as S_1, S_2, and S_{T}, respectively. The total number of users (M) is fixed at 8 and the number of contention slots (N) is set to 16. The ratio of the number of class-1 users to the number of class-2 users ($M_1 : M_2$) is varied between 1:7, 2:6, 4:4, 6:2, and 7:1 to represent different traffic mixes. The γ is also illustrated in this section in order to show the extent to which different quality of services can be controlled.

Figs. 3(a), 3(b) and 3(c) illustrate the performance of FPT+MP for class-1, class-2, and overall users, respectively, as

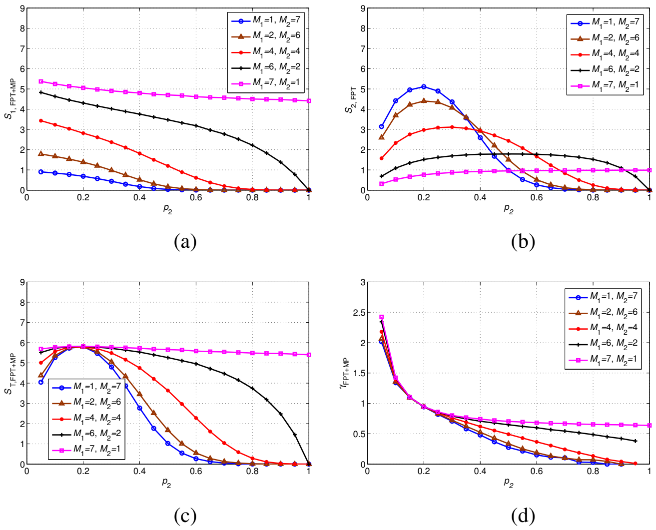


Fig. 3. Performance of FPT+MP.

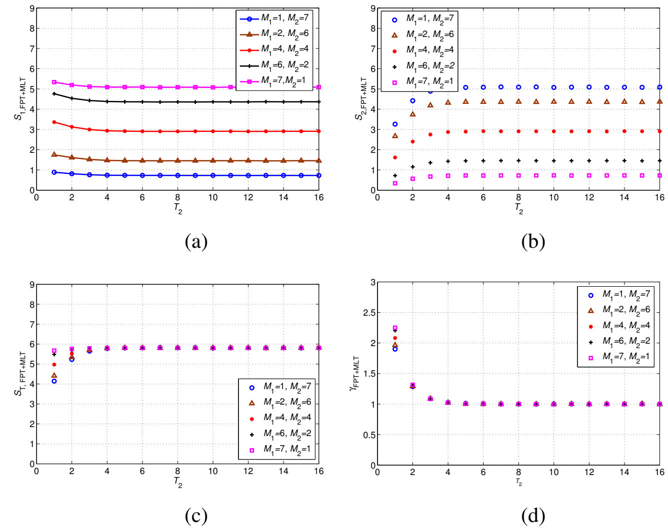


Fig. 4. Performance of FPT+MLT.

functions of the permission probabilities of class-2 users (p_2). The permission probability of class-1 users (p_1) is fixed at 0.18 which is selected from the optimal point of FPT system with $M = 8$ and $N = 16$. As we can see, when p_2 is set to less than 0.18, the average number of successful class-2 users, S_2, is significantly decreased, but there is a relatively small increase in the values of S_1. This means that the reduction in the channel access of class-2 users does not bring in substantial improvement to class-1 users. As a result, when the value of p_2 is set to a value other than 0.18, the overall average number of successful reservations is always lower than the optimal value. The achievable range of γ as illustrated in Fig. 3(d) is found to be rather limited between 0 and 2.5. That is, the class-1 users can have higher success rates than the class-2 users only by up to a factor of 2.5. Note however that the range of γ may be further extended by reducing the values of p_2, but it will be difficult to accurately control the desired value of γ because in this range γ is highly sensitive to the change of p_2.

On the other hand, when p_2 is set to a value slightly greater than 0.18, the class-2 users achieve a marginally improved performance, at the expenses of the class-1 users. When p_2 is increased further, the performance of both class-1 and class-2 users drop and more rapidly degrade when there are a larger number of class-2 users in the system. Since the achievable range of γ in this case is always lower than 1, we will not be discussing it further in this paper. To be more specific, we are only interested in the case whereby γ is greater than 1 since this implies that the higher priority users have higher success rate, than the lower ones, in obtaining the channel.

We further investigate the effect of the number of tokens of class-2 users (T_2) on the system performance. Figs. 4(a), 4(b), and 4(c) show the performance of FPT+MLT for class-1, class-2, and overall users respectively, as a function of T_2. p_1 and p_2 are set to 0.18 corresponding to the optimal point of FPT where $M = 8$ and $N = 16$, as discussed in the previous

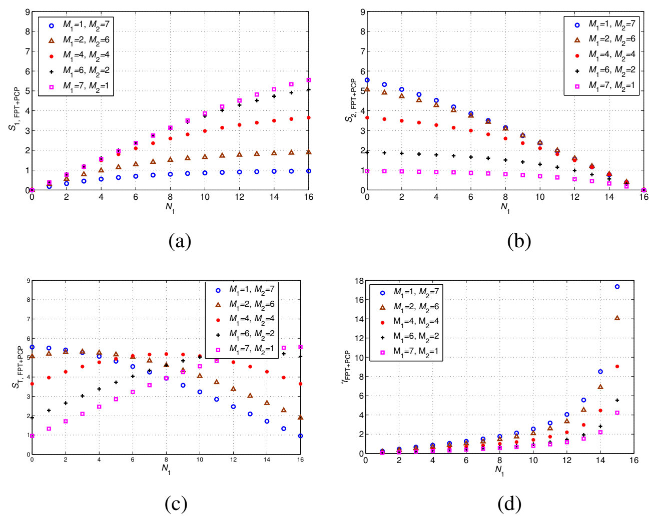
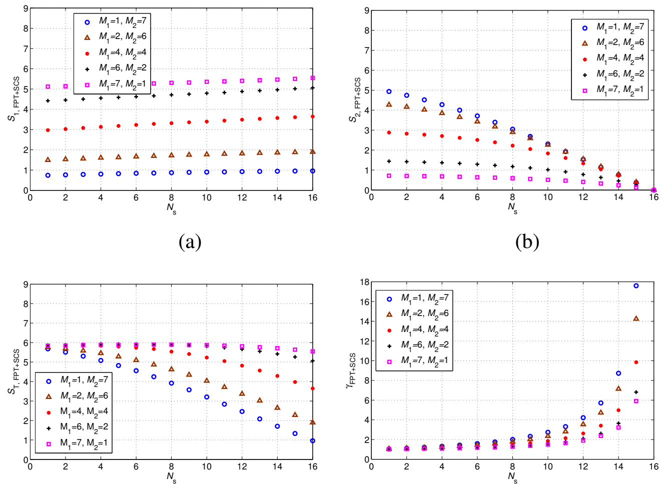


Fig. 5. Performance of FPT+PCP.

scheme. The number of tokens for class-1 users (T_1) is fixed at 16 while T_2 is varied from 1 to 16. It can be seen that when T_2 is increased from 1 to 4, S_1 is decreased while S_2 and S_T are increased. This means that class-2 users can make use of their increased number of tokens in achieving a higher number of successful reservations at the expense of class-1 users. However, when T_2 is increased from 5 to 16, no change in performance of either S_1 or S_2 is observed. Furthermore, the controllable range of γ is limited within a short range (between 1 to 2.3).

Figs. 5(a), 5(b), and 5(c) illustrate the performance of FPT+PCP for class-1, class-2, and overall users, respectively, as functions of the number of contention slots for class-1 users (N_1). p_1 and p_2 are set as 0.18 which is selected from the optimal point of the FPT scheme with $M = 8$ and $N = 16$. N_1 is varied from 0 to 16 and thus the number of slots for class-2



(a) (b)

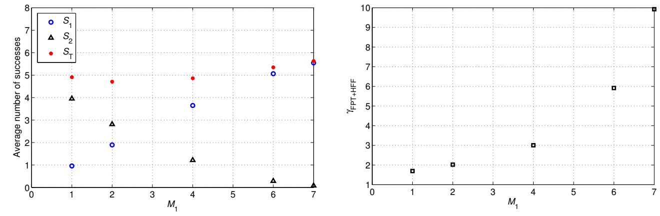
(c) (d)

Fig. 6. Performance of FPT+SCS.

users (N_2) is given by N_2 = 16 - N_1. As we can see, when N_1 is increased, S_1 also increases while S_2 decreases. This is as expected because an increase of N_1 means that more slots are available to the class-1 users and, on the contrary, fewer slots are available for the class-2 users. Results in Fig. 5(d) reveal an interesting key feature of this scheme that the controllable range of γ is much larger than for the previous two schemes, i.e., 0 to 18 for FPT+PCP and only about 0 to 2.5 for FPT+MP and 1 to 2.3 for FTP+MLT. This means that FPT+PCP can support different classes of users with a larger range of γ requirements.

Figs. 6(a), 6(b), and 6(c) illustrate the performance of FPT+SCS for class-1, class-2, and total users, respectively, as functions of the number of shifted contention slots (N_s). For the same reason as in the previous case, p_1 and p_2 are set to 0.18. The number of shifted contention slots (N_s) is varied from 1 to 16 while N is fixed to 16. It can be seen that when N_s is increased (meaning that the number of available slots for class-2 users is reduced), S_2 is largely decreased especially when the majority of users are the class-2 users. Interestingly, only a slight increase of S_1 is observed. This implies that S_T always decreases with increasing N_s, as evident in Fig. 6(c). Since unlike other schemes, the class-1 users are always given priority over the class-2 users, the values of $\gamma_{\mathrm{FPT+SCS}}$ are always greater than one; this is illustrated in Fig. 6(d). It is shown that FPT+SCS provides a wide range of γ, i.e., 1 to 18, which is a much larger range than that of FPT+MP and FPT+MLT and nearly the same as that of FPT+PCP.

Fig. 7(a) shows the average number of successful reservations of FPT+HFF for class-1, class-2, and overall users, as the functions of M_1. The total number of users and the number of contention slots are $M = 8$ and $N = 16$, respectively. The number of class-1 users (M_1) is varied as 1, 2, 4, 6, and 7. The permission probability of both classes of users is fixed at 0.18. As we can see, when only a small number of class-1 users contend for the reservation channel, a big portion of contention slots is left for class-2 users. Hence, the average number of successful reservations of class-2 users will be relatively high. For example, when M_1 equals to 1 and 2, the average number of successful reservations of class-2 is 3.9 and 2.81, respectively. However, when the number of class-1 users gets higher, the number of successful reservations of class-2 users drops considerably since there are only a few slots left available for them. For example when M_1 equals to 6 and 7, the average number of successful reservations of class-2 users is as small as 0.2 and 0.01, respectively.

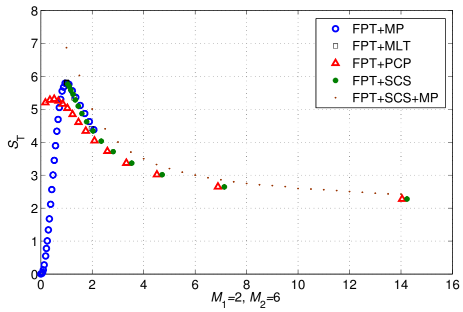


(a) (b)

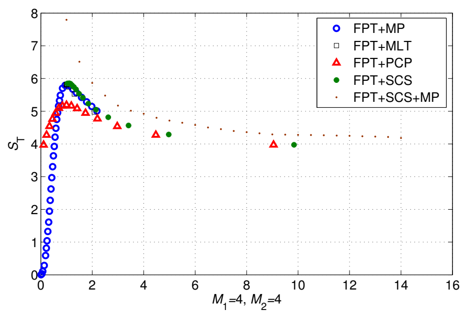
Fig. 7. Performance of FPT+HFF.

Fig. 7(b) illustrates the relationship between γ and M_1. It indicates that the value of γ increases rapidly with M_1. For $M_1 = 1$, the value of γ is 1.7 and when M_1=7, the value of γ is 10. Moreover, we notice that there is always only a single value of γ corresponding to any proportion between class-1 and class-2 users. As a result, unlike other schemes, FPT+HFF has no mechanism to control the value of γ.

Having discussed the advantages and disadvantages of each channel access scheme rigorously, we are ready to compare them directly with respect to the achievable overall average number of successful reservations (S_T) given the same targeted γ. Fig. 8 shows the relationship between S_T and γ for all five schemes plus another scheme that combines the key features of SCS and MP mechanisms and is referred to as the FPT+SCS+MP scheme under different ratios of the controllable ranges of γ of FPT+MP and FPT+MLT are almost the same and obviously shorter than that of FPT+PCP and FPT+SCS, while FPT+HF can provide only a single value of γ. For a given value of γ, that is greater than 1, FPT+PCP provides the lowest value of S_T, while other schemes provide comparable performance with respect to S_T. As we can see, FPT+SCS is the only scheme that possesses two key desirable features: achieving high overall average number of successful reservations and offering a wide controllable range of γ. However, this scheme has a weakness in that only a finite number of feasible values of γ can be obtained. In contrast, there are many feasible values of γ for FPT+MP. Therefore, in order to reach a higher level of performance, we propose to combine key features of FPT+SCS and FPT+MP, and this combined scheme is called the FPT+SCS+MP. Numerical results in Fig. 8 show that FPT+SCS+MP is superior to all other schemes, as it is able to control an arbitrary level of γ by assigning both the number of shifted contention slots for



(a)



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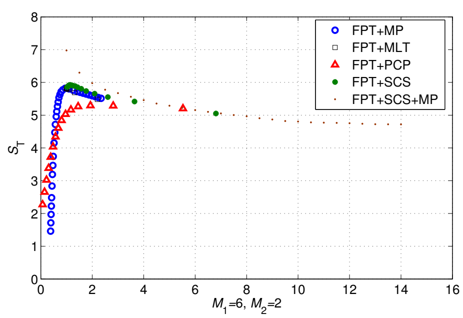

(c)

Fig. 8. Performance comparison of all proposed schemes for different two traffic classes.

class-2 users and the different values of limiting probability for each traffic class. The overall average number of successful reservations is also higher than all other schemes.

It is also worth mentioning that in all schemes the values of S_{T} always decrease at high values of γ. This implies that, if the quality of service between two traffic classes is intended to be greatly differentiated, the overall system throughput will be affected. The reason is as follows: in order to achieve high values of γ, it is necessary to limit the access from user class-2, to reduce the success rate of the class-2 users. Thus, the overall success will generally be degraded. Notice also that the controllable range shown in Fig. 8(a) is greater than in Figs. 8(b) and 8(c). This is because there are a larger number of class-2 users in the systems in Fig. 8(a) than the others, meaning that more class-2 users can be suppressed.

IV. Conclusion

In this paper, we have proposed five channel reservation schemes for supporting two-class traffic with different success ratio (γ) requirements. Theses proposed schemes include FPT+MP, FPT+MLP, FPT+PCP, FPT+SCS, and FPT+HFF which are extended from FPT. The performance of all proposed schemes in terms of the average number of successful reservations and the controllable range of γ are evaluated through extensive simulations. The results show that each scheme has different characteristics and is useful for different γ requirements. FPT+MP can provide very fine control on γ, but the controllable range is quite limited. FPT+MLT offers similar features and the same level of performance to that of FPT+MP, except that the control of γ is rather coarse. In contrast, when a wide controllable range of γ is a prime concern, FPT+PCP and FTP+SCS are preferable, as the values of γ can be extended much further. Between these two, FTP+SCS can, in general, accomplish higher throughput than FTP+PCP. A more effective scheme than these five schemes is devised by combining the key features of FTP+MP and FPT+SCS into a new scheme namely, FTP+SCS+MP. The resulting FTP+SCS+MP scheme is found to be superior to all other schemes in both aspects: achieving a wide controllable range of and maximizing the overall average number of successful reservations. Another important finding is that a strictly discriminated prioritization policy as adopted in FTP+HFF lacks flexibility in differentiating between two classes of users. This suggests that a useful and desirable controllability feature can be obtained by applying the schemes that are less discriminated against low priority users.

References

[1] S. Tasaka, K. Hayashi, and Y. Ishibashi, "Integrated video and data transmission in the TDD ALOHA-reservation wireless LAN," *IEEE Proc. ICC'95*, vol. 3, pp. 1387-1393, 1995.

[2] J. F. Frigon, V. C. M. Leung, and H. C. B. Chan, "Dynamic reservation TDMA protocol for wireless ATM networks," *IEEE J. Select. Areas Commun.*, vol. 19, no. 2, pp. 370-383, Feb. 2001.

[3] N. Amitay and L. J. Greenstein, "Resource auction multiple access (RAMA) in the cellular environment," *IEEE Trans. Veh. Technol.*, vol. 43, no. 4, pp. 1101-1111, Jan. 1994.

[4] X. Ma and H. H. Refai, "Analysis of sliding frame R-ALOHA protocol for real-time distributed wireless networks," *Wireless Networks*, vol. 15, no. 8, pp. 1102-1112, Nov. 2009.

[5] S. Elnoubi and A. M. Alsayh, "A packet reservation multiple access (PRMA)-based algorithm for multimedia wireless system," *IEEE Trans. Veh. Technol.*, vol. 53, no. 1, pp. 215-222, Jan. 2004.

[6] X. Qiu and V. O. K. Li, "Dynamic reservation multiple access (DRMA): A new multiple access scheme for personal communication system (PCS)", *Wireless Networks 2*, pp. 117-128, 1996.

[7] T. P. -Kazakos, N. B. Likhanov and B. S. Tsybakov, "A protocol for random multiple access of packets with mixed priorities in wireless networks," *IEEE J. Select. Areas Commun.*, pp. 1324-1331, Nov. 1995.

[8] I. Stavrakakis and D. Kazakos, "A multiuser random-access communication system for users with different priorities," *IEEE Trans. Commun.*, pp. 1538-1541, Nov. 1991.

[9] W. S. Chung and C. K. Un, "Collision resolution algorithm for M-priority users," *IEE Proceedings Communications 142*, pp. 151-157, June 1995.

[10] J. G. Lee and M. S. Corson, "The performance of an "imbedded" Aloha protocol in wireless networks," *Proceedings of PIMRC'96*, Oct. 1996.

[11] L. Kleinrock and F. A. Tobagi, "Packet switching in radio channels: Part I - Carrier sense multiple-access modes and their throughput - delay characteristics," *IEEE Trans. Commun.*, vol. COM-23, no. 12, Dec. 1975.