ADAPTIVE METHOD FOR MEASURING RECEIVED SIGNAL POWER USING PROBABILITY JUDGEMENT FORMULA FOR SDR BASED MULTI-MODE TERMINALS

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ABSTRACT

Recently, demand has increased for a mobile terminal that can adapt to a variety of different wireless communication systems. In order for the mobile terminal to seamlessly switch wireless communication systems, depending on the condition of the wireless channel between the mobile terminal and the base station of each system, simultaneous operation of both the processing for communication with the system that the mobile terminal connects to and periodically measuring the received signal power to find other candidate systems is imperative. The computational complexity for this measuring operation should be reduced in terms of total power consumption.

In this paper, we propose an effective method of measuring the received signal power. In our proposal, the measurement interval changes depending on the variations in the wireless channel. This enables a reduction in [operation required for the measuring operation while maintaining the tracking capability of the wireless channel.

To demonstrate the effectiveness of our proposal, a computer simulation was executed. The results show that the proposed method realized good tracking performance while reducing the amount of the processing numbers required for measuring the received signal power.

1. INTRODUCTION

With the widespread success of wireless and mobile communications, a large variety of wireless communication systems have been created, including several cellular systems, WLAN (wireless local area network), and WiMAX (worldwide interoperability for microwave access). In addition, the next generation wireless communication systems, such as LTE (long-term evolution) or IMT-Advanced, will be introduced in the near future. In such an environment, it is desirable for a mobile terminal to have the flexibility to support different wireless communication systems. In order to realize this requirement, the SDR (software-defined radio) technique is very effective. The SDR technique makes it possible to change wireless communication systems via software replacements while using only one device. As the number of systems the mobile terminal must support increases, the effectiveness of this approach stands out in terms of cost, size, power consumption, and other factors.

To utilize the advantage of this mobile terminal, it should dynamically switch between different systems depending on the received signal power, such as RSS (received signal strength) or SINR (signal-to-interference and noise power ratio). This handoff is called a *vertical handoff*, in contrast to the conventional method, the horizontal handoff, which means the handoff process is performed between two base stations with the same system [1]. A number of vertical handoff algorithms have been proposed in the research literature [2,3,4]. The focus of these algorithms is how to determine the system that the mobile terminal will use, considering the RSS, SINR, quality of service (QoS), application types, and power requirements. However, there is little discussion about how to obtain these values. The main target of this paper is to effectively measure the received signal power.

In order for the mobile terminal to achieve a seamless vertical handoff, simultaneous operation of both the processing for communication with the system that the terminal connects to and periodically monitoring the received signal power to find other candidate systems is imperative. The main operation is related to communication with the current system, so the operation required for measuring the received signal power should be reduced in terms of total power consumption. In the case of applying the SDR technique to the mobile terminal, in particular, the influence of this computation complexity is very crucial. This is because both processing for communication and measuring are executed on a DSP, despite the severe limitations of the resource.

In this paper, we propose a simple method that enables the mobile terminal to effectively measure the received signal power of other candidate systems. In the proposed method, the measurement interval changes depending on the condition of the wireless channel.

This paper consists of the following sections described below. In chapter 2, we present our approach for measuring the received signal power. In chapter 3, the algorithm of the proposed method is described. In chapter 4, the performance of the proposed method obtained by computer simulation is shown. In chapter 5, we conclude the paper and discuss future work.

2. REQUIREMENTS FOR SIGNAL STRENGTH MEASUREMENTS

There are some proposals for signal strength measurements for handoff decisions [5,6]. In [5], the interval for averaging the received signal power changes depending on the maximum Doppler frequency. And in [6], the wavelet transform is used to average the received signal power. In these methods, the received signal power is measured periodically for a certain period. So the amount of processing cannot be reduced using these approaches. In order to reduce the computational complexity, the measurement interval should be changed in accordance with the communication environment. However, there is a trade-off problem between the tracking capability and the amount of processing. If the measurement interval shortens, the tracking capability of the variance in the wireless channel improves. However, the amount of processing for measuring increases. On the other hand, if the measurement interval lengthens, tracking capability is lost, although the amount of processing can be reduced.

Figure 1 shows our approach to solving this problem. As Fig. 1 shows, when the variance in the wireless channel is fluent, the interval of the measurement may be long. On the other hand, when the variance in the wireless channel is intensive, the measurement interval should be shortened in order to catch up with the fluctuation. To realize this control, the variance in the wireless channel should be detected. The requirements for this control are shown below.

(1) Little complexity
(2) Flexibility

Regarding (1), the main requirement is to reduce the computation complexity required for measuring the received signal power, so the algorithm to realize the control mentioned above should be simple with little complexity. And about (2), the condition of the wireless channel varies by many factors, such as location, time, and velocity. So the algorithm should have the flexibility that can be applied to different conditions.

3. PROPOSAL

We propose a new method to control the measurement interval by satisfying the requirements described in the previous chapter. In the proposed scheme, the measurement interval ΔT lengthens when the variance in the wireless channel is fluent, and if a drastic change can be detected, the measured interval shortens. In the proposed method, Chebyshev's inequality is applied in order to detect the drastic change. Chebyshev's inequality is defined as below.

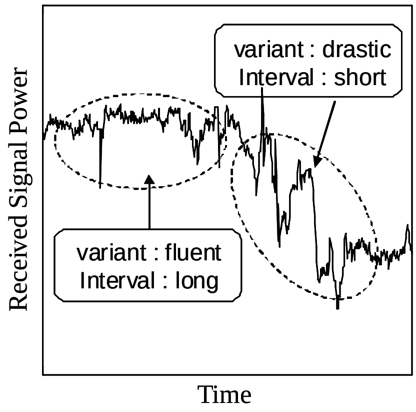


Fig.1 : Concept of adaptive control of measurement interval

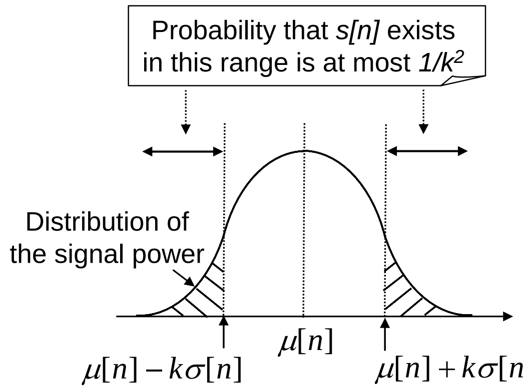


Fig. 2 : Image of Chebyshev's inequality

$$\Pr[|\,s[n]-\mu[n]\,| \ge k\sigma[n]] \le 1/k^2 \qquad (1),$$

where $s[n]$, $\mu[n]$ and $\sigma[n]$ are the instantaneous value of the received signal power at time n, the average value and the standard deviation of $s[n]$, respectively. And k is a constant value. The image of this equation is shown in Fig. 2. As this figure shows, this expression means the probability that $s[n]$ exists outside the range of $\mu[n]-k\,\sigma[n]$ and $\mu[n]+k\sigma[n]$ is at most $1/k^2$. Because $\mu[n]$ and $\sigma[n]$ are statistics of the past, if $s(t)$ exceeds the range defined by this equation, it means the condition of the current wireless channel changes intensely compared with that of the past.

Fig .3 shows the state transition diagram of the proposed method. As this figure shows, the proposed scheme using this inequality consists of two states. One is *training state* and the other is *judgment state*. When the power of mobile terminal is on, this algorithm will start from the *training state*. In the *training state*, it is considered that the variant of the wireless channel is drastic, so the measurement interval is set short and $\mu[n]$ and $\sigma[n]$ are calculated base on the $s[n]$. After a certain period, it goes to the *judgment state*. On the other hand, it is considered that the variant of the wireless channel is fluent in the *judgment state*, so the measurement interval is set long. And the judgment using Eq. (1) is executed in order to find the variant of the wireless channel. If $s[n]$ exceeds the range defined by this equation, it returns to the *training state*.

3.1. Training state

In this state, the interval is set short ($\Delta T = T_S$) and $s[n]$ is measured. Based on the measured $s[n]$, the average value $\mu[n]$ and the standard deviation $\sigma[n]$ are calculated with an exponential smoothing method.

$\mu[n]$ is calculated as the tracking equations.

$$\mu[n] = \begin{cases} s[0] & (t = 0) \\ (1-\alpha) * \mu[n-1] + \alpha * s[n] & (t \geq 1) \end{cases} \quad (2),$$

where α is a forgetting factor. $\sigma[n]$ is calculated as the tracking equation.

$$\sigma[n] = \sqrt{| x[n] - \mu^2[n] |} \quad (3),$$

where $x[n]$ is calculated as the tracking equations.

$$x[n] = \begin{cases} s^2[0] & (t = 0) \\ (1-\alpha) * x[n-1] + \alpha * s^2[n] & (t \geq 1) \end{cases} \quad (4)$$

After a certain period ($T_{training}$), it goes to the *training state.*

3.2. Judgment state

In this state, the interval is set long ($\Delta T = T_L$) and s[n] is measured. After that, the judgment as to whether the condition of the current wireless channel drastically varies compared with that of the past is executed using Chebyshev's inequality. Here, in order to reduce the influence of singular values, this judgment is repeated M times. The probability P that $s[n]$ exceeds the range defined by Eq. (1) by M continuous times equals $(1/k^2)^M$. If $s[n]$ eclipses $\mu[n]+k\,\sigma[n]$ or falls down $\mu[n]-k\,\sigma[n]$ by M continuous times, it returns to the *training state*. As it is clear to see in Eq. (1), the proposed method has very little complexity because only $\mu[n]$ and $\sigma[n]$ should be calculated. Moreover, to change k and M, the precision of the detection can be changed adaptively, so the proposed method can be easily adapted for different environments.

4. SIMULATION RESULT

To demonstrate the effectiveness of the proposed method, a computer simulation was executed. This simulation was an offline operation using actually measured SINR. In this paper, we targeted the condition where the mobile terminal moved slowly and measured SINR in 3 cases while walking. Fig. 4 shows measured SINR, and the performance of the proposed method was evaluated using these SINR values.

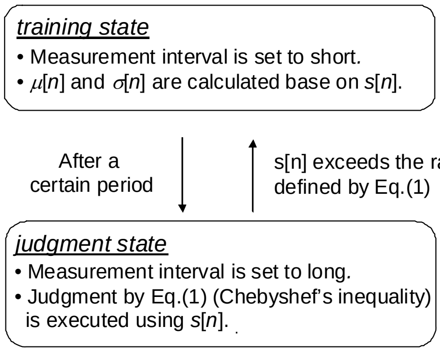


Fig. 3 : State transition diagram of the proposed method

Table 1 : Simulation Parameters

Total simulation time (T)	300 [s]
Sample interval (Δt)	1.67 [ms]
Measurement interval (T_S ,T_L)	$60\Delta t$, $1000\Delta t$
Forgetting factor (α_S , α_L)	0.1, 0.5
Number of judgments (M)	3
Training period ($T_{training}$)	6[s]

The parameters used for this simulation are shown in Table 1. The total measured time is 300 seconds, and the interval for each sample (Δt) is 1.67 ms, which is the length of the minimum data unit for the CDMA2000 1x EV-DO system [7, 8]. The proposed method was applied to these variations, and the measurement interval was changed adaptively. Fig. 5 shows the measurement interval of the proposed scheme in each state. As this figure shows, in the *training state*, SINR was sampled every 0.1 second. In the *judgment state*, SINR was sampled every 1.67 seconds to search for a candidate system. Detailed information about other parameters is provided below.

- Forgetting factor (α_S,α_L)

Values for these forgetting factors were selected in order to reduce the effect of fluctuations due to multi-path fading in each state. α_S is used in the *training state* and α_L is used in the *judgment state*. This avoids frequent switching between the systems.

- Number of judgment[s] (M)

This value determines the precision of the judgment for the variance in the wireless channel. If M is set large, the precision of judgment improves. However, the time required for judgment ($=MT_L$) is lengthened. This leads to the lack of tracking capability. In this simulation, considering both the precision of judgment and the required time, M is set to 3. In this case, the required time for the judgment is about 5 seconds.

- Constant value *(k)*

This value determines the sensitivity for the variance in the wireless channel. If k is set small, sensitivity to the variance increases because the probability that $s[n]$ exceeds the range defined by Eq. (1) becomes high. However, the influence of a singular value measured by accident also increases. We will discuss how to set this value in our simulation in next section.

A periodic measuring method was used for the performance comparison. In this method, SINR was measured at every $n\Delta t$ ($n > 0$) interval using α_n. This method is referred to as the *$n\Delta t$ - periodic method* in this paper. For example, if n is set to 1, it means that the SINR is measured at every slot (=1.67 ms).

4.1. Effect of constant value *k*

In this section, we evaluated the performance of the proposed method by changing the constant value k. Fig.6 shows the judgment probability P versus Normalized Mean Square Error (NMSE) N of the averaged value of the measured SINR. As mentioned in the previous section, P equals $(1/k^2)^M$. Now M is set to 3, so P equals $1/k^6$. NMSE was calculated as the tracking equation.

$$N = \frac{\sum_{n=1}^{S_{prop}} (\mu_{prop}[n] - \mu_{\Delta t\_perio}[n])^2}{\sum_{n=1}^{S_{prop}} (\mu_{\Delta t\_perio}[n])^2} \qquad (5)$$

Here, S_{prop}, $\mu_{prop}[n]$ and $\mu_{\Delta t\_prio}[n]$ mean the number of SINR samples which were measured by the proposed method during 300s, the averaged value acquired by the proposed method and the averaged value acquired by the *Δt - periodic method*, respectively. The N indicates the difference in the averaged values of the proposed method and the "*Δt - periodic method*". The latter method employs minimum measurement interval (=1.67ms) and the precision of the averaged value should be best.

As Fig. 6 shows, NMSE improves as P increases. This is because the probability that $s[n]$ exceeds the range defined by Eq.(1) increases, therefore the number of times that the state is changed from the *judgment state* to *the training state* also increases. More samples are measured in the *training state* than in the *judgment state*, so the precision of the averaged value improves. However, when P is over 0.2, the amount of the improvements of NMSE is small, meanwhile the number of SINR sample increases, which leads the increment of the computational complexity. Considering this result, P=0.2 is used from the next section.

4.2. Tracking capability

The tracking capability of the proposed method and *Δt – periodic* was evaluated and compared in this section. The CDF (cumulative distribution function) of the difference in

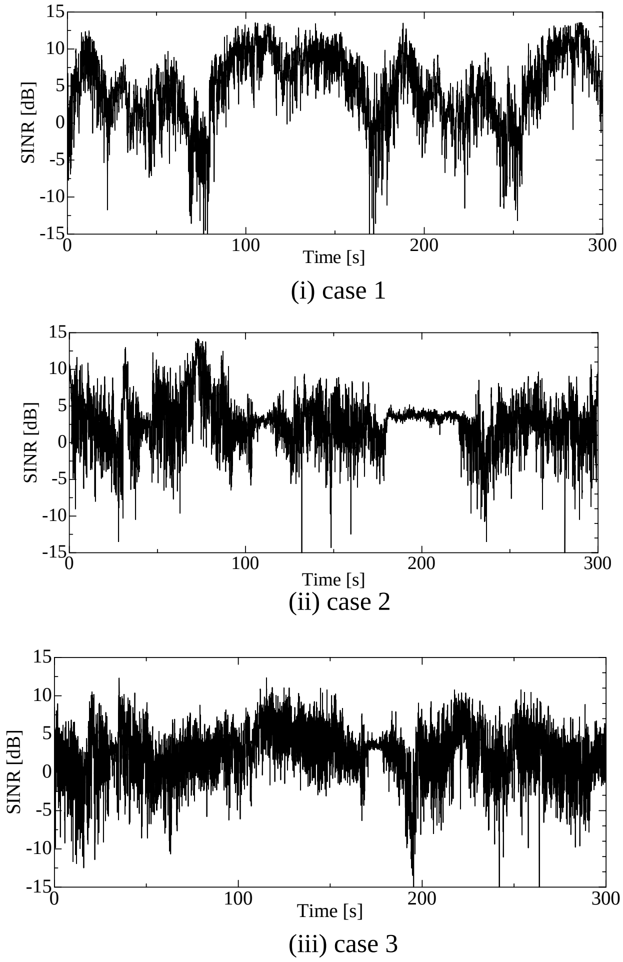


Fig.4 Examples of measured SINR when mobile terminal moved slowly

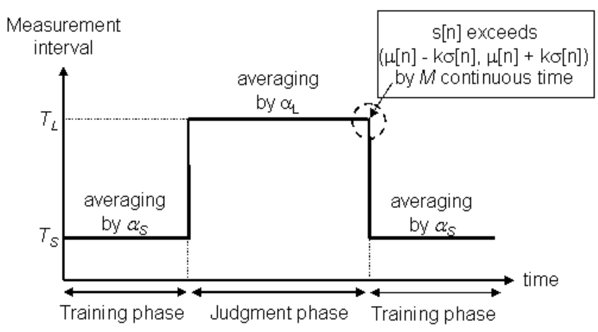


Fig. 5 Measurement interval of the proposed method

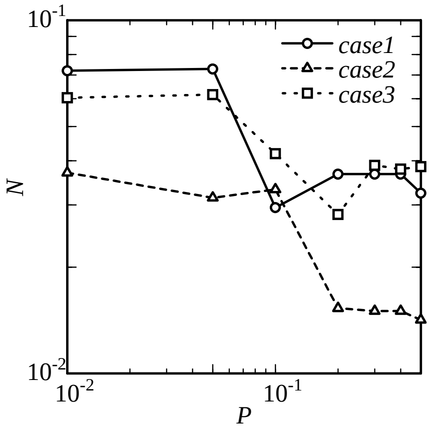


Fig.6 Performance of judgment probability *P* versus *N*

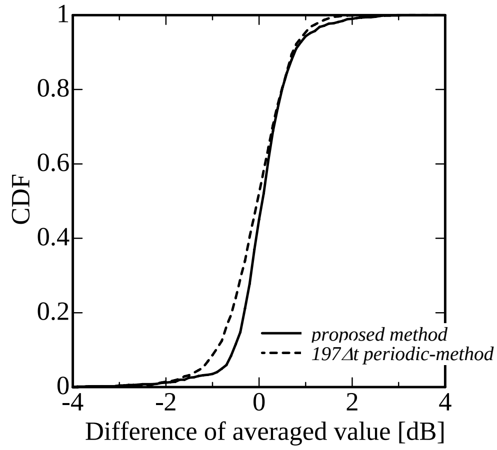
the averaged value between the proposed method and the *Δt - periodic method* (α_1 =0.003) in each case is shown in Fig.7. The horizontal axis of this figure shows the difference in the averaged value between the proposed method and *Δt - periodic method*. The vertical axis shows the percentage of the CDF. Here, the CDF of the difference in the averaged value between the *nΔt - periodic method* and *Δt –periodic method* is also shown in the figure as a reference. The number of SINR samples required for the *nΔt - periodic method* was the same in each case as that of the proposed method in order to equalize the computational complexity of both methods. In order to equalize the number of SINR samples, *n* was set to 197, 240 and 225 in each case.

As Fig. 7 shows, the performance of the proposed method is better than that of *nΔt - periodic method*, especially when the difference in the averaged value is in the range of -2 and +2 dB. This is because the proposed method can detect the variance correctly and measure SINR with high accuracy.

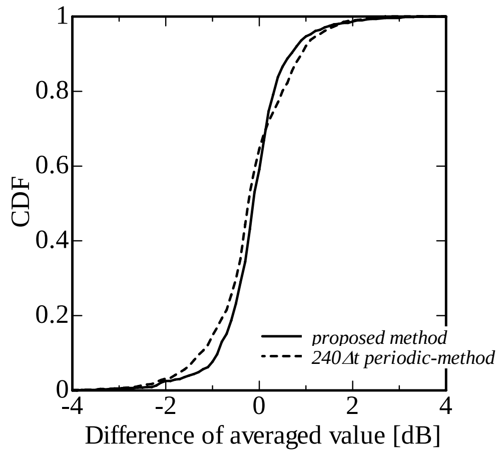
Table 2 shows the difference in the averaged value obtained by each method at the probabilities of 10% and 90%. As this table shows, the proposed method achieves a 0.8 dB improvement in the best case and a 0.4 dB improvement in the worst case compared to the *nΔ*t - periodic method.

4.3. Computational complexity

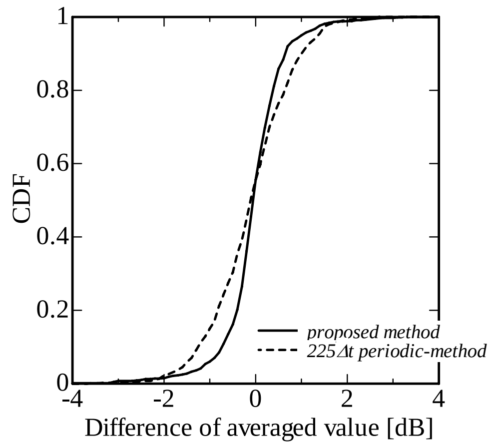
In this section, the computational complexity of the proposed method was evaluated. In this evaluation, the number of SINR samples for the *nΔt - periodic method* was adjusted to achieve the same tracking capability as the proposed method in each case. That is, the difference in the averaged value between the probability of 10% and that of 90% is same between the proposed method and the *nΔt - periodic method.* It is fair to compare the computational complexity of the proposed method to that of the *nΔt - periodic method*.



(i) case 1 (*n* = 197)



(ii) case 2 (*n* = 240)



(iii) case 3 (*n* = 225)

Fig. 7 CDF performance of the proposed method and *nΔt - periodic method* in terms of difference in average value compared with *Δt - periodic method*

Table 3 shows the number of SINR samples for both the proposed method and $n\Delta t$ - *periodic method* in each case. As this table shows, by using the proposed method, the number of required samples was reduced by about 50% in the best case and about 39% in the worst case. As the results in section 4.1 and 4.2 show, it can be concluded that the proposed method realizes good tracking performance while reducing the number of times processing needs to be carried out to measure the received signal power.

5. CONCLUSION

In this paper, we proposed an effective method for measuring the received signal power in order for multi-mode terminals to achieve seamless handover within different wireless systems while reducing power consumption. In our proposal, the measured interval changes depending on the variations in the wireless channel. This enables a reduction in the number of operations required for measurement while maintaining the tracking capability of the wireless channel. To demonstrate the effectiveness of our proposed method, a computer simulation was executed with some test cases using actually measured SINR. The simulation results show that the proposed method achieves about 0.4-0.8 dB improvement in the measurement on average for the averaged value at a probability of 80% while the number of operations required to measure the received signal power was reduced by about 39-50 % on average compared with periodic measurement. These results show that the proposed method realizes good tracking capability while reducing the amount of processing when a mobile terminal is moving slowly.

On the other hand, when a mobile terminal moves at high speed, SINR tends to vary rapidly, so the effect of applying the proposed method is very limited. A control method for use in a high speed environment will be proposed in the future.

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Table 2 : difference in the averaged value obtained by the proposed method and $n\Delta t$ - *periodic method*

(i) case 1

	difference of averaged value [dB]	
	proposed method	$197\Delta t$-periodic method
10%	-0.5	-0.9
90%	0.7	0.7
difference	1.2	1.6

(ii) case 2

	difference of averaged value [dB]	
	proposed method	$240\Delta t$-periodic method
10%	-0.9	-1.3
90%	0.7	0.9
difference	1.6	2.2

(iii) case 3

	difference of averaged value [dB]	
	proposed method	$225\Delta t$-periodic method
10%	-0.7	-1.3
90%	0.8	1
difference	1.5	2.3

Table 3 : Required SINR samples for the proposed method and $n\Delta t$ - *periodic method* and the reduction rate of the calculation

	Required SINR sample		
	case1	case2	case3
proposed method	911	752	799
$n\Delta t$-periodic method	1495	1496	1382
reduction rate (%)	39	50	42