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# Adaptive vertical handoff algorithm in heterogeneous networks

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**Abstract** The integration of cellular network (CN) and wireless local area network (WLAN) is the trend of the next generation mobile communication systems, and nodes will handoff between the two kinds of networks. The received signal strength (RSS) is the dominant factor considered when handoff occurs. In order to improve the handoff efficiency, this study proposes an adaptive decision algorithm for vertical handoff on the basis of fast Fourier transform (FFT). The algorithm makes handoff decision after analyzing the signal strength fluctuation which is caused by slow fading through FFT. Simulations show that the algorithm reduces the number of handoff by 35%, shortens the areas influenced by slow fading, and enables the nodes to make full use of WLAN in communication compared with traditional algorithms.

**Keywords** vertical handoff, signal strength, slow fading, fast Fourier transform

## 1 Introduction

With the development of wireless communication technologies, wireless networks are advancing toward integration of different kinds of networks [1], which engenders a large coverage and high bandwidth network. Next generation wireless networks typically combine CN, which has a large coverage (reaching several kilometers) and WLAN, which has a wide bandwidth (IEEE 802.11 b, 11 Mb/s). In order to acquire perfect quality of service (QoS) in communications, a mobile user (MS) will select the better one from CN and WLAN, and thus it is inevitable to bring about frequent handoffs. Handoff in wireless networks can be classified into two types: horizontal and vertical handoff. Vertical handoff occurs when users move between different networks, while horizontal handoff occurs when users move between the same networks. The vertical handoff is discussed in this article.

Handoff in wireless networks includes two successive procedures: handoff decision [2, 3] and mobility management [4–6]. Before handoff, MS makes judgment initially, that is, MS selects one which has better performance by comparing the two kinds of networks. Thereafter, the mobility management will be executed; including MS sending handover requirements to the old base station (BS) to release the channel and new base to apply to bandwidth, and the new base allocating the bandwidth to the MS. This procedure may result in delay and packet loss; however it is not of importance. In this study, attention has been paid to the first procedure, that is, an effective vertical handoff decision algorithm has been designed to enable MS handoff in time.

There are many factors which affect handover, however, for simplicity, the RSS has been taken into consideration, which is the primary factor being considered in most studies [7–10]. In hybrid networks, MS can receive the signal from different bases either in homogeneity networks or in heterogeneous networks, and the base can be selected to communicate depending on the RSS. However, due to the effect of path loss and slow fading, the RSS is not perfectly reversed to the distance between MS and BS, that is, the RSS in the site which is long to the BS may be stronger than the RSS in the site which is nearer to the BS, and when MS moves away from the BS, the RSS may fluctuate, leading to handover occurring frequently, which increases the handoff signals, and plays down the network performance. Certain amelioration measures have been taken in traditional horizontal handoff algorithms [11], such as using threshold where handover occurs only when the RSS from target BS is the strongest and the RSS from the severing BS is below a preset threshold, and using hysteresis when handover occurs only when the RSS from the target BS are stronger than that from the severing BS as much as a hysteresis value. Although these methods can reduce the number of handoffs and are easy to be realized, they increase the handoff delay. And these amelioration methods are also used in vertical handoff. Albeit, the complex algorithms [12] can bring down the handoff number and reduce the handoff delay, and it is difficult to be implemented because the parameters for a certain region are not applicable to other regions. From the point of practice, this study proposes a vertical handoff decision algorithm on the basis of FFT, in which the handoff decision is made according to the

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comparison between the mean value and harmonic amplitudes of the samples. The algorithm introduces the hysteresis value (equal to the sum of all the harmonic amplitudes multiplying the weight) which varies with the samples, and it is the essential difference compared to the traditional handover algorithm. Through simulation, it can be concluded that the algorithm can reduce handoff number and cut down handoff delay. It is worth noticing that the algorithm can also be applied to the horizontal handover by modification.

## 2 The analysis of WLAN signal strength

RSS referring to power (unit: dBm) received by MS from BS is one of the essential factors. Only when RSS is above a certain threshold can the information be recovered precisely from the signal. RSS is mainly affected by three aspects: path loss, slow fading, and fast fading. Path loss is caused by the distance between the MS and BS. Fast fading is the result of multi-path which can be averaged out by low pass filter, and hence is not taken into consideration in this study. Slow fading is caused by the variation of terrain and the refraction of atmosphere, and it is a random variable following normal distribution with mean 0 and variance $\delta^2$ ($\delta$ is between 5–10 dB in general). In this study, only the effect of path loss and slow fading are considered.

The RSS received by MS affected only by path loss is:

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \text{dBm} \tag{1}$$

Here $P_t$ is the power of transmitter; $G_t$ is the antenna gain of transmitter; $G_r$ is the antenna gain of receiver; $\lambda$ is the wavelength; and $d$ is the distance between transmitter and receiver.

The correlation value of random variable of slow fading at the same time is [13]:

$$R(d_1, d_2) = E\left[X(d_1)X(d_2)\right] = \delta^2 \exp\left(-\frac{|d_1 - d_2|}{d_0}\right) \tag{2}$$

Here $d_1$ and $d_2$ are the positions of the two sample points, and $d_0$ is the correlation distance. The value is only related to the distance and not to the positions, so the process of slow fading along any path is a Gaussian stationary stochastic process, noted as $X(d)$. The value of $d_0$ reflects the fluctuation degree of $X(d)$, and the larger the $d_0$, the smaller the degree will be. The value of slow fading in a certain point can be calculated using the recursive equation [14]:

$$P_s(n)_{\text{dB}} = \rho P_s(n-1) + \sqrt{1-\rho^2}\, N(0, \delta^2) \tag{3}$$

Here $\rho$ is the correlation coefficient between point $n$ and point $n-1$, which can be calculated by:

$$\rho = \frac{R(d_1, d_2)}{\delta^2} = \exp\left(-\frac{|d_1 - d_2|}{d_0}\right) \tag{4}$$

## 3 The vertical handoff algorithm

The handoff algorithm in this article [15] considers two cases: handoff from CN to WLAN where the factors are WLAN signal strength and bandwidth, and handoff from WLAN to CN where the factor is WLAN signal strength. In Ref. [16], the number of users in WLAN is predicted by neural network, and the handoff decision is made by fuzzy control where inputs denote the number of users in WLAN, bandwidth, and the mobile speed. In Ref. [17], the decision is also made through fuzzy control where inputs are mobile speed, the traffic in WLAN, and RSS. In Ref. [18], the complex algorithms, such as neural network and fuzzy control can cut down handoff number and reduce delay compared to traditional algorithms, although the former is complicated than the latter. However, in Ref. [12], it is obvious that the complex algorithms are harder to be implemented. Only through plenty of trials in a region can the optimal parameters be obtained. In this study, RSS is assumed to be the dominant factor which affects handoff, and certain other factors, such as error bit rate (EBR) depend on RSS, and so only RSS has been taken into consideration.

The vertical handoff in this study follows two patterns: handoff from CN to WLAN and handoff from WLAN to CN, but all these depend on the RSS. According to Sect. 2, although the RSS is affected by slow fading, because of regularity of slow fading, that is, the values of slow fading strength of the two nearest points are approximate, the RSS is also regular. In general, the harmonic amplitudes are relatively smaller compared to direct-current part at a low mobile speed. WLAN is sampled in signal strength in equal time, FFT for the successive $n$ samples are determined. If the result satisfies:

$$\frac{|X(0)|}{n} > R_h + \sum_{k=1}^{n/2} m_k \frac{|X(k)|}{n} \tag{5}$$

and if the mobile is in the CN, then it handoffs to WLAN. $m_k$ denotes the gain of corresponding harmonic ponderance, which will affect the handoff number and handoff delay, and equals to 2 in general, that is, the sum of all harmonic amplitudes. $R_h$ denotes the handoff threshold where slow fading is not considered. From Eq. (5), if the speed of mobile is high, it should not handoff to WLAN, because the time that the mobile stays in WLAN is shorter in probability, and only when the RSS is somewhat larger should the handover to WLAN take place. On the contrary, if the speed of the mobile is low, then the time that mobile stays in WLAN is longer in probability if the mobile handovers to WLAN. Thus the threshold when handoff occurs can be somewhat smaller.

In order to utilize the WLAN which has sufficient wide bandwidth, the MS should not handover to CN as soon as RSS