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Broadband channel measurement and analysis

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Abstract An outdoor propagation measurement campaign for beyond 3G (B3G) as well as a wide-band indoor measurement campaign have been performed recently in Beijing, China, in which the sounding signals are transmitted by an one-antenna base station and received by a two-antenna mobile receiver operated at 3.49～3.51 GHz bandwidth. Different scenarios: stationary line-of-sight (LoS), stationary non-LoS (NLoS) scenarios, and dynamic NLoS are deliberately chosen in a classic urban environment and office environment. The initial results are presented in this article. Parameters including vector channel impulse response, path loss, rays number, excess delay spread etc. are extracted, analyzed, and briefly reported here.

Keywords Broadband measurement, Beyond 3G, path loss, multipath delay, rays number

1 Introduction

A complete understanding of propagation characteristics of wireless channel is the key for designing a mobile wireless communication system as the outcomes of various researches on wireless channel are regarded as the basis of mobile wireless communications. In recent years, considerable attention has been drawn toward the so-called beyond 3G (B3G) as the user's needs for higher data rates and mobilization are increasing. However, at present, several problems still exist in this area, such as influence of different antenna configuration, mobilization, broadband to system.

Several campaigns [1, 2] linked to the B3G wireless channel are performed internationally since 2000 . But, except for theoretical research[7], similar campaigns in China have not been reported yet. Also, such literatures are still unavailable. The purpose of this article is to present such experiments carried out in China for B3G and broadband indoor wireless channel 1.

2 System description and theory

The indoor measurement campaign had been conducted recently before a outdoor field experiment in the same band around Beijing University of Posts and Telecommunications (BUPT) within a medium range macrocell (less than 2 km that is the distance being assumed by B3G) has been conducted. The frequency was centered at 3.5 GHz. To measure the channel realizations, a periodic PN23 signal with 20 MHz bandwidth was sent out by the Agilent ESG4438C at 38 dBm average transmit power and was captured by two Agilent 89600 VSAs synchronously, as shown in Fig. 1. The transmitter consists of azimuth omni-directional antennas with a gain of 7 dBi and 20° elevation main lobe width, while in the receiver side, two vertical polarization antennas were deployed with the same antenna prototype. The clocks at both Tx and Rx side were reciprocally calibrated in advance. The coarse timing references of either sides were derived from 1pps GPS impulse, respectively. The VSAs downconverted the received signal and sampled at 40 MHz. The origin date were sampled per certain seconds and stored in hard disc through 1394 port for offline analysis and computation. The design of the measurement system was based on slide correlation technique to catch the synchronous head of data and generate the channel impulse response (CIR) in the time domain.

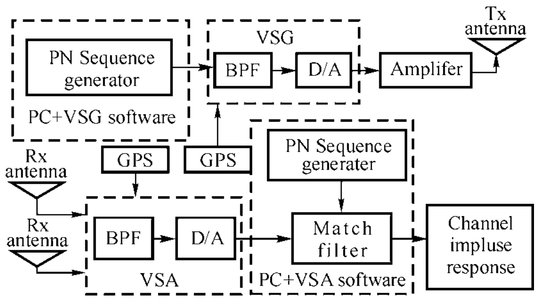

Fig. 1 Measurement setup with one-input and two-output antenna system

In the indoor scenario, measurements were carried out in the third floor of a three-story building where the JSI-MTLab was located. The general layout of the test site includes two rows of office rooms filled with PC desks, computers, and cabinets. An inner corridor is connected to all rooms. Each room has wooden door, huge plastic-frame window, and curtains. In such an environment, three scenarios, which will be described later, are performed. Both LoS and NLoS scenarios were measured. The receiving antennas are mounted on a cart at a height of 1.4

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m while the transmitter is installed on a desktop in one office room at a total height of 1m to the ground.

In the outdoor scenario, measurements were carried out around the BUPT, in which the environment bore the classic urban environment that includes crossroads, high buildings, large mansions, and heavy traffic. The transmitter antenna was mounted on the top of the main building of BUPT about 50 m high. The receiver antennas were mounted on the top of the 3 m high test vehicle. LoS and NLoS scenarios were selected and measured deliberately. Obviously, since the range is up to 2 km, in most measurement spots, the LoS condition is not satisfied. The maximum velocity was 100 km/h. During each measurement, one 3-millisecond "vector snapshot" (i.e., single measurement from two received elements) per 3 seconds was taken by the receiver. Obviously, the overall sampling time for one snapshot is well within the coherence time of the outdoor scenario.

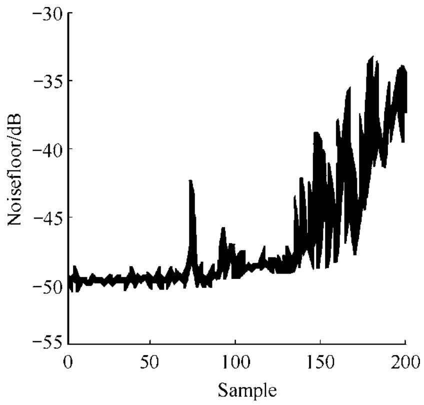

Fig. 2 The dynamic noise floor of 200 CIR samples in one measure action

Generally, a noise floor is applied to raw CIRs to separate actual multipath components from noise. There are several methods that can be found in recent literatures to calculate the noise floor. Some articles concern the side-lobe level of the windows [3, 4], whereas other articles, such as literature [1] and [5], take into account the thermal noise and finite length of A/D converter of the system. Actually, because of the mobilization of receiver, the power of receiving signal varied within a broad range. Dynamic range noise floor is more reasonable and feasible for parameter statistic and analysis. The dynamic noise floor is described as follows. First, the head 125 points of one amplitude sample of raw CIRs are chosen in the outdoor environment, while in the indoor environment, the end 200 points are chosen. Second, the lowest 20 % and the highest 20 % points of the chosen points are discarded, which is equivalent to a lower pass filtering. Third, the noise floor of the CIR sample is extracted by averaging the remaining points. Fig. 2 shows the classic dynamic noise floor versus different CIR samples.

3 Measurement result

3.1 The results from outdoor

1) Path loss (PL)

PL is used to denote the local average received signal power relative to the transmit power. In realistic urban mobile radio channel, free space is not applicable. A general PL model that has been demonstrated using measurement uses a parameter, n, to denote the power law relationship between distance and receive power. PL (in decibels), a function of distance, is expressed as

$$P(d) = P(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

where n=2 for free space, path loss exponent n is determined by linear regression.

$$P(d_0) = 20\log\left(\frac{4\pi d_0}{\lambda}\right)$$

Which gives a reference PL in reference distance d_0, which is the distance of transmitting signal propagating freely and $\lambda = 8.57$ cm is the carrier wavelength. Considering the realistic environment around transmitter, we set $d_0 = 10$ m. X_σ denotes a zero mean Gaussian random variable in decibel, and it reflects the variation of received power.

For a 1×2 system, two receiving power are averaged for PL calculation. For comparison, the dashed line in Fig. 3 is the path loss for free space propagation and the solid line in the figure is the mean PL of the log-distance model with reference distance $d_0 = 10$ m. In this figure, different colors of asterisks represent different measurement zones. Table 1 lists the PL exponent n and the rms error σ_X, which is the standard deviation of X_σ for each zone and over all zones. The PL measurement shows that the PL exponent is around 3.37 with a modest rms error σ_X.

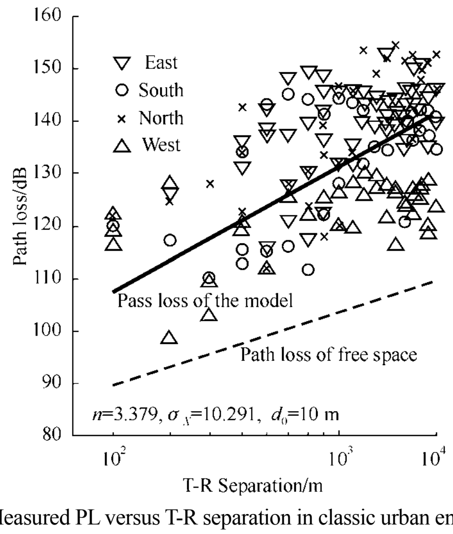

Fig. 3 Measured PL versus T-R separation in classic urban environment

Table 1 The PL exponent n and rms error σ_X for different direction and for over all direction

Zone	North	South	West	East	All
n	3.76	3.51	3.09	3.14	3.39
σ_x	0.62	6.55	10.90	1.94	10.29

2) CIR

The CIR is generated with a time-domain carrier-frequency-constraining slide correlator designed under the fact that all of the transmitted data on transmit antennas is known. The length of slide window is set to 600 chips that allow a maximum delay up to 15 us[1]. The correlator output is averaged per 15 us among all 3 ms-length origin data to built one CIR sample.

A total of 8 400 CIR samples in outdoor campaign as well as 4 397 CIR samples in indoor campaign are extracted. The power delay profile (PDP) is given by the amplitude of the estimated CIR. The PDP peak should be 15 dB greater than the dynamic noise floor. Otherwise, the CIR is omitted. An effective ray is counted only when the margin between the amplitude of PDP and the dynamic noise floor is at least 15 dB. On verification using the above criteria, 5 148 effective CIR samples in outdoors as well as 4 394 samples in indoors is remained

Two couples of CIR examples, measured at classic LoS and NLoS environments, respectively, are shown in Fig. 4 to illustrate some characteristics of the channels. The peak amplitude has been normalized to 0 dB. When the LoS condition is met, represented by the upper two images in Fig. 4, the envelope of CIR fits the exponent distribution approximately, while in the NLoS condition, represented by the lower two images in Fig. 4, this similarity phenomenon is unapparent and fits to the model proposed in the Fig. 1 of literature [6]. In either LoS or NLoS environments, cluster of signals reflected from the same building arrive at the receiver end approximately simultaneously. The rays in the same cluster are superposed and can be hardly distinguished.

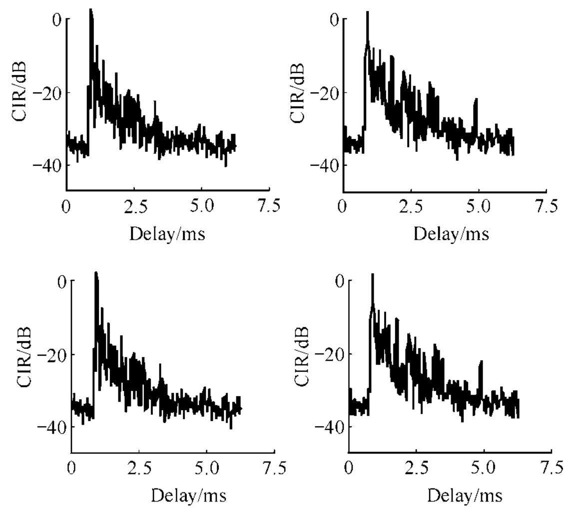

Fig. 4 Vector CIR for transmitter to two receivers

Fig. 5 shows the magnitude of the frequency response of the NLoS channel of 80 km/h vehicle speed with time, illustrating the time-selected and frequency-selected characteristics in the measured channels.

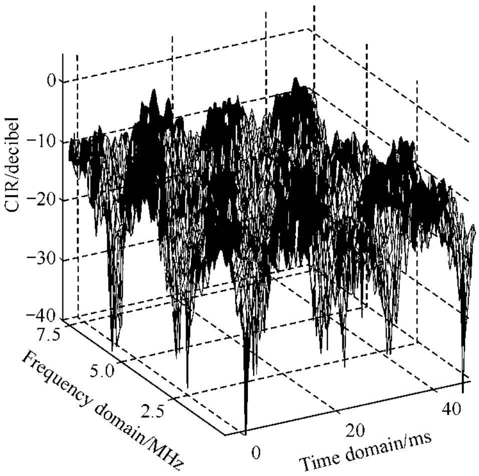

Fig. 5 Channel frequency response vs. time

Table 2 lists the mean number of rays whose power is greater than the dynamic noise floor by a certain value Normally, there are approximately seven rays in the outdoor environment. Relative amplitudes of rays is equal to the amplitude of rays minus the amplitude of dynamic noise. Fig. 6 shows that the pdf of relative amplitudes of rays accords with minus exponent distribution.

Table 2 The mean number of rays of different amplitudes

15 dB	20 dB	25 dB	30 dB	35 dB	40 dB
7.30	4.06	2.07	0.90	0.31	0.06

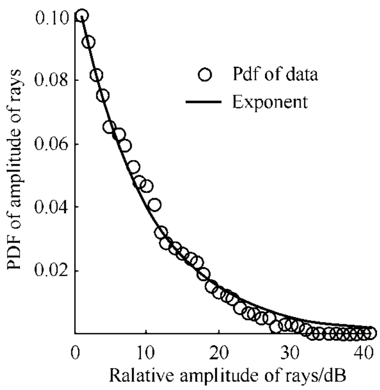

Fig. 6 The distribution of number of rays

3.2 The results from indoor

In the indoor environment, measurements are performed according to three scenarios. First, the transmitter was mounted on a table in the office room, with antennas approximately 1 m from the floor. The whole 13m*33m2 measurement area was equally divided into 300 lattices. At the center spot of each lattice referred to as a node, 10 samples with 1 s interval and 1 ms length were collected by the receiver. The samples are taken when the receivers are stationary at the nodes. Second, the transmitter was mounted on the same location as scenario 1, but the receiver antennas was mounted on a cart and kept moving when the measurement was conducted. Three routes were chosen deliberately to represent different cases. The first was to move along the corridor at different velocities. The second was to move from the LoS to the NLoS environment. The third was to traverse across the corridor between two rooms. In the third scenario, the receivers were located in the room next to the room in which the transmitter was located. The channel took on the apparent multipath dispersion that was selected particularly to study the correlation between different paths. Also in this room, samples are collected for different antenna separations, say 1/2, 1, 2,⋯,10 wavelengths. The polarization impact on system is also measured.

The 414 73 ms raw data and 250 1 ms raw data were collected extensively. All the 4397 CIR samples were extracted. The maximum expected indoor channel excess delay was set as 2 us, corresponding to 80 samples. A noise threshold was applied to raw CIRs to distinguish actual multipath components from noise. On verification using the noise floor threshold criteria, 4394 CIRs remained.

From Fig. 7, it can be noted that when receiver travels from one room (image A) to another room (image C) through the corridor (image B), the number of rays apparently has an increasing and decreasing trend.

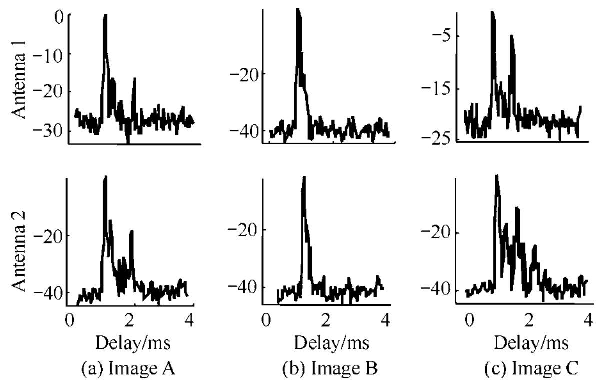

Fig. 7 Vector CIRs in different environment

Here the mean delay spread and rms delay spread, defined in the Section 3 of Ref. [1], are chosen to provide the first and second moment statistical description of the multipath effects. Ray number and maximum differential delay are also introduced. As a result, the rms delay among all the scenarios and all the samples equals to 0.45 us. Table 3 lists the statistic mean number of relative amplitude of rays. There are approximately two rays in the indoor environment. Fig. 8 shows the cdf and pdf of a number of rays.

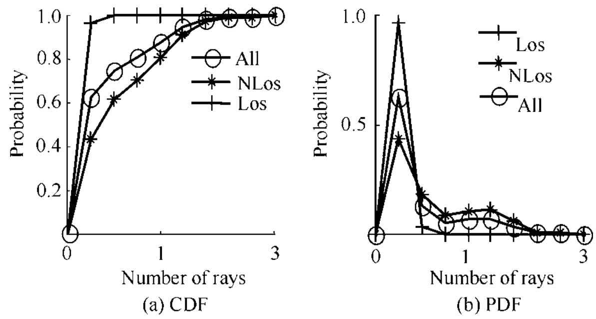

Fig. 8 CDF and PDF of mean number of rays in which data are partitioned into LoS and NLoS locations

Table 3 The mean number of rays of different amplitudes

15dB	20dB	25dB	30dB	35dB	40dB
2.00	1.56	1.22	0.90	0.79	0.57

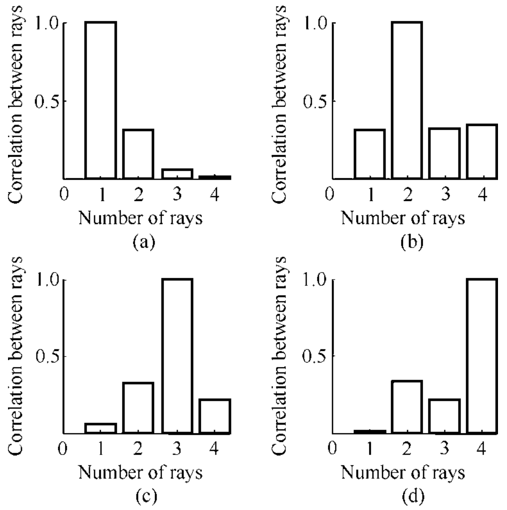

Fig. 9 The correlations between rays

A location was chosen deliberately, in which all CIRs consisted of four rays apparently, to study the correlation between the rays. In of Fig. 9(a), the results show that the correlations between the maximum ray and other rays are decreasing according to the separation time between rays. Figs. (b), (c) and (d) show that the correlations between the other rays are nearly constant regardless of the separation time between rays.

Result of correlation between antennas shows that although the antenna separation varies from 1/2 wavelength to 10 wavelengths, the correlations in most cases sustain the range of 0.6～0.8. The indoor results rallied with the conclusion from outdoor trial. Polarization measurement shows that use of orthogonally polarized antennas can dynamically decrease the antenna correlation.

4 Conclusions

When outdoor environment is considered, several statistics presented here indicate a typical urban environment. Most of the rms delay spread range lies between 0 and 4 μs. The correlation between antennas does not change dynamically while the separation between receiving antennas is changed. On the contrary, in most of the cases, the correlation lies within the range of 0.6 and 0.8. When the threshold is set 15 dB above the dynamic noise floor, the number of rays is approximately seven. The PL measurement shows that the PL exponent is around 3.37 with a modest rms error σ_x.

When indoor environment is considered, result of correlation between antennas rallies with our conclusion from outdoor campaign. Polarization measurement shows that use of orthogonally polarized antennas can dynamically decrease the antenna correlation. The mean number of rays among all the scenarios and all the samples is 2.00 and rms delay equals to 0.45 us.

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References

1. Ichitsubo S, oda Y, Imai T. Study on multipath propagation characteristics toward the fourth-generation mobile communication systems. NTT DoCoMo Technical Journal, 2004, 6(1): 45 – 55
2. Kepler J F, KraussT P, Mukthavaram S. Delay spread measurements on a wideband MIMO channel at 3.7GHz. Proceedings of 56 th Vechieular Technology Conferemce: V01 4, Sep 24-28, Vancouver, Canade. Piscaraway, NJ, USA: IEEE, 2002: 345 – 350
3. Varela Mes Sz, Sanchez Ml G. RMS delay and coherence bandwidth measurements in indoor radio channels in the UHF band. IEEE Transactions on Vehicular Technology, 2001, 50(2): 515 – 525
4. Nobles P, Halsall F. Delay spread measurements within a building at 2 GHz, 5 GHz and 17 GHz. Proceeding of Propagation Aspects of Future Mobile Systems: Vol 2, Oct 25, 1996, London, UK. Stevenage, UK: IEEE, 1996: 81 – 86
5. Kim S C, Bertoni H L, M Stern. Pulse propagation characteristics at 2.4GHz inside buildings. IEEE Transactions on Vehicular. Technology, 1996, 45(3): 579 – 592
6. Witrisal K, Kim Yong-Ho, Prasad R A. New method to measure parameters of frequency-selective radio channels using power measurements Communications. IEEE Transactions on Communication, 2001, 49(10): 1788 – 1800
7. XIE Qiong, ZHU Hong-bo. Analysis on the simulation model of the frequency-dispersion mobile channels. Journal of Chongqing University of Posts and Telecommunications: Natural Science, 2003, 15(1) 20-24 (in Chinese)

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