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Receiver Diversity Evaluation for a VHF Band Broadband Mobile Communication System

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***Abstract*—In this paper, diversity receiver performance at base station for VHF-band broadband mobile communication systems is examined by using measurement results. Diversity gain of two RX antennas for link budget calculation has been calculated by using a selective combining and an equal gain combining schemes. By analyzing the diversity gain statistically, it is found that the diversity gain of selective combining and its variation are increased in larger antenna separation and shorter transmission range. On the other hand, the diversity gain of equal gain combining and its variation are decreased in larger antenna separation and in shorter transmission range. In addition, a path loss model has been developed for a link budget design. The path loss model parameters are extracted for over 1 km transmission range. By considering the path loss model with analytically-extracted constant diversity gains for BS antenna separation lengths of 1, 5, and 10 wavelengths, the system service coverage can be estimated.**

Keywords*—*VHF band, Mobile Communication, Broadband, Radio Propagation, Receiver diversity

I. INTRODUCTION

Digitalization of Japanese television broadcast was completed on March 31, 2012. The newly available VHF/UHF band had been discussed to use for other applications by the Ministry of Internal Affairs and Communications (MIC, Japan), and a part of VHF band from 170 to 202.5 MHz was allocated for public broadband mobile communications for safety and security. PHY and MAC specifications for this broadband wireless communication system between portable base station and mobile stations were standardized by ARIB STD T-103 [1] as well as IEEE Standard 802.16n-2013 [2]. Recently some prototypes were developed and their performances have been reported [3]. This broadband system is attracting attention as a candidate of control plane in the next generation mobile communications [4].

In this paper, a receiver diversity performance at base station for the systems is examined by propagation experiments. A base station (BS) was located at the Japan National Police Academy in an urban area, and a mobile station (MS) was moved around within 3 km transmission range from the BS. By measuring the transmitting signal power with two RX antennas at the BS, diversity gains for each selective combining and equal gain combining schemes are calculated. By analyzing the diversity gain statistically, it is found that the diversity gain of selective combining and its variation are increased in larger antenna separation and shorter transmission range. On the other hand, the diversity gain of equal gain combining and its variation are decreased in larger antenna separation and in shorter transmission range. Moreover a path loss model with constant diversity gains for BS antenna separation lengths, which is applicable for over 1 km transmission range, is proposed for a link budget design and an estimation of the system service coverage.

II. PROPAGATION EXPERIMENT

A. Receiver Diversity of the System

Diversity receiver is a popular method to compensate fading channels. Since the developed prototype based on ARIB STD-T103 (Mode 1, Mode 2 with FFT size 1024) has a two-brunch diversity reception function, the communication performance improvement is expected by obtaining a diversity gain. For a system evaluation, the diversity gain is examined by two RX antennas installed at the BS while the MS moving around the BS.

B. Measurement Condition and Environment

A continuous OFDM-BPSK transmitting signal with a constant envelope modulation was selected for a long transmission range measurement. Total number of active sub-carriers is 840 within 1024 FFT size. Since a spectrum analyzer (Advantest Cross Domain Analyzer U3841) was used to measure the signal power at the BS, the diversity gain is evaluated without RF device non-linear characteristics of the developed prototype. Also the spectrum analyzer has a capability to measure the two channel responses in the synchronized timing, and received signals of each brunch are measured in the same time.

Diversity receiver techniques of selective combining and equal gain combining [5] are applied to the measured received signals, and the results are analyzed statistically with parameters of transmission distance and BS antenna separation

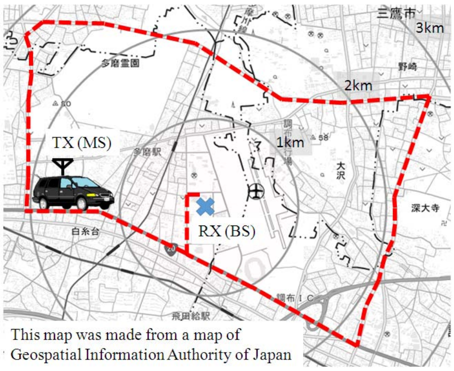

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Fig. 1. Position of the BS (X-point) and the route of MS (broken lines).

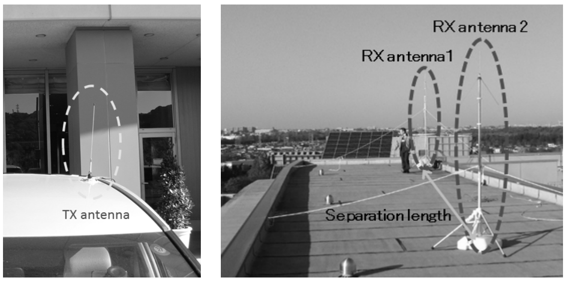

Fig. 2. Installation of antennas (TX antenna of the MS on the left side, RX antennas at the BS on the right side).

TABLE I. PARAMETER OF TX AND RX

Frequency band	5 MHz bandwidth in 200 MHz band
TX signal	Continuos OFDM-BPSK (FFT Size 1024), Output power: 37 dBm (5 W)
TX antenna	Whip antenna of 2.15 dBi gain, 2 m height above the ground (rooftop of a vehicle)
TX RF losses	Cable loss: 1.3 dB, Filter loss: 1.1 dB
RX antenna	Brown antenna of 2.15 dBi gain, 45 m height above the ground
RX RF losses	Cable loss: 1.4 dB
RX measurement instrument	Spectrum Analyzer (Advantest Cross Domain Analyzer U3841)
Instrument settings	SPAN 5.47 MHz (5.47 KHz frequency step by 1001 point measurement), RBW: 30 KHz, VBW: 30 KHz, Sweep time: 20 ms
RX antenna separation	1, 5, and 10 lambda in North-South direction

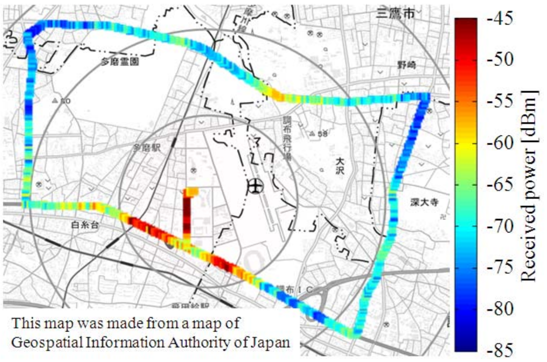

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Fig. 3. Measured received power by RX antenna 1 (RX antenna separation : 10 wavelengths).

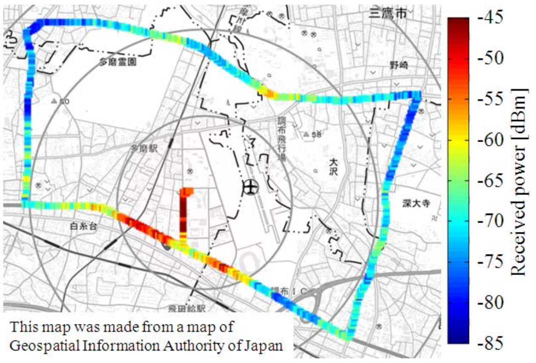

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Fig. 4. Measured received power by RX antenna 2 (RX antenna separation :10 wavelengths).

length. Received power for each diversity technique is evaluated by following equations. Eq. (1) and Eq. (2) are applied for selective combining and equal gain combining respectively. These techniques are applied for all 840 active sub-carriers of the OFDM signal.

$$P_s = \sum_{i=1}^{840} \max\left(P_{1i}, P_{2i}\right) \qquad (1)$$

$$P_e = \sum_{i=1}^{840} \frac{\left(\sqrt{P_{1i}} + \sqrt{P_{2i}}\right)^2}{2} \qquad (2)$$

where, P_s and P_e are total channel power when selective combining and equal gain combining are applied respectively. P_{1i} and P_{2i} are the power of each active sub-carrier measured by two antennas in the same time, and i is the number of active sub-carrier.

The BS was set up on a building of the National Police Academy of Japan (located in Fuchu-shi, Tokyo) by assuming a security application. A vehicle equipped with a TX mobile terminal, was moving around the building within 3 km range. Figure 1 shows the map of measurement area. The BS building is located at the X-point and the route of vehicle is shown by a broken line in the figure. The continuous OFDM signal was transmitting from the MS to the BS. Antenna heights of TX (at the MS) and RX (at the BS) were 2 m and 45 m above the ground, respectively. Figure 2 shows a whip antenna on the vehicle roof top and two receiver antennas on the building. RX antenna 1 was located at North side and RX antenna 2 is located at South side. In the measurement, the RX antenna separation was changed to 1, 5, and 10 wavelengths, respectively. TX and RX specifications are summarized in Table I.

III. MEASUREMENT RESULTS AND STATISTICAL ANALYSIS

A. Diversity Gain

As examples of measurement results in RX antenna separation of 10 wavelengths, received power of RX antennas 1 and 2 are shown in Figs. 3 and 4, respectively. Since received powers of RX antenna 1 and 2 are different by shadowing and multipath fading, some diversity gain is expected. Each received power of selective combining and

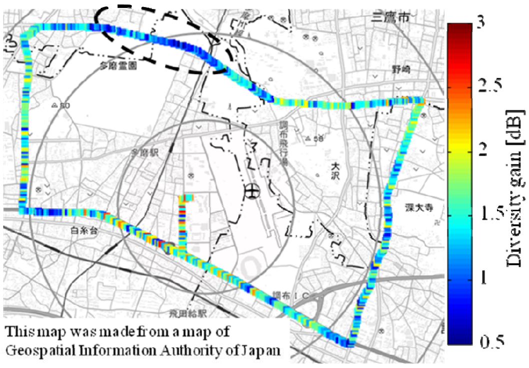

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Fig. 5. Calculated received power obtained by selective combining (RX antenna separation :10 wavelengths).

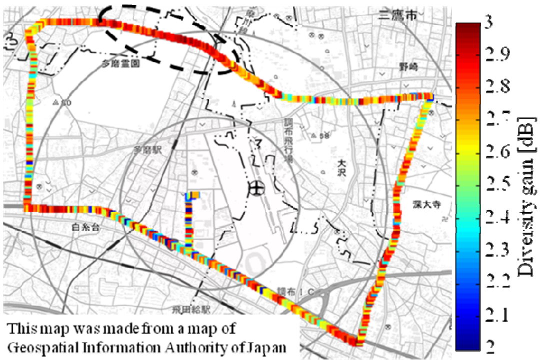

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Fig. 6. Calculated received power obtained by equal gain combining (RX antenna separation:10 wavelengths).

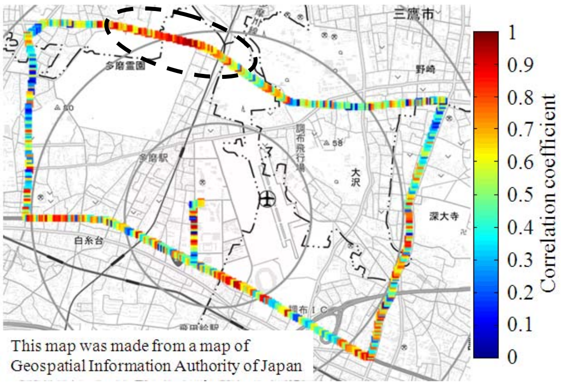

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Fig. 7. Correlation coefficient of 2 received signals (RX antenna separation :10 wavelengths).

equal gain combining is calculated by applying Eqs. (1) and (2), respectively and also average power of the received signals is calculated by Eq. (3).

$$P_a = \sum_{i=1}^{840} \frac{P_{1i} + P_{2i}}{2} \tag{3}$$

Diversity gain as difference between received powers (P_s - P_a, P_e - P_a) is plotted on the map shown in Figs. 5 and 6. The diversity gain of selective combining is 0.5~3 dB in Fig. 5. On the other hand, the diversity gain of equal gain combining is 1.5~3 dB in Fig. 6. Correlation coefficients between the received signals on the measurement route are shown in Fig.7.

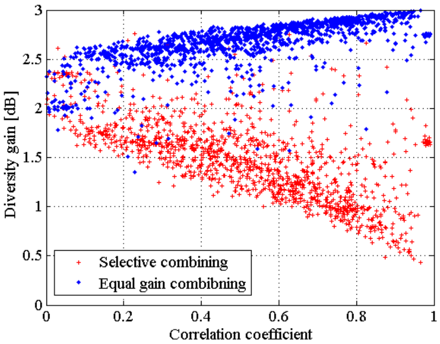

Fig. 8. Relationship of correlation coefficient and diversity gain (RX antenna separation :10 lambda).

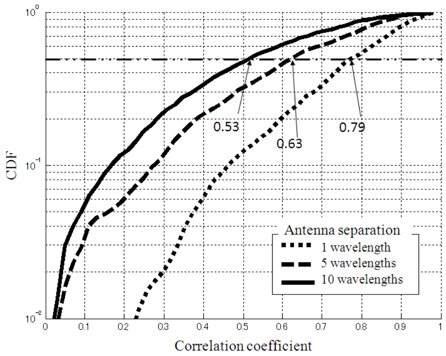

Fig. 9. Cumulative distribution function of the correlation coefficients for each RX antenna separation.

The correlation coefficients are calculated by using each power of active sub-carrier in two received signals at measured locations. In the area encircled by a broken line in Fig. 7, the correlation coefficient is around 0.8. Such a high correlation coefficient causes low diversity gain of the selective combining, and 3 dB gain of equal gain combining. To confirm these phenomena, a relationship between correlation coefficient and the diversity gain is shown in Fig. 8. In the lower correlation coefficient, selective combining is functioning effectively by complementing each signal. On the other hand, the diversity gain of equal gain combining is slightly decreased. Figure 9 shows the cumulative distribution function of the correlation coefficient in the case of changing the RX antenna separation. The correlation coefficient at CDF=50 % is 0.79, 0.63, and 0.535 in 1, 5, and 10 wavelengths separation, respectively. Thus larger antenna separation can be expected larger diversity gain of selective combining.

Next, diversity gain of selective combining for each antenna separation is statistically analyzed and the distribution results are shown in Fig. 10. Since the difference of the received signals becomes small when the antenna separation is small, the median of the diversity gain becomes lower and its gain variation also becomes smaller. Figure 11 shows the diversity gain distribution of equal gain combining. In this case the median of diversity gain was slightly changed around 3 dB and its gain variation becomes smaller in smaller antenna separation. This is because the gain converges to 3 dB when similar received signals are received.

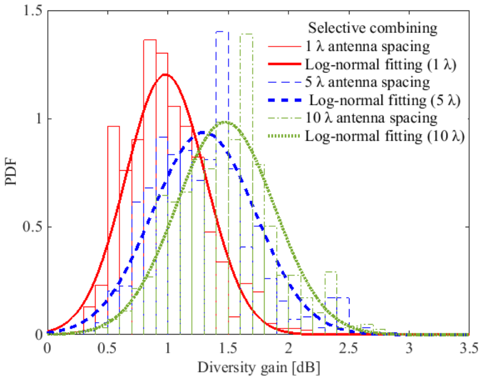

Fig. 10. Diversity gain distribution of selective combining

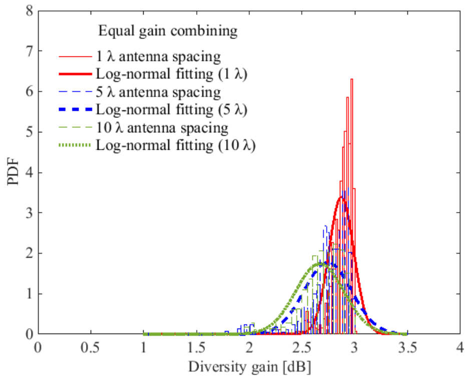

Fig. 11. Diversity gain distribution of equal gain combining

By classifying the gain according to horizontal transmission range of 1 km less and over, diversity effect is evaluated. As an example, the diversity gain in the antenna separation of 10 wavelengths is shown in Fig. 12. The diversity gain has large variation within 1 km range and becomes small in 1-3 km distance, and also its median value becomes small into the far distance. The reason is that the difference of two received signals becomes small in the far distance. As shown in the same figure, the diversity gain in equal gain combining has also small variation in far distance, while the median is around 2.5~2.7 dB.

By above analysis, the diversity gain characteristics for the antenna separation and the transmission distance the antenna separation can be summarized as follows.

- Diversity gain of selective combining and its variation are increased in larger antenna separation and shorter transmission range.
- Diversity gain of equal gain combining and its variation are decreased in larger antenna separation and in shorter transmission range.

B. Path Loss Model for Link Budget Design

In order to estimate the service coverage using link budget calculation, a path loss model and diversity gain characteristics are required. Figure 13 shows the distance characteristics of the received power. The received power has large variation within 1 km distance by mixing line of sight (LoS) and non LoS (NLoS) situations and also it includes two path fading effect of including direct and ground reflection waves.

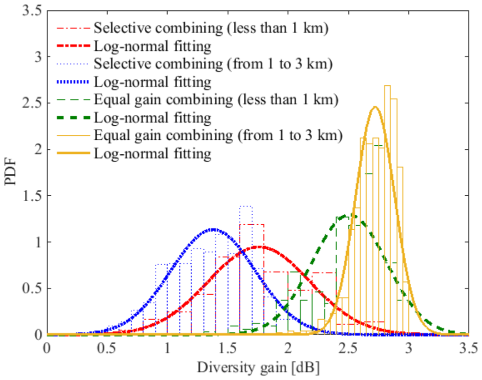

Fig. 12. Classified diversity gain distribution by 1 km transmission distance.

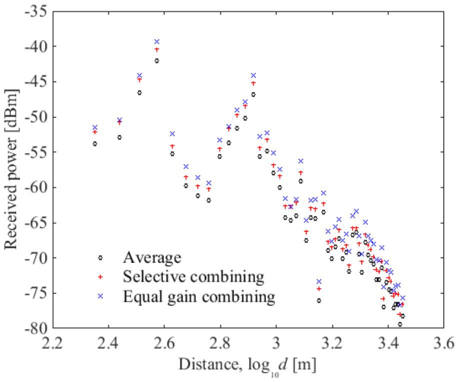

Fig. 13. Relationship between distance and received power in 10 wavelengths antenna separation.

Considering from TX and RX antenna heights, transmission range of 1 km is larger than a break point of two path model [5]. Thus a huge variation of received power did not occur in this range. Since it is focused on the expansion of service coverage by the receiver diversity effect, a path loss model is developed for over 1 km distance in NLoS situation. A path loss model is assumed as the following equation (4), and its model parameters are extracted by the least squares method.

$$PL = 10n\log d + PL_0 + N(0,\sigma) \qquad (4)$$

where, PL is the propagation loss, n is the path loss coefficient, d [m] is the horizontal distance between the transmitter and the receiver. PL_0 is a propagation loss at 1 km distance, N (0, σ) indicates a variation of path loss given by the log-normal distribution with zero mean.

As an example, the parameters were extracted for the 10 wavelengths RX antenna separation. Calculated path loss characteristics including diversity gain is shown in Fig.14 by excluding the transmit power, TX and RX antenna gains, and RF losses. Average path loss of two RX antennas and liner approximation lines for each path loss including diversity gain

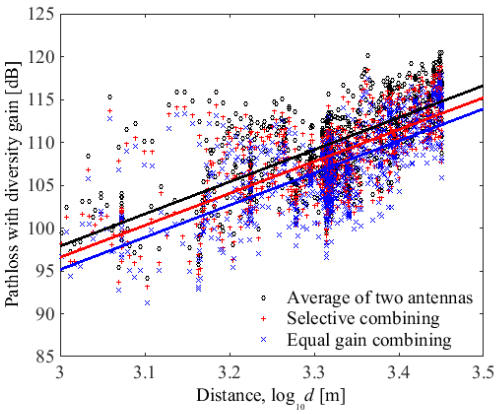

Fig. 14. Path loss characteristics including the diversity gain in the 10 wavelength RX antenna separation.

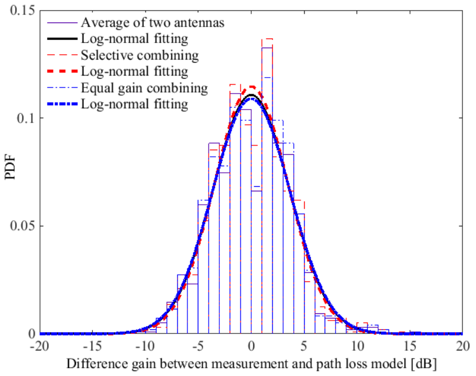

Fig. 15. Path loss variation in the 10 wavelengths RX antenna separation.

TABLE II. PATH LOSS MODEL APPLICABLE FOR 1-3 KM RANGE

PL_0	n	$N(0, \sigma)$
97.9	3.69	σ=3.6

TABLE III. AVERAGED DIVERSITY GAIN APPLICABLE FOR 1-3 KM RANGE IN THE RX ANTENNA SEPARATION OF 1, 5, AND 10 WAVELENGTHS

Antenna separation	Selective combining	Equal gain combining
1 wavelength	0.7 dB	3.0 dB
5 wavelength	1.1 dB	2.8 dB
10 wavelength	1.3 dB	2.7 dB

are also shown in Fig.14. The path loss exponents are extracted as n=3.75, 3.72, and 3.60 from the slope of approximated straight lines for average, selective, and equal gain combining, respectively. The values are almost same in spite of the presence of receiver diversity. As discussed in Sec. III-A, this could be estimated from the analysis results that the diversity gain converged to a constant value in over 1 km range. Therefore the average path loss exponent n=3.69 is used for a representative value. From Fig. 14, each PL_0 is extracted as 97.9 dB for two antenna average, 96.6 dB for selective combining, and 95.2 dB for equal gain combining, respectively. If the path loss exponent n is considered as a constant value of 3.69, the difference of PL_0 corresponds to the diversity gain. Thus each diversity gain can deal as 1.3 dB for selective combining, and 2.7 dB for selective combining.

The variation of path loss is analyzed by the difference between the measured values and the linear approximation equation for the distance shown in Fig. 14, and is approximated assuming a log-normal distribution as a cumulative distribution function shown in Fig. 15. The standard deviation is about σ = 3.6 in spite of the presence of receiver diversity. In the same manner, the diversity gains for 1 and 5 wavelengths RX antenna separation were also extracted. These result are summarized in Tables II and III. PL_0 and n are slightly decreased in larger antenna separation. The first and second terms of the model without the third term is enough for link budget design. The third term is useful for a simulation using statistical received power distribution.

IV. CONCLUSIONS

Receiver diversity characteristics at the base station was investigated using measured data for the VHF band broadband mobile communication systems. The diversity gain characteristics for the antenna separation and the transmission distance can be summarized as follows (1) Diversity gain of selective combining and its variation are increased in larger antenna separation and shorter transmission range. (2) Diversity gain of equal gain combining and its variation are decreased in larger antenna separation and in shorter transmission range.

Also the path loss model was developed for 1 km over range in the urban environment. Constant diversity gain can be used in the 1~3 km distance as 0.7, 1.1, and 1.5 dB for selective combining and 3.0, 2.8, and 2.7 dB for equal gain combining in the antenna separations of 1, 5, and 10 wavelengths, respectively. These results would be useful for service area estimation for the system.

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