**行政院國家科學委員會補助專題研究計畫** □ 成果報告 ■期中進度報告

# 廣義的機會式通訊：無線行動網路中之競爭、合作與感知--子計畫二:感知無線行動網路之協力式跨層設計（2/3）

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中 華 民 國 98 年 5 月 26 日

# 行政院國家科學委員會專題研究計畫成果報告

## 廣義的機會式通訊：無線行動網路中之競爭、合作與感知
## 子計畫二：感知無線行動網路之協力式跨層設計（2/3）

## Cooperative Cross-Layer Design in Cognitive Wireless Mobile Networks (2/3)

計畫編號：NSC 96-2628-E-009-003-MY3
執行期間： 97/08/01~98/07/31
計畫主持人：李大嵩 教授 國立交通大學電信工程學系
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**中文摘要**

協力式網路的中的媒體存取控制(MAC)協定設計在多封包接收(MPR)通道是一個富挑戰性的題目，但是尚未有文獻發表。在本計畫中，我們提出一個利用合作變異(cooperation diversity) 的媒體存取控制協定來改進多封包接收通道的吞吐量(throughput)。我們提出的方法可以有效率地利用使用者沒有封包傳送的空檔，因此降低了一般中繼階段可能產生的吞吐量損失。透過馬可夫鏈(Markov Chain)模型，我們做了最壞狀況的吞吐量數學分析。並且得到(i)因同時傳輸的中繼封包干涉對直接鏈結造成的吞吐量懲罰的封閉式上界; (ii)傳送失敗的使用者因協力式中繼傳輸所獲得吞吐量增益的封閉式下界。分析的結果讓我們可以直接根據多封包接收通道係數檢視所提出協定的吞吐量性能。模擬結果不但證實了提出方法在系統吞吐量的優點，也驗證了分析的正確性。

***Abstract*—**Medium access control (MAC) protocol design for cooperative networks over multi-packet reception (MPR) channels is a challenging topic, but has not been addressed in the literature yet. In this paper, we propose a MAC protocol to exploit the cooperation diversity for throughput enhancement over MPR channels. The proposed approach can efficiently utilize the idle periods for packet relaying, and can thus effectively limit the throughput loss resulting from the relay phase. By means of a Markov chain model, the worst-case throughput analysis is conducted. Specifically, we derive (i) a closed-form upper bound for the throughput penalty of the direct link that is caused by the interference of concurrent packet relay transmission; (ii) a closed-form lower bound for the throughput gain that a user with packet transmission failure can benefit thanks to cooperative packet relaying. The results allow us to investigate the throughput performance of the proposed protocol directly in terms of the MPR channel coefficients. Simulation results confirm the system-wide throughput advantage achieved by the proposed scheme, and also validate the analytic results.

***Keywords*—*Multi-Packet Reception; Medium Access Control; Cross-Layer Design; Cooperative Communications.***

## I. INTRODUCTION

Effective medium access control (MAC) mechanisms are crucial for achieving high throughput, low delay, and quality-of-service (QoS) provisioning. Most of conventional MAC protocol designs are based on the collision channel model, which however ignores the multi-packet reception (MPR) capability at the physical (PHY) layer. Recent works that exploit a realistic MPR channel model [1] for MAC protocol design can be found in [2]-[4]. All of these proposals require dynamic adaptation of the active user set for exploiting the MPR advantage, either through exhaustive search over the network traffic conditions or resorting to certain channel reservation mechanisms. Cooperative communication is known as an important technique for exploiting the multi-user diversity for system performance improvement. In the MAC layer, different types of cooperative MACs [5-7] are proposed, all of which are however devised only for the single packet reception scenario.

MAC protocol design for cooperative systems over MPR channels is more challenging, and is typically subject to the following concerns. Firstly, the central controller (CC) may require the knowledge of the MPR channels of all links, as well as the traffic conditions of all users, to determine the access set. However, this calls for extra communication overhead, and will degrade the system-wide throughput, especially in a large-scale mobile network. Secondly, when packet reception failure occurs due to collision, a certain portion of the users may have to serve as the relay for data retransmission. Without properly designed MAC protocols for realizing the cooperative advantage, this may again lead to overall throughput degradation. To the farthest of our knowledge, MAC protocol designs for cooperative MPR channels have not been found in the literature yet.

Recently, relying on a simple flag-assisted mechanism and an associated multi-group priority (MGP) scheduling strategy, a new MPR MAC protocol was proposed in [8]. The MGP scheme has several distinctive features that make it a potential candidate for cooperative MPR MAC designs. Firstly, in the MGP scheme the users are allowed to access the channel according to some prescribed service priority. There is no need for active user selection through exhaustive search based on the channel knowledge and local traffic conditions. This will thus considerably reduce the communication overhead in dense cooperative networks. Secondly, the flag-bit can provide the CC with the knowledge of each user’s buffer status. Combined with the multi-group service priority, channel access can then be reserved for both direct data transmission and packet relaying in a more balanced fashion. Hence, in a high collision environment, the throughput penalty incurred by the relay period can be largely reduced. To realize the aforesaid advantages, we extend the MGP scheme and propose a MAC protocol for cooperative networks over MPR channels. Specific contributions of this paper can be summarized as follows.

1) The proposed protocol, hereafter termed as the cooperative MGP (CMGP), is to our best knowledge the first cooperative MPR MAC scheme. It is free from any assumptions on the channel and is applicable to the general heterogeneous environment [9].

2) The number of users permitted for channel access is deterministically set to attain the MPR channel capacity. This prevents the channel from being over-loaded, thereby avoiding irrecoverable packet failure due to collisions.

3) Based on the Markov chain analysis, the closed-form formulae of the average throughput penalty and gain from cooperation are derived. The results allow us to investiage such throughput impact based on various PHY and MAC performance indeces. In particular, it can be shown that, under a slight traffic condition, the throughput degradtion due to packet relaying tends to diminish if the MPR capability of the PHY layer is strong enough.

4) Even though the direct-link users may suffer certain throughput loss, the proposed CMGP protocal exploits the cooperative diversity and does result in a system-wide throughput advantage. This will be verified through numerical simulation.

## II. Preliminary

### A. System Scenario

We consider the uplink transmission of a centralized cooperative wireless network, in which the CC and the user terminals are equipped with the MPR capability. We assume that the transmission is slotted, and the CC controls the user access to a common wireless channel. At the beginning of each time slot the CC determines an access set according to some user scheduling rule to be specified later, and broadcasts this message to initialize data transmission. Due to the broadcast nature of the wireless channel, the CC and all the inactive users can receive the transmitted packets. Depending on whether or not the packet is successfully received at the CC, an ACK or NAK is sent by the CC over the wireless channel and will be received by all users. When the packet reception failure occurs, one of the inactive users who successfully decode the packet will serve as the relay during some future channel access period.

### B. MPR Matrix

In this paper we extend the so-called MPR channel matrix [2] to specify the MPR capability at the receiver. Assume that the total number of users is $M$. Let $U$ be a permutation of the index set

$\{1,2,\cdots,M\}$ that represents a particular order of the user service schedule. Then the MPR matrix for a given $U$ is described as

$$\mathbf{C}(U) \triangleq \begin{bmatrix} C_{1,0}(U) & C_{1,1}(U) & & & \\ C_{2,0}(U) & C_{2,1}(U) & C_{2,2}(U) & & \\ \vdots & \vdots & \vdots & & \\ C_{M,0}(U) & C_{M,1}(U) & C_{M,2}(U) & \cdots & C_{M,M}(U) \end{bmatrix}, \quad (1)$$

where

$$C_{n,k}(U) = \Pr\{\, k \text{ packets correctly received} \mid n \text{ packets from first } n \text{ users in } U \text{ are transmitted}\}$$

for $1 \le n \le M$ and $0 \le k \le n$. We note that, according to the setting (1), different permutation index sets $U$ in general result in different MPR matrices. Denotes $C_n(U) \triangleq \sum_{k=1}^{n} kC_{n,k}(U)$ the expected number of correctly received packets when $n$ packets are concurrently transmitted. The capacity of an MPR channel for the particular $U$ is defined as $\eta(U) = \max_{n=1,\cdots,M} C_n(U)$ . Note that the numbers of simultaneously transmitted packets to achieve the channel capacity may not be unique. Let

$$n_0(U) \triangleq \min\left\{\arg \max_{n=1,\cdots,M} C_n(U)\right\} \quad (2)$$

be the minimum amount of capacity-achieving packets. Hence the maximal number of users permitted to access the channel should be $n_0(U)$, since there will be no further improvement in system capacity if more than $n_0(U)$ users are simultaneously served. Note that the MPR matrix (1) can be determined via the physical layer performance metric such as bit error rate; an illustrative example based on CDMA communication can be found in [2].

### C. *Highlight of the MGP Protocol [8]*

As in [2] it is assumed that each user has a buffer of size two for storing two data packets. The central idea behind the MGP scheme is to append a flag-bit at the tail of the transmitted packet to inform the CC with the next buffer status (see Figure 1 for a schematic description). The flag will be set ON if there is a packet in the buffer,

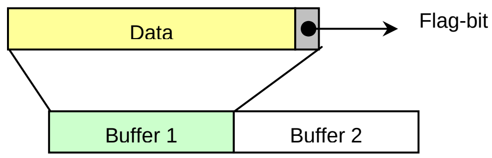



Figure 1. Packet formats.

and is set OFF when otherwise. By exploiting such an on-off flag signature, the MGP scheme classifies the users into three groups with different service priorities: the ACTIVE group consisting of the users with flag-bit ON, the STANDBY group consisting of those with flag-bit OFF, and the PRe-Emptive (PREM) group accommodating those who have stayed in the STANDBY or the ACTIVE group for longer than a certain waiting period $S$ . The inclusion of the complementary PREM group is to avoid unfair scheduling that can occur in a binary grouping strategy: Without the PREM mechanism, users in the STANDBY group would suffer an unlimited service delay since the channels could be constantly reserved for some ACTIVE links with heavy traffic. Based on the tri-group user classification scheme, the channel access priority (from high to low, respectively) is PREM, ACTIVE, and STANDBY. According to such a service strategy, at the beginning of each time slot a total number of $n_0$ users are selected for data transmission, where $n_0$ is the minimal number of users that achieves the capacity of the MPR channel. In case that the CC fails to successfully received the packet sent from, say, user $i$, the CC schedules the service priority of user $i$ according to the previous flag record. We shall note the followings:

a) In the MGP scheme the number of users permitted for channel access is deterministically set to attain the MPR channel capacity. This prevents the channel from being overloaded, thereby avoiding irrecoverable packet failure due to collision.

b) Under light or moderate traffic environments, a significant portion of the users could be in the idle phase (i.e., no data packets to send). If packet reception failure occurs, the idle periods can then be exploited for packet relaying to reduce the possible throughput loss. This can be effectively accomplished via a natural extension of the MGP protocol, as discussed next.

## III. COOPERATIVE MULTI-GROUP PRIORITY PROTOCOL

The flag-bit is the instrumental mechanism for facilitating the multi-group priority based user service in the MGP protocol. The central idea of the proposed CMGP scheme is to exploit the flag-bit message for distinguishing the direct links from the relay ones. By assigning different service priority to different types of links, the throughput degradation due to packet relaying can be limited, and an increase in the network-wide throughput can be achieved.

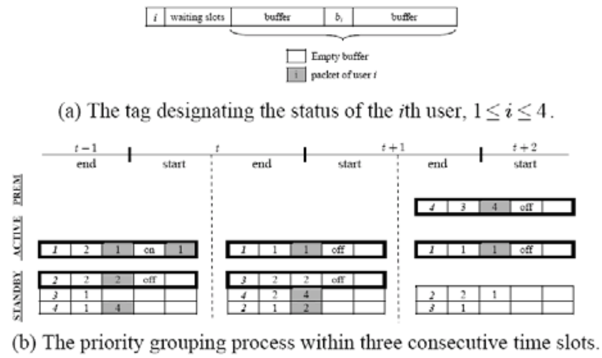
### *A. Operation of the Proposed CMGP Protocol*

If user $i$ is permitted to access the channel, as in the MGP scheme a flag-bit $b_i$ is appended at the tail of the packet upon transmission. The flag signature is ON ($b_i = 1$) only if the second buffer is non-empty and contains a data packet also of user $i$. The flag signature is instead OFF ($b_i = 0$) when either one of the following cases is true: i) the second buffer is empty, ii) the second buffer is nonempty but the packet therein is received from user $j \neq i$. Upon successful packet reception, the CC decodes the flag-bit message and then schedules the user access according to the MGP protocol. If packet reception failure occurs at the CC and user $k$ ($k \neq i$), who has empty second buffer, successfully decodes this packet, user $k$ can serve as the relay in some upcoming channel access period. If none of the users can serve as the relay, which happens when all other users' buffers are non-empty or none of the users can successfully received the packet, user $i$ then re-transmit this packet during his/her next channel access. We note the following key features regarding the proposed protocol:

1) The adoption of the flag-bit provides an inbuilt mechanism for CC to dintinguish between the direct and relay-or-idle links for service scheduling. Users with flag-bits ON for direct data transmission will be arranged into either the ACTIVE or the PREM group, and thus enjoy potentially higher channel access priority. This prevents possibly frequent data relaying when collision occurs, thereby reducing the throughput penalty.

2) Thanks to the PREM mechanism, users who are not permitted to access the channel over a time duration longer than the threshold $S$ will be granted with the highest service priority. This can limit the processing delay of the relay links,and maintain the QoS requirement.

3) In the proposed protocol, each user takes his/her turn to access the channel according to the prescribed service priority. There is no need for active user identification, and the protocol complexity can be substantially reduced.



(a) The tag designating the status of the $i$th user, $1 \le i \le 4$.

(b) The priority grouping process within three consecutive time slots.

Figure 2. An illustrative example.

### *B. An Illustrative Example*

This subsection uses an example to demonstrate the proposed CMGP protocol. We consider a network of $M = 4$ users, and assume for simplicity that i) the MPR channel capacity is $n_0(U) = 2$ irrespective of the index set, and ii) the time slot threshold for being promoted into the PREM group is $S = 3$. The traffic status of user $i$ is summarized in a tag shown in Figure 2 (a), in which the first field represents the user ID, second field is the counts of waiting slots, forth field marks the status of the flag-bit, third and fifth fields represent the content of the two buffers. Figure 2 (b) depicts the operation of the proposed protocol during three consecutive time slots, and is also explained below.

At the end phase of slot *t-1*:

The PREM group is empty; user 1 is in the ACTIVE group, users 2, 3, 4, are in the STANDBY group.

At the start phase of slot $t$:

User 1 (with $b_1 = 1$) and user 2 (with $b_2 = 0$) are allowed for channel access.

At the end phase of slot $t$:

(i) The packet of user 1 is successfully received by CC; user 1 remains ACTIVE but the flag is updated to $b_1 = 0$ since its second buffer is empty.

(ii) The packet of user 2 is not successfully received by CC; user 2 is put into the bottom of the STANDBY group (assumes current $b_2 = 0$ at CC).

(iii) User 3 successfully decodes the packet of user 2 and will serve as the relay.

At the start phase of slot $t+1$:

User 1 (with $b_1 = 0$) and user 3 (with $b_3 = 0$) are allowed for channel access.

At the end phase of slot $t+1$:

(i) User 3 successfully relays the packet of user 2 to CC, and is then put to the STANDBY group since $b_3 = 0$.

(ii) The CC fails to successfully receive the packet of user 1, and thus does not correctly decode the current bit message. User 1 remains ACTIVE since the latest flag message available to the CC is the previous setting $b_1 = 1$.

(iii) User 2 successfully received the packet of user 1 and will serve as the relay.

(iv) User 4 (with $b_4 = 0$) has not been allowed to access the channel for more than $S = 3$ time slots, and is moved into the PREM group.

At the start phase of slot $t+2$:

User 1 (with $b_1 = 0$) and user 4 (with $b_4 = 0$) access the channel.

## IV. Analysis of the Proposed Protocol

Recall that the proposed CMGP protocol exploits the idle periods of the MGP scheme for packet relaying. Hence, during each time slot there are in general more concurrently transmitted packets as compared with the MGP method. Even though packet relying can compensate for the throughput loss due to packet reception failure, the increase in the number of active relay links, however, will introduce stronger interference toward direct data transmissions. The throughput loss caused by the relay-induced interference is thus one major limiting factor for the overall system performance. By regarding the achievable throughput of the MGP scheme as a benchmark, this section aims to characterize the throughput performance of the proposed CMGP protocol. We shall note that the exact analysis for the general case, however, is quite difficult. In this section we will focus on the interference-limited worst case, in which *there is only one direct link, and the other* $n_0(U)-1$ *users serve as the relay*. Although the performance evaluation based on such a worst-case scenario could be conservative, our analyses are quite appealing in that the problem formulation becomes tractable. As will be shown below, we can derive a closed-form upper bound for the throughput penalty incurred by the relay interference, as well as a closed-form lower bound for the throughput gain benefiting from user cooperation, directly in terms of the MPR matrix coefficients. This allows us to deduce several interesting features regarding the proposed CMGP protocol.

We shall note that the *effective* relay candidates are those users with a good link condition and low packet generating probability (or, low packet blocking probability). Based on this observation, we can derive a closed-form upper bound for the worst-case throughput penalty suffered by the direct-link user in terms of the MPR matrix coefficients in (1); the result allows us to further analyze the throughput results under various direct-link channel conditions. In the sequel we let $\{u_1,\cdots,u_{n_0(U)}\}$ be the index set for the active users; without lose of generality we assume that $u_1$ denotes the direct-link user.

To proceed, we resort to the Markov chain based analysis. A reasonable model for the evolution of the buffer status is the birth-and-death process with a finite number of states [10]. With the aid of this model, we have the following theorems (see appendix for the proofs).

**Theorem 4.1:** Assume that, without user cooperation, the packet blocking probability $p_{u_1}^B$ of user $u_1$ is smaller than some positive $\delta$, i.e., $p_{u_1}^B \le \delta$. Then the throughput penalty $\Delta_{u_1}^p$ of the direct-link user $u_1$ in the CMGP protocol is upper bounded by

$$\Delta_{u_1}^p \le \Delta_{u_1} + \frac{\delta\left(A_{u_1} + B_{u_1}\right)}{A_{u_1} + \delta B_{u_1}}, \qquad (3)$$

where

$$\Delta_{u_1} = C_1\left(\{u_1\}\right) - C_{n_0(U)}\left(U\right) + C_{n_0(U)-1}\left(U \setminus \{u_1\}\right), \qquad (4)$$

and $A_{u_1}$ and $B_{u_1}$ are some constants which depend on the packet generating probability and the successful packet transmission probability. □

The upper bound in (3) splits into a sum of two terms: the first term $\Delta_{u_1}$ is completely characterized by the PHY-layer signal separation capability in terms of the MPR matrix, whereas the second term $\frac{\delta\left(A_{u_1}+B_{u_1}\right)}{A_{u_1}+\delta B_{u_1}}$ depends also on the MAC traffic condition. In the extreme case that $\delta \to 0$ (or $p_{u_1}^{B} \to 0$), the throughput upper bound (3) is entirely determined by the MPR channel quality as

$$\Delta_{u_1}^{p} \le \Delta_{u_1} = C_1\left(\{u_1\}\right) - C_{n_0(U)}\left(U\right) + C_{n_0(U)-1}\left(U \setminus \{u_1\}\right). \quad (5)$$

In the considered worst-case scenario, we can also specify a lower bound for the throughput gain that a user with packet transmission failure can benefit owing to cooperative packet relaying. More specifically, we have the following theorem.

**Theorem 4.2:** Suppose that the user $u_j$, where $u_j \in U \setminus \left\{u_2, \cdots, u_{n_0(U)}\right\}$, suffers from the packet transmission failure. Then, due to cooperative packet relay from some other user $u_k \in \left\{u_2, \cdots, u_{n_0(U)}\right\}$, the user $u_j$ can enjoy at least a throughput gain $\Delta_{u_j}^{g}$:

$$\Delta_{u_j}^{g} \ge p\left(C_{n_0(U)}\left(U\right) - \min_{u_k \in \left\{u_2, \cdots, u_{n_0}\right\}} C_{n_0(U)-1}\left(U \setminus \{u_k\}\right)\right), \quad (6)$$

where $p$ is the packet generating probability. □

We emphasize that, even though there could be a throughput penalty for the direct-link users, the proposed CMGP protocol does exploit the cooperative diversity: This will enhance the throughput of users with poor channel conditions (i.e., the users subject to frequent packet reception failure can benefit from data relaying through cooperation with other strong MPR links), and therefore can result in a network-wide throughput gain, as will be seen in the simulation section.

## V. SIMULATION RESULTS

We consider a CDMA network with randomly generated spreading codes. The packet length, spreading gain, and number of correctable errors in each packet are, respectively, 200, 6, and 2. We assume that there are a total number of $M = 8$ users square deployed in the network, among which users 2, 4, 5, and 7 are nearby the CC and users 1, 3, 6, and 8 are located far away from the CC. The MPR matrix of the considered system scenario can be derived in an analogue way as in [2].

### *A. Throughput Results for Near- and Far-End Users*

We investigate the throughput results for near-end and far-end users in both cooperative and non-cooperative environments. The results are depicted in Figure 3. As we can see, due to poor channel conditions the average throughput of the far-end users is almost zero without cooperation. However, when cooperation with near-end users is allowed, throughput up to about $0.4$ for the far-end users can be achieved when the packet generating probability $p$ is not large. Also, there is a significant increase in the overall throughput when compared with the non-cooperative case. For the near-end users, it is important to see that the throughput penalty is almost zero even though a certain portion of the channel access will be dedicated to packet relaying. This is mainly because, in the proposed CMGP protocol, only the idle periods are exploited for the relay phase, and the service priority of the relay users are potentially lower than the direct data transmission links. Figure 4 further shows the resultant average delay performance. It can be seen that, without cooperation, even a small packet generating probability ($p \approx 0.1$) results in severe delay penalty. However, if cooperation is allowed, the delay performance become more robust against the increase in $p$. Fig. 5 compares the simulated average throughput gain (per user) with the theoretical lower bound (6). As we can see, the analytic result shows close agreement with the simulated outcome in a low traffic scenario ($p \le 0.15$). However, there is a large discrepancy as the traffic load becomes heavy. This is reasonable since the lower bound (6) is derived specifically for the low traffic environment, in which idle periods are available and can be exploited for packet relaying. Fig. 6 further compares the simulated throughput penalty (per user) with the theoretical upper bound (3). The result shows that the upper bound (3) tends to be conservative. Actually, the throughput loss due to packet-relaying interference is pretty small (<0.02) in the proposed CMGP protocol.

### *B. Throughput Results in a Dense Environment*

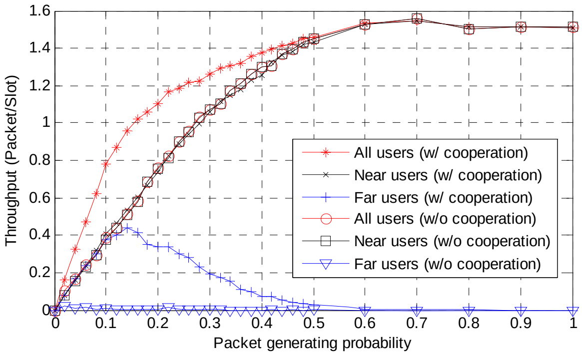



Figure 3. Average throughput of near, far and all users.

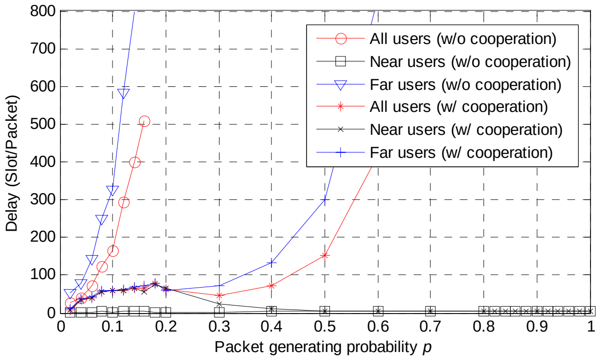



Figure 4. Average delay of near, far and all users.

Figure 7 further illustrates the throughput performance as the total number of users increases; the aggregate traffic load is set to be 80% of the channel capacity, i.e., 1.2 packets per slot. The proposed CMGP method is seen to achieve the maximal throughput of 1.18 when the number of users equals 48; this yields about a 140% throughput gain as compared with the MGP. As the number of users increases, both methods are subject to throughput floors, but the CMGP still results in a 34% gain as compared with the MGP.

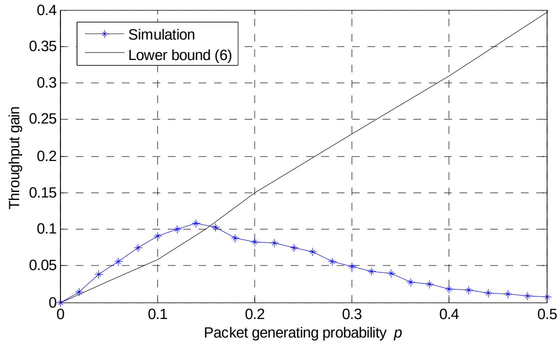



Figure 5. Lower bound of throughput gain derived from Theorem 4.2.

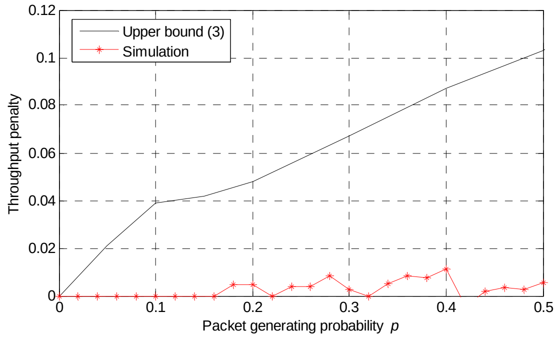



Figure 6. Upper bound of throughput penalty derived from Theorem 4.1.

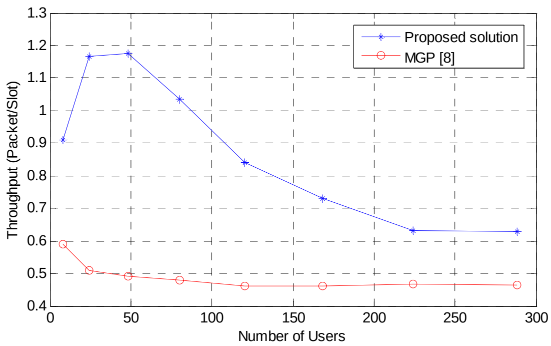



Figure 7. Average throughput in a dense environment.

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# 計畫成果自評

一、研究內容與原計畫相符程度

部份相符。

二、達成預期目標情況

1. 以第一年發展之協力式通訊架構為基準，探討用戶增加時對系統效能包含吞吐量的影響。
2. 基於吾人所提之協力系統架構下，與現存的方法進行效能比較，藉以修正改良吾人所提出的方法。
3. 經由理論分析與模擬驗證，深入探討用戶數量的改變如何影響本計劃所提出之協力式媒體存取控制協定。
3. 利用已建立之多節點協力式通訊系統模擬平台，驗證整體研究成果。
4. 計畫成果已投稿於國際會議（PIMRC 2009），目前審核中。

三、研究成果之學術或應用價值

協力式多封包接收媒體存取控制協定之理論分析方法。

四、是否適合在學術期刊發表或申請專利

適合在學術期刊發表。

五、主要發現或其他有關價值

由於數位信號處理能力及微波技術的日新月異，通訊網路的實體層多具備多封包接收的能力，例如 CDMA、MIMO、WiMAX 等。因此能充分利用此特性的跨階層媒體存取控制愈顯重要。

# 可供推廣之研發成果資料表

□ 可申請專利　　■ 可技術移轉　　　　　　　　　　　　　　　　　日期：98 年 5 月 26 日

| | |
|---|---|
| **國科會補助計畫** | 計畫名稱：廣義的機會式通訊：無線行動網路中之競爭、合作與感知--子計畫二:感知無線行動網路之協力式跨層設計<br>計畫主持人：李大嵩 教授<br>計畫編號：NSC 96-2628-E-009-003-MY3　　學門領域：通訊 |
| **技術/創作名稱** | 具多封包接收能力之協力式媒體存取控制協定 |
| **發明人/創作人** | 楊雯芳、吳卓諭、李大嵩 |
| **技術說明** | 中文：<br>透過馬可夫鏈(Markov Chain)模型，我們做了最壞狀況的吞吐量數學分析。並且得到(i)因同時傳輸的中繼封包干涉對直接鏈結造成的吞吐量懲罰的封閉式上界; (ii)傳送失敗的使用者因協力式中繼傳輸所獲得吞吐量增益的封閉式下界。。 |
| | 英文：<br>By means of a Markov chain model, the worst-case throughput analysis is conducted. Specifically, we derive (i) a closed-form upper bound for the throughput penalty of the direct link that is caused by the interference of concurrent packet relay transmission; (ii) a closed-form lower bound for the throughput gain that a user with packet transmission failure can benefit thanks to cooperative packet relaying. |
| **可利用之產業<br>及<br>可開發之產品** | 可利用之產業：<br>1. 寬頻無線通訊產業<br>可開發之產品：<br>1. 第四代行動通訊系統 |
| **技術特點** | 利用實體層多封包接收的能力來設計協力式媒體存取控制協定，能有效改善傳統非跨層、非協力式的媒體存取控制性能。 |
| **推廣及運用的價值** | 由於數位信號處理能力及微波技術的日新月異，通訊網路的實體層多具備多封包接收的能力，例如 CDMA、MIMO、WiMAX 等。因此能充分利用此特性的跨階層媒體存取控制愈顯重要。 |

※　1. 每項研發成果請填寫一式二份，一份隨成果報告送繳本會，一份送　貴單位研發成果推廣單位（如技術移轉中心）。

※　**2. 本項研發成果若尚未申請專利，請勿揭露可申請專利之主要內容。**

※　3. 本表若不敷使用，請自行影印使用。