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

為 IEEE 802.11 (b) 無線區域網路所設計的動態負載平衡方法

計畫類別：☑ 個別型計畫　　□ 整合型計畫
計畫編號：NSC 91－2213－E－009－064－
執行期間：　91　　年　8　月　1　日至　92　　年　7　月　31　日

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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

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中　華　民　國　92　年　7　月　31　日

一、計畫中文摘要及關鍵詞

隨著無線技術漸漸地被普遍採用來架構區域網路，以無線方式傳輸資料的品質愈加重要。由電氣和電子工程師協會(IEEE)所提出的 802.11 標準中提出一種無線網路傳輸資料的方法，稱為基礎建設模式(Infrastructure mode)。在基礎建設模式的無線網路中，所有的無線裝置都要透過一台稱為存取中心(Access Point)的機器來接收或傳送資料。若是一個無線裝置可以有機會連接到多個存取中心來傳輸資料，此無線裝置會選擇能夠提供最好的傳輸品質的那個存取中心來連接。舉例來說，在一個大型的會議廳中，同時有數百台以無線方式上網的筆記型電腦要透過分布在此會議廳的四個存取中心來連接上網際網路(Internet)，對任何一台筆記型電腦而言，要如何選擇連接上哪一台存取中心才能有較好的傳輸品質，便是本計劃所要研究探討的。

如何在基礎建設模式的無線網路中達到動態平衡執行負荷(dynamic load balancing)並不只是單純的將所有的無線裝置平均分配給所有的存取中心而已，有許多因素是可以列入考量的，比方說根據無線訊號的強度或是分配到的頻寬傳輸量等。在參考文獻[2]中就提出了一種以無線訊號強度為考量的演算法來達到動態平衡執行負荷。本計劃將根據頻寬傳數量的考量來設計與實作三個不同的基礎建設模式無線網路系統，同時也分析評估此三種提供動態平衡執行負荷的設計在有效性、效能、與計算時間消耗上的關係。

關鍵詞：無線區域網路、基礎建設模式、動態平衡執行負荷

二、計畫英文摘要及關鍵詞

As the wireless technology becomes a common solution to set up a local area network (LAN) gradually, the quality of transmitting data by wireless media is more important. One of the general applications of wireless local area network (WLAN) is called infrastructure mode proposed by IEEE Std 802.11[1]. The infrastructure mode is a centralized wireless network and all wireless devices send or receive data through a special device called access point (AP). If there were more than one AP that a wireless device can connect to, the wireless device would choose and connect to the one that can provide the best transmission quality. For example, there are hundreds of notebook computers with wireless interface cards in a big conference hall and all of the computers have to access the Internet through the only four APs distributed in the conference hall. How to select the best AP dynamically for a notebook computer so that it can get the best accessing quality is the issue that we research into in this project.

The problem of dynamic load balancing for IEEE 802.11 infrastructure mode wireless network is not just a problem of distributing all wireless devices equally to all APs. There are many factors that could be considered, such as signal strength [2] or data throughput. This project will design and implement three variances of infrastructure mode system that support the dynamic load balancing for IEEE 802.11 wireless network by detecting the immediate data throughput. This project will also study the effectiveness, performance, and computation overhead of dynamic load balancing mechanism on the three different IEEE 802.11 infrastructure mode wireless network systems.

Keywords： wireless area network, infrastructure mode, dynamic load balancing

三、報告內容

(一) 前言

隨著無線技術快速發展與成熟，利用無線方式來連接上網際網路(Internet)的應用漸漸地被普遍的採用，而隨著網際網路上的資料型態漸漸趨向於有豐富聲光效果的多媒體資料，對於無線介質(wireless media)所能提供的頻寬也成為提供無線網路服務的重要條件。

在現實生活裡，由電氣和電子工程師協會所提出 802.11 標準的(IEEE Std 802.11)無線區域網路中，使用的傳輸介質(medium)為無線電波，由於無線介質的特性，所有要利用無線電波上網的無線裝置必須共享特定無線電波頻帶所提供的頻寬來上網，而在基礎建設模式(Infrastructure mode)的架構下，被稱為存取中心(Access point)的主機會提供一個特定的無線電波頻率供其他使用相同頻率的無線主機透過此存取中心來連接上網際網路，而當有超過一台存取中心主機存在時，這些存取中心主機便可以使用相同或是不同的頻率來構成一個基礎的無線網路架構，而要透過此無線網路架構來連接上網際網路的無線主機，便可以選擇任何一個可以連接上的存取中心來連接上網。因為單一存取中心主機所能提供的頻寬有其上限，所以由多台存取中心主機所構成的無線網路架構便可以提高整個無線網路的總頻寬，但若是大多數的無線主機都選擇透過相同的存取中心上網，那這些無線主機平均所能分配到的頻寬便會受到單一存取中心主機所能提供頻寬的限制，而同時其它的存取中心所提供的頻寬可能就不會被充分的使用。

在基礎建設模式的無線網路中採用動態平衡執行負荷(Dynamic load balancing)的機制，是以控制無線主機選擇連接上網的存取中心主機的方式來有效利用頻寬。根據無線主機與存取中心主機之間的資料傳輸品質來做動態調整，使無線主機可以隨時找到能夠提供較好的傳輸品質的無線資料傳輸連線(Wireless data link)，並透過提供此連線的存取中心主機上網。

(二) 研究目的

隨著無線網路設備逐漸被普遍用來架設區域網路，特別是基礎建設模式的無線網路架構應用更是一般架設無線區域網路的方法，再加上網際網路上的資料類別逐漸偏向多媒體化，對於無線網路頻寬的大量需求是可以預期的。因此，除了積極開發擁有更加快速傳輸頻率的無線硬體裝置外，設計更有效率的控制方式來使整個無線網路系統更能充分有效的使用頻寬，更是可以增加無線網路的應用能力。而將現有的無線網路硬體設備的功能與所使用的媒體存取控制協定(Media access control protocol)結合動態平衡執行負荷的機制，便可以達到在無線區域網路中充分使用頻寬而使得所有無線裝置的使用者可以享有高速的無線網路頻寬。

（三）文獻探討

參考文獻列表

編號	文獻
1	Shiann-Tsong Sheu and Chih-Chiang Wu, “Dynamic Load Balance Algorithm (DLBA) for IEEE 802.11 Wireless LAN”, Tamkang Journal of Science and Engineering, vol 2, No 1, pp.45-52 (1999).
2	I. Papanikos and M. Logothetis, “A Study on Dynamic Load Balance for IEEE 802.11b Wireless LAN”, Proc. 8th International Conference on Advances in Communication & Control, COMCON 8, Rethymna, Crete, June, 2001.

在參考文獻[1]中，提出一種可以動態平衡在基礎建設模式(Infrastructure mode)無線區域網路中所有存取中心(Access point)的演算法，稱為 DLBA(Dynamic Load Balance Algorithm)。此演算法是以 RSSI(Received Signal Strength Indicator)當作判斷依據來調整所有無線主機與所有存取中心連線配對關係，而 RSSI 簡言之就是無線電波的能量大小，由於無線介質大多具有隨著距離增加而能量衰減的特性，因此 DLBA 便以單一無線主機與所有存取中心主機之間的 RSSI 大小關係再加上所有存取中心主機上的平均 RSSI 值來當作單一無線主機選擇要連線上哪台存取中心主機的依據。

在參考文獻[2]中，提出另一種演算法，分別在三個層次中執行動態負載平衡的機制。第一個層次為存取中心的頻道自動選擇（The AP Channel Auto-selection Level），主要是協調各個存取中心的頻道使用，以求有效率的分配可用頻道。第二個層次為無線主機選擇加入層次（The Station Join Decision Level），主要是控制無線主機選擇最好的存取中心連接上網。第三個層次為連線觀測層次（The Link Observation Level），主要控制無線主機在不同存取中心之間的漫遊（Roaming）協定。

在文獻[1]與[2]中，作者均嘗試將所有的無線主機平均分配到所有的存取中心上，然而，他們卻沒有考慮到所有無線主機的動態存取資料行為，這容易使得有些存取中心的頻寬供不應求，而有些存取中心的頻寬卻沒被使用的情況，所以需要其他的機制來改善此現象。

在基礎建設模式無線區域網路中，動態平衡執行負荷的研究參考文獻目前並沒有被大量提出，而目前市面上一些無線網路設備的說明書上有提到這些無線設備具有動態平衡執行負荷的功能，當然基於商業機密的理由，這些設備所採用的設計方法無從得知，也因此就無法深入研究分析這些設計方法，進而評估這些設計上的優缺點。

（四）研究方法

本計劃所提出的動態負載平衡(Dynamic load balancing)的方法是一種較創新的解決方案，這是一種根據在基礎建設模式(Infrastructure mode)無線網路中所有存取中心(Access point)主機所能提供無線網路頻寬的使用量(Throughput)來做動態調整，讓所有無線主機都能連線到可以分配最高傳輸頻寬的存取中心主機，藉此增加整體網路的頻寬並達到頻寬充分利用的效果。為了達到此目的，我們必須假設在任何存取中心上，具有運算能力可以收集所有連接上此存取中心之無線主機的頻寬使用情況，並且存取中心之間可以定期互相交換頻寬使用率的資訊，藉由這些資訊，一個存取中心可以動態得知在它的頻寬使用率滿載的時候，是不是有其它的存取中心可以分擔它的負載，進而通知連接上它的部分無線主機去重新選擇其它的存取中心。而無線主機也必須有接受存取中心的建議並且切換到新的存取中心的能力。我們假設動態負載平衡的機制是建立在媒體存取控制層（MAC Layer）的韌體中，因為並無法直接取得任何 802.11 規格的 MAC Layer 程式碼可供修改，因此我們是採用軟體模擬的方式先做初步的研究分析。在接下來的說明裡，將會分別介紹存取中心與無線主機的操作流程。

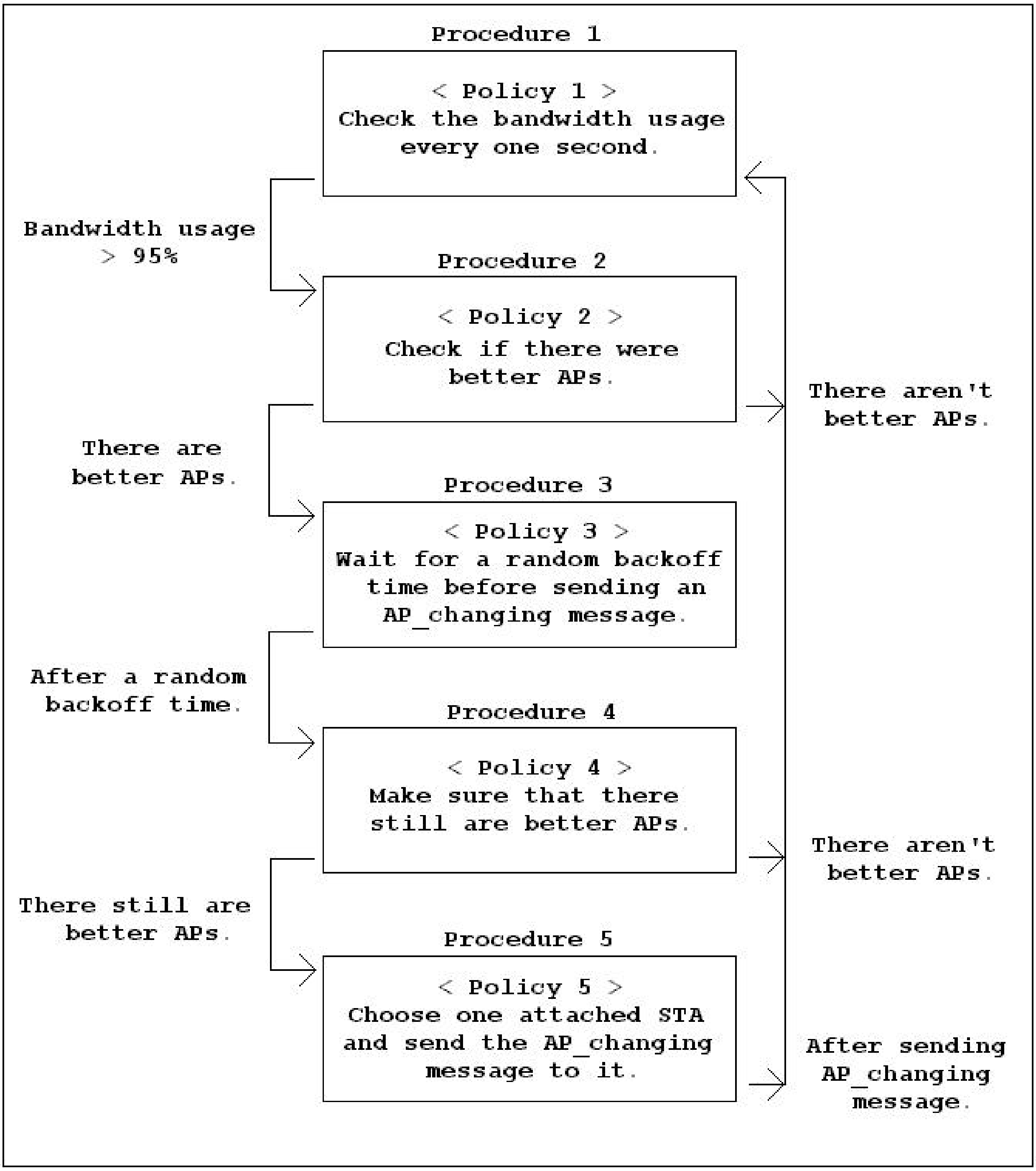
存取中心的操作流程：

在附圖 3.1 中，描繪了存取中心的操作流程，由圖上可看到，一共分為五個操作方針（Policy）。

第一個操作方針在於決定存取中心的頻寬使用量，此方針用意在於節省不必要的動態負載平衡的控制機制，對於一個存取中心而言，只有當它所能提供的頻寬供不應求的時候（在我們的設計中，視頻寬使用率大於 95%為判斷依據），才需要啟動動態負載平衡的機制讓部分無線主機轉換到能提供較高頻寬的存取中心。

第二個操作方針是在頻寬使用率大於 95%時啟動，去找出能提供較高的頻寬的存取中心。在這個操作方針下，每一個存取中心需要定期交換資訊好讓其它的存取中心有比較的依據，交換的資訊內容有存取中心認證碼（AP_ID）、存取中心的 MAC Address（MAC_Addr）、存取中心的無線網路頻道（Channel）、存取中心所能提供最大的頻寬（Max_Thr）、存取中心在上個週期內平均被使用的頻寬（Consume_Thr）、連接上存取中心的無線主機數量（Num_Attached_STA）以及在上個週期內有在做資料傳輸的無線主機數量（Num_Active_STA），其中，Num_Active_STA 是根據以下的公式算出來的。

```
PAT : The potential average throughput for each STA under an AP.
TT i : The transmission throughput of each attached STA i during the last second.
AV i : The active value of each attached STA i during the last second.
    PAT = ( Max_Thr ) / ( Num_Attached_STA ) ;
    AV i =  {(TT i / PAT) or 1 if (TT i / PAT)＞1} ;
    Num_Active_STA = Ｓ ( AV i ) ;
```



附圖 3.1 存取中心的操作流程

在收集到所有存取中心的資訊之後，任何頻寬使用率大於 95%的存取中心就可以透過這些資訊去尋找看看是不是有其它的存取中心可以提供額外的頻寬，尋找的方法是依據下面的公式計算出來的。

Definitions: Poten_Avg_Thr : The potential average throughput of an AP itself. Max_Thr : The maximum throughput of an AP itself.

Num_Active_STA : The number of active STAs of an AP itself.

Poten_Avg_Thr i : The potential average throughput of another AP i.

Max_Thr i : The maximum throughput of another AP i.

Num_Active_STA i : The number of active STAs of another AP i.

Consume_Thr i : The throughput consumption of another AP i.

Unused_Thr i : The unused bandwidth of another AP i.

Poten_Best_Thr i : The potential best throughput of another AP i.

Formulas:

1. The information of an AP itself :

   Poten_Avg_Thr = Max_Thr / Num_Active_STA ;

2. The information of another AP i :

   Unused_Thr i = (Max_Thr i) － (Consume_Thr i) ;

   Poten_Avg_Thr i = (Max_Thr i) / (Num_Active_STA i + 1) ;

   Poten_Best_Thr i = max {Unused_Thr i , Poten_Avg_Thr i} ;

3. Find out the better APs :

   If (Poten_Best_Thr i ＞ Poten_Avg_Thr)

   Then AP i is a better AP.

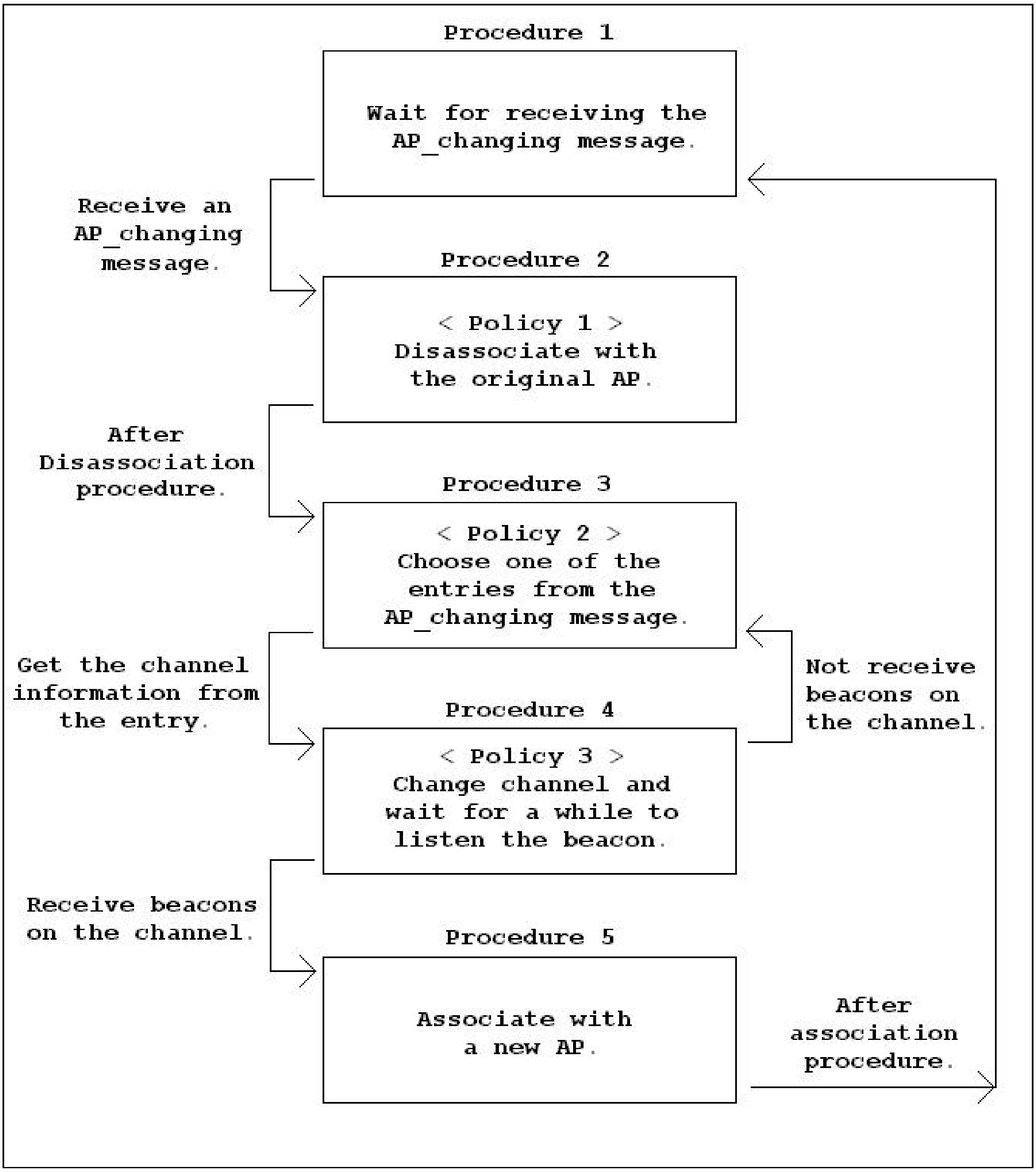
在找到可以提供更多頻寬的存取中心後，就進入第三與第四操作方針，在第三操作方針中，存取中心會等待一個隨機選取的等待時間，之後，在第四操作方針中，再做一次確認能提供更多頻寬的存取中心仍然存在之後，才真正開始要求部分無線主機切換存取中心。這兩個看似額外的操作方針，是為了防止同時有多個存取中心選擇同一個能提供較好頻寬的存取中心，並且同時要求無線主機切換到那台存取中心，而導致那台存取中心一下子便成頻寬使用率最高且供不應求的存取中心，之後它還得將轉換到連接上它的無線主機轉出。利用隨機選取的等待時間，可以讓轉換存取中心的動作盡量一個一個進行，而所有存取中心在等待的時候，就會接收到這些改變的資訊，因此在等待時間結束之後，再做一

次確認能提供較高頻寬的存取中心存不存在的動作，以避免多餘的切換動作。

在第五操作方針中，存取中心選擇了使用最多頻寬的那台無線主機，發出一個轉換存取中心的要求封包給它，此封包裡帶了所有可以切換的存取中心的 MAC Address 與所使用的頻道（Channel）。選擇使用最多頻寬的無線主機，是因為它最有可能是需要更多頻寬的無線主機。

無線主機的操作流程:

在附圖 3.2 中，描繪了無線主機的操作流程，一共分為五個執行程序（Procedure）。



附圖 3.2 無線主機的操作流程

無線主機的執行程序主要就是被動的等待存取中心的命令，若是接到來自存取中心的轉換存取中心的要求封包，便會根據封包內所指示的第一個目標存取中心的 MAC Address 與使用頻道去嘗試連些上新的存取中心，若是無法接上目標存取中心，便會選擇第二個目標存取中心並嘗試連接上它，直到連接上為止。

(五) 結果與討論

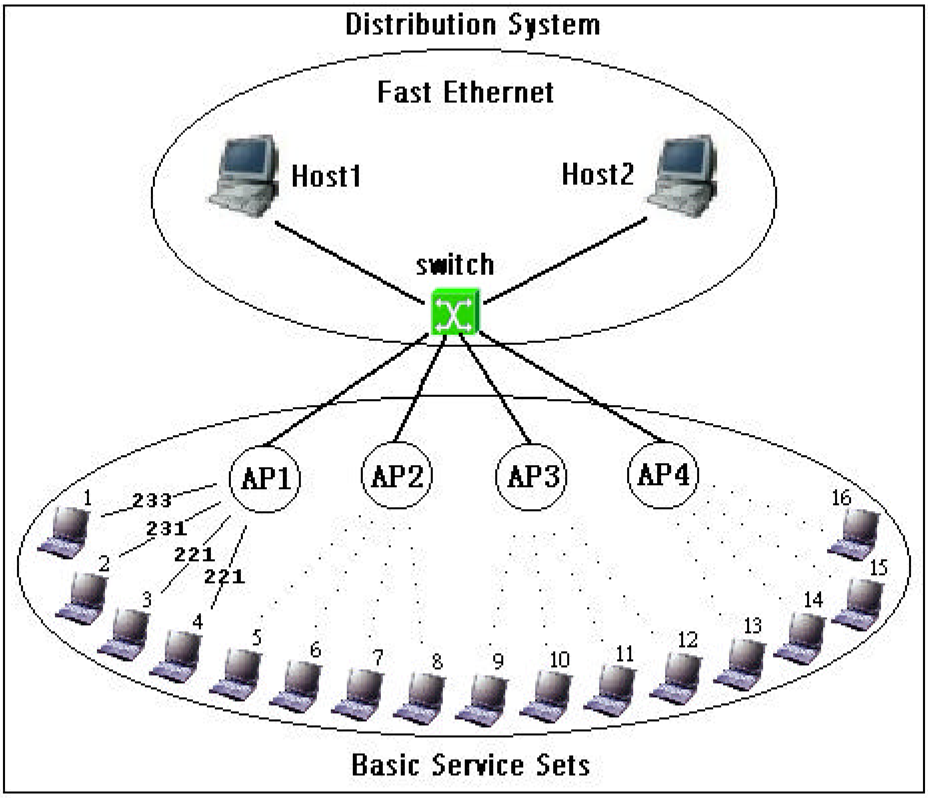
模擬結果:

在此節中，我們將利用圖表展示展示兩個模擬結果，在此展示流程中，我們將直接利用模擬初始與最後的頻寬使用情形來點出我們所設計的方法是如何達到動態負載平衡的效果的。詳細的執行步驟將放在後面的附錄中。

（模擬一）

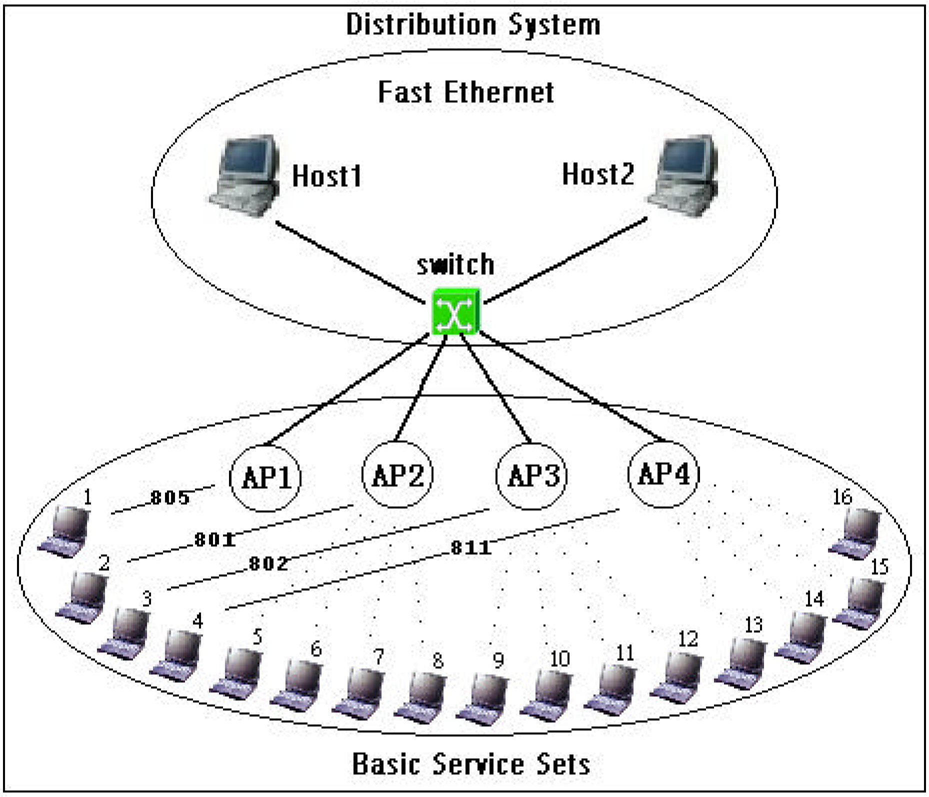
模擬初始

由下圖我們可以看到，在模擬初始時，無線主機 1 到 4 都透過存取中心 1 連接上網，而存取中心 2 到 4 的頻寬都沒有被使用到。



模擬最後

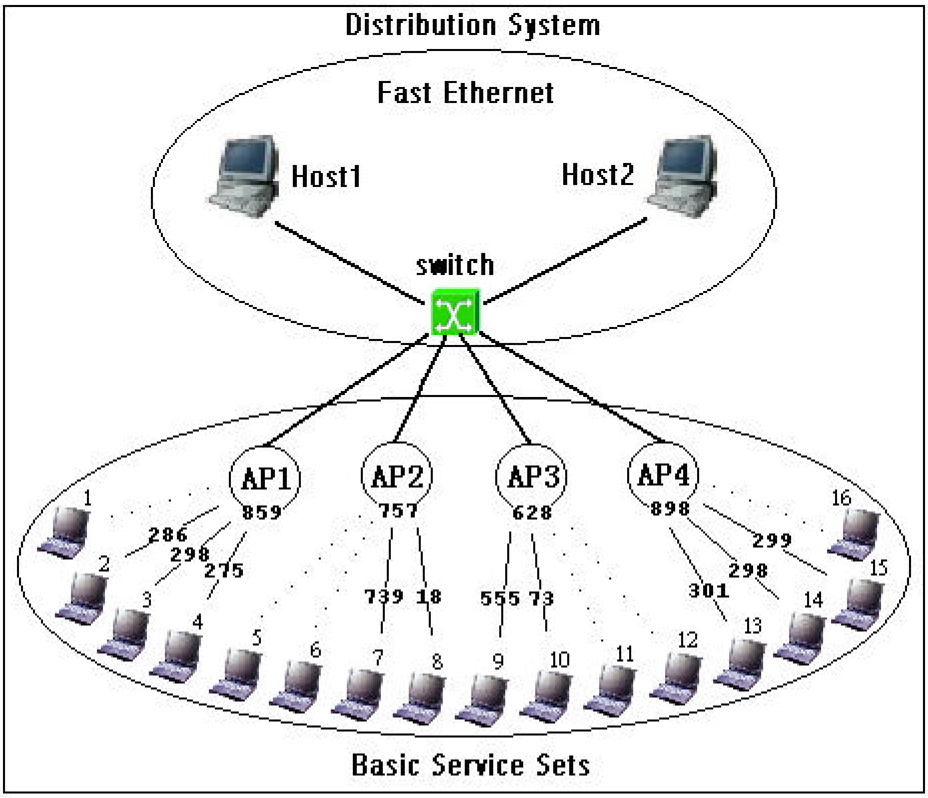
由下圖我們可以看到，動態負載平衡機制將四台無線主機平均分配到四台存取中心，而每台無線主機的可使用頻寬也變成了三倍多(平均 225Kbytes 到 800Kbytes)。



（模擬二）

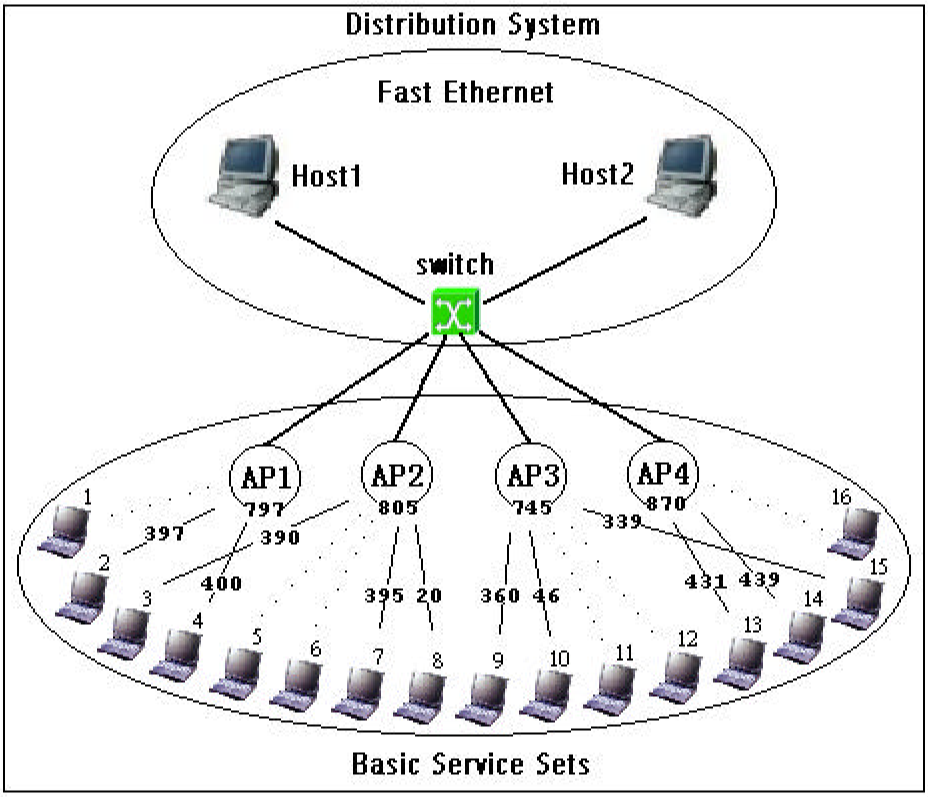
模擬初始

　　由下圖可看到，模擬初始，存取中心 1 與 4 均有三條相同的傳輸連線共同使用頻寬，相較起來存取中心 2 與 4 就是負載較輕的存取中心。



模擬最後

由下圖可看到，無線主機 3 與 15 切換到新的存取中心上，使得無線主機 2、3、4、13、14、15 能使用的頻寬增加了,進而使整個網路的總頻寬使用率也增加了。



結論:

在此計畫中，我們設計了一個新的動態負荷平衡的方法，根據無線主機使用頻寬的情況去動態分配無線主機與存取中心的連接情況，進而更有彈性且更有效率地利用頻寬。然而真實世界中的資料存取型態或許較實驗所使用的更為複雜，而真實世界的網路設置也可能不同與實驗所設置的，需要根據不同的情況做機制的適應性調整。

附錄： 動態負載平衡機制的詳細模擬過程 – 兩個例子

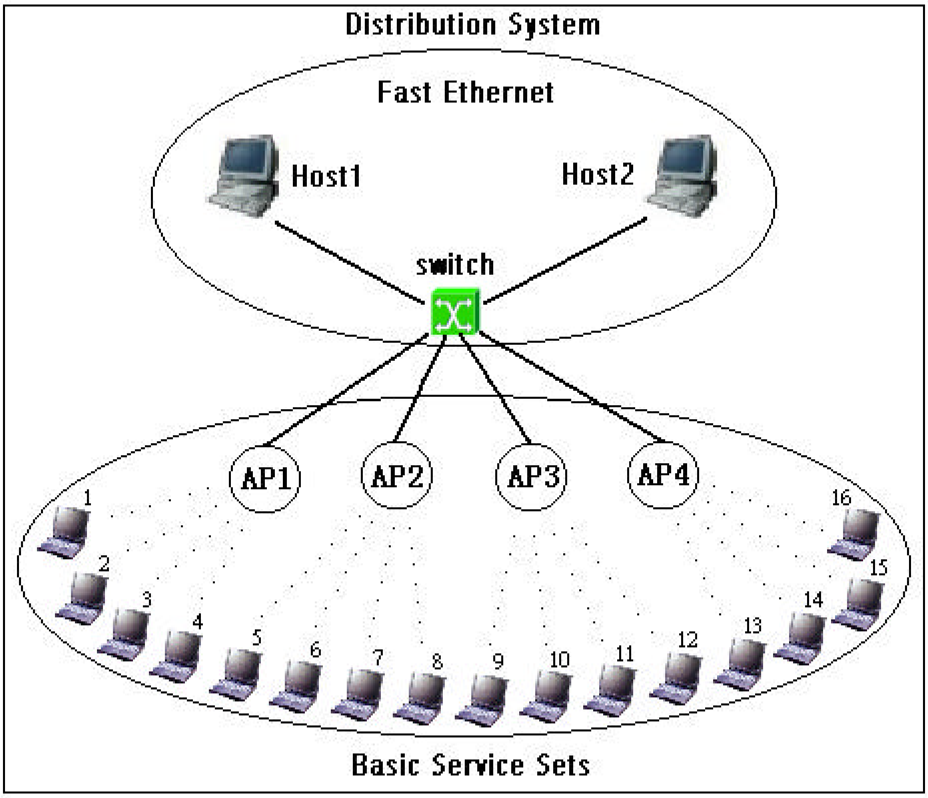
< Example 1 >

Figure 3.1(a) shows the initial setup of the infrastructure-mode wireless network used in this example. We can see that all STAs are evenly distributed among all APs, and all STAs are covered under all APs. In this example, each one of AP 1's attached STAs, (including STA 1, STA 2, STA 3, and STA 4), has greedy UDP connection to Host 1 at the beginning. We let all APs start exchanging AP_Info messages after 5 seconds from the beginning.

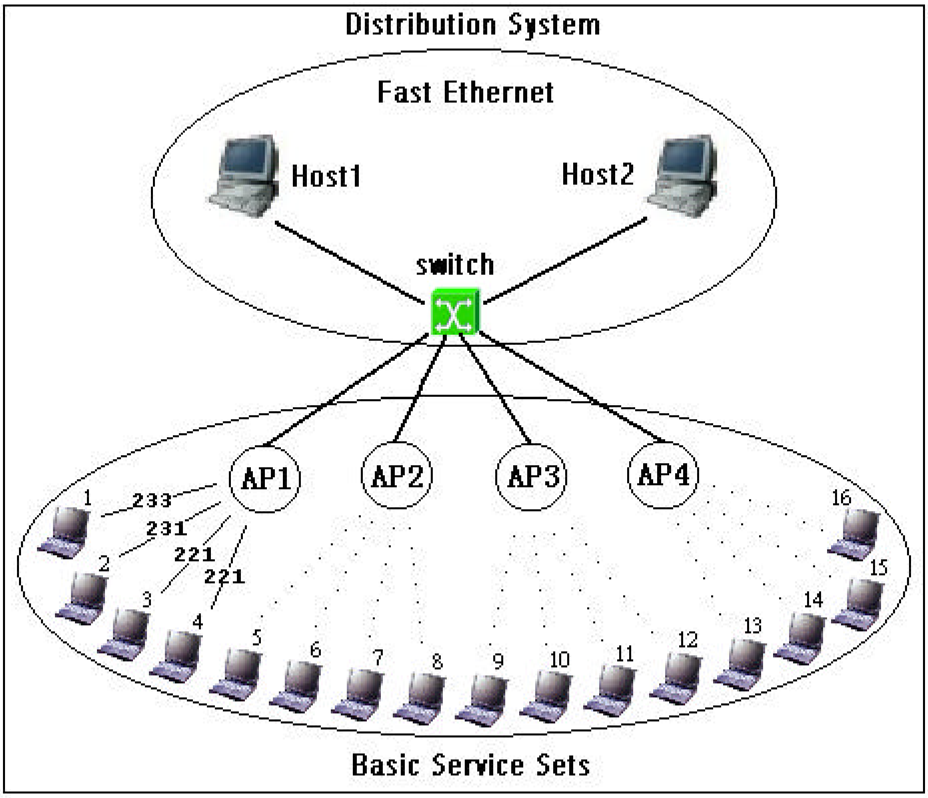
[The 5th second]

Figure 3.1 (b) shows the transmission throughput of each STA at 5 second. After exchanging AP_Info messages with each other, all APs can get the following information stored in their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	907.740	4	4.000
AP_2	2:2:2:2:2:2	3	780.000	0.000	4	0.000
AP_3	3:3:3:3:3:3	5	780.000	0.000	4	0.000
AP_4	4:4:4:4:4:4	7	780.000	0.000	4	0.000



(a) Initial setup of the infrastructure-mode wireless network



(b) The transmission throughput of each STA at 5 second

Figure 3.1: Example 1 for dynamic load balancing

Note that AP 1's throughput consumption is greater than the maximum throughput that it can provide. That is because we set the value of maximum throughput according to the throughput that a STA can obtain when there is only one STA attached to an AP. If there are multiple STAs attached to an AP, due to the MAC property of IEEE Std 802.11 [1] they can obtain more total throughput than only one STA can obtain.

Each AP checks if its bandwidth usage is over 95%. If it is, the AP then checks its AP_Info table to search if there are better APs.

On AP 1 :

1) Bandwidth usage = 1.163769 > 0.95, so try to search better APs.

2) AP 1's potential average throughput = 195.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	* Potential best throughput (KB)	If the potential best throughput > 195.000	** Sort
AP_2	780.000	780.000	780.000	It is a better AP.	1st
AP_3	780.000	780.000	780.000	It is a better AP.	2nd
AP_4	780.000	780.000	780.000	If is a better AP.	3rd

* Potential best throughput = max {Potential average throughput , Unused throughput} .

** The AP will put the APs' information into AP_changing message by the sort result.

3) AP 1 finds 3 better APs and schedules to send an AP_changing message after 2 seconds (random backoff time).

On AP 2 :

1) Bandwidth usage = 0.000000 < 0.95, so no action.

On AP 3 :

1) Bandwidth usage = 0.000000 < 0.95, so no action.

On AP 4 :

1) Bandwidth usage = 0.000000 < 0.95, so no action.

[The 7th second]

On AP 1:

1) AP 1 is going to send an AP_changing message. It checks if there are still better APs.

2) AP 1's potential average throughput = 195.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 195.000	Sort
AP_2	780.000	780.000	780.000	It is a better AP.	1st
AP_3	780.000	780.000	780.000	It is a better AP.	2nd
AP_4	780.000	780.000	780.000	If is a better AP.	3rd

3) There are still better APs. Therefore, AP 1 checks the bandwidth usage of each attached STA and chooses the one that has highest bandwidth usage. Then it sends the following AP_changing message to it.

STA_ID	Bandwidth usage (KB)	Sort
STA_1	227.304	3rd
STA_2	237.636	1st
STA_3	230.256	2nd
STA_4	214.020	4th

4) AP 1 sends an AP_changing message to STA 2.

On STA 2 :

1) STA 2 receives an AP_changing message from AP 1. The contents of that message are shown as follows.

AP_MAC_Addr	Channel
2:2:2:2:2:2	3
3:3:3:3:3:3	5

4:4:4:4:4:4	7

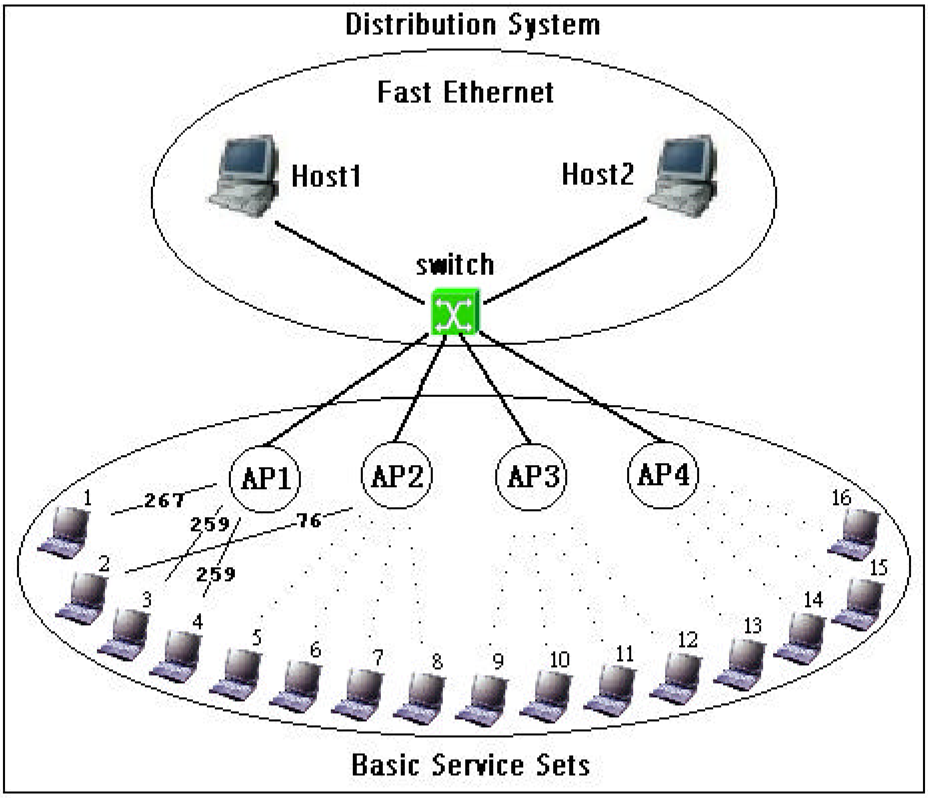
2) STA 2 disassociates with AP 1 and then changes its channel to 3 to listen for the beacons issued from AP 2 (2:2:2:2:2:2).

3) STA 2 detects the beacons and then performs association procedure to attach to AP 2 successfully.

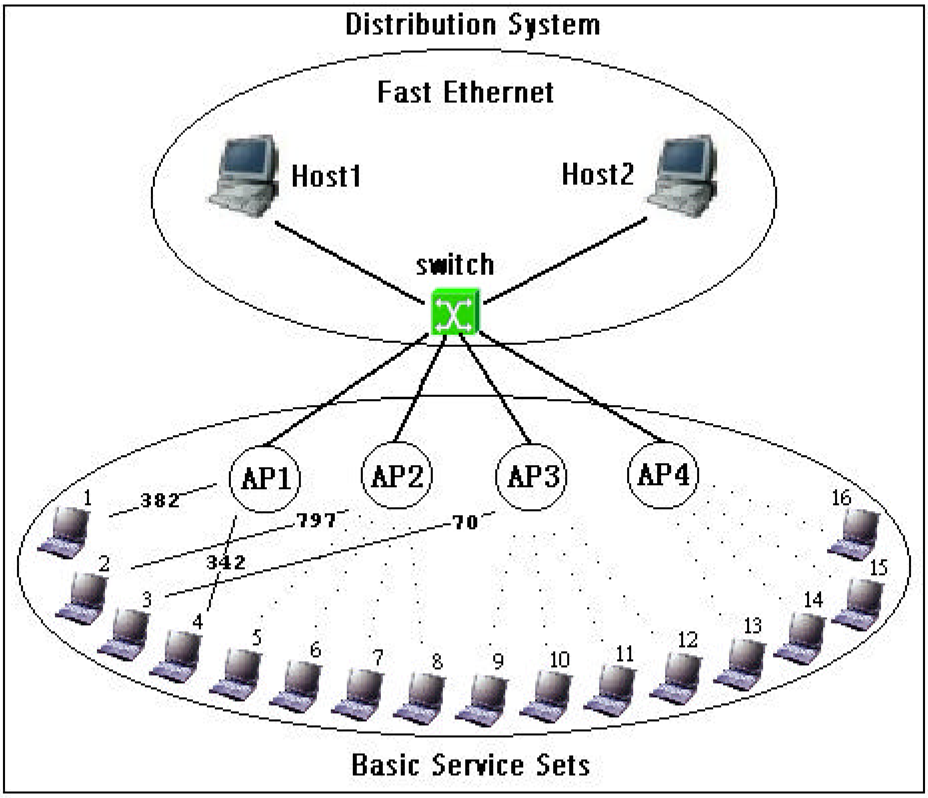
[The 8th second]

Figure 3.1 (c) shows the transmission throughput of each STA at 8 second. After exchanging AP_Info messages with each other, all APs can get the following information from their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	904.788	3	2.998
AP_2	2:2:2:2:2:2	3	780.000	76.752	5	0.492
AP_3	3:3:3:3:3:3	5	780.000	0.000	4	0.000
AP_4	4:4:4:4:4:4	7	780.000	0.000	4	0.000



(c) The transmission throughput of each STA at 8 second



(d) The transmission throughput of each STA at 11 second

Figure 3.1: Example 1 for dynamic load balancing

Each AP checks if its bandwidth usage is over 95%. If it is, the AP then checks its AP_Info table to search if there are better APs.

On AP 1 :

1) Bandwidth usage = 1.159985 > 0.95, so try to search better APs.

2) AP 1's potential average throughput = 260.149 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 260.149	Sort
AP_2	522.788	703.248	703.248	It is a better AP.	3rd
AP_3	780.000	780.000	780.000	It is a better AP.	1st
AP_4	780.000	780.000	780.000	If is a better AP.	2nd

3) AP 1 finds 3 better APs and schedules to send an AP_changing message after 2 seconds (random backoff time).

On AP 2 :

1) Bandwidth usage = 0.098400 < 0.95, so no action.

On AP 3 :

1) Bandwidth usage = 0.000000 < 0.95, so no action.

On AP 4 :

1) Bandwidth usage = 0.000000 < 0.95, so no action.

[The 10th second]

After exchanging AP_Info messages with each other, all APs can get the following information from their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	895.932	3	3.000
AP_2	2:2:2:2:2:2	3	780.000	798.516	5	1.000
AP_3	3:3:3:3:3:3	5	780.000	0.000	4	0.000

AP_4	4:4:4:4:4:4	7	780.000	0.000	4	0.000

On AP 1:

1) AP 1 wants to send AP_changing message, it tries to check if there are still better APs.

2) AP 1's potential average throughput = 260.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 260.000	Sort
AP_2	390.000	0.000	390.000	It is a better AP.	3rd
AP_3	780.000	780.000	780.000	It is a better AP.	1st
AP_4	780.000	780.000	780.000	If is a better AP.	2nd

3) There are still better APs. So, AP 1 checks the bandwidth usage of each attached STA and chooses the one that has the highest bandwidth usage. AP 1 then sends the AP_changing message to it.

STA_ID	Bandwidth usage (KB)	Sort
STA_1	293.725	2nd
STA_3	308.484	1st
STA_4	293.723	3rd

4) AP 1 sends an AP_changing message to STA 3.

On STA 3 :

1) STA 3 receives an AP_changing message from AP1. The contents of that message are shown as follows.

AP_MAC_Addr	Channel
3:3:3:3:3:3	5
4:4:4:4:4:4	7
2:2:2:2:2:2	3

2) STA 3 disassociates with AP 1 and then changes its channel to 5 to listen for the beacons issued from AP 3 (3:3:3:3:3:3).

3) STA 3 detects the beacons and then performs association procedure to attach to AP 3 successfully.

[The 11th second]

Figure 3.1 (d) shows the transmission throughput of each STA at 11 second. After exchanging AP_Info messages with each other, all APs can get the following information from their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	879.696	2	1.858
AP_2	2:2:2:2:2:2	3	780.000	797.040	5	1.000
AP_3	3:3:3:3:3:3	5	780.000	70.848	5	0.454
AP_4	4:4:4:4:4:4	7	780.000	0.000	4	0.000

Each AP checks if its bandwidth usage is over 95%. If it is, the AP then checks its AP_Info table to search if there are better APs.

On AP 1 :

1) Bandwidth usage = 1.127815 > 0.95, so try to search better APs.

2) AP 1's potential average throughput = 419.750 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 419.750	Sort
AP_2	390.000	0.000	390.000	It isn't a better AP.	X
AP_3	536.451	709.152	709.152	It is a better AP.	2nd
AP_4	780.000	780.000	780.000	If is a better AP.	1st

3) AP 1 finds 2 better APs and schedules to send an AP_changing message after 4 seconds (random backoff time).

On AP 2 :

1) Bandwidth usage = 1.021846 > 0.95, so try to search better APs.

2) AP 2's potential average throughput = 780.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 780.000	Sort
AP_1	272.918	0.000	272.918	It isn't a better AP.	X
AP_3	536.451	709.152	709.152	It isn't a better AP.	X
AP_4	780.000	780.000	780.000	It isn't a better AP.	X

3) AP 2 doesn't find any better AP.

On AP 3 :

1) Bandwidth usage = 0.090831 < 0.95, so no action.

On AP 4 :

1) Bandwidth usage = 0.000000 < 0.95, so no action.

[The 15th second]

After exchanging AP_Info messages with each other, all APs can get the following information from their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	873.792	2	2.000
AP_2	2:2:2:2:2:2	3	780.000	801.468	5	1.000
AP_3	3:3:3:3:3:3	5	780.000	797.040	5	1.000

AP_4	4:4:4:4:4:4	7	780.000	0.000	4	0.000

On AP 1:

1) AP 1 is going to send its AP_changing message It checks if there are still better APs.

2) AP 1's potential average throughput = 390.000KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 390.000	Sort
AP_2	390.000	0.000	390.000	It isn't a better AP.	X
AP_3	390.000	0.000	390.000	It isn't a better AP.	X
AP_4	780.000	780.000	780.000	If is a better AP.	1st

3) There is still a better AP. So, AP 1 checks the bandwidth usage of each attached STA and chooses the one that has the highest bandwidth usage. AP 1 then sends the AP_changing message to it.

STA_ID	Bandwidth usage (KB)	Sort
STA_1	425.088	2nd
STA_4	448.704	1st

4) AP 1 sends an AP_changing message to STA 4.

On STA 4 :

1) STA 4 receives an AP_changing message from AP 1. The contents of that message are shown as follows.

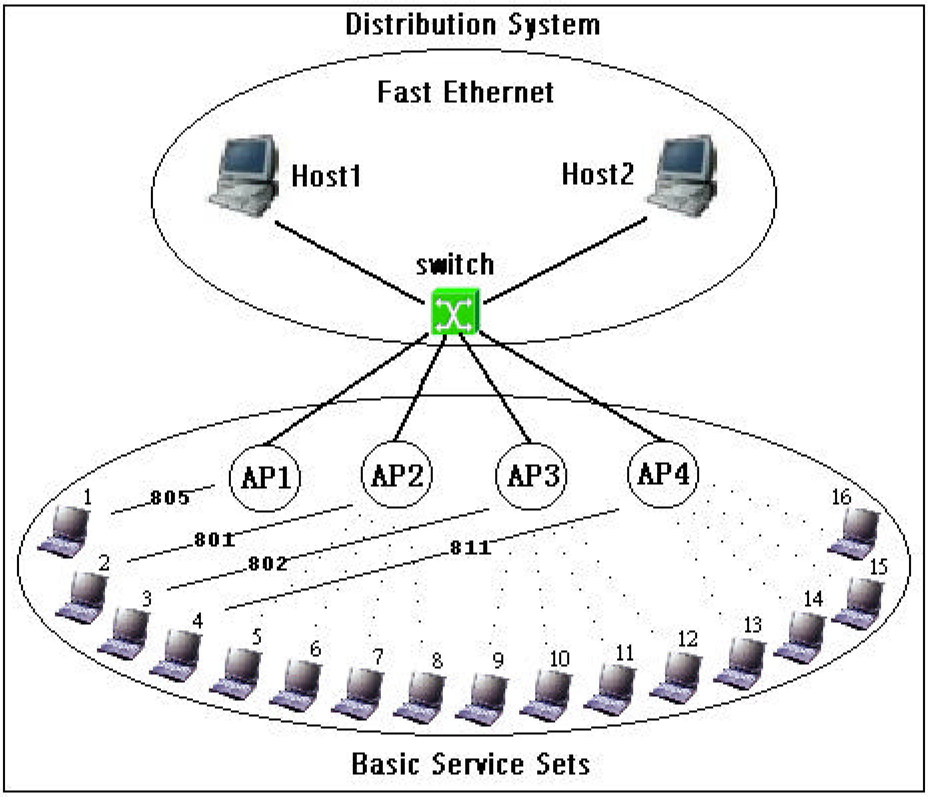
AP_MAC_Addr	Channel
4:4:4:4:4:4	7

2) STA 4 disassociates with AP 1 and then changes its channel to 7 to listen for the beacons issued from AP 4 (4:4:4:4:4:4).

3) STA 4 detects the beacons and performs the association procedure to attach to AP 4 successfully.

[The 17th second]

Figure 3.1 (e) shows the transmission throughput of each STA at 17 second. We can see that this infrastructure-mode wireless network is under a load balancing condition among all APs. The final average throughput of each UDP connection is about 3.5 times the original average throughput. It is the best result that can be achieved in this example. Our control mechanism of dynamic load balancing can achieve this result successfully.



(e) The transmission throughput of each STA at 17 second

Figure 3.1: Example 1 for dynamic load balancing

< Example 2 >

Figure 3.2 (a) shows the initial setup of the infrastructure-mode wireless network used in this example. We can see that all STAs are evenly distributed

among all APs, and all STAs are covered under all APs. At the beginning, some STAs which include STA 2, STA 3, STA 4, and STA 7 have greedy UDP connections to Host 1 through their attached APs, and some other STAs which include STA 9, STA 13, STA 14, and STA 15 have greedy UDP connections to Host 2 through their attached APs. STA 8 has a ping traffic (ping dst_IP) through AP 2 to Host 1. STA 10 has a flood ping traffic (ping –f dst_IP) through AP 3 to Host 2. In this example, we can see how the concept of the number of active nodes works and how the policy of random backoff time works in our control mechanism. We let all APs start exchanging AP_Info messages after 5 seconds from the beginning.

[The 5th second]

Figure 3.2 (b) shows the transmission throughput of each STA at 5 second. After exchanging AP_Info messages with each other, all APs can get the following information from their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	859.308	4	3.000
AP_2	2:2:2:2:2:2	3	780.000	757.428	4	1.092
AP_3	3:3:3:3:3:3	5	780.000	628.236	4	1.375
AP_4	4:4:4:4:4:4	7	780.000	898.884	4	3.000

Each AP checks if its bandwidth usage is over 95%. If it is, the AP then checks AP_Info table to search if there are better APs.

On AP 1 :

1) Bandwidth usage = 1.101677 > 0.95, so try to search better APs.

2) AP 1's potential average throughput = 260.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 260.000	Sort
AP_2	372.849	22.572	372.849	It is a better AP.	1st
AP_3	328.421	151.764	328.421	It is a better AP.	2nd
AP_4	195.000	0.000	195.000	It isn't a better AP.	X

3) AP 1 finds 2 better APs and schedules to send an AP_changing message after 2 seconds (random backoff time).

On AP 2 :

1) Bandwidth usage = 0.971062 > 0.95, so try to search better APs.

2) AP 2's potential average throughput = 714.286 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 714.286	Sort
AP_1	195.000	0.000	195.000	It isn't a better AP.	X
AP_3	328.421	151.764	328.421	It isn't a better AP.	X
AP_4	195.000	0.000	195.000	It isn't a better AP.	X

3) AP 2 doesn't find any better AP.

On AP 3 :

1) Bandwidth usage = 0.805431 < 0.95, so no action.

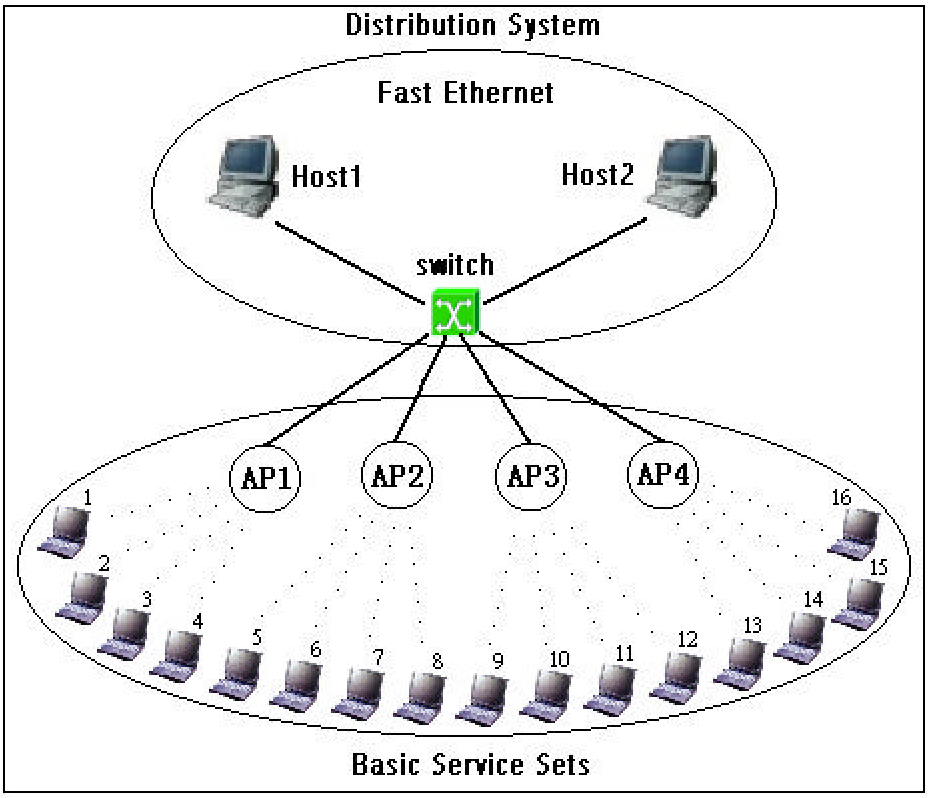
On AP 4 :

1) Bandwidth usage = 1.152415 > 0.95, so try to search better APs.

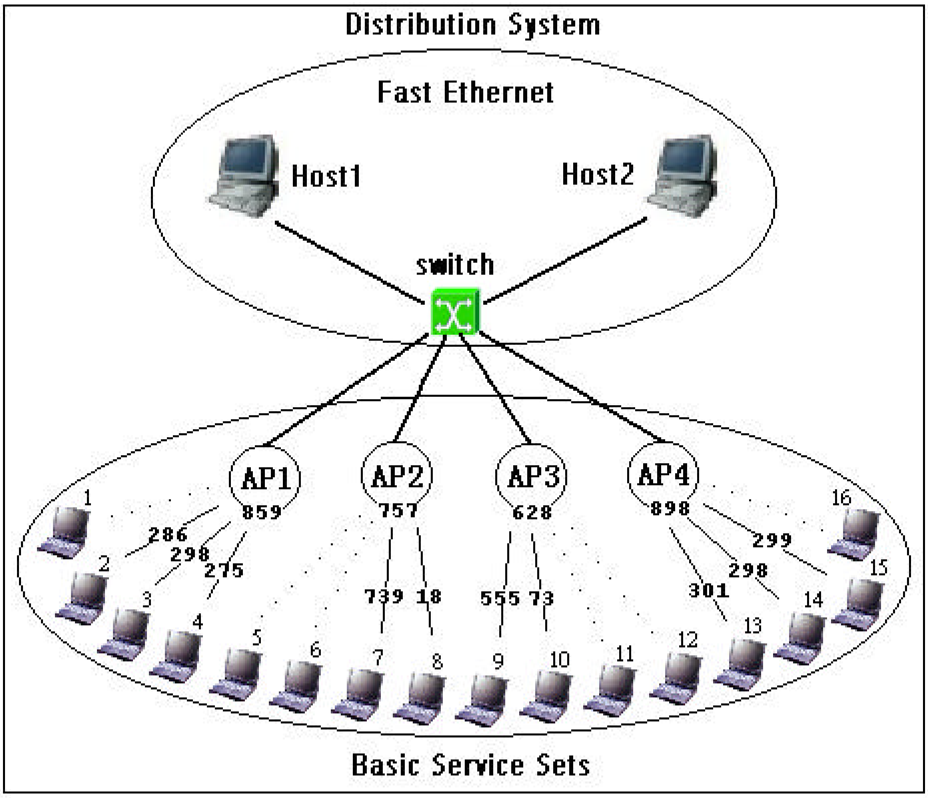
2) AP 4's potential average throughput = 260.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 260.000	Sort
AP_1	195.000	0.000	195.000	It isn't a better AP.	X
AP_2	372.849	22.572	372.849	It is a better AP.	1st
AP_3	328.421	151.764	328.421	It is a better AP.	2nd

3) AP 4 finds 2 better APs and schedules to send an AP_changing message after 4 seconds (random backoff time).



(a) Initial setup of the infrastructure-mode wireless network



(b) The transmission throughput of each STA at 5 second

Figure 3.2: Example 2 for dynamic load balancing

[The 7th second]

After exchanging AP_Info messages with each other, all APs can get the following information from their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	852.012	4	3.000
AP_2	2:2:2:2:2:2	3	780.000	746.256	4	1.103
AP_3	3:3:3:3:3:3	5	780.000	610.032	4	1.403
AP_4	4:4:4:4:4:4	7	780.000	898.884	4	3.000

On AP 1:

1) AP 1 is going to send AP_changing message. It checks if there are still better APs.

2) AP 1's potential average throughput = 260.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 260.000	Sort
AP_2	370.899	33.744	370.899	It is a better AP.	1st
AP_3	324.594	169.968	324.594	It is a better AP.	2nd
AP_4	195.000	0.000	195.000	It isn't a better AP.	X

3) There are still better APs. So, AP 1 checks the bandwidth usage of each attached STA and chooses the one that has the highest bandwidth usage. AP 1 then sends the AP_changing message to it.

STA_ID	Bandwidth usage (KB)	Sort
STA_1	0.0	4th
STA_2	276.012	3rd
STA_3	298.152	1st
STA_4	277.848	2nd

4) AP 1 sends an AP_changing message to STA 3.

On STA 3 :

1) STA 3 receives an AP_changing message from AP 1. The contents of that message are shown as follows.

AP_MAC_Addr	Channel
2:2:2:2:2:2	3
3:3:3:3:3:3	5

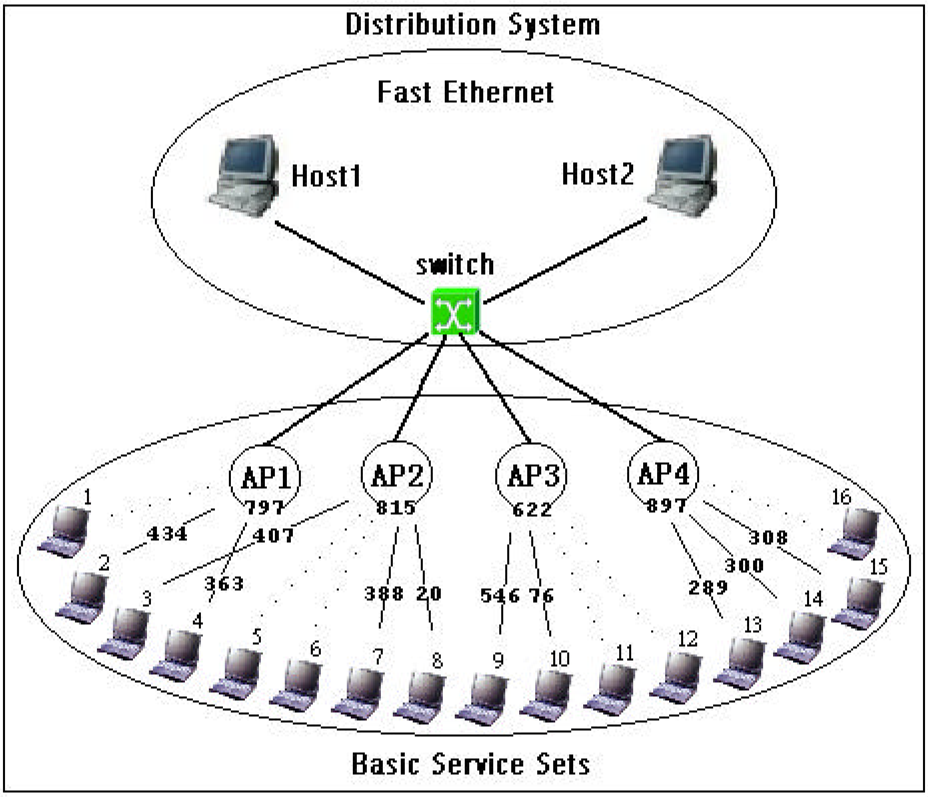
2) STA 3 disassociates with AP 1. It then changes its channel to 3 to listen for the beacons issued from AP 2 (2:2:2:2:2:2).

3) STA 3 detects the beacons and performs the association procedure to attach to AP 2 successfully.

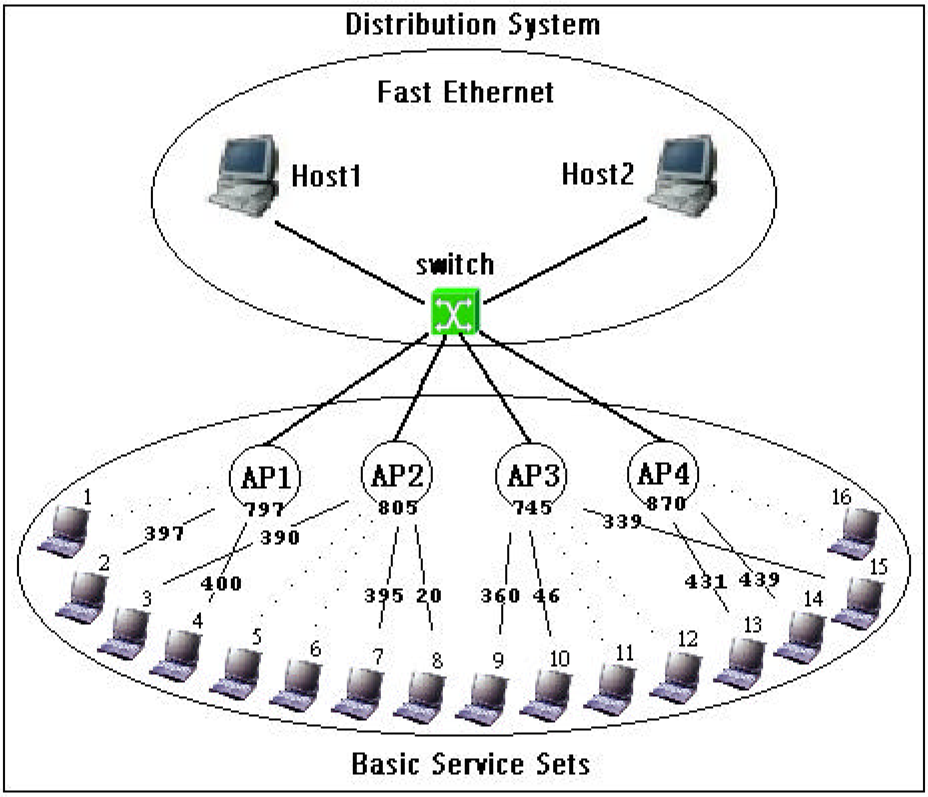
[The 9th second]

Figure 3.2 (c) shows the transmission throughput of each STA at 9 second. After exchanging AP_Info messages with each other, all APs can get the following information from their AP_Info tables.

AP_ID	MAC	Channel	Max_Thr	Consume_Thr	Attached STA	Active STA
AP_1	1:1:1:1:1:1	1	780.000	797.072	3	2.000
AP_2	2:2:2:2:2:2	3	780.000	815.892	5	2.130
AP_3	3:3:3:3:3:3	5	780.000	622.284	4	1.391
AP_4	4:4:4:4:4:4	7	780.000	897.408	4	3.000



(c) The transmission throughput of each STA at 9 second



(d) The transmission throughput of each STA at 11 second

Figure 3.2: Example 2 for dynamic load balancing

On AP 4:

1) AP 4 is about to send its AP_changing message. It checks if there are still better

APs.

2) AP 4's potential average throughput = 260.000 KB.

AP_ID	Potential average throughput (KB)	Unused throughput (KB)	Potential best throughput (KB)	If the potential best throughput > 260.000	Sort
AP_1	260.000	0.000	260.000	It isn't a better AP.	1st
AP_2	249.201	0.000	249.201	It isn't a better AP.	2nd
AP_3	326.223	157.716	326.223	It is a better AP.	X

3) There is still a better AP. So, AP 4 checks the bandwidth usage of each attached STA and chooses the one that has the highest bandwidth usage. AP 4 then sends the AP_changing message to it.

STA_ID	Bandwidth usage (KB)	Sort
STA_13	289.296	3rd
STA_14	299.628	2nd
STA_15	308.484	1st
STA_16	0.000	4th

4) AP 1 sends an AP_changing message to STA 15.

On STA 15 :

1) STA 15 receives an AP_changing message from AP 4. The contents of that message are shown as follows.

AP_MAC_Addr	Channel
3:3:3:3:3:3	5

2) STA 15 disassociates with AP 4. It then changes its channel to 5 to listen for the beacons issued from AP 3 (3:3:3:3:3:3).

3) STA 15 detects the beacons and performs the association procedure to attach to AP 3 successfully.

[The 11th second]

Figure 3.2 (d) shows the transmission throughput of each STA at 11 second. We can see that this infrastructure-mode wireless network is under a load balancing condition among all APs. Each STA can't find another AP that can provide more bandwidth for itself if it would switch to that AP. This is already the best result in this example. Our control mechanism of dynamic load balancing can successfully achieve this best result.

At 5 second in this example, AP 1 and AP 4 find that there are other better APs and both of them take AP 2 as the best target AP. AP 1 waits for 2 seconds and then it sends an AP_changing message to request STA 3 to change to AP 2 at 7 second. AP 4 waits for 4 seconds before it sends its AP_changing message. When AP 4 is going to send the AP_changing message, it finds that AP 2 is not the best target AP anymore because STA 3 attached to it at 7 second. Therefore, AP 4 takes AP 3 as the best target AP. If AP 1 and AP 4 would wait for the same backoff time and send the AP_changing messages at the same time, two STAs will switch to AP 2 at almost the same time. This will cause AP 2 to become the AP that has the most traffic load. Then AP 2 will find that AP 3 is a best target AP and request one of its attached STAs to change to it. Finally, it will achieve the same result as that in this example. That is how the policy of random backoff time works on an AP to reduce unnecessary actions.

In Figure 3.2 (b), we can see that although AP 2's wireless link utilization is greater than AP 3, it's number of active nodes (It's 1.092.) is less than that of AP 3 (It's 1.375.). This is why both AP 1 and AP 4 take Ap 2 as the best target AP instead of AP 3. Actually, AP 2 provides more bandwidth for a new attached STA than AP 3 does. Check both Figure 3.2 (b) and Figure 3.2 (d), we can find that STA 3's transmission throughput is improved from 298 to 390 KB/sec and STA 15's transmission throughput is improved from 299 to 339 KB/sec. Obviously, STA 3 gets more improvement than STA 15 does. That is how the concept of the number of active nodes works on an AP to choose better APs.

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 7 月 31 日

國科會補助計畫	計畫名稱：為 IEEE 802.11 (b) 無線區域網路所設計的動態負載平衡方法 計畫主持人：　交大資工系王協源 助理教授 計畫編號：　NSC 91－2213－E－009－064－ 學門領域：　資訊
技術/創作名稱	為 IEEE 802.11 (b) 無線區域網路所設計的動態負載平衡方法
發明人/創作人	王協源、周智良
技術說明	中文： 如何在基礎建設模式的無線網路中達到動態平衡執行負荷(dynamic load balancing)並不只是單純的將所有的無線裝置平均分配給所有的存取中心而已，有許多因素是可以列入考量的，比方說根據無線訊號的強度或是分配到的頻寬傳輸量等。在參考文獻[2]中就提出了一種以無線訊號強度為考量的演算法來達到動態平衡執行負荷。本計劃根據頻寬傳數量的考量來設計與實作三個不同的基礎建設模式無線網路系統，同時也分析評估此三種提供動態平衡執行負荷的設計在有效性、效能、與計算時間消耗上的關係。
	英文： The problem of dynamic load balancing for IEEE 802.11 infrastructure mode wireless network is not just a problem of distributing all wireless devices equally to all APs. There are many factors that could be considered, such as signal strength [2] or data throughput. This project designs and implements three variances of infrastructure mode system that support the dynamic load balancing for IEEE 802.11 wireless network by detecting the immediate data throughput. This project will also study the effectiveness, performance, and computation overhead of dynamic load balancing mechanism on the three different IEEE 802.11 infrastructure mode wireless network systems.
可利用之產業 及 可開發之產品	無線區域網路產品 (e.g., wireless card, access points, etc.)

技術特點	**動態平衡執行負荷**
推廣及運用的價值	**能增進網路可用頻寬及降低傳輸延遲**

※ 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。