Original Article

Channel quality map construction scheme using location information for heterogeneous wireless network

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Abstract

Heterogeneous wireless systems, such as a combination of mobile broadband wireless access (MBWA) and wireless local area network (WLAN), are candidates to achieve large capacity in next generation mobile communication systems. For capacity expansion, small cells of multiple wireless networks are deployed densely in these systems. Many cells overlap. Therefore, users must discover many cells at once for cell selection. Consequently, radio resources are used intensively for cell selection. Cell selection errors occur in dense small cell environments. As described herein, a channel quality map construction scheme using multi-Global Navigation Satellite System (GNSS) signals for heterogeneous wireless networks is proposed. The scheme uses positioning information and the average of signal strength for cell selection. Using positioning information, users can select cells which have a better channel quality quickly and easily. The proposed scheme is considered to be useful to optimize data traffic offloading in the heterogeneous wireless network. The 50 % user throughput and system throughput of the proposed scheme by comparison with the conventional scheme which uses measured instantaneous signal strength was studied. Computer simulation results show that the proposed scheme can improve the 50 % user throughput by 68 % in comparison with the conventional scheme. In addition, the system throughput is enhanced by 10 % compared with the conventional scheme. Furthermore, based on measured data, the positioning accuracy with multi-GNSS signals is a realizable level for the channel quality map construction scheme. This report describes the developed channel quality map construction scheme prototype system.

Key words
wireless network, cell selection, channel quality map, GNSS, positioning accuracy

1. Introduction

Broadband service demand has increased in wireless communication systems and wireless data traffic has been increasing sharply. One candidate to satisfy that burgeoning demand is a heterogeneous wireless system (Tsubouchi et al., 2012; Takagi et al., 2013; Kuboniwa et al., 2014). A heterogeneous wireless system combines a multiple wireless systems such as mobile broadband wireless access (MBWA) and wireless local area network (WLAN). It is particularly effective because small cells are deployed densely for capacity expansion. For example, the number of WLAN access points (APs) has been increasing in recent years. In third Generation Partnership Project (3GPP), Small Cell Enhancement (SCE) has been discussed for fourth generation mobile networks (3GPP, 2013). By increasing the number of small cells, multiple network cells will overlap in a heterogeneous wireless system. For optimum data traffic offloading, users must select cells which have better channel quality. For cell selection, users generally discover neighbor cells by listening on the broadcast channel, and by measuring the instantaneous value of signal strength, such as the received signal strength indicator (RSSI) and reference signal received power (RSRP). However, using this scheme, network efficiency decreases in a dense small cell environment for the following reasons. First, users must discover many cells and measure the instantaneous value of signal strength for each. Radio resources are used more for cell selection in this environment. Next, cell selection error occurs because the instantaneous value of signal strength fluctuates by fading. Users cannot select the cell which has the highest channel quality because of cell selection error. Finally, users cannot get the traffic load information merely by measuring signal strength. Even if users select the cell which has the highest signal strength in neighboring cells, the cell might be congested. The throughput might not be the highest. For example, WLAN uses Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) as a multiple access scheme. It decreases the channel efficiency dramatically when numerous users are connected to the WLAN. To improve network efficiency in a dense small cell environment, the cell selection scheme must satisfy the following requirements:

- Reduction of radio resource utilization for cell selection
- Suppression of cell selection errors
- Provision of a method to acquire cell traffic load information

Systems that provide high-accuracy positioning information with Global Navigation Satellite System (GNSS), such as the Quasi-Zenith Satellite System (QZSS) (Japan Aerospace Exploration Agency, 2013) in Japan and the GLObal Navigation Satellite System (GLONASS) (Information-analytical centre, 2014) in Russia with a Global Positioning System (GPS) were specifically examined. These systems can provide submeter grade positioning information. As described in this paper, the cell selection scheme using positioning information is proposed.

In the proposed scheme, users select a cell using their location and the channel quality information. Channel quality information at each location is provided for cell selection. Users can guess the channel quality of each cell by measuring only their location. Therefore, users need not discover cells for cell selection. Furthermore, this channel quality information consists of the average of signal strength and traffic load information. Therefore, users can suppress the cell selection error and select a cell in response to real-time traffic load variation. The throughput enhancement of the proposed scheme by computer simulation is presented. The proposed scheme is compared with the conventional scheme, which uses the instantaneous value of signal strength. The effect of suppression of cell selection error is evaluated. Traffic-load information is not considered in this paper. Evaluation results demonstrate that the proposed scheme suppresses cell selection error. It has superior throughput to that of conventional systems. This paper has five sections. Section 2 explains the proposed scheme. Section 3 presents an evaluation of the user throughput and the system throughput of the proposed scheme by computer simulation. Section 4 describes the measured positioning accuracy of various GNSS and development of the prototype system on the channel quality map construction scheme. Section 5 presents conclusions.

2. Cell selection scheme using positioning information

This section explains the proposed cell selection scheme. As described in the introduction, the proposed scheme uses a user's location and channel quality information. By knowing where the user is, channel quality information of neighbor-

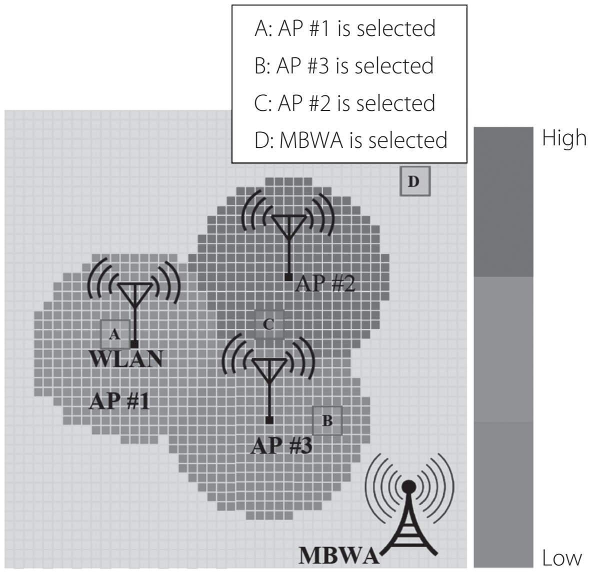

Figure 1: Image of a channel quality map

ing cells is referenced. The cell which the user should select is decided. This information the channel quality map is called. Figure 1 depicts an image of the channel quality map, which shows which cell users should select at each location. Figure 1 shows that if a user is in area A, the user should select the AP1. The channel quality map uses the average of signal strengths as physical channel quality of the cells. In the handover of heterogeneous wireless system, the average of signal strength is suitable for the cell selection criteria. For example, the cellular system has a high-speed closed-loop transmission power control and adaptive modulation and coding (AMC) for the signal strength fluctuation. However, no such function exists in a self-distribution wireless system like the WLAN.

The user terminal cannot cope with instantaneous fluctuation of signal strength in the WLAN. The handover in a heterogeneous wireless system is executed much more slowly compared to the signal strength fluctuation speed. Therefore, the average of the signal strengths is applied for the channel quality map as the common cell selection criteria in the proposed scheme. The proposed scheme requires the channel quality map in addition to obtaining the positioning information.

Figure 2 presents an outline of the method to make the channel quality map. To construct the map, calculation of the average signal strength at each location is needed. The user's measurement information of the instantaneous value is used. The Heterogeneous Control Server (HCS) in Figure 2 accumulates the measurement information from numerous users' terminals. Furthermore, HCS statistically processes the gathered information to construct the channel quality map. HCS holds the map and users take it from this server. Hereinafter, we explain the method of creating the channel quality map, which is made using the following two steps is explained.

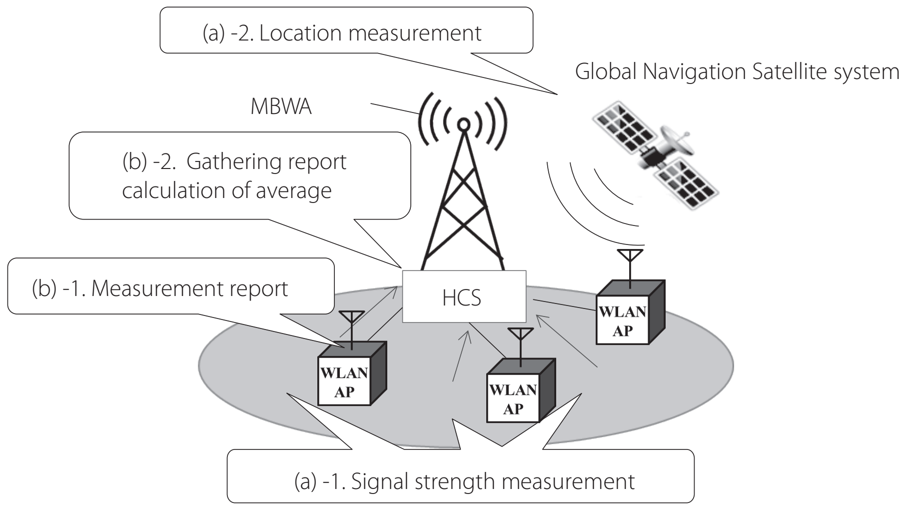

Figure 2: Steps of making the channel quality map
Source: Control ServerHCS: Heterogeneous

(a) Measurement signal strength and location
(b) Gathering measurement report and making the map

(a) Measurement signal strength and location
First, to calculate the average, the users measure the instantaneous signal strengths of each cell. At the same time, users measure their own location. These two pieces of information are stored by the individual users. Even in the proposed scheme, users must measure the signal strengths, but this measurement is executed by numerous users and not for cell selection. Therefore, users can carry out this measurement at any time. The proposed scheme is expected to reduce the measurements per user.

(b) Gathering measurement reports and making the map
Next, the information explained in (a) is gathered for making the map. In this process, users transmit this information to HCS. This transmission has a low real-time demand because the average signal strength is static unless the neighboring environment greatly changes. Therefore, the timing by which the user transmits this information can be adjusted flexibly. However, HCS executes statistical information processing to every cell to produce the channel quality map. Figure 3 presents an example of averaging and the areas are segmented into rectangles. The gathered information is averaged in each segment. The square size should be decided by considering the positioning accuracy. If the square is wide, then the channel quality map becomes unreliable because small cells have narrow coverage. High positioning accuracy is necessary to produce a reliable map. As described in the introduction, users can obtain sub-meter grade positioning information using QZS or GLONASS with GPS.

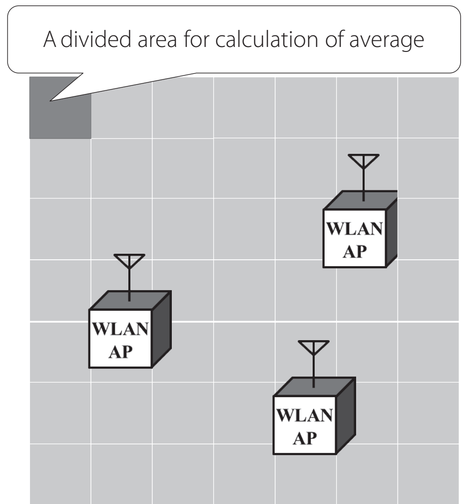

Figure 3: Example of averaging for making the map

3. Evaluating throughput performance of the proposed cell selection scheme

This section presents evaluation of the user throughput and the system throughput of the proposed scheme. It is assumed that channel quality map is ideal.

3.1 Selection criteria and the factor of cell selection error

This subsection explains the selection criteria and the factor of cell selection error. The proposed scheme is compared with the conventional one, which uses instantaneous measurement value. Figure 4 shows the selection criteria and the factor of cell selection error in this evaluation. It is assumed that two cells exist in Figure 4. The horizontal axis is the distance from MBWA base station (BS) to the user terminal. The vertical axis is the signal-to-noise ratio (SNR) as a channel

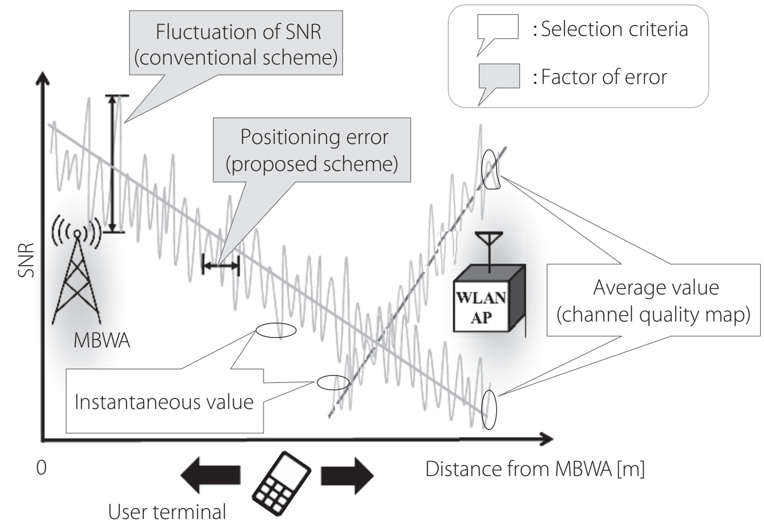

Figure 4: Selection criteria and the factor of cell selection error

quality in this evaluation. Wavy lines in Figure 4 show the instantaneous SNR including fluctuation by fading. A user measures the instantaneous SNR of two cells in the conventional scheme and selects the cell with the higher instantaneous SNR. The SNR fluctuation causes the cell selection error. However, in the proposed scheme, the user refers to the channel quality map using user's location. The straight lines in Figure 4 show the short range average of SNR, i.e., the channel quality map. The user should select the cell with a higher average SNR. When a positioning error occurs, the user might employ the wrong information related to the channel quality map. Therefore, cell selection error can occur even in the proposed scheme according to the degree of positioning error. As described herein, the positioning error to the proposed scheme as a simulation parameter is applied.

3.2 System model

This subsection explains the system model used in this evaluation. Figure 5 presents the cell arrangement of this evaluation. An MBWA cell comprising of three sectors was assumed and one-sector cell was the evaluation area. Assuming the dense small cell environment, three clusters were deployed in the MBWA cell. The cluster included four WLAN cells. The MBWA cell was isolated; inter-cell interference was not considered. The MBWA cell range was adjusted to 250 m. The transmission power of each WLAN cell was equal, so WLAN cell range was varied depending on the cell position. Users select a cell by the selection criteria in each scheme.

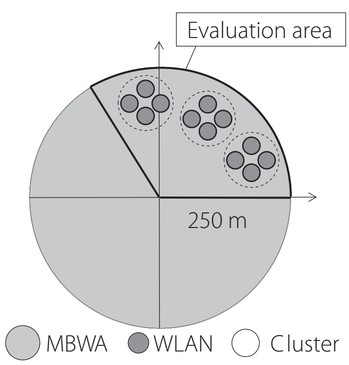

Figure 5: Cell arrangement of this evaluation

User throughput was calculated from AMC and bandwidth per user. AMC was decided by SNR of the cell which each user selects. Table 1 shows the look-up table of AMC. For SNR γ less than 0 dB, AMC is not assigned. If γ is more than 18 dB, then 64QAM and coding rate 3/4 is assigned. In this evaluation, the average SNR was used for γ. Bandwidth per user was calculated using the system bandwidth and the number of connected users. It is assumed that the system bandwidth was divided by the number of connected users and assigned to each user equally. Therefore, user throughput R was calculated as follows:

Table 1: Look-up table of AMC

SNRγ [dB]	γ< 0	0 ≤ γ< 3	3≤ γ< 6	6 ≤ γ< 9
AMC	N/A (0 bps)	BPSK&1/2	QPSK&1/2	BPSK&3/4
SNRγ [dB]	9 ≤ γ< 12	12≤ γ< 15	15≤γ< 18	18≤γ
AMC	16QAM&1/2	16QAM&3/4	64QAM&2/3	64QAM&3/4

$$R = \frac{B}{N} MC \; [bit/s] \qquad (1)$$

B and N respectively denote the system bandwidth and the number of connected users. Therefore, B = N is the bandwidth per user. M and C respectively denote the bit rate per symbol and the coding rate. In the case of WLAN, considering CSMA/CA, the channel efficiency of WLAN the WLAN

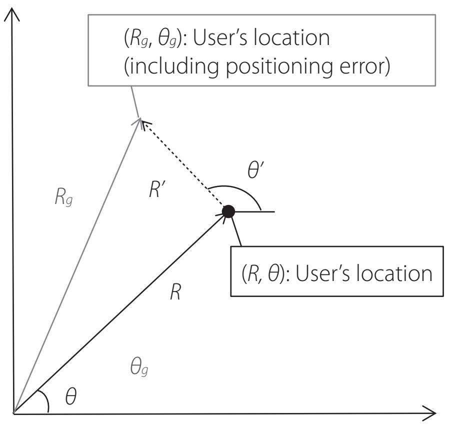

Figure 6: Method of positioning generation

cell, the user throughput was multiplied by this efficiency. The method of positioning error generation in the proposed scheme is explaned. Figure 6 presents a description of this method. Therein, R and θ respectively denote the distance and angle of user's location in polar coordinates: the coordinate (R, θ) denotes a user's actual location. However, R' and θ' generate the positioning error. Here, R' is given by the normal distribution with zero mean and standard deviation σ. Here, σ was used as the parameter of positioning error (explained in the next subsection). θ' is given by the uniform distribution between [0 2π]. As described, users regard the coordinate (Rg, θg) in Figure 6 as their location, and refer to the channel quality map for cell selection.

3.3 Evaluational condition

Table 2 shows the evaluational condition. For the path loss model in MBWA and WLAN, Non-Line-Of-Sight (NLoS) models of Urban Macro (UMa) and Urban Micro (UMi) (3GPP, 2010) were used respectively. As described, SNR including path loss was used as the average for the channel quality map. The BS antenna heights of MBWA and WLAN were set respectively to 25 and 10 m. Mobile terminal (MT) antenna height was set to 1.5 m. The number of users connected to MBWA was set to 50. MBWA users were generated uniformly in the evaluation area. The number of users per WLAN AP was set to 8. WLAN users were generated in each cluster uniformly. Therefore, 32 users were generated per cluster. In the conventional scheme, Rayleigh fading was used for the fading channel. Positioning error was set to 3 and 10 m in the proposed scheme.

Table 2: Evaluation condition

	MBWA	WLAN
Carrier frequency [MHz]	2000	2500
Bandwidth [MHz]	10	20
Transmission power [dBm]	30	23
Noise power spectrum density [dBm/Hz]	–174	
Number of users per BS / AP	50	8
Number of BSs / APs	1	12
Path loss model	UMa (NLoS)	UMi (NLOS)
Base station / AP antenna height [m]	25	10
Mobile terminal antenna height [m]	1.5	
Fading channel model	Rayleigh	
Positioning error σ [m]	0, 3, 10	

3.4 Simulation result

The cumulative distribution function (CDF) of user throughput was evaluated. Figure 7 shows the CDF of the proposed scheme and the conventional scheme. The horizontal axis in Figure 7 is the user throughput. The vertical axis is the CDF. Here, the users in the WLAN cell edge were specifically examined. These users might cause cell selection error. Figure 8 shows a CDF of more than 50 %. Figure 8 shows that if the positioning error is 3 m, then the proposed scheme improves the user throughput in comparison with the conventional scheme. High positioning accuracy suppresses the cell selection error. Users can select the cell which has high throughput at their location. However, for positioning error of 10

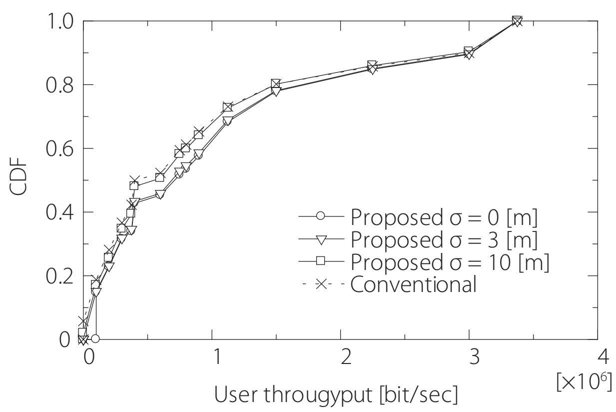

Figure 7: User throughput CDF

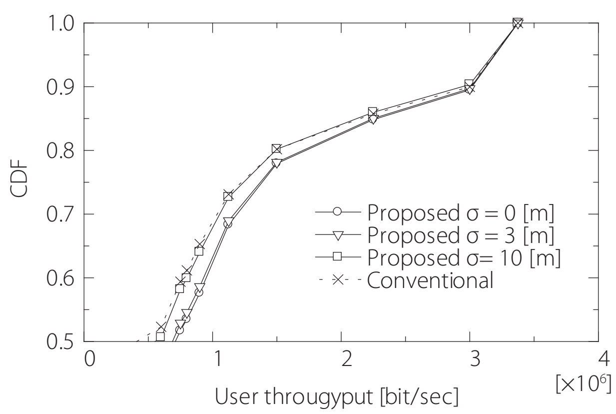

Figure 8: User throughput CDF (more than 50 %)

m, the user throughput resembles that of the conventional scheme. In the proposed scheme, users select the cell by their location irrespective of the SNR magnitude. If the positioning error is large, then cell selection error occurs even in the center of a WLAN cell, which has a much higher SNR than the neighboring cells. However, using the channel quality map, users are not required to discover numerous cells and execute measurement by themselves, even in a dense small cell environment. In terms of radio resource utilization, the proposed scheme is favorable. The 50 % throughput among them was compared. Table 3 presents 50 % throughput CDF. In the case in which the positioning error is 3 m, 50 % throughput is greater by 68 % in comparison with the conventional scheme. The cell selection error is suppressed by high positioning accuracy. Therefore, users in the WLAN cell edge can select the cell which has better channel quality. The system throughput in each case was also evaluated. System throughput was calculated from the CDF. Table 4 presents the system throughput. For the case in which the positioning error is 3 m, system throughput increases by 10 % in comparison with the conventional scheme. Therefore, by suppressing the cell selection error, the proposed scheme enhances system performance. Considering the radio resources for cell selection, the actual throughput of the conventional scheme will be greatly decreased.

Table 3: Comparison of 50 % user throughput

	50 % User Throughput [Mbit/sec]
Proposed scheme: σ = 0 [m]	0.71
Proposed scheme: σ = 3 [m]	0.69
Proposed scheme: σ = 10 [m]	0.55
Conventional scheme	0.41

Table 4: Comparison of system throughput

	System Throughput [Mbit/sec]
Proposed scheme: σ = 0 [m]	1.13
Proposed scheme: σ = 3 [m]	1.12
Proposed scheme: σ = 10 [m]	1.03
Conventional scheme	1.01

4. Channel quality map development

This section describes the measured positioning accuracy of various GNSS, and the implementation of the channel quality map construction scheme.

4.1 Measured positioning accuracy of GNSS

This subsection presents evaluation of the GPS signal positioning accuracy, QZSS L1-SAIF signal, and Mulch GNSS

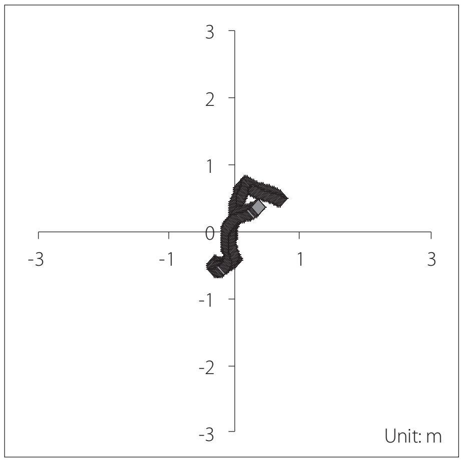

Figure 9: Positioning trajectory on the fixed point (QZSS L1-SAIF)

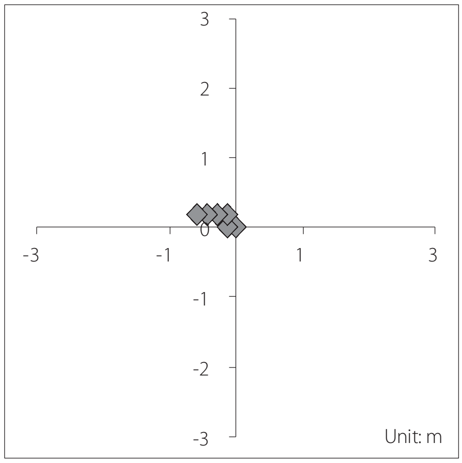

Figure 10: Positioning trajectory on the fixed point (DGPS + GLONASS)

(DGPS+GLONASS, GPS+GLONASS) signal. The GPS and QZSS receiver is CD311 of CORE Corp. and the Mulch-GNSS receiver is NV08C-EVK of NVS Technologies Inc. The authors developed data analysis software using MATLAB/Simulink of Mathworks Corp. Figure 9 presents the measured result of QZSS L1-SAIF signal on the fixed point data on top of the building of National Institute of Technology, Toyama College. The horizontal axis shows latitude and the vertical axis shows longitude. The unit is meters. The positioning error was 1 m or less. Figure 10 presents the measured result of DGPS+GLONASS signal at the same place. Using GLONASS, an improvement of the positioning accuracy was obtained. At the same place, GPS+GLONASS receiver was measured, the positioning error was 1 m or less. Moreover, the multi-GNS receiver with GPS, QZSS, GLONASS to be realized in the near future is expected to stabilize and improve the positioning accuracy. Therefore, the proposed cell selection scheme can be realized at the point of the positioning accuracy.

4.2 Channel quality map prototype system

This subsection explains the development of the proposed cell selection scheme prototype system. Figure 11 shows the channel quality map construction system. First, to calculate the average, the users measure RSSI of each cell (i.e., AP: Access Point) using Android smartphones. Users also measure their own locations with GNSS devices. This information and other information (BSSID, SSID, channel frequency, etc.) is stored by individual users. This data is transmitted to a server. This transmission has a low real-time demand because the average of signal strength is static unless the neighboring environment changes greatly. Therefore, the timing with which the users transmit this information can be adjusted flexibly. The server executes statistical information processing in every cell to produce the channel quality map.

Figure 12 presents an example of the channel quality map after averaging. The location information is used by GPS and GLONASS. The signal strength is used by Wi-Fi AP. The square size should be decided by considering the positioning accuracy. If the square is wide, then the channel quality map becomes unreliable because small cells have narrow coverage. Therefore, a reliable map requires high positioning accuracy. Using high accuracy positioning information (QZSS/DGPS + GLONASS + another satellite system), the proposed scheme can improve the system performance in a dense small cell environment.

Figure 12: Example of a channel quality map

5. Conclusions

A cell selection scheme using positioning information for the optimization of data traffic offloading in heterogeneous wireless systems is proposed. In the proposed scheme, users can select a cell with better channel quality by measuring only their location. User throughput of the proposed scheme was evaluated by computer simulation. The cell allocation model was assumed for a dense small cell environment. Simulation results show that if the positioning error is 3 %, the proposed scheme improves the 50 % throughput by 68 % in comparison with the conventional scheme.

The system throughput was evaluated. In the proposed scheme (=3 [m]), system throughput improved by 10 % in comparison to the conventional scheme. Furthermore, based on measured data, the positioning accuracy with multi-GNSS signals was a realizable level for the channel quality map construction scheme. This report described the prototype system of the channel quality map construction scheme. The proposed scheme improves the system performance in a dense small cell environment.

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References

3GPP (2010). TR36.814 (v9.0.0), Further advancements for E-UTRA physical layer aspects.

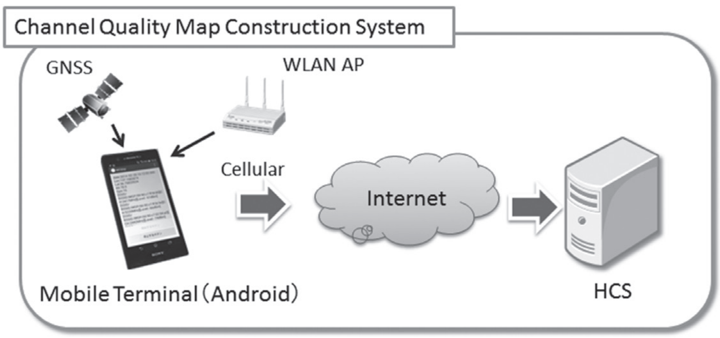

Figure 11: Channel quality map construction system prototype

3GPP (2013). TR36.932 (v12.1.0), Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN.

Japan Aerospace Exploration Agency (2013). Quasi zenith satellite system navigation service: Interface specification for QZSS ver. 1.5.

Kuboniwa, J., Miyake, Y., Kameda, S., Taira, A., Suematsu, N., Takagi, T. and Tsubouchi, K. (2014). A novel cell selection scheme using positioning information for heterogeneous wireless system. The 7th International WDN Workshop on Cooperative and Heterogeneous Cellular Networks (WDN-CN2014).

Takagi, T., Kameda, S., Suematsu, N. and Tsubouchi, K. (2013). Dependable air and wireless dependability. Sixth Global Symposium on Millimeter Wave (GSMM2013).Tsubouchi, K., Kameda, S. and Suematsu, N. (2012). Dependable air. *IEICE Transactions on Electronics* (Japanese Edition), Vol. J95-C, No. 12, 460-469.

Tsubouchi, K., Kameda, S. and Suematsu, N. (2012). Dependable air. *IEICE Transactions on Electronics* (Japanese Edition), Vol. J95-C, No. 12, 460-469.

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