Large-Scale Characteristics of 5.25 GHz Based on Wideband MIMO Channel Measurements

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Abstract—Based on the channel measurements at 5.25 GHz in the hotspot area, empirical path loss (PL) models are developed and discussed for the IMT-Advanced system design. The measured scenarios include indoor line-of-sight (LOS), non-LOS, outdoor LOS/obstructed LOS, and outdoor-to-indoor propagations. The PL exponent, intercept, and standard deviation of shadow fading are obtained by using the least square method in each scenario. Moreover, the floor attenuation factor and penetration loss are determined from the cross-floor measurement and outdoor-to-indoor measurement, respectively.

Index Terms—Attenuation factor, 5.25 GHz, IMT-advanced, least square, path loss, shadow fading.

I. INTRODUCTION

BEYOND third generation was named officially “IMT-Advanced” by the International Telecommunication Union—Radiocommunications (ITU-R) in October 2005 [1]. For the IMT-Advanced system, the radio-frequency bandwidth and carrier frequency will be up to 100 MHz and 5 GHz, which are suitable for the hotspot application to provide the maximum 1 Gbps data rate transmission. Measurement and modeling are the most efficient way to get the accurate channel characteristics for the link-level simulation and system-level design. To contribute to the research of the IMT-Advanced system, we conducted wideband multiple-input multiple-output (MIMO) channel measurements in the hotspot area in Beijing, China.

The large-scale effects on wireless transmission are important for coverage prediction and interference analysis in radio systems. In this paper, both the path loss (PL) and shadow fading (SF) are modeled in the log-distance expression based on the measured channel impulse responses (CIRs). Relative to the free-space loss, the attenuation factors are analyzed to provide the partition loss between floors and penetration loss.

II. CHANNEL MEASUREMENT CAMPAIGN

A. Measurement System

Extensive channel measurements were performed at the center frequency of 5.25 GHz with 100 MHz bandwidth at Beijing University of Posts and Telecommunications (BUPT), China. Measured MIMO channel data were recorded with Elektrobit PropSound Channel Sounder [2], which utilizes the periodic pseudorandom binary signals (PRBS) and time-domain multiplexed switching of transmit and receive antennas. The transmitted power was 26 dBm and the lengths of PRBS were 511 and 1022 for indoor and outdoor measurements, respectively. The transmitter (Tx) employed a three-dimensional dual-polarized omnidirectional array (ODA) with maximum 50 elements shown in Fig. 1(a); the receiver (Rx) employed eight elements of vertically polarized uniform circular array (UCA) shown in Fig. 1(b). The element spacing of both ODA and UCA is half of a wavelength.

B. Measurement Scenarios and Environment Description

A seven-floor building was selected as the measurement site representing the indoor hotspot environment. Both the Tx and Rx were mounted on the trolley during the measurements. The Tx array was about 1.5 m above the ground using all 50 elements of ODA; the Rx array was about 2.5 m above the ground with eight elements of UCA. The transmitted power was 26 dBm and the lengths of PRBS were 511 and 1022 for indoor and outdoor measurements, respectively. The transmitter (Tx) employed a three-dimensional dual-polarized omnidirectional array (ODA) with maximum 50 elements shown in Fig. 1(a); the receiver (Rx) employed eight elements of vertically polarized uniform circular array (UCA) shown in Fig. 1(b). The element spacing of both ODA and UCA is half of a wavelength.

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Fig. 2. Measurement scenarios: (a) Top views of the first floor in indoor. (b) Outdoor routes.

with aluminum frame. Between the Rx and Grid C there are huge concrete poles, escalators, a staircase with aluminum banisters, notice boards with glass sheets, etc.

For the outdoor hotspot scenario, altogether six routes were measured on the streets and marked as the dashed lines in Fig. 2(b). The lengths of mobile routes were from 380 to 520 m. The Rx was also fixed and mounted on a trolley with antenna height of about 2.5 m. The Tx was mounted on the top of a car with vehicle speed of nearly 20 km/h, only using 18 elements of ODA with antenna height of about 2.75 m. The streets were lined with trees, and the Rx was surrounded by trees, grasses, flowers, two sculptures made of stone, tall lamp poles, etc. Thus, the propagation in this scenario is characterized as line-of-sight (LOS)/obstructed LOS (OLOS). During the measurements, the mobile routes of the Tx were recorded using the Global Positioning System.

III. EMPIRICAL MODELS

In order to satisfy the wide-sense stationary and uncorrelated scattering (WSSUS) condition, the raw CIRs should be divided into subsets and averaged as

$$h_{\text{av}}(\tau) = E_t \{ h(t, \tau) \}$$

(1)

where $E_t \{ \cdot \}$ denotes the average in time domain. As for mobile measurements, the averaging corresponds to a suitable window length around $20\lambda$ [3] (about 1.15 m), and for static measurements the averaging corresponds to 100 CIRs at each measurement location.

Dynamic noise floor is applied to raw CIRs in order to separate actual multipath components from noise [4]. In addition, a delay search threshold is used to determine if the power delay profiles (PDPs) have enough dynamic range to ensure the integrity of the results [5]. For the results reported hereafter, the delay threshold was set 15 dB below the PDP peak. In addition, the peak must be 20 dB above the noise floor to allow a 5 dB margin between threshold and noise floor. If this margin of one PDP is not met, it will be omitted from the statistical description.

After noise cutting and delay search, the measured PL values are calculated in decibels as

$$PL = -10 \log_{10} \left( \sum_\tau |h_{\text{av}}(\tau)|^2 \right) + G_{Tx} + G_{Rx}$$

(2)

where $G_{Tx}$ and $G_{Rx}$ are antenna gains of the Tx and Rx, which can be derived from antenna radiation pattern. Let $P(\theta, \phi)$ be the power angular spectrum (PAS) related to the azimuth $\theta$ and
Then the antenna gain can be calculated as the ratio of the maximum PAS over the average PAS
\[ G = k \cdot \frac{P(\theta, \phi)_{\text{max}}}{P(\theta, \phi)_{\text{av}}}, 0 \leq k \leq 1 \]  
where \( k \) is the efficiency factor. For the well-designed antenna, \( k \) is close to one. In this letter, we choose \( k \) to be one.

The modeling method used for the large-scale characteristics is a linear curve fitting the decibel path loss to the decibel distance with a random variation. The empirical model of log-distance PL [6] is expressed as
\[ \text{PL}(d) = \text{PL}_0 + 10n \cdot \log_{10}(d) + X_\sigma \]  
where \( \text{PL}_0 \) is the intercept, \( d \) is the Tx–Rx separation distance in meters, and \( n \) is the PL exponent dependent on the specific propagation environment indicating the rate at which PL increases with distance. Considering the fact that the surrounding environmental clutter may be vastly different at two different locations having the same Tx–Rx distance, the log-normal shadow fading is denoted by a zero-mean Gaussian random variable \( X_\sigma \) in (4) with standard deviation \( \sigma \).

The values of \( \text{PL}_0 \) and \( n \) are extracted by using the least square (LS) method such that the difference between the measured and estimated PL is minimized in a mean square error sense over a wide range of measurement locations.

For the purpose of comparison, the free-space propagation model is given by Friis free-space equation [7] as
\[ \text{PL}_{\text{FS}}(d) = 20 \log \left( \frac{4\pi d}{\lambda} \right) \]  
where antenna gains are excluded and \( \lambda \) denotes the wavelength. This model is used to predict the received signal strength when the transmitter and receiver have a clear, unobstructed LOS path between them. In this case the PL exponent \( n \) is equal to two.

### IV. MEASUREMENT RESULTS

#### A. Indoor Scenario

1) From LOS to NLOS: On the first floor, the measured data of Grid A and Grid C are typical as LOS and NLOS propagation, respectively. Fig. 3 plots these two PL models on the same floor. For LOS propagation, the exponent \( n \) is 1.18, which is smaller than two in free space, indicating the waveguide effect available in the corridor of high building. For NLOS, the exponent \( n \) is 4.33 and standard deviation is 1.1 dB. From LOS to NLOS, the propagation PL difference is about 26.5 dB.

2) Attenuation Factor Model: The loss between floors is determined by the external dimensions and materials of the building as well as the type of construction used to create the floors. In order to estimate the attenuation introduced by floors, a constant, named the floor attenuation factor (FAF) in decibels [8], is added to the free-space loss. The model is expressed as
\[ \text{PL}(d) = \text{PL}_{\text{FS}}(d) + \text{FAF} + X_\sigma \]  
where \( X_\sigma \) is the zero-mean Gaussian variable.

The statistical results derived from the measured data on the second and third floor are shown in Table I. The average value of FAF is 30.1 dB through one floor and 38.5 dB through two floors. This factor is useful to predict the interfloor interference for the vertical frequency reuse on different floors of the high building in the hotspot area.

#### B. Outdoor-to-Indoor Scenario

An important requirement of mobile radio systems is the provision of reliable services to the increasing number of indoor users across the outdoor-to-indoor interface. Extracted from measured data of Grid D and Path F, the fitted curve of outdoor-to-indoor propagation is given in Fig. 4. The exponent \( n \) is 3.61 and the standard deviation is 2.1 dB.

As the LOS is obstructed, signals transmitted through the high building become significant. Compared with the free-space PL value, the penetration loss is determined as the extra loss
\[ L_p = \text{PL}(d) - \text{PL}_{\text{FS}}(d) \]  
at the given Tx–Rx distance \( d \). Our measurements were done with the obstruction caused by two layers of the windowed walls and doors approximately. Therefore, the median penetration loss per layer is derived as 11.8 dB. This value together with the log-distance model in Fig. 4 can be extended to the scenarios where the antenna heights of outdoor Tx and indoor Rx are similar above the ground level.
C. Outdoor Scenario

From the measurement data of six routes, the PL model for outdoor LOS/OLOS propagation is shown in Fig. 5. The modeling result is

$$PL(d) = 47.2 + 23.2 \cdot \log_{10}(d)$$  \hspace{1cm} (8)

and the standard deviation of SF is 6.0 dB. The valid Tx–Rx distance range is from 30 to 200 m.

Since both the Tx and Rx have very low antenna heights, it is a totally different propagation environment from the traditional microcellular system with higher base station antennas (5–15 m). This model is suitable for peer-to-peer communication [9] or cooperative transmission [10] in the next-generation wireless network.

V. Conclusion

This paper presents the large-scale characteristics of 5.25 GHz band in the hotspot environment. Based on the extensive channel measurements, the empirical log-distance PL models are derived with exponents of 1.18, 4.33, 3.61, and 2.32 for indoor LOS, NLOS, and outdoor-to-indoor and outdoor LOS/OLOS, respectively. The floor attenuation factor is 30.1 dB through one floor and 38.5 dB through two floors. The penetration loss is about 11.8 dB for one layer of windowed wall and door in the outdoor-to-indoor propagation.

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