行政院國家科學委員會專題研究計畫　成果報告

子計劃四:寬頻網際網路上區域無線網路之頻寬存取控制技術(2/2)

計畫類別： 整合型計畫
計畫編號： NSC91-2219-E-009-037-
執行期間： 91 年 08 月 01 日至 92 年 07 月 31 日
執行單位： 國立交通大學資訊工程學系

計畫主持人： 楊啟瑞

報告類型： 完整報告

處理方式： 本計畫可公開查詢

中　華　民　國 92 年 10 月 6 日

行政院國家科學委員會補助專題研究計畫成果報告

寬頻網際網路端對端技術之研究(2/2)–子計劃四
寬頻網際網路上區域無線網路之頻寬存取控制技術

計畫類別：□個別型計畫　　■整合型計畫
計畫編號：NSC91-2219-E-009-037
執行期間： 91 年　8　月　1　日至　92　年　7　月　31　日

計畫主持人：楊啟瑞　教授
共同主持人：
計畫參與人員：

成果報告類型(依經費核定清單規定繳交)：□精簡報告　■完整報告

本成果報告包括以下應繳交之附件：
□赴國外出差或研習心得報告一份
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□出席國際學術會議心得報告及發表之論文各一份
□國際合作研究計畫國外研究報告書一份

處理方式：除產學合作研究計畫、提升產業技術及人才培育研究計畫、列管計畫及下列情形者外，得立即公開查詢
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執行單位：交通大學資訊工程系所

中　華　民　國　92　年　9　月　18　日

行政院國家科學委員會專題研究計畫成果報告

寬頻網際網路上區域無線網路之頻寬存取控制技術

Multiple Access Control Technology for Local Wireless Networks in Broadband Internet

計畫編號：NSC91-2219-E-009-037

執行期限：91 年 8 月 1 日至 92 年 7 月 31 日

主持人：楊啟瑞　　國立交通大學資訊工程研究所

一、中文摘要

大部分現今的頻寬存取方法皆不甚穩定，結果當訊務增加時，效能急遽地降低。去年，我們提出一個穩定且有效的方法，*Hexanary-Feedback Contention Access (HFCA)*，除了能提供高效能的訊務處理能力外，同時在無線網路上亦能提供最大的的產能。HFCA採用漸進式的contention resolution，透過一個two-phase的程序處理部份的使用者。這個two-phase的程序是以hexanary feedback control與Pdf-based Multi-user Estimator (PMER)在網路實體層實作而成。PMER在contention slot內藉由比對接收訊號的envelope/phase pdf's histograms與預先建立的pdf函式庫，來推估正確的使用者個數(0到5)。為了能更進一步了解HFCA的效能，在今年我們以嚴謹的方式進行其效能(throughput)與穩定性(stability)分析，結果顯示HFCA滿足wide-sense stable與stric-sense stability condition的特性。

關鍵詞：無線存取網路，競爭存取，回饋控制，最大穩定產能，飽和產能，envelope/phase機率函數。

二、英文摘要

Most existing contention access schemes are inherently unstable resulting in exponentially deteriorating throughput under increased traffic loads. In the last year, we proposed a *wide-sense stable*, efficient *Hexanary-Feedback Contention Access (HFCA)* scheme, capable of providing signaling traffic high performance while retaining maximal throughput for wireless access networks. HFCA performs incremental contention resolution, managing a small subset of users at a time via a two-phase process. The two-phase process is augmented with hexanary feedback control facilitated by a Pdf-based Multi-user Estimator (PMER) implemented at the physical layer. Basically, PMER measures the exact number of transmitting users (zero to five) in a contention slot by matching the envelope/phase pdf's histograms of received signals to a pre-constructed pdf's library. To formally justify the performance of HFCA, in this year we present throughput and stability analyses in which HFCA is shown wide-sense stable and the strict-sense stability condition is derived.

Keywords: Wireless access networks, contention access, feedback control, maximum stable throughput, saturated throughput, envelope/phase probability density function

(pdf).

三、計畫緣由與目的

Wireless access networks are expected to support multiple services [1] with a wide range of service rates and different Quality of Service (QoS) requirements. Expected supported services include Constant Bit Rate (CBR), Variable Bit Rate (VBR), Available Bit Rate (ABR), and in-band signaling traffic for making bandwidth reservation for above traffic. It has been shown that the former three types of guaranteed (or semi-guaranteed) traffic could be efficiently governed by reservation access [2]. The signaling traffic, on the other hand, is most suitably directed by contention access [2,3,4]. It is well known that contention access incurs inevitable collisions, resulting in throughput deterioration and dissatisfaction of QoS requirements under increased traffic loads. A key challenge pertaining to such wireless access networks has been the design of contention access satisfying access efficiency and QoS guarantees [3].

Existing Time Division Multiple Access (TDMA) [5,6] methods can be categorized as either Frequency-Division-Duplex (FDD) [5], or Time-Division-Duplex (TDD) [6]. In our work, we focus on the design of a TDMA FDD-based contention access scheme. Due to high cost for maintaining global minislot synchronization, we disregard the mini-slot-based approach in our work.

Among prevailing schemes, splitting-based collision-resolution algorithms [9,10,11] have been considered promising. The basic idea behind the design is to speed up the resolution process by probabilistically [9] or time [10,11] splitting contenders into transmitting and non-transmitting sets based on various types of feedback that is made available to users. There are three types of feedback- binary feedback, ternary feedback [9,11], and multiplicity feedback [10]. In particular, multiplicity feedback allows users to have full knowledge of the exact number of users involved in a collision. Compared to binary/ternary feedback, multiplicity feedback enables greatly improved access efficiency, however, at the expense of unmanageable implementation complexity.

The goal of the last year's project was to design an efficient, tractable *hexanary feedback-based* contention access (HFCA) scheme, in which hexanary feedback can simply be facilitated in hardware, as shown in Figure 1. In this year, we further complete the detailed throughput analysis. In addition, we analytically prove that HFCA is wide-sense stable, and derive the necessary and sufficient condition for HFCA to be strict-sense stable.

四、結果與討論

The basic idea behind the design is to overcome system instability by probabilistic reducing the contention size to less than six, followed by efficient collision resolution with the aid of hardware-based hexanary feedback. The hexanary feedback informs six possible outcomes- idle, success, and two- to five-user collisions.

4.1. Basic Operation

The HFCA operation within a frame consists of repeated executions of admission and resolution phases. The two-phase process repeats until the maximum blocking probability is satisfied (before all users are resolved). Notice that new users that become active during the current frame's contention period are inhibited from transmitting.

Immediately prior to the first phase, the mean number of MT's wishing to transmit, i.e., the initial group size (denoted as N), is

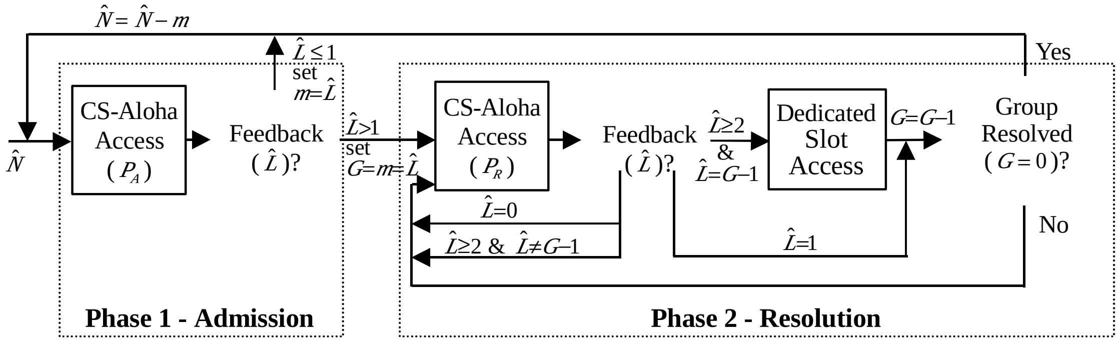

Figure 1. Two-phase algorithm of HFCA.

revealed to the BS via a priori call distribution or simple prediction. Notice that it can be easily shown that HFCA is robust against prediction discrepancy. The priori or predicted initial group size, denoted as $\hat{N}$, is then broadcast to all MT's via the downlink channel. In the admission phase, each active MT accesses the subsequent slot based on the Controlled Slotted-Aloha (CS-Aloha) protocol parameterized by admission probability, $P_A(\hat{N}) = \copyright_{opt} / \hat{N}$, where $\copyright_{opt}$ is the optimal value yielding maximized saturated throughput. Upon receiving the signal, PMER estimates the number of colliding MT's ($\hat{L}$). If a collision occurs ($2 \le \hat{L} \le 5$), the operation proceeds to the second phase. All active MT's are in turn notified with the $\hat{L}$ value, and assign the value to the reduced group size (m). If $\hat{L} \le 1$, the current two-phase cycle terminates. If the number of colliding MT's exceeds five ($\hat{L} > 5$), which happens with small probability, no user can be admitted and a feedback of $\hat{L} = 0$ is returned, resulting in one-slot waste.

In the resolution phase, each admitted unresolved MT designates its transmitting probability inversely proportional to the current number of MT's in the group. Namely, each MT accesses the next contention slot based on the CS-Aloha protocol parameterized by resolution probability $P_R(G) = 1/G$, where G is the current group size. At the end of slot access, each MT takes different actions depending on the feedback ($\hat{L}$). If $\hat{L} = 1$ (success), the current group size (G) is decremented by one. If $\hat{L} = 0$ (idle), or $\hat{L} \ge 2$ (collision) but $\hat{L} \ne G-1$, resolution recursively repeats with G remained unchanged. Significantly, if $\hat{L} \ge 2$ (collision) but $\hat{L} = G-1$, by taking advantage of having a single MT in the non-transmission set, HFCA allows dedicated access within the subsequent slot to this MT. All other MT's in the transmission set result in one slot delay and reduce G by one. The phase-two operation repeats until all admitted group users are resolved, i.e., $G = 0$.

4.2. Throughput and Stability Analyses

System regenerative points are placed at the beginning of each contention period. Let $\tilde{N}$ and N respectively represent the random variable and variable for the total number of active MT's wishing to transmit requests at the beginning of the contention period of a frame. $\tilde{N}$ is assumed Poisson distributed with parameter ~. We assume all N users are resolved at the end of the contention period. Denote by random variable $\tilde{C}_N$ the contention period length, namely the total number of slots required to resolve the user group of size N; and $C_N = E[\tilde{C}_N]$. Let variable m denote the first reduced group size, i.e., the number of active MT's admitted at the end of phase one. Denote by random variable $\tilde{D}_m$ the total number of slots required to resolve all m users in a reduced group in phase two; and $D_m = E[\tilde{D}_m]$.

(i) Computation of C_N

If there is no request ($N = 0$), or only a single request ($N = 1$), wishing to transmit in the first slot (first phase), the contention period lasts for one slot, that is $\tilde{C}_0 = \tilde{C}_1 = 1$. For $N \ge 2$, the probability that exactly m of N users make transmissions and are admitted in the first phase is

$$Q_N(m) = \binom{N}{m}(\frac{\copyright}{N})^m(1-\frac{\copyright}{N})^{N-m} \qquad 0 \le m \le N. \tag{1}$$

Given that m of N users have made transmissions, the contention period length can be expressed recursively as

$$\begin{cases} \tilde{C}_{N|m} = 1 + \tilde{D}_m + \tilde{C}_{N-m} & N > m \ge 2,\ N \ge 2 \\ \tilde{C}_{N|m} = 1 + \tilde{D}_m & N = m \ge 2,\ N \ge 2 \\ \tilde{C}_{N|m} = 1 + \tilde{C}_{N-m} & m < 2,\ N \ge 2\ . \end{cases} \tag{2}$$

We now compute C_N. First, we have $C_0 = C_1 = 1$. For $N \ge 2$, C_N can be derived by taking expectation from Equation (2). Taking expectation on both sides of Equation (2), and by unconditioning, one gets

$$C_N = 1 + \sum_{m=2}^{N} Q_N(m) \cdot D_m + \sum_{m=1}^{N-1} Q_N(m) \cdot C_{N-m} + Q_N(0) C_N,\ N \ge 2\ . \tag{3}$$

Solving for C_N, we obtain

$$C_N = \frac{1 + \sum_{m=2}^{N} Q_N(m) \cdot D_m + \sum_{m=1}^{N-1} Q_N(N-m) \cdot C_m}{1 - Q_N(0)} \qquad N \ge 2\ . \tag{4}$$

(ii) Computation of D_m

Given that i of m users ($m \ge 2$) in the reduce group made transmissions in the first slot of phase two, the phase-two period length can be formulated recursively as

$$\tilde{D}_{m,i} = \begin{cases} 1+\tilde{D}_{m-1} & i=1 \\ 2+\tilde{D}_{m-1} & i=m-1 \\ 1+\tilde{D}_{m} & i=0,\ 2\le i<m-1, \text{ or } i=m \end{cases} \quad (5)$$

For $m \geq 2$, the probability that exactly i of m users have made transmissions in the first slot of phase two is

$$R_m(i) = \text{鷸}\text{偎} (\frac{1}{m})^i (1- \frac{1}{m})^{m-i} \quad m \quad 2 . \quad (6)$$

To compute D_m for $2 \le m \le N$, we first have $D_1 = 1$. We next solve the second boundary condition for D_2 by the following recursive equation: $D_2 = 1 + R_2(1)?D_1 - [1 \quad R_2(1)] \ D_2$. We get $D_2 = 3$. For $m > 2$, taking z-transform from both sides of Equation (5), unconditioning variable i, and solving for $F^*_{\tilde{D}_m}(z)$, we obtain the recursive form as

$$F^*_{\tilde{D}_m}(z) = \frac{F^*_{\tilde{D}_{m-1}}(z)\text{賑}z \ R_m(1) + z^2 ?R_m(m \quad 1)]}{1- z?[1- R_m(1) - R_m(m \quad 1)]} \quad m \quad 3 . \quad (7)$$

Taking the first derivative of $F^*_{\tilde{D}_m}(z)$ at $z=1$, we obtain

$$D_m = \sum_{k=3}^{m} \frac{1+ R_k(k-1)}{R_k(1) + R_k(k-1)} + D_2 + D_1 \quad m \quad 3 , \quad (8)$$

where $D_1 = 1$ and $D_2 = 3$ which have been previously derived.

(iii) Throughput Computation

Since $\tilde{N}$ is Poisson distributed, with C_N (and D_m) given by Equations (4) and (8), the system throughput can be given as

$$\bar{S} = \frac{E[\tilde{N}]}{E[C_{\tilde{N}}]} = \frac{\sum_{N=0}^{\infty} N \cdot \frac{e^{-\sim} \sim^N}{N!}}{\sum_{N=0}^{\infty} C_N \cdot \frac{e^{-\sim} \sim^N}{N!}} . \quad (9)$$

Notice that $\bar{S}$ in Equation (9) is a function of ~ and ©. We now define *saturated throughput* ($\bar{S}_{sat}$), and *maximum stable throughput* ($\bar{S}_{\max}$). First, $\bar{S}_{sat}$ is defined as

$$\bar{S}_{sat} \ \square \lim_{\sim \to \infty} \bar{S}. \quad (10)$$

The optimal value $©_{opt}$ applied during phase one is chosen such that $\bar{S}_{sat}$ is maximized, i.e., $\bar{S}_{sat}(©_{opt}) = \max\{\bar{S}_{sat}(©), \forall ©\}$. A system is WSS if it has a positive saturated throughput. Maximum stable throughput ($\bar{S}_{\max}$) is the maximum achievable throughput when the system is stable.

To numerically evaluate $©_{opt}$, $\bar{S}_{sat}$, and $\bar{S}_{\max}$, we carried out analytic computation via Mathematica 4.0. Since Poisson converges to the Gaussian distribution with the same mean and variance ~, we consider $N_{\max} = \sim + 5\sqrt{\sim}$ to be applied in Equation (10), resulting in sufficiently high confidence to the evaluation ($P(N > \sim + 5\sqrt{\sim}) < 2.86653 \times 10^{-7}$). First of all, for a given ~, $©_{opt}$ was determined by using Mathematica function *FindMinimum*[1- $\bar{S}$ [$N_{\max}$, ~ , $©_{opt}$], $©_{opt}$]. We obtained that $\bar{S}_{sat}$ is maximized under $©_{opt} = 1.52$. Applying $©_{opt}$ to $\bar{S}$ in Equation (10) with $\sim \geq 400$, we got $\bar{S}_{sat} \approx 0.522$. HFCA is proved WSS. Applying the $©_{opt}$ value and using *FindMinimum*[1- $\bar{S}$ [$N_{\max}$, ~ , 1.52], ~], we reveal that $\bar{S}$ is maximized at $\sim_{\max} = 1.88$. Applying the $\sim_{\max}$ value to $\bar{S}$ in Equation (9), we arrive at that $\bar{S}_{\max} = 0.605$ at $\sim_{\max} = 1.88$.

(iv) Stability Analysis

First, since $\bar{S}_{sat} \approx 0.522$, HFCA is WSS. Second, notice that ratio N / C_N can be perceived as the effective service rate. Then, if there exists a lower bound of N / C_N, then there exists a *system capacity* [17] defined as the supremum of new arrival rates that ensure strict-sense stability of the system. Due to mathematical intractability for deriving the closed form of C_N from Equation (4), we derived C_N and N / C_N by means of numerical computation. We claim in the following remark that the system capacity of HFCA is $\bar{S}_{sat}$, i.e., HFCA is SSS is the new arrival rate is lower than $\bar{S}_{sat}$.

Remark: The HFCA system is SSS if the new arrival rate is lower than $\bar{S}_{sat}$.

First, numerical results show that N / C_N ($N \geq 1$) is a monotonically decreasing function. Next, by taking advantage of linearty of C_N, we obtain

$$\bar{S}_{sat} = \lim_{\sim \to \infty} \frac{E[\tilde{N}]}{E[C_{\tilde{N}}]} = \lim_{\sim \to \infty} \frac{\sim}{C_{E[\tilde{N}]}} = \lim_{\sim \to \infty} \frac{\sim}{C_{\sim}} . \quad (11)$$

Namely, N / C_N converges to $\bar{S}_{sat}$. We can conclude that N / C_N is lower bounded by $\bar{S}_{sat}$, i.e., $N / C_N \geq \bar{S}_{sat} \approx 0.522$. Therefore, if the new arrival rate is lower than $\bar{S}_{sat}$, it is lower than the effective service rate N / C_N, the system is SSS. ■

五、計畫成果自評

The complete work including the design and analysis has been accepted by *IEEE Transaction on Wireless Comm.*. Finally, the basic design and architecture has been applied for patents.

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七、可供推廣之研發成果資料表

■ 可申請專利　■ 可技術移轉　　日期：92 年 9 月 18 日

國科會補助計畫	計畫名稱：寬頻網際網路上區域無線網路之頻寬存取控制技術 計畫主持人：楊啟瑞　教授

	計畫編號：NSC91-2219-E-009-037　　學門領域：電信
技術/創作名稱	在無線區域存取網路上以六回饋方法所設計的競入存取技術
發明人/創作人	楊啟瑞 教授
技術說明	中文： 發展這個技術的主要目的在於克服無線通訊環境下，當系統同時要競入的使用者過多時，會造成系統不穩定的情形。此技術的基本概念是以機率方法來降低競入群中使用者的數量，使其不超過 6，再以硬體支援的 6 回饋機制來有效解出同時競入的使用者。詳細的運作過程可分為兩個階段，當同時要競入的使用者在第一階段被隨機選擇後，被選中者在第二階段依續解出，直到所有的使用者都完成競入過程或已滿足最大的阻斷機率時才停止。
	英文： The basic idea behind the technique is to overcome system instability by probabilistic reducing the contention size to less than six, followed by efficient collision resolution with the aid of hardware-based hexanary feedback. The operation of this design within a frame consists of repeated executions of two phases-admission and resolution phases. While a group of MT's is randomly selected in the admission phase, the selected group is resolved in the resolution phase. The two-phase process repeats until either the maximum blocking probability is satisfied or all users are resolved.
可利用之產業 及 可開發之產品	可供無線區域網路相關產業開發高效能之無線網卡。
技術特點	目前的無線網路的競入存取技術(contention access)大部份是利用 2 或 3 回饋的設計，已知最高的穩定效能只能到 0.487，本技術能將效能提高至 0.522(穩定)/ 0.552(最高值)，為目前全球已知相關研究的最高數值。
推廣及運用的價值	無線區域網路的應用日漸多元，但最基本的競入效能問題仍不能有效解決，透過本技術之輔助，不僅能大幅提昇無線網路的效能，同時也能增加在訊務量大時的網路穩定度。

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。