行政院國家科學委員會專題研究計畫　成果報告

子計畫四：多點擁塞的無線 ATM 網路流量控制(2/2)

計畫類別：整合型計畫
計畫編號：NSC93-2213-E-216-005-
執行期間：93 年 08 月 01 日至 94 年 07 月 31 日
執行單位：中華大學電機工程研究所

計畫主持人：李柏坤

報告類型：完整報告

處理方式：本計畫可公開查詢

中 華 民 國 94 年 10 月 13 日

中文摘要

本計畫對於多頻道的無線通訊系統，提出一個結合以效用函數為基礎的功率控制法則與動態頻道分配的演算法。在很多功率控制的論文中，使用者使用傳輸功率所得到的滿足感，被表示成效用函數。而使用者需付出的成本，被表示成費用函數。每個使用者都希望自己能得到最大的傳輸功率，但是使用較高的傳輸功率，必須付出較大的成本，因此每個使用者都努力去達到自己最佳的淨效用。然而在802.11 的網路系統中，系統是多頻道系統，除了調整功率外，另一個可控制的變數是頻道的選擇。我們不只使用淨效用函數來控制功率，我們還設計了一個動態頻道分配的演算法，來降低干擾，以提升平均 SNR、網路效用、與連線傳輸速率。

Abstract

In this work, we provide a dynamic channel selection algorithm together with a utility-base power control scheme for a multi-channel wireless network. The utility function quantifies the level of satisfaction a user gets from using the system resources. Each player in the game maximizes function of net utility in a distributed system. Since users act selfishly, the equilibrium point is not necessarily the best operating point from a social point of view. Pricing of services in wireless networks emerges as an effective tool for radio resource management because of its ability to guide user behavior toward a more efficient operating point. However, in 802.11 wireless network system, it is a multi-channel system. Therefore, not only control power by a net utility function, we also design a dynamic channel selection algorithm to reduce co-channel interference so as to improve average SNR, average net-utility, and connection rate.

Keywords: Dynamic channel selection, Dynamic power control, OFDM

I. INTRODUCTION

The channel models of a wireless network can be categorized as single-channel and multi-channel. In the single-channel case, all mobile hosts operate on the single common channel for communication. In multi-channel model, the overall bandwidth is divided into a set of channels, and every host can operate on one or some of these channels for communication. Bandwidth is rare and valuable for wireless networks, therefore, it is important to increase channels utilization. In a wireless network, the most important factor that dictates channels utilization is contention/collision. One common problem with single channel is that the network performance will degrade quickly as the number of mobile hosts increases, due to high contention/collision. Using multiple channels has several advantages, for example, the total throughput may be increased and the collision probability may be reduced immediately. Therefore, it is important to design a dynamic channel algorithm to reduce contention/collision and increase channels utilization and throughput. However, it is a challenge, too. Many dynamic channel allocation algorithms have been proposed in wireless communication networks and cellular mobile networks. For example an adaptive channel assignment algorithm for cellular mobile systems has been proposed in [18], and a channel assignment algorithm for time-varying demand systems has been developed in [19].

In a wireless system, a common and important method to increase users and decrease contention/collision is to control power of all users. It is well known that minimizing interference using power control increase capacity [29]-[31] and also extends battery life. Recently, several alternative approaches to the power control problem in wireless systems based on the economic model have been proposed in [27], [28]. With this economic model, service preference for each user is represented by a utility function[27]. As the name implies, the utility function quantifies the level of satisfaction with which a user can get from using the system resources. Game-theoretic methods are applied to study power control under this new model [27], [28]. However, these game-theoretic methods are proposed for a single-channel system.

In this work, we shall design a dynamic channel selection algorithm to reduce co-channel interference and extend the power control utility-based power control (UBPC) to increase signal to interference-and-noise ratio (SINR) to all STAs in a multi-channel system, such as an OFDM system as defined in the standard IEEE 802.11h. In a standard WLAN as defined in the standard IEEE 802.11, if two co-located Basic Service Sets (BSSs) operate at the same channel, which are referred to as overlapping BSSs, it is not easy to support Quality-of-Service (QoS) due to the possible contentions among overlapping BSSs. However, by having the dynamic channel selection been implemented, an Access Point (AP) can determine the best channel to work at, and initiate the switch of all the stations (STAs) associated with its BSS to the newly selected channel. Another goal of our dynamic channel selection algorithm is to supply every station as fair as possible, i.e., giving the most poorly treated station (i.e., the station who receives the lowest SNR) the largest possible SNR. After designing a dynamic channel algorithm to reduce co-channel interference and increase channels utilization, we shall construct a power control algorithm based on a utility function to represent service preference for each user. The utility function quantifies the level of satisfaction a user can gets from using the system resources. Each player in the game maximizes some function of utility in a distributed system. Since users act selfishly, the equilibrium point is not necessarily the best operating point from a social point of view. Pricing the system resources appears to be a powerful tool for achieving a more socially desirable result. Pricing of services in wireless networks emerges as an effective tool for radio resource management because of its ability to guide user behavior toward a more efficient operating point.

The report is organized as follows: In Section II, we explain a multi-channel system model, and problem formulation of this work. Then we apply utility-based power control to this system model. In Section III, we present our dynamic channel selection algorithm, which is based on the max-min fairness concept. And applying power control game and dynamic channel selection to run our simulation is presented in Section V. Then, we summarize our conclusions and future work in Section VI.

II. System Modeling and Problem Formulation

A. Signal Model

In this subsection, we derive an equivalent discrete-time baseband signal model of the OFDM system. In an OFDM system with N subcarriers, $S_n(k)$ denotes the frequency-domain signal before the modulator and is transmitted via the k-th subcarrier in the n-th symbol interval. The time-domain samples of the n-th OFDM symbol $s_n(m)$ are produced by IDFT as follows[32]

$$s_n(k) = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} S_n(m) e^{\frac{j2\pi mk}{N}}, \quad k = 0, ..., N-1 \tag{1}$$

Suppose the interval of an OFDM symbol without the guard interval is defined as T, then the sampling time can be defined as $T_s = T/N$. The cyclic prefix is adopted as the guard interval, which is inserted in front of the N time-domain samples of a symbol to prevent the ISI and to maintain the orthogonality among subcarriers. The time-domain samples with the guard interval, denoted as $s_n^g(k)$, in a total n-th OFDM symbol can be expressed as

$$s_n^g(k) = s_n(k + N - G)_N, \quad 0 \le k \le N + G - 1 \tag{2}$$

where G denotes the number of samples in the guard interval, and $(n)_N$ denotes the remainder of n divided by N, i.e., (n mod N). The guard interval is chosen to be larger than the multipath delay spread L of the channel, so the ISI can be eliminated.

As this waveform is transmitted over the multipath channel, the received sampling data $y_n^g(k)$ at the k-th instant of the n-th OFDM symbol can be expressed as

$$y_n^g(k) = \sum_{l=0}^{k} s_n^g(k-l) h_n^g(k,l) + \sum_{l=k+1}^{L} s_{n-1}^g(k - l + N + G) h_n^g(k,l) + v_n^g(k) \tag{3}$$

where L denotes the maximum delay spread, $v_n^g(k)$ represents the ambient channel noise, and $h_n^g(k,l)$ denotes the equivalent discrete time channel response at position l and instant k. At the receiver end, the samples in guard interval are first removed to obtain the signal

$$\begin{aligned} y_n(k) &= y_n^g(k+G),\ 0 \le k \le N-1 \\ &= \sum_{l=0}^{L} s_n(k-l)_N h_n(k,l) + v_n(k) \end{aligned}$$

The above signal is then fed into the DFT demodulator to obtain the following signal

$$Y_n(m) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} y_n(k) e^{-\frac{j2\pi mk}{N}}$$

For further analysis, it is assumed that the multipath channel model is fixed within one symbol time interval, i.e., $h_n(k,l) = h_n(l)$. Note that due to the periodic property $e^{-\frac{j2\pi m(k-l)}{N}} = e^{-\frac{j2\pi m(k-l)_N}{N}}$, we have

$$\begin{aligned} s_n(k-l)_N &= \frac{1}{\sqrt{N}} \sum_{d=0}^{N-1} S_n(d)\ e^{\frac{j2\pi d(k-l)_N}{N}} \\ &= \frac{1}{\sqrt{N}} \sum_{d=0}^{N-1} S_n(d)\ e^{\frac{j2\pi(k-l)d}{N}} \end{aligned}$$

Then it follows that

$$\begin{aligned} Y_n(m) &= \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \left\{ \sum_{l=0}^{L} s_n(k-l)_N h_n(l) + v_n(k) \right\} e^{-\frac{j2\pi mk}{N}} \\ &= \frac{1}{N} \sum_{k=0}^{N-1} \sum_{l=0}^{L} \sum_{d=0}^{N-1} S_n(d)\ e^{\frac{j2\pi(k-l)d}{N}} h_n(l) e^{-\frac{j2\pi mk}{N}} + V_n(m) \\ &= \frac{1}{N} \sum_{k=0}^{N-1} \sum_{d=0}^{N-1} S_n(d)\ e^{-\frac{j2\pi(m-d)k}{N}} \sum_{l=0}^{L} h_n(l) e^{-\frac{j2\pi dl}{N}} + V_n(m) \\ &= \frac{1}{\sqrt{N}} \sum_{d=0}^{N-1} S_n(d) \left(\sum_{k=0}^{N-1} e^{-\frac{j2\pi(m-d)k}{N}} \right) H_n(d) + V_n(m) \end{aligned}$$

where

$$V_n(m) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} v_n(k) e^{-\frac{j2\pi mk}{N}}$$

and

$$\begin{aligned} H_n(m) &= \frac{1}{\sqrt{N}} \sum_{l=0}^{L} h_n(l) e^{-\frac{j2\pi dl}{N}} \\ &= \frac{1}{\sqrt{N}} \sum_{l=0}^{N-1} h_n(l) e^{-\frac{j2\pi ml}{N}} \end{aligned}$$

with the identification $h_n(l) = 0$ for $L+1 \leq l \leq N-1$. As $\sum_{k=0}^{N-1} e^{-\frac{j2\pi(m-d)k}{N}} = N\delta(m-d)$, we then have

$$Y_n(m) = \sqrt{N} S_n(m) H_n(m) + V_n(m)$$

With the Parseval identity, we obtain

$$\sum_{m=0}^{N-1} |V_n(m)|^2 = \sum_{k=0}^{N-1} |v_n(k)|^2$$

The mean energy contained in demodulated signal for the n-th symbol is then calculated as

$$\begin{aligned} E_n &= \sum_{m=0}^{N-1} E\left\{|Y_n(m)|^2\right\} \\ &= \sum_{m=0}^{N-1} E\left\{\left|\sqrt{N} S_n(m) H_n(m) + V_n(m)\right|^2\right\} \\ &= N \sum_{m=0}^{N-1} E\left\{|S_n(m)|^2\right\} E\left\{|H_n(m)|^2\right\} + \sum_{k=0}^{N-1} E\left\{|v_n(k)|^2\right\} \\ &= N \sum_{m=0}^{N-1} E\left\{|S_n(m)|^2\right\} E\left\{|H_n(m)|^2\right\} + N\sigma_v^2 \end{aligned}$$

Let R_n be the average power of the received demodulated signal within the n-th symbol, i.e., $R_n = E_n/N$. By the assumption that $S_n(m)$ is stationary within a symbol time interval with the signal power level $E\left\{|S_n(m)|^2\right\} = \sigma_{S,n}^2 \triangleq P_n$, it follows that

$$\begin{aligned} R_n &= \sigma_{S,n}^2 \sum_{m=0}^{N-1} E\left\{|H_n(m)|^2\right\} + \sigma_v^2 \\ &= P_n G_n + \sigma_v^2 \end{aligned} \tag{4}$$

where G_n is the average channel power gain defined as

$$G_n = \sum_{l=0}^{L} E\left\{|h_n(l)|^2\right\}$$

B. Interference Model

In this subsection, we shall derive a model for representing the co-channel interference in the OFDM system.

Lemma 1: Assume that

$$x(k) = \frac{1}{\sqrt{N}}\sum_{m=0}^{N-1} X(m)e^{\frac{j2\pi mk}{N}}, \quad k = 0, ..., N-1,$$
$$y(k) = \frac{1}{\sqrt{N}}\sum_{m=0}^{N-1} Y(m)e^{\frac{j2\pi mk}{N}}, \quad k = 0, ..., N-1,$$

and $E\left\{|X(m)|^2\right\} = E\left\{|Y(m)|^2\right\} = \sigma^2$. Now define a new signal $z(k)$ by combining some parts of $x(k)$ and $y(k)$ as

$$z(k) = \begin{cases} x(k-\tau), & 0 \le k \le N-1-\tau \\ y(k-N+\tau), & N-\tau \le k \le N-1 \end{cases}$$

for some positive integer τ with $0 \le \tau \le N-1$ and let $Z(m)$ be the DFT of $z(k)$. Then we have

(i) $E\left\{|y(k)|^2\right\} = E\left\{|Y(m)|^2\right\} = \sigma^2$

(ii) $E\left\{\sum_{m=0}^{N-1}|Z(m)|^2\right\} = N\sigma^2$

Proof: By the IDFT of $Y(m)$, it follows that

$$|y(k)|^2 = \frac{1}{N}\sum_{m=0}^{N-1}\sum_{m'=0}^{N-1} Y(m)Y^*(m')e^{\frac{j2\pi(m-m')k}{N}}$$

and thus

$$E\left\{|y(k)|^2\right\} = \frac{1}{N}\sum_{m=0}^{N-1}\sum_{m'=0}^{N-1} E\left\{Y(m)Y^*(m')\right\}e^{\frac{j2\pi(m-m')k}{N}}$$
$$= \frac{1}{N}\sum_{m=0}^{N-1}\sum_{m'=0}^{N-1} \delta(m-m')\sigma^2 e^{\frac{j2\pi(m-m')k}{N}}$$

as $\{Y(m)\}_{m=0}^{N-1}$ is an independent sequence. Therefore, we can obtain

$$E\left\{|y(k)|^2\right\} = \frac{1}{N}\sum_{m=0}^{N-1}\sigma^2 = \sigma^2 = E\left\{|Y(m)|^2\right\}$$

Similarly, we can also get $E\left\{|x(k)|^2\right\} = E\left\{|X(m)|^2\right\} = \sigma^2$. By the Parseval identity, we have

$$\sum_{m=0}^{N-1}|Z(m)|^2 = \sum_{k=0}^{N-1}|z(k)|^2$$
$$= \sum_{k=0}^{N-\tau-1}|x(k)|^2 + \sum_{k=N-\tau}^{N-1}|y(k)|^2$$

and thus

$$E\left\{\sum_{m=0}^{N-1}|Z(m)|^2\right\} = N\sigma^2$$

■

A co-channel OFDM interference source signal in the time domain is expressed by

$$\tilde{s}_n^g(k) = \begin{cases} \tilde{s}_n(k+\tau+N-G)_N, & \text{for } 0 \le k \le N+G-\tau-1 \\ \tilde{s}_{n+1}(k-2G+\tau)_N, & \text{for } N+G-\tau \le k \le N+G-1 \end{cases}$$

which is to be sent during the n-th symbol time interval of the target receiver. The corresponding frequency-domian interference is denoted by $\tilde{S}_n(m)$, which is obtained by passing $\tilde{s}_n(k)$ through the IDFT modulator. Let $\left\{\tilde{h}_n(l)\right\}_{l=0}^{L}$ be the corresponding channel impulse response from the interference source to the the target receiver. Assume that the time offset between the target receiver and the interference OFDM source is denoted by τ. Then the received interference signal can be expressed as

$$\tilde{y}_n^g(k) = \sum_{l=0}^{L}\tilde{s}_n^g(k-l)_N\tilde{h}_n(l), \text{ for } 0 \le k \le N+G-\tau-1 \quad (5)$$

and

$$\tilde{y}_n^g(k) = \sum_{l=0}^{k'}\tilde{s}_{n+1}^g(k'-l)_N\tilde{h}_n(l) + \sum_{l=k'+1}^{L}\tilde{s}_n^g(k'-l+N+G)_N\tilde{h}_n(l), \text{ for } N+G-\tau \le k \le N+G-1 \quad (6)$$

where $k' = k-(N+G-\tau)$. After the operation of removing the guard interval performed by the target receiver, the effective interference is

$$\tilde{y}_n(k) = \tilde{y}_n^g(k+G), \text{ for } 0 \le k \le N-1$$

and the interference signal after the DFT demodulation is given by

$$\tilde{Y}_n(m) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}\tilde{y}_n(k)e^{-\frac{j2\pi mk}{N}}$$

The mean energy contained $\tilde{E}_n$ in the demodulated interference signal for the n-th symbol time interval of the target receiver is defined as

$$\tilde{E}_n = E\left\{\sum_{m=0}^{N-1}\left|\tilde{Y}_n(m)\right|^2\right\}$$

Let $\tilde{R}_n$ be the average power of the demodulated interference signal within the n-th symbol, i.e., $\tilde{R}_n = \tilde{E}_n/N$.

Lemma 2: Assume that the frequency-domain interference is stationary within a control interval which is several symbol time intervals and let

$$E\left\{\left|\tilde{S}_n(m)\right|^2\right\} = \tilde{\sigma}_{S,n}^2 \triangleq \tilde{P}_n$$

and

$$\tilde{P}_n = \tilde{P}_{n+1}$$

if the n-th and $(n+1)$th symbols are located in the same control interval. Then we have

$$\tilde{R}_n = \tilde{P}_n \tilde{G}_n \tag{7}$$

where $\tilde{G}_n$ is the average power gain of the channel from the interference source to the target receiver and is defined as

$$\tilde{G}_n = \sum_{l=0}^{L} E\left\{\left|\tilde{h}_n(l)\right|^2\right\}$$

Proof: First, by the Parseval identity, we have

$$\begin{aligned}\sum_{m=0}^{N-1}\left|\tilde{Y}_n(m)\right|^2 &= \sum_{k=0}^{N-1}|\tilde{y}_n(k)|^2 \\ &= \sum_{k=G}^{N+G-\tau-1}|\tilde{y}_n^g(k)|^2 + \sum_{k=N+G-\tau}^{N+G-1}|\tilde{y}_n^g(k)|^2\end{aligned}$$

and, from (8) and Lemma 1,

$$\begin{aligned}E\left\{\sum_{k=G}^{N+G-\tau-1}|\tilde{y}_n^g(k)|^2\right\} &= E\left\{\sum_{k=G}^{N+G-\tau-1}\sum_{l_1=0}^{L}\sum_{l_2=0}^{L}\tilde{s}_n^g(k-l_1)_N\tilde{s}_n^{g*}(k-l_2)_N\tilde{h}_n(l_1)\tilde{h}_n^*(l_2)\right\} \\ &= \sum_{k=G}^{N+G-\tau-1}\sum_{l_1=0}^{L}\sum_{l_2=0}^{L}E\left\{\tilde{s}_n^g(k-l_1)_N\tilde{s}_n^{g*}(k-l_2)_N\right\}E\left\{\tilde{h}_n(l_1)\tilde{h}_n^*(l_2)\right\} \\ &= \sum_{k=G}^{N+G-\tau-1}\sum_{l=0}^{L}E\left\{|\tilde{s}_n^g(k-l)_N|^2\right\}E\left\{\left|\tilde{h}_n(l)\right|^2\right\} \\ &= (N-\tau)\,\tilde{\sigma}_{S,n}^2\tilde{G}_n\end{aligned} \tag{8}$$

where we have used the facts

$$
\begin{aligned}
& E\left\{\tilde{s}_n^g(k-l_1)_N \tilde{s}_n^{g*}(k-l_2)_N\right\} \\
= \; & E\left\{|\tilde{s}_n^g(k-l_1)_N|^2\right\}\delta(l_1-l_2) \\
= \; & E\left\{\left|\tilde{Y}_n(m)\right|^2\right\}\delta(l_1-l_2)
\end{aligned}
$$

and the stationarity of $\tilde{Y}_n(m)$. On the other hand, from (6) and Lemma 1, we have

$$
\begin{aligned}
& E\left\{\sum_{k=N+G-\tau}^{N+G-1} |\tilde{y}_n^g(k)|^2\right\} \\
= \; & E\left\{\sum_{k=N+G-\tau}^{N+G-1} \sum_{l_1=0}^{k-(N+G-\tau)} \sum_{l_2=0}^{k-(N+G-\tau)} \tilde{s}_{n+1}^g(k-(N+G-\tau)-l_1)_N \right. \\
& \left. \times \tilde{s}_{n+1}^{g*}(k-(N+G-\tau)-l_2)_N \tilde{h}_n(l_1)\tilde{h}_n^*(l_2)\right\} \\
& + E\left\{\sum_{k=N+G-\tau}^{N+G-1} \sum_{l_1=k-(N+G-\tau)+1}^{L} \sum_{l_2=k-(N+G-\tau)+1}^{L} \tilde{s}_n^g(k+\tau-l_1)_N \right. \\
& \left. \times \tilde{s}_n^{g*}(k+\tau-l_2)_N \tilde{h}_n(l_1)\tilde{h}_n^*(l_2)\right\} \\
= \; & \sum_{k=N+G-\tau}^{N+G-1} \sum_{l=0}^{k-(N+G-\tau)} E\left\{|\tilde{s}_{n+1}^g(k-l)_N|^2\right\} E\left\{\left|\tilde{h}_n(l)\right|^2\right\} \\
& + \sum_{k=N+G-\tau}^{N+G-1} \sum_{l=k-(N+G-\tau)+1}^{L} E\left\{|\tilde{s}_n^g(k-l)_N|^2\right\} E\left\{\left|\tilde{h}_n(l)\right|^2\right\} \\
= \; & \tau\tilde{\sigma}_{S,n+1}^2 \sum_{l=0}^{k-(N+G-\tau)} E\left\{\left|\tilde{h}_n(l)\right|^2\right\} + \tau\tilde{\sigma}_{S,n}^2 \sum_{l=k-(N+G-\tau)+1}^{L} E\left\{\left|\tilde{h}_n(l)\right|^2\right\} \\
= \; & \tau\tilde{P}_n \sum_{l=0}^{L} E\left\{\left|\tilde{h}_n(l)\right|^2\right\} \\
= \; & \tau\tilde{P}_n\tilde{G}_n \qquad (9)
\end{aligned}
$$

Then, combining (8) and (9), the result in (7) is concluded. ∎

C. System Model and Assumption

We consider the IEEE 802.11h standard that there are nineteen 20 MHz channels between 5 GHz and 6 GHz allowed in Europe. Consequently, we consider the set of channels $K = \{1,\ldots,k\}$ with $k = 19$. Consider in an environment such as office building, there is a 802.11 WLAN consisting of a set of n infrastructure BSSs, denoted as $N = \{1,\ldots,n\}$. And we assume that the i-th BSS ($i \in N$) has a unique AP_i as a decision maker of the DCS and $m(i)$ stations denoted by M_i={$STA_{i,1}$, $STA_{i,2}$, …,$STA_{i,m(i)}$}, as shown as figure 1. Denote Ω as the set containing all AP_i. Let Γ be the set containing all STAs, i.e., $\Gamma = M_1 \cup M_2 \cup \cdots \cup M_n$. In the 802.11 WLAN system, we assume that there isn't any centralized decision maker of the DCS among all BSSs, that is to say, AP_i is the unique decision maker of the DCS for the i-th BSS. In order to avoid co-channel interference and support good Quality-of-Service (QoS), each AP_i must independently select the best channel to work at. Because inter-access point communications are not standardized, mobility of station between access points supplied by different vendors is not guaranteed, therefore, we assume any station can't take hand-off between different BSSs.

D. Channel Model

The indoor communication channel can be seen as a time varying power gain G_n made up by the long-term fading $f_{long}(k)$ and the short-term fading $f_{short}(k)$, i.e., $G_n = f_{long}(n) + f_{short}(n)$. The long-term fading $f_{long}(n)$ takes into account the path loss

$$f_{long}(n) = C - 10n_e \log_{10}(D) \tag{10}$$

where C is a constant, D the distance between the access point and the mobile station, and n_e the path loss exponent. The short-term fading $f_{short}(n)$ is used to describe the fast fading over the mobile radio channel, where the signal strength is rapidly varied due to rapid scattering around a moving mobile and typically follows Rayleigh distribution in signal envelop. In this paper, the short-term fading is simulated by the well-known Jakes' models [?].

III. Dynamic Channel Selection Algorithm

Besides providing SNR to all stations as high as possible, another goal of our dynamic channel selection algorithm is to supply every station as fair as possible. Because the SNR of all stations in all channels are different, so it is impossible to provide a DCS algorithm that supplies every station the same SNR. That is to say, it is impossible to provide a DCS algorithm that satisfies SNR of every station fairly indeed. Even though we can't provide a DCS algorithm that satisfy SNR of every station fairly indeed, but we can gives the most poorly treated station (i.e., the station who receives the lowest SNR) the largest possible SNR [8]. When it is impossible to increase the SNR of a station without reducing the SNR of another user. Roughly, this definition states that a max-min fair allocation gives the most poorly treated station the largest possible SNR, while not wasting any network resources [8].

In this section, we focus on the case that AP_i would like to take the dynamic channel selection process. We describe an algorithm of how APi selects a channel. The steps are showed as following, which output the channel number that AP_i selects.

Step 1. From the SINR measurement stage, AP_i retrieves the SINR measurement $SNR(\gamma, k)$ made by each mobile station $\gamma \in M_i$ in the i-th BSS by scanning each channel $k \in K$.

Step 2. For all $k \in K$, compute $CSNR(k)$=min$\{SNR(\gamma, k)|\gamma \in M_i\}$.

Step 3. Choose $k_o \in K$ such that $CSNR(k_o) = \max\{CSNR(k)|k \in K\}$ and let k_o be the output.

Give a simple example of our algorithm. Consider the case $i = 1$, $N = 8$, $k = 5$, and $m_1 = 5$, i.e., the target AP is AP_1 controlling five MSs to select a new channel from the existing 5 channels and there are 8 APs to compete for the 5 channels. From Step 1, we can obtain the table of the SINR measurements $SNR(\gamma, k)$ as shown in Table 1 for $\gamma \in M_1 = \{STA_{1,1}, STA_{1,2}, STA_{1,3}, STA_{1,4}, STA_{1,5}\}$ and all $k \in \{1,2,3,4,5\}$.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
STA1,1	21	19	23	19	26
STA1,2	23	18	26	20	23
STA1,3	25	23	24	21	27
STA1,4	23	25	25	24	28
STA1,5	22	20	22	19	29

Table 1: The SINR measurements $SNR(\gamma, k)$.

And from Step 2, we can obtain the table of $CSNR(k)$ as shown in Table 2.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
$CSNR(k)$	21	18	22	19	23

Table 2: The table of $CSNR(k)$.

Consequently, the channel we choose in our algorithm is channel 5, i.e., k=5.

IV. Dynamic Power Control

We consider a power-controlled wireless network system where the transmitted powers are continuously tunable. Within a BSS, every STA is associated with an AP. To maintain a reliable connection between the STA and the AP it belonged to, the SIR at the receiver should be no less than some threshold that corresponds to a QoS requirement such as the bit error rate. We consider only downlink transmissions in this paper because the uplink case can be treated similarly [21][22]. Assume that in the i-th BSS, there are $m(i)$ stations, $M_i = \{STA_{i,1}, STA_{i,2}, \ldots, STA_{i,m(i)}\}$, shown as Figure 1. And let $P_{(i,\gamma,k)}(l)$, $i \in \Omega, \gamma \in M_i, k \in K$, be the transmitted power level on the downlink from AP_i to the target receiver $STA_{i,\gamma}$, $\gamma \in M_i$, at the l-th control sampling interval. Let $G_{(i,\gamma,k)}(l)$, $i \in \Omega, \gamma \in M_i, k \in K$, denote the channel power gain from AP_i to the target receiver $STA_{i,\gamma}$ on channel k at the l-th control sampling interval. Then, from (4), the average received power within a symbol time interval at the target station $STA_{i,\gamma}$ on the k-th downlink channel from its host access point

AP_i is $G_{(i,\gamma,k)}(l)P_{(i,\gamma,k)}(l)$. And, from Lemma 2, the average interference power received at $STA_{i,\gamma}$ on downlink channel k from the other APs is $\sum_{b\in\Omega,b\neq i} G_{(b,\gamma,k)}(l)P_{(b,\gamma,k)}(l)$. Let $v_{(\gamma,k)}$ be power level of the background noise received at $STA_{i,\gamma}$ on downlink channel k. Then, at the l-th control sampling interval, the SINR measured at the target receiver $STA_{i,\gamma}$ is given by

$$SINR_{(\gamma,k)}(l) = \frac{G_{(i,\gamma,k)}(l)P_{(i,\gamma,k)}(l)}{\sum_{b\in\Omega,b\neq i} G_{(b,\gamma,k)}(l)P_{(b,\gamma,k)}(l) + v_{(\gamma,k)}}$$

And let $SINR\_Th_{(\gamma,k)}$ be the desired SNR threshold for the receiver $STA_{i,\gamma}$. For the system considered, the constraint $SINR_{(\gamma,k)}(l) \geq SINR\_Th_{(\gamma,k)}$ must be enforced for each mobile station $STA_{i,\gamma}$. The objective of a power-control scheme is to find the minimum power satisfying this constraint. To this end, there is a well-known power-control algorithm given by

$$P_{(i,\gamma,k)}(l+1) = \frac{SINR\_Th_{(\gamma,k)}}{SINR_{(\gamma,k)}(l)} P_{(i,\gamma,k)}(l) \tag{11}$$

This algorithm and its stability have been studied extensively by Foschini and Miljanic [23], Mitra [24], and Bambos, Chen, and Pottie [25][26]. The algorithm is distributed and autonomous because it relies only on locally available information. It allows each user to have different target SNR values. It has also been shown in [3] to be asynchronously convergent (with geometric rate) to the Pareto optimal power assignment, when the system is feasible (i.e., when there exists a power assignment such that SNR for all). However, if the system becomes infeasible, this algorithm diverges.

Instead of using the conventional power control law in (11), we shall extend the concept of the paper [27] in which a economic model is considered. Although achieving satisfactory QoS is important for users, they may not be willing to achieve it at arbitrarily high power levels, because power is itself a valuable commodity. This observation motivates a reformulation of the whole problem using concepts from microeconomics and game theory [27]. In this section, we will use such a reformulation to develop a mechanism for power control where the desire for increased SIR is weighed against the associated cost. Instead of enforcing the constraint $SINR_{(\gamma,k)}(l) \geq SINR\_Th_{(\gamma,k)}$ as in the hard constraint case, we use a utility function U_γ, which is a function of SINR, to represent the degree of satisfaction of $STA_{i,\gamma}$ to the service quality, and introduce a cost function C_γ,which is a function of transmission power, to measure the cost incurred.

Generally, the QoS depends on SINR, so we let the utility $U_\gamma(SINR)$ be a function of SINR satisfying: $U_\gamma(0) = 0$, $U_\gamma(\infty) = 1$, and the utility function is a increasing function of SINR. Because SNR is a function of power, so utility function is a function of power. This means that utility is more and more satisfied with power increasing. We choose $C_\gamma(P)$, the cost for user, as a function of power. As mentioned before, power is itself a valuable commodity. The specific cost function should reflect the expenses of power consumption to the STA. There are at least two requirements for the cost function:

1. $C_\gamma(0) = 0$,
2. $C_\gamma(P)$ increases in power.

In this work, we will use a linear cost function, i.e.,

$$C_\gamma(P) = c_\gamma P$$

where c_γ is the "price" coefficient. The goal is to maximize the net utility UN_γ defined as

$$UN_\gamma(SINR_{(\gamma,k)}(l), P_{(i,\gamma,k)}(l)) = U_\gamma(SINR_{(\gamma,k)}(l)) - C_\gamma(P_{(i,\gamma,k)}(l))$$

by adjusting the transmitted power $P_{(i,\gamma,k)}(l)$. Since each user in the system will try to maximize its own net utility, regardless of what happens to the other users, this problem is a typical non-cooperative game. Define a function $f_{(\gamma,k)}$ as

$$f^{-1}_{(\gamma,k)}(x) = \frac{dU_\gamma(x)}{dx}$$

With the derivation in [27], the optimal power update law is given by

$$P_{(i,\gamma,k)}(l+1) = \frac{\overline{SINR}_{(\gamma,k)}(l)}{SINR_{(\gamma,k)}(l)} P_{(i,\gamma,k)}(l) \tag{12}$$

where $\overline{SINR}_{(\gamma,k)}(l)$ is defined as

$$\overline{SINR}_{(\gamma,k)}(l) = f^{-1}_{(\gamma,k)}(\frac{c_\gamma P_{(i,\gamma,k)}(l)}{SINR_{(\gamma,k)}(l)})$$

In order to satisfies our requirements for utility function, we choose the sigmoid utility function as mentioned in [27], which has been widely used in the study of neural networks. The utility function for $STA_{i,\gamma}$ is given by

$$U_\gamma(SINR_{(\gamma,k)}(l)) = \frac{1}{1 + e^{-\alpha_r(SINR_{(\gamma,k)}(l) - \beta_r)}} \quad (13)$$

There are two tunable parameters in the sigmoid utility function (13): parameters α_r and β_r, which can be used to tune the steepness and the center of the utility, respectively. We illustrate the utility functions and the corresponding derivative functions for two different values of α_r in Fig. 2. When the parameter α_r increases, the utility becomes steep, and its derivative function becomes narrow and high. In Fig. 3, we fix α_r and vary β_r . The two utility functions and their derivative functions have the same shape, but with different centers (at β_r). Based on the effect of the two parameters on our power control, we observe that the effect of the two parameters can be explained in integrated wireless systems with both voice users and data users, important in the third-generation wireless networks. For a voice user, the essential objective is low delay, and transmission errors are tolerable up to a relatively high point. Thus, the voice user does not want to be easily turned off, but its target SIR can be relatively low. This means that for a voice user, the cost should be low, and the utility function should be steep and with low turnoff SINR. With (13), the optimal power law in (12) can be rewritten as

$$P_{(i,\gamma,k)}(l+1) = \frac{\beta_r P_{(i,\gamma,k)}(l)}{SINR_{(\gamma,k)}(l)} - \frac{P_{(i,\gamma,k)}(l)}{SINR_{(\gamma,k)}(l)} \ln\left[\left(\frac{\alpha_r}{2\frac{c_r P_{(i,\gamma,k)}(l)}{SINR_{(\gamma,k)}(l)}} - 1\right)^2 - 1\right] \quad (14)$$

V. SIMULATION

A. Simulation Model

The simulation environment we considered is a wireless network such as Fig.4. There are 37 BSSs in our simulation system, and there are 10 STAs in each BSS. In each connection, AP transmits data to one STA only. The available channel numbers are 6, 12 (in 802.11a) or 19 (802.11h). In the system, all APs use omnidirectional antennas and are located at the centers of the BSSs. The distance of each AP is about 17 meters. We assume that the locations of all STAs in a BSS are uniform distribution. We consider that implement dynamic channel selection period is after 10 times power update iteration. We consider the case that implement by power control and dynamic channel selection is after 10 times power update iteration, dynamic channel selection will be performed. That is to say, in our simulation, we record 10 times dynamic channel selection and 100 times power control update results in one experiment. In each dynamic channel selection, if the SNR value of connection STAs in BSS is blew down $\beta_r/2$, then the AP will perform the dynamic channel selection.

In our simulation, we compare the case only implement by power control with the case that implement by power control and dynamic channel selection. We investigate the factors β_r, and channel number. The factor β_T is target SNR, which implies that the higher the β_T is, the more difficult the STAs connection to the network is. The channel number implies that the fewer channel number is, the more interference the simulation system is.

And we observe the major results in average SNR of STAs, average net utility of STAs, channel assignment result, and total connection rate of STAs:

1. Average SNR of STAs: In our simulation, we observe the average SNR of STAs in each power update iteration. From average SNR of STAs, we can comprehend the signal strength in each power update iteration. It is also an important index of quality of service.

2. Average Net Utility of STAs: In our simulation, average net utility is also a meaningful observation. From average net utility in each power update iteration, we can understand the average net utility, maybe can be called as satisfaction of users during connection period.

3. Channel Assignment Result: From channel assignment result, we can observe the channel change trend chart.

4. Total Connection Rate of STAs: In order to compare the case which only implements by

the power control algorithm with the case which implements both power control and dynamic channel selection algorithms, the total connection rate of STAs in each power update iteration is an important index, because of it presents the use rate of the network. The higher the total connection rate is, the more users can be serviced by the system provided.

B. Results and Analysis

We show some cases of our experiment results in the section. We shall use the utility-based distributed power control in [27] and compared with our proposed dynamic channel selection and power control. The BSSs number in our simulation system is 37, and there are 10 STAs in each BSS. We shall consider the following four cases.

Case 1. The value of β_γ is 15 and the channel number is 6.

Case 2. The value of β_γ is 20 and the channel number is 6.

Case 3. The value of β_γ is 20 and the channel number is 12.

Case 4. The value of β_γ is 20 and the channel number is 19.

Comparing Fig. 5 for Case 1 with in Fig. 6 for Case 2, we can observe that average net utility and connection rate go down obviously with β_γ increasing. This is because that as β_γ increasing, there are more STAs that will be dropped, then connection rate will go down, so the average net utility and connection rate go down obviously. In Case 1 and Case 2, we can observe that the average net utility and connection rate are improved significantly by performing dynamic channel selection scheme.

Comparing Fig. 7 for Case 3 and Fig.8 for Case 4, we can observe that average SNR, average net utility and connection rate rise with channel number increasing obviously. This is because that with channel number increasing, there are more channel that APs can be dynamically selected, so interference by other APs can be improved, and then average SNR can increase. Therefore, the average net utility and connection rate increase obviously. Therefore the average SNR, average net utility and connection rate are improved significantly by performing dynamic channel selection scheme together with power control.

VI. CONCLUSIONS

In this work, we provide a dynamic channel selection algorithm together with a utility-base power control scheme for a multi-channel wireless network so as to improve average SNR, average net-utility, and connection rate. In simulation results, we discover several remarkable results. By variations of channel numbers, SNR thresholds, and numbers of STAs in a BSS, the propose scheme outperforms the utility-base power control scheme without the dynamic channel selection algorithm.

The feature study may head to the following possible directions. The centralized algorithm could be considered to develop the dynamic channel selection. It could shorten the number of iterations before stabilization. Applying DCS to time-division wireless networks or MC-CDMA (multi-carrier CDMA) wireless networks could have more interesting results.

REFERENCES

[1] LAN/MAN Standards Committee of the IEEE Computer Society, "Supplement to IEEE Standard for Information technology— Telecommunications and information exchange between systems— Local and metropolitan area networks— Specific requirements— Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHZ Band, " *IEEE Std 802.11a*, 1999.

[2] LAN/MAN Standards Committee, "IEEE Standard for Information technology— Telecommunications and information exchange between systems— Local and metropolitan area networks— Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 5: Spectrum and Transmit Power Management Extensions in the 5 GHz band in Europe," *IEEE Std 802.11h*, 2003.

[3] Matthew S. Gast, *802.11 Wireless Networks: The Definitive Guide*, O'REILLY, 2002.

[4] Gerard Cervell, Sunghyun Choi, Stefan Mangold, and Amjad Soomro, "Dynamic Channel Selection (DCS) Scheme for 802.11," Doc.: IEEE 802.11-00/195, July 2000. Available at http://grouper.ieee.org/groups/802/11/Documents.

[5] S. Choi, S. Gray, M. Kasslin, S. Mangold, A. Soomro, Andrew Myles, David Skellern, and Peter Ecclesine, "Transmitter Power Control (TPC) and Dynamic Frequency Selection (DFS) Joint Proposal for 802.11h WLAN," Doc.:IEEE 802.11-01/169r2, May 2001. http://grouper.ieee.org/groups/802/11/Documents.

[6] Christopher Hansen, Matthew Fischer, Raju Gubbi, Joonsuk Kim Broadcom Corporation, "TPC/DFS Proposal for 802.11h," Doc.: IEEE 802.11-01/217, May 2000. Available at http://grouper.ieee.org/groups/802/11/Documents.

[7] Peter Larsson , "Tiered Transmitter Power Control (TTPC) Proposal for 802.11h WLAN," Doc.: IEEE 802.11-01/215r1, May 2001. Available at http://grouper.ieee.org/groups/802/11/Documents.

[8] Peter Marbach, "Priority service and max-min fairness," *IEEE/ACM Trans.Networking*, Vol. 11, No. 5, pp. 733 - 746, Oct. 2003.

[9] Chun-Ting Chou and Kang G. Shin," Analysis of adaptive bandwidth allocation in wireless networks with multilevel degradable quality of service," *IEEE Transaction on Mobile Computing*, VOL. 3, NO. 1, pp. 5-17, Jan.-March 2004.

[10] T. Korakis, O. Ercetin, S. Krishnamurthy, L. Tassiulas, S. Tripathi, "Link quality based association mechanism in IEEE 802.11h compliant wireless LANs," *1st workshop on Resource Allocation in Wireless NETworks*, April 3rd, 2005, Riva Del Garda, Italy.

[11] V. Paxson and S. Floyd, "Wide area traffic: The failure of poisson modeling," *IEEE Trans. Networking*, vol. 3, no. 3, pp. 226-244, March 1995.

[12] Anmol Sheth and Richard Han, "Adaptive power control and selective radio activation For low-power infrastructure-mode 802.11 LANs," *Proceedings of the 23 rd International Conference on Distributed Computing Systems Workshops*, 2003.

[13] Shin Horng and Jan J. Wassell, "Application of game theory for distributed dynamic channel allocation," *IEEE 55th Vehicular Technology Conference*, 2002, Vol. 1, pp. 404 - 408, 6-9 May, 2002.

[14] Taegyu Lee, Myungsook Ko, and Chong-Sun Hwang, "Aladdin: a lending algorithm for distributed dynamic channel allocation in wireless networks," *IEEE 50th Vehicular Technology Conference*, 1999, Vol. 2, pp. 1248 - 1252, 19-22 Sept, 1999.

[15] Amit Butala and Lang Tong, "Dynamic channel allocation and optimal detection for MAC in CDMA ad hoc networks," *Conference Record of the Thirty-Sixth Asilomar Conference on Signals, Systems and Computers*, Vol. 2, pp. 1160 - 1164, 3-6 Nov., 2002.

[16] Wangli Fei, Borhanuddin Mohd. Ali, Malay R. Mukerjee, "Dynamic channel allocation for wireless ATM," Proceedings of IEEE TENCON 2000, vol. 3, pp. 387 - 392, 24-27 Sept, 2000.

[17] Angeline Anthony, Mohd. Hadi Habaebi, Sahar Talib and Borhanuddin Mohd. Ali, "Dynamic Channel Allocation Scheme for Mobile Satellite Systems," *4' National Conference on Telecommunication Technology Proceedings*, Shah Alam, Malaysia, 2003.

[18] Yongbing Zhang, "A new adaptive channel assignment algorithm in cellular mobile systems," *Proceedings of the 32nd Hawaii International Conference on System Sciences*, Vol. 8, 5-8 Jan., 1999.

[19] Sa Liu, Karen Daniels and Kavitha Chandra, "Channel assignment for time-varying demand," *IEEE Global Telecommunications Conference 2001*, GLOBECOM '01, Vol. 6, pp. 3563 - 3567, 25-29 Nov., 2001 .

[20] Theodore S. Rappaport, *Wireless communications*, 2nd edition, Prentice Hall, Communications Engineering and Emerging Technologies Series.

[21] N. Bambos, S. C. Chen, and G. J. Pottie, "Radio link admission algorithm for wireless networks with power control

and active link quality protection," *Proc. IEEE INFOCOM*, Boston, MA, pp. 97–104, Apr. 1995.

[22] J. Zander, "Performance of optimum transmitter power control in cellular radio systems," *IEEE Trans. Veh. Technol.*, vol. 41, pp. 57–62, Feb. 1992.

[23] G. J. Foschini and Z. Miljanic, "A simple distributed autonomous power control algorithm and its convergence," *IEEE Trans. Veh. Technol.*, vol. 42, pp. 641–646, Nov. 1993.

[24] D. Mitra, "An asynchronous distributed algorithm for power control in cellular radio systems," *Proc. 4th Winlab Workshop Third Generation Wireless Information Network*, New Brunswick, NJ, pp.249–257, Oct. 1993.

[25] S. C. Chen, N. Bambos, and G. J. Pottie, "Admission control schemes for wireless communication networks with adjustable transmitter powers," *Proc. IEEE INFOCOM*, Toronto, ON, Canada, pp. 21–28, June 1994.

[26] N. Bambos, S. C. Chen, and G. J. Pottie, "Radio link admission algorithm for wireless networks with power control and active link quality protection," *Proc. IEEE INFOCOM*, Boston, MA, pp.97–104, Apr. 1995.

[27] Mingbo Xiao, Ness B. Shroff, and Edwin K. P. Chong, "A utility-based power-control scheme in wireless cellular systems," *IEEE/ACM Trans. Networking*, Vol. 11, No. 2, pp. 210 - 221, April 2003.

[28] Cem U. Saraydar, Narayan B. Mandayam, and David J. Goodman, "Efficient power control via pricing in wireless data networks," *IEEE Trans. Communications*, Vol. 50, No. 2, pp. 291 - 303, Feb. 2002.

[29] R. D. Yates, "A framework for uplink power control in cellular radio systems," *IEEE J. Select. Areas Commun.*, vol. 13, no. 7, pp. 1341–1347, Sep. 1995.

[30] J. Zander, "Performance of optimum transmitter power control in cellular radio systems," *IEEE Trans. Veh. Technol.*, vol. 41, pp. 57–62, Feb. 1992.

[31] S. Grandhi, R. Yates, and D. J. Goodman, "Resource allocation for cellular radio systems," *IEEE Trans. Veh. Technol.*, vol. 46, no. 3, pp. 581–587, Aug. 1997.

[32] W.-S. Hou and B.-S. Chen, "ICI cancellation for OFDM communication systems on time-varying multipath fading channels," to appear *IEEE. Trans. Wireless Communication.*

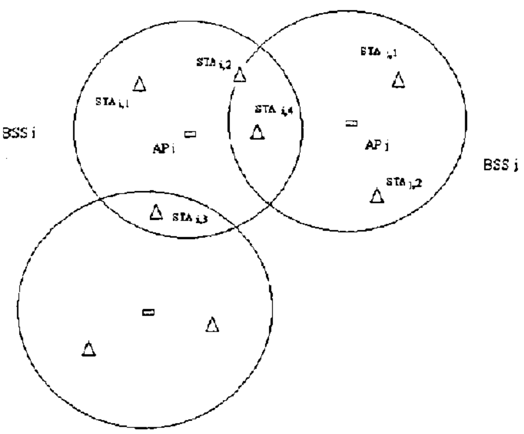

Fig. 1. AP_i and M_i={$STA_{i,1}$, $STA_{i,2}$, ...,$STA_{i,m(i)}$} in BSS.

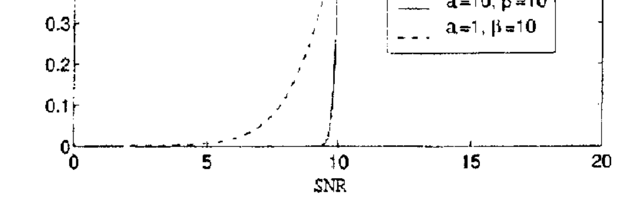

Fig. 2 Sigmoid utility versus SNR with different α_γ.

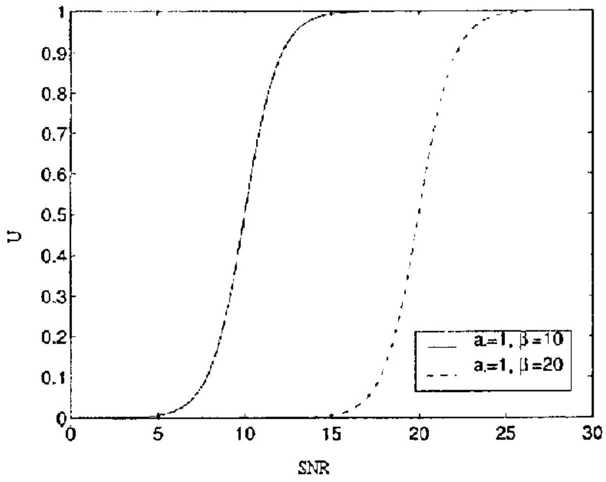

Fig. 3. Sigmoid utility versus SNR with different β.

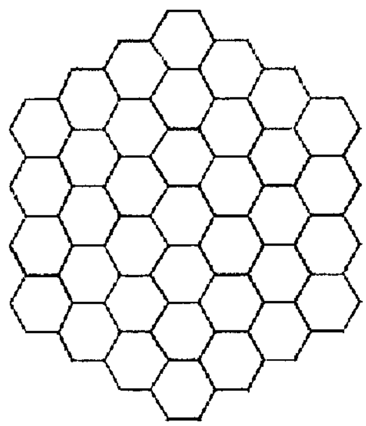

Fig. 4. Wireless network configuration.

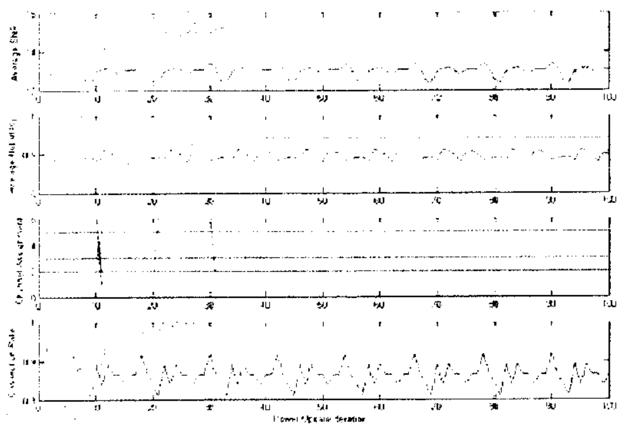

Fig. 5. β_r=15 and the channel number is 6 for case 1.

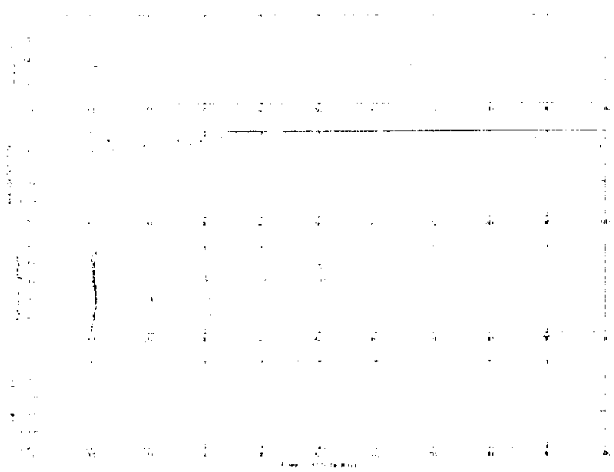

Fig. 6. β_r=20 and the channel number is 6 for case 2.

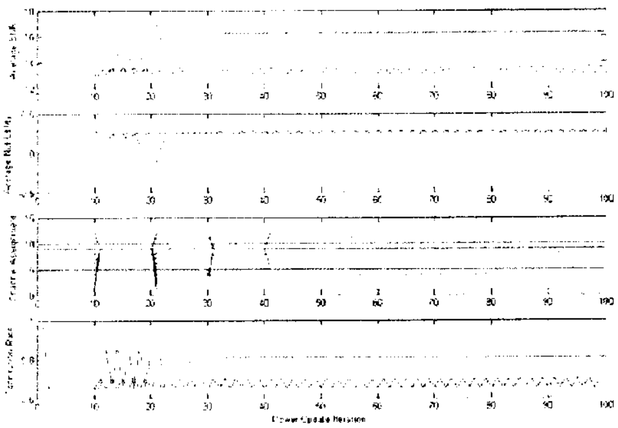

Fig. 7. β_γ=20 and the channel number is 12 for Case 3.

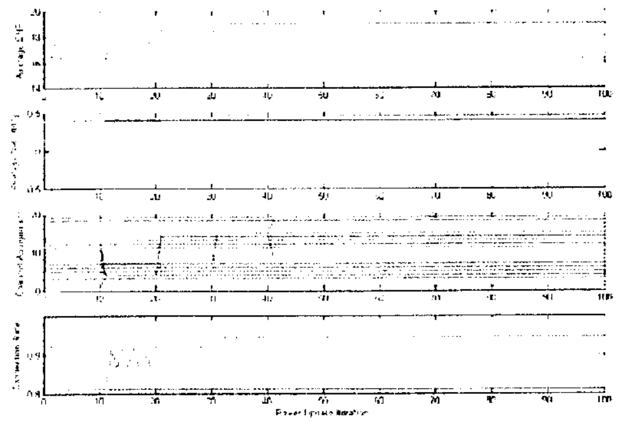

Fig. 8. β_γ =20 and the channel number is 19 for case 4.