SPECIAL TOPIC

Link Budget and Networking Analysis of FuTURE 4G TDD Trial System

Abstract:
The FuTURE 4G Time Division Duplex (TDD) trial system uses 3.5 GHz carrier frequency and several crucial technologies including broadband Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM). These technologies challenge the link budget and networking analysis of the FuTURE 4G TDD trial network. This paper analyzes the practical 3.5 GHz propagation model and the link budget of Radio Frequency (RF) parameters of the trial system. Moreover, it introduces networking analysis and network planning of the trial system, which combines the field test results of the MIMO system. The FuTURE 4G TDD trial system and its trial network have been accomplished with successful checkup. The trial system fulfills all the requirements with two Access Points (AP) and three Mobile Terminals (MT), which supports multi-user, mobility, a high peak rate of 100 Mb/s, High-Definition TV (HDTV), high-speed data download, and Voice over IP (VoIP) services.

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The research and development of next generation mobile communication systems has drawn much attention worldwide. Among other issues, researchers' main concern is how to further improve the spectrum efficiency and offer subscribers with better experience of services.

China has begun its research on next generation mobile communication systems since 2001 and has developed Future Technology for Universal Radio Environment (FuTURE) project, which is a part of the National High Technology Research and Development Program of China (i.e. , 863 Program)[1]. This project is designed to develop a testing platform for 4G mobile communication systems and its trial systems in China, with the aims of studying the trends and demands in the field of wireless communication in the next 10 years. The project also has the goals of developing technologies for next generation communication systems, and establishing related critical technology verification system so as to support future-oriented, new wireless communication services and to play an important role in 4G standardization.

Two branches are involved in the FuTURE plan: 4G Frequency Division Duplex (FDD) system and 4G Time Division Duplex (TDD) system[2].

The FuTURE 4G TDD trial system, consisting of two Access Points (AP) and three Mobile Terminals (MT), was accomplished in June 2006. It provides a multi-user networking test environment that supports mobility, and adopts several advanced technologies including Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Soft Fractional Frequency Reuse (SFFR) and generalized distributed network architecture[3].

According to the networking requirements of the FuTURE 4G TDD trial system, it is required to make the link budget and conduct networking analysis to make better network planning after the joint debugging of the trial system and before the construction and networking test of the trial network.

The FuTURE 4G TDD Trial system uses 3.5 GHz carrier frequency with central frequency of 3.45 GHz, but the study on the propagation characteristics of 3.5 GHz radio waves has just stepped into the startup period in China, and in other countries as well, and no general propagation models have been developed.

Besides, the MIMO technology used in the trial system has high requirements for antenna installation location and radio propagation environment.

Therefore, the link budget and networking analysis of the trial system are critical to the construction of the trial network.

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▼Table 1. RF parameters of FuTURE 4G TDD trial system

RF Parameter	Setting
Working Frequency	3 440–3 460 MHz
Bandwidth	20 MHz
Maximum Linear Transmit Power	AP: 30 dBm; MT: 27 dBm
Noise Figure of Receiver	AP: 5 dB; MT: 7 dB
Transmit Power Control Range	AP: 30 dB, with 1 dB step; MT: 60 dB, with 1 dB step
Maximum Received Signal	AP/MT: –25 dBm
Antenna Pattern	AP: directional antenna; MT: omni antenna
Antenna Gain	AP: 14 dBi; MT: 5 dBi
Number of Transmitting /Receiving Antennas	AP: 8 MT: 4
AP: Access Point	MT: Mobile Terminal

This paper discusses the link budget and the field test–based networking analysis of the trial system in detail.

1 RF Parameters of the Trial System

Before making the link budget of the FuTURE 4G TDD trial system, it is necessary to determine the related parameters of Radio Frequency (RF) equipment of the system, especially the transmit power, receiver sensitivity, noise figure, antenna pattern, antenna height, and gain. In addition, as MIMO technology is used, the configuration and geometric distribution of antennas should also be taken into account.

The detailed RF parameters of the FuTURE 4G TDD trial system are listed in Table 1.

2 Link Budget

In order to deploy the link budget of the FuTURE 4G TDD trial system, we should first compute the coverage area based on the propagation model, which is set up according to the propagation characteristics of 3.5 GHz radio waves. Then the coverage of the FuTURE 4G TDD trial system can be obtained.

2.1 Propagation Characteristics of 3.5 GHz Radio Waves

The FuTURE 4G TDD trial system uses 3.5 GHz carrier frequency, with central working frequency of 3.45 GHz and 20 MHz bandwidth. Currently, the common models used to study the propagation characteristics of radio waves are Okumura and Hata. And the Hata model is further divided into two kinds: the Okumura–Hata model for frequencies from 150 MHz to 1 500 MHz and the Cost231–Hata, an extension of Okumura–Hata, for frequencies up to 2 GHz[4–5]. However, due to the complexity of the actual radio environment, no theoretical model can perfectly suit a specific situation, and no model can be applied to all propagation environments. As a result, in actual application, a proper model has to be selected for a specific environment.

As the FuTURE 4G TDD trial system uses 3.45 GHz carrier frequency, neither Okumura nor Hata model, which covers frequencies no more than 2 GHz, is applicable here. Nowadays, the study of the propagation characteristics of 3.5 GHz radio waves has attracted more and more attention in China, as well as in other countries. The reason for this comes from the crowded situation at the carrier frequency of 2 GHz or lower, and the future mobile communication systems may have to work at higher frequencies. The research on the propagation characteristics of 3.5 GHz and 5 GHz radio waves has been launched recently.

In recent years, the Wireless Technology Innovation Institute (WTI) of Beijing University of Posts and Telecommunications (BUPT) has done much research on the propagation characteristics of 3.5 GHz radio waves; it has also conducted many field tests and measurements in the urban environment around BUPT. After analyzing a large number of field test data, the WTI has set up a 3.5 GHz–based propagation model[6–7].

Figure 1 shows the BUPT–centered test area for studying the propagation characteristics of 3.5 GHz radio waves. The black point in the center is the antenna installation location, which is on the top of the main building of BUPT. Three antennas are configured in the test: one for sending and two for receiving. The radius of the test area exceeds 2 km, and moving speed is up to 100 km/h.

Table 2 lists the average path loss factors of the four directions. These values are all calculated from the field test data. The test center is at the antenna installation location.

The following link budget of the FuTURE 4G TDD trial system is based on the above model. As the trial network is centered on the campus of BUPT, the model from the BUPT–centered field test data is no doubt an accurate and proper one.

Based on the model, the computing formula for the path loss of 3.5 GHz band can be expressed as follows:

▲Figure 1. The BUPT–centered field test area.

▼Table 2. Path loss factors

Test Area	Path Loss Factor
Northern	3.76
Southern	3.51
Western	3.09
Eastern	3.14
Average	3.39

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$$PL(d)=PL(d_0)+10n\lg(\frac{d}{d_0})$$
$$=20\lg(\frac{4\pi d_0}{\lambda})+10\times3.76\times\lg(\frac{d}{d_0})$$
$$=138.4+10\times\lg(d) \quad (1)$$

Where $PL(d)$ is the path loss through a distance of d (unit: km); λ is the wavelength; and d_0 is a reference distance, for which 10 m is used. To make the link budget more reliable, a certain margin should be reserved. So, in actual calculation, the largest path loss factor n (i.e., North; see Table 2) is used.

2.2 Receiver Sensitivity

Another important parameter involved in the link budget is receiver sensitivity, which is the lower limit for the receiver to correctly receive and identify signals. To ensure good communication, the transmitted signal, which will experience space attenuation when traveling, must be correctly identified at the receiver. That is to say, the signal strength at the receiver must be greater than the receiver sensitivity.

In the FuTURE 4G TDD trial system, the maximum transmit power of uplink MT is smaller than that of AP, making the trial system uplink limited. Therefore, the coverage of the system should be calculated based on the uplink.

The receiver sensitivity at AP end is calculated as follows:

According to the performance index requirements, to ensure a Bit Error Rate (BER) of 10^{-6}, the required E_b/N_0 should be 3 dB. When the hardware overhead is taken into consideration, the required E_b/N_0 shall be converted into 12.3 dB of Signal-to-Noise ratio (SNR) (the trial system adopts 16QAM mode and 1/3 coding). That means the output SNR (SNR_{out}) is 12.3 dB. From Table 1, the noise figure (F) of the AP receiver is 5 dB. So the required input SNR (SNR_{in}) at the AP receiver end should be:

$$SNR_{in}=SNR_{out}+F=17.3\text{ dB} \quad (2)$$

The thermal noise power can be computed using the formula: $N=\mathrm{K}TB$, where K is the Boltzmann constant whose value is 1.381×10^{-23} W/Hz/K, T is the room temperature (290 K), and B is the bandwidth (20 MHz). The noise power is:

$$N=\mathrm{K}TB$$
$$=10\lg(1.381\times10^{-23}\times290\times20\times10^{6})$$
$$=-131.9\text{ dBW}$$
$$=-101.9\text{ dBm} \quad (3)$$

From Table 1, we can see the antenna gain at AP end (G_{AP}) is 14 dBi. Therefore, the minimum signal power that can be received by the AP (i.e., the receiver sensitivity) is:

$$P_{rmin}=SNR_{out}+F-G_{AP}+N=-98.9\text{ dBm} \quad (4)$$

2.3 Maximum Path Loss

Once the receiver sensitivity and the maximum transmit power of MT are known, the maximum path loss allowed by the system can be calculated out.

According to Table 1, the antenna gain at MT (G_{MT}) is 5 dBi, and the maximum transmit power at MT end is 27 dBm when the BER is required to be 10^{-6}. So, the theoretical maximum path loss allowed by the system is:

$$PL_{max}=P_{tmax}-P_{min}+G_{MT}-L_{other}$$
$$=27+98.9+5-2$$
$$=128.9\text{ dB} \quad (5)$$

Where L_{other} is the loss of other devices in the trial system, such as feeder, which is about 2 dB.

In practice, shadow fading protection margin and fast fading protection margin should be taken into consideration. By experience from actual engineering[8–9], the estimated fast fading protection margin is 3 dB, and the shadow fading protection margin is 7 dB. Therefore, the maximum path loss allowed by the system is:

$$PL'_{max}=128.9\text{ dB}-3\text{dB}-7\text{dB}=118.9\text{dB} \quad (6)$$

2.4 Maximum System Coverage

Replace the $PL(d)$ in equation (1) with the result of equation (6), and equation (7) is obtained:

$$PL(d_{max})=PL(d_0)+10n\lg(\frac{d_{max}}{d_0})$$
$$=138.4+10\times3.76\times\lg(d_{max})$$
$$=118.9\text{ dB} \quad (7)$$

So the maximum uplink coverage radius of the FuTURE 4G TDD trial system can be calculated:

$$d_{max}=0.303\text{ km} \quad (8)$$

As mentioned above, this trial system is uplink limited. To ensure service continuity and smooth handover of an MT from one AP to another, the coverage of the trial system should be no more than the maximum uplink coverage radius.

3 Networking Analysis

With the above link budget calculations, we can go on to the networking analysis of the FuTURE 4G TDD trial network. The trial network is built with its center located at the BUPT campus, and configured with two APs and three MTs to support multi-user, mobility and a peak data rate of 100 Mb/s.

Although the practical 3.5 GHz-based propagation model from the study of the propagation characteristics in BUPT is used in the link budget calculation, the theoretical result may still differ from the actual radio environment, especially in a case where MIMO technology is used, which is subject to antenna layout, installation and radio environment. Therefore, in addition to link budget, the networking analysis of the actual radio environment is necessary to better plan the two APs' installation locations, the spacing between them, and the handover area.

3.1 Field Test

The basic RF parameters used in the real radio environment field test for the FuTURE 4G TDD trial system are listed in Table 3. For the purpose of hardware debugging, a simplified configuration of two transmit and four receiver antennas is applied in the MIMO system for the field test. The two transmit antennas are 120° directional, with a maximum transmit power of 27 dBm; while the four receiver antennas are omni. At the transmitter end, the antennas are laid in a horizontal array, with a spacing of 1.5 m in between and a tilt angle less than 15 degrees, so that a higher gain can be obtained. At the receiver end, the antennas are also laid in a horizontal array, but with a spacing of 1 m.

▼Table 3. Basic RF parameters for the field test of radio environment

RF Parameter	Setting
Central Frequency	3.45 GHz
Bandwidth	20 MHz
Number of Transmit Antennas	2
Pattern of Transmit Antenna	120° directional antenna
Height of Transmit Antennas	10 m (on the second floor platform of Teaching Building No. 1 of BUPT)
Number of Receiver Antennas	4
Pattern of Receiver Antenna	Omni antenna
Height of Receiver Antennas	2 m (on the top of the test vehicle)
Transmit Power	27 dBm

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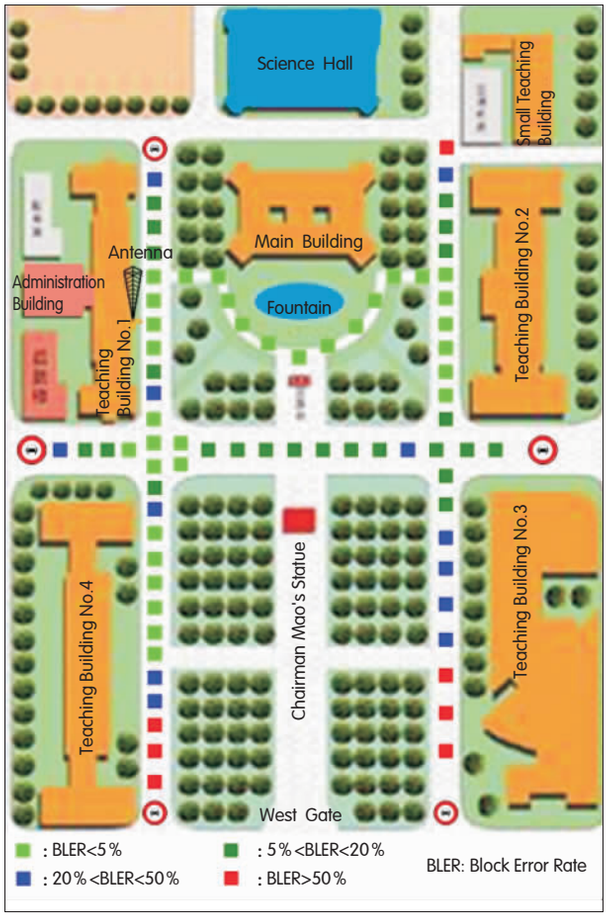

▲Figure 2. Field test Result of the radio environment in BUPT.

In the field test, the receiver judges the communication quality based on the Block Error Rates (BLER) of the data it receives. The test is conducted on the BUPT campus, within a rectangular area of 350 m × 200 m. This area is a built-up area surrounded with buildings and trees that act as reflectors, diffractors or scatters of signals during the test.

After several measurements with the test vehicle moving in the area, the average data in Figure 2 are obtained.

3.2 Test Data Analysis

As the field test uses actual MIMO links to measure the radio environment, the measurement results are valuable materials for studying the coverage of the MIMO system, as well as the layout of the antennas.

In general, the MIMO system performs quite well in the test. At the transmit power of 27 dBm, the coverage is about 200 m, and the BLER can reach its best value of 0. In most part of the area, the signal reception is quite good, with the BLER less than 5% (that is to say, BER is between 10^{-5} and 10^{-6}). The trees and buildings in the area have little impact on the system. Even in the case of scattering and diffraction, the system works well, with a BLER of less than 5%.

3.3 Networking Analysis with two APs and three MTs

A FuTURE 4G TDD trial network on the BUPT campus is built based on the above link budget and test data analysis.

The network, consisting of one Control Unit (CU), two APs and three MTs, supports multi-user and mobility management like handover. The coverage radius of each AP reaches 200 m. With a BER of 10^{-6}, a BLER of less than 5% and a peak data rate of 122 Mb/s, the system can support High-Definition TV (HDTV), high-speed data download, and Voice over IP (VoIP) services.

4 Conclusions

The FuTURE 4G TDD trial system uses 3.5 GHz carrier frequency and several key technologies including MIMO and OFDM. Configured with two APs and three MTs, the system supports multi-user, mobility and a peak data rate of 100 Mb/s. At present, the trial system has been established and approved. The link budget and networking analysis have played an important role in the successful construction of the trial network. Moreover, the data obtained from the link budget and the field test are useful references for the network construction of next generation mobile communication system.

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