Spectrum Sharing | MIC Technical Examination Service | Next-Generation Mobile Communications Systems

Technology Reports

Results of Basic Studies on Spectrum Sharing for Next-Generation Mobile Communications Systems

Toward the introduction of IMT-Advanced systems in the 3-4 GHz band, a study group called "Spectrum-sharing technology for Next-Generation mobile communications systems" was established as a technical examination service by the MIC, to conduct technical studies on spectrum-sharing technologies contributing to more efficient use of spectrum. NTT DOCOMO has participated in this study group from FY2006 through FY2009, actively contributing to the propagation model for interference study, evaluation of interference mitigation techniques and other issues.

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1. Introduction

NTT DOCOMO is advancing R&D on International Mobile Telecommunications-Advanced (IMT-Advanced), which is a 4th Generation mobile communications system, toward the realization of broadband mobile communications. To achieve efficient broadband mobile communications, sophisticated radio communications technology as well as use of continuous, wideband spectrum is necessary. The need for broadband mobile communications was recognized at the International Telecommunications Union (ITU) World Radiocommunications Conference (WRC)[*1]-2007, and a total of 428 MHz of new bandwidth was identified for use by IMT (3rd and 4th Generation mobile communications systems)[1]. With this development, many countries began studying use of these frequencies with IMT systems.

Among these new frequencies, the band from 3.4 to 3.6 GHz (200 MHz) is suitable for broadband communication. Additional frequencies above 3.6 GHz are also being considered to be used for broadband mobile communications, including IMT-Advanced, in Japan and Europe [2][3]. However, Fixed Satellite Services (FSS) are also allocated to use these frequencies all over the world, so establishing technology to share spectrum with these existing systems is very important for the introduction of IMT-Advanced. Thus, achieving adequate communications range and throughput for IMT-Advanced, without producing harmful interference to these existing systems is a major issue.

With this background, a study group was established regarding "Spectrum-sharing technologies for Next-Generation mobile communications systems" as a technical examination service[*2] of the Ministry of Internal Affairs and Communications (MIC), conducting a technical survey of spectrum sharing between IMT-Advanced and existing systems.

NTT DOCOMO has actively

*1 **WRC**: A conference that reviews, and if necessary, revises Radio Regulations, the international treaty governing the use of radio-frequency spectrum, and the orbits of geostationary and non-geostationary satellites. The conference normally meets once every three to four years, and is attended by administrations, ITU registered corporations and related organizations.

contributed to this study group, with the goal of an early and smooth introduction of IMT-Advanced, with its high spectral efficiency*3 [4][5]. The background and the objectives of the study and intermediate results during the first two years of the study were reported in an article in the previous issue of this journal [4].

This article focuses on subsequent progress at NTT DOCOMO related to spectrum-sharing technologies, and describes an overview of the main results obtained over the four years of the study group. Note that the following studies were conducted together with Panasonic Mobile Communications Co., Ltd., which is a member of the study group.

2. Survey of Spectrum-sharing Technologies for Next-Generation Mobile Communications Systems

The study group for "Spectrum-sharing technologies for Next-Generation mobile communications systems" was established over the four years from FY2006 to FY2009, with participation from mobile communications operators including NTT DOCOMO, satellite communications operators, and major Japanese and international manufacturers. It conducted studies on various aspects of spectrum sharing for Next-Generation mobile communications systems.

Within this study group, our objective was to contribute to settling technical conditions for spectrum sharing between Next-Generation mobile communications systems and FSS systems in Japan, and to the efficient use of spectrum mainly in the microwave band (3-4 GHz).

Specifically, the major studies conducted for the frequency band where introduction of IMT-Advanced is being considered (3-4 GHz) were as follows:

- Verification of a common propagation model across systems
- Experimental tests of reception performance by existing systems
- Feasibility studies for possible spectrum-sharing techniques.

3. Validation of Recommendation ITU-R P.452 - Propagation Model for Studying Interference among Systems

Recommendation ITU-R*4 P.452 specifies a propagation model for calculating interference when sharing among systems [6].

In this study, we verified this model in order to ensure its validity for studying spectrum sharing between IMT-Advanced and FSS, focusing on anomalous propagation probabilities and clutter losses, which have significant effects on estimated interference [7]-[10].

3.1 Verification of Anomalous Propagation Probabilities

Through testing, we verified the probabilities for occurrence of phenomena in which radio waves propagate much farther than they normally would. One of the main effects is ducting, which is caused by inversion of the temperatures in a layer of air due to nighttime cooling or other effects.

This phenomenon is an important factor in reducing the estimated value for propagation losses, so in order to check the validity of Recommendation ITU-R P.452 calculations estimating propagation losses, in this study we experimentally checked a parameter in the calculations, the probability of anomalous propagation.

For these experiments, we installed transmitter and receiver in Musashino City, Tokyo, and Yokosuka City in Kanagawa Prefecture and monitored the propagation conditions for a period of over one-year.

The results of evaluating cumulative probability (time ratio) that measured propagation losses (PL_{MES}) fall below the corresponding free space loss (PL_{FSL}) are shown in **Figure 1**. The results confirm that the experimental results correspond closely to the values derived using the estimation method specified by Recommendation ITU-R P.452.

3.2 Verifying the Appropriateness of Clutter Losses

Clutter refers to physical features (buildings, terrain, etc.) existing in the vicinity of transmitter and receiver and having a significant effect on propagation between them.

*2 **Technical examination service**: A project established by the MIC to perform technical studies on highly practical technologies for efficient spectrum use, to promote the early introduction of those technologies.

*3 **Spectral efficiency**: The number of data bits that can be transmitted per unit time and unit frequency band.

*4 **ITU-R**: The radiocommunication sector of the ITU, which is an international organization in the telecommunications field. It conducts studies required to revise international regulations for radio communications and conducts research on radio communications technology and operation.

We evaluated the validity of clutter parameters specified in Recommendation ITU-R P.452 for computing estimated clutter losses in urban areas, and it was revealed that with the continual development of urban construction, the estimated average building height in the parameter set for the current computation method is too low. Based on the results, we proposed adding a new set of parameters for areas such as urban centers at the ITU-R Study Group 3 (SG3) Working Party 3M (WP3M)[*5] meeting, held in June 2009 [7]. This proposal was approved and the changes were reflected in the 14th edition of Recommendation ITU-R P.452.

We also proposed a new calculation method which considers frequency characteristics and interfering probabilities that are not considered in current method [10]. We plan to make further proposals to have this calculation method included in a revised edition of Recommendation ITU-R P.452 in the future.

4. Survey of Systems for Applying Spectrum-sharing Technology

To study technical conditions and techniques for spectrum sharing, it was necessary to understand the reception characteristics of the systems sharing the spectrum in order to decide the width of the guard band[*6] needed between bands used by the IMT-Advanced and FSS systems.

Thus, we conducted tests on Low Noise Block converters (LNB)[*7] and Low Noise Amplifiers (LNA)[*8] available on the market and used in FSS satellite communications receivers that would share spectrum with IMT-Advanced (**Figure 2**). Based on the test results, we proposed a model applicable to LNB/LNA for Amplitude Modulation (AM)-AM characteristics[*9] and AM-Phase Modulation (PM) characteristics[*10] [11][12].

When evaluating the AM-PM characteristics, the overall measurement system must operate with stable frequencies. LNB devices, however, have a frequency conversion function, and their local oscillator frequency is not always stable. Thus we proposed a method which enables accurate measurements even under such conditions [11].

The out-of-band distortion waveforms estimated by the model and those obtained experimentally using commercial LNBs matched closely, and this confirms that the proposed model, and evaluations done using the model, are valid (**Figure 3**)

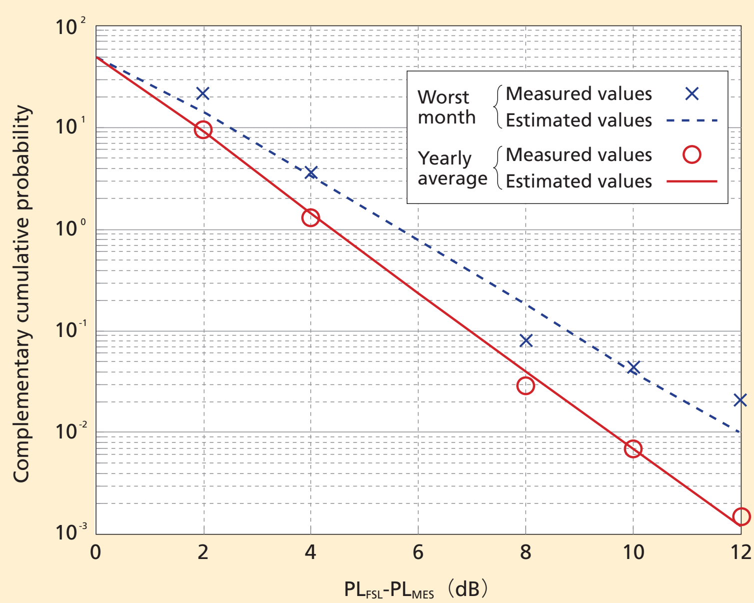

Figure 1 Anomalous propagation probability test results

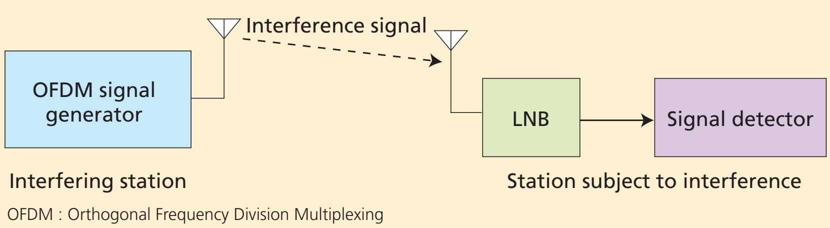

Figure 2 Interference evaluation model for LNB study

*5 **ITU-R SG3 WP3M**: A working party, established under the umbrella of SG3 in the ITU-R, which handles radio-wave propagation. The working party specializes in point-to-point propagation and propagation between earth and satellite stations.

*6 **Guard band**: A frequency band set between the signal frequency bands of systems to prevent radio signal interference between systems.

*7 **LNB**: An LNA that also incorporates a frequency conversion function (see *8).

*8 **LNA**: Equipment which is used to amplify a signal directly after it is received by the antenna. Very little noise is added to the signal in amplification, so even very weak signals can be amplified with little distortion.

[13]. We also evaluated the effects caused by only the AM-AM characteristic and only the AM-PM characteristic and found that the AM-AM characteristic is dominant as a distortion-causing factor, but that the AM-PM characteristic must also be considered for accurate estimations [14].

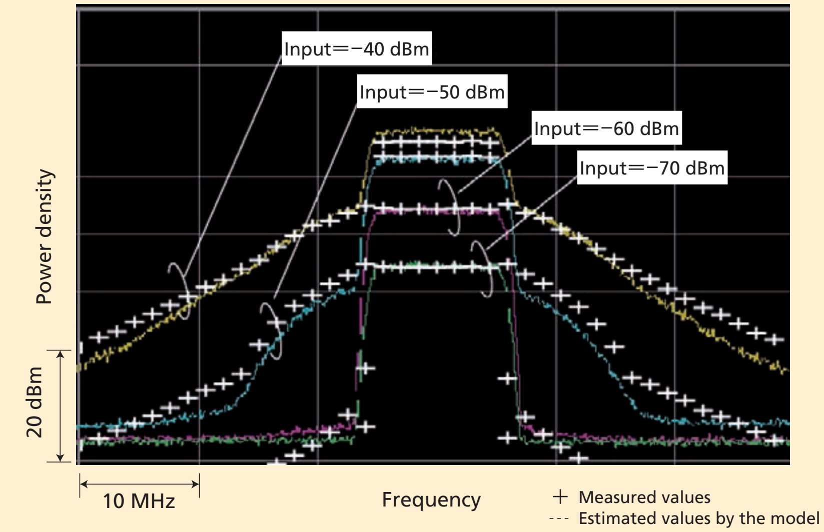

Figure 3 Comparison of out-of-band distortion between simulation and testing

5. Validation of Spectrum-sharing Technology

In Report ITU-R M.2109 [15] three technologies are mentioned that are effective in mitigating interference for spectrum sharing between IMT-Advanced and FSS. These are: Multiple Input Multiple Output (MIMO)[*11], sector disabling, and Dynamic Spectrum Access/Allocation (DSA). In this study we conducted field tests to verify these technologies and demonstrated their effectiveness for interference suppression. We provided some of these results as input for the ITU-R SG5 WP5D[*12] meeting, held in June 2010 [16], and these were reflected in the working documents towards a new ITU-R Recommendation on spectrum sharing between IMT and FSS [17].

5.1 Field Test Overview

This testing was conducted near YRP in Yokosuka City in Kanagawa Prefecture. An overview of the area where the tests were conducted and the transmitter antenna installations are shown in **Figure 4**.

For the sector disabling and DSA

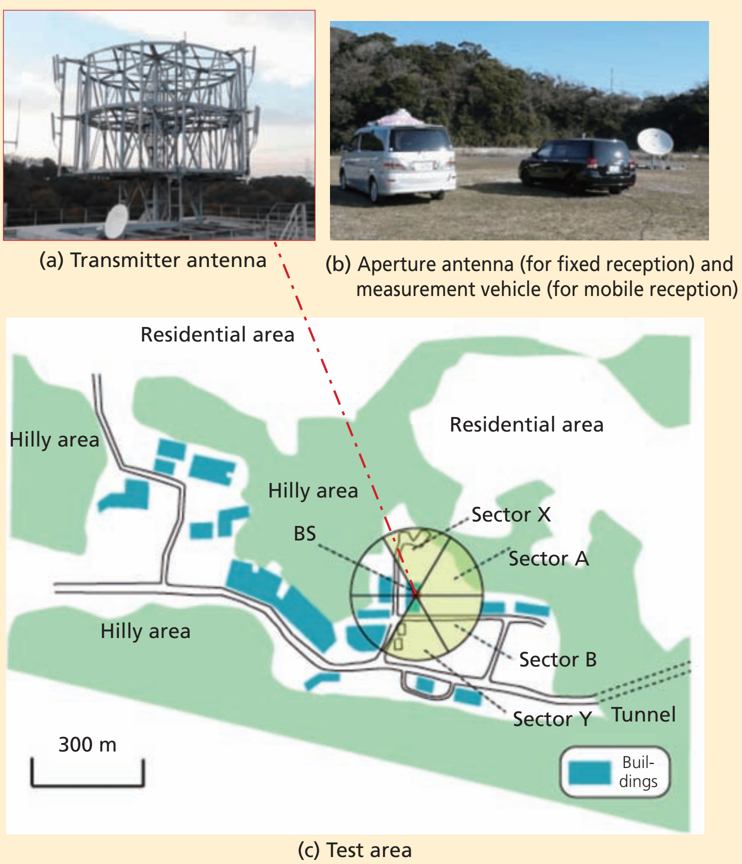

Figure 4 Overview of field-test area and transmitter antenna equipment conditions

*9 **AM-AM characteristic**: The characteristic of the output amplitude relative to the input amplitude. Ideally, the input amplitude and output amplitude are proportional, but output amplitudes are generally lower than ideal values for excessively large inputs.

*10 **AM-PM characteristic**: The characteristic of the output phase shift relative to the input amplitude. Ideally, the phase shift between input and output should be a fixed value, independent of the input amplitude, but phase shift can differ from this ideal, especially for excessively large input amplitudes.

tests, the equipment in the measurement vehicle was used to measure the received signal, and for the MIMO tests, an aperture antenna was used to measure the interference signal.

5.2 Effect of Interference Suppression by MIMO Technology

Generally, MIMO refers to wireless communications that uses multiple antennas for transmitting and receiving, but in Report ITU-R M.2109, MIMO is used to denote methods that suppress interference using beam forming with multiple transmitter antennas [18][19]. In this study, we verified these interference-suppressing techniques through field testing. Specifically, we used a three configurations, which are intra-sector, inter-sector at a site and inter-site (**Figure 5**) [16][17].

The results of these tests are shown in **Table 1**. The results show that beam forming with MIMO technology was capable of suppressing the amount of interference significantly, by approximately 15 dB. It is not shown in the table, but we also confirmed that the fluctuation in oscillator frequencies greatly reduces the suppression effects when separate stations use independent local oscillators[*13] in the inter-sites cases.

5.3 Effect of Interference Suppression by Sector Disabling

Sector disabling is a method which disables the sectors facing toward interfered-with stations to suppress interference levels. This method can be expected to be very effective in suppressing interference without using advanced techniques.

The results of tests to confirm the effectiveness of this method in a field environment are shown in **Table 2**. With four sectors, A, B, X and Y, we examined the effectiveness suppressing interference when only sector A or sector B was disabled, measuring across the whole sector and in the center of the sector (**Figure 6**). The results show that interference was suppressed over the whole sector by approximately 7 dB, and in the center by about 8 dB. This corresponds closely to results obtained in a simulation study [16][17].

5.4 Effect of Interference Suppression by DSA

Broadly speaking, DSA refers to methods in which spectrum is allocated/accessed dynamically, and here we

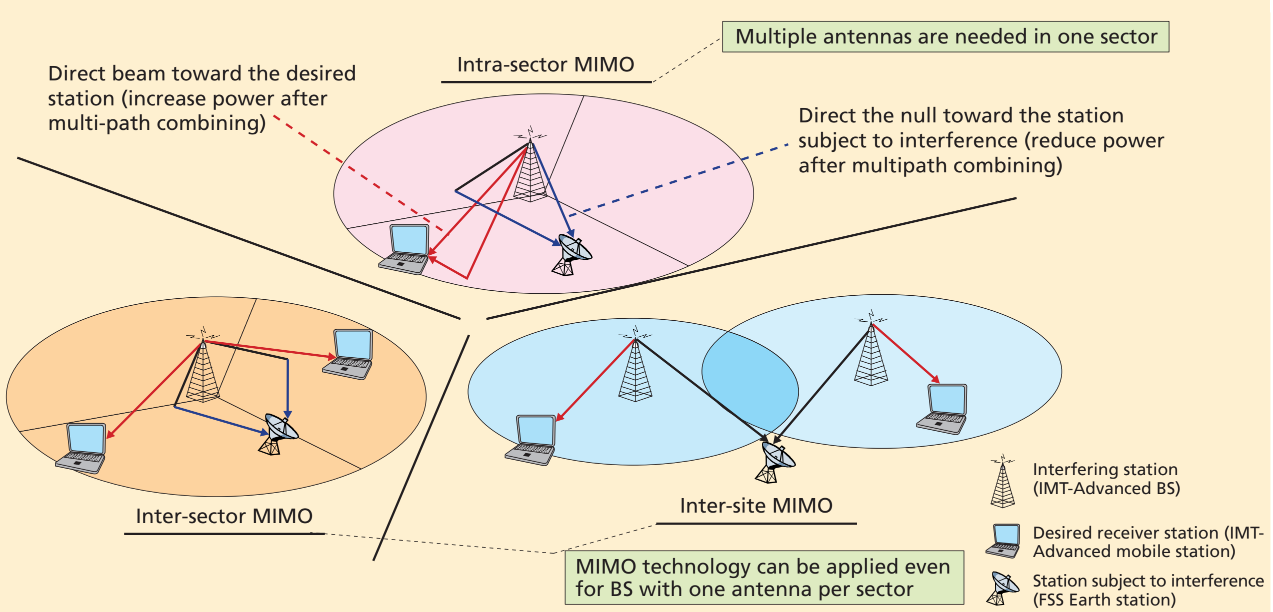

Figure 5 Assumed MIMO configuration for field verification tests

*11 **MIMO**: A wireless technology that uses multiple antennas for transmitting and receiving, and by making use of the differences in propagation paths in such multipath conditions, allows the power of the signal received at a specific antenna to be controlled, or allows multiple information streams to be transmitted at the same time. In this case, it can be used to control transmitter antenna weightings to suppress the power of the interfering signal at the interfered-with station, and to increase the received signal power at the desired receiving station.

*12 **ITU-R SG5 WP5D**: A working party specializing on IMT and established under the umbrella of SG5 of the ITU-R, which handles mobile, fixed, and other terrestrial communications issues.

are referring to methods that use information, such as the interference power at the interfered-with station, to control aspects at the interfering station such as the frequency used or the transmission power.

DSA may be a key technique to achieve spectrum sharing based on the criteria of a practically allowable level of interference by the interfered-with station. NTT DOCOMO is proposing a spectrum-sharing method for non-priority systems that is classified as DSA and uses Transmist Power Control (TPC)*14 [20][21]. This study verifies its effectiveness through field tests [22].

Measurement results from these field tests are shown in **Figure 7**. As a result of calculations based on these results, we were able to show that transmission capacity can be greatly increased relative to Fixed TPC (FTPC) by using Adaptive TPC (ATPC). We also confirmed that as the permitted reference level, M_{IN}, (relative to the noise level) is increased; the transmission capacity achievable with IMT-Advanced increases greatly (**Figure 8**). These results indicate that the efficiency of spectrum use can be dramatically improved, if the level of permitted interference is dynamically controlled based on the desired-signal reception state at the interfered-with station.

Table 1 Effect of interference suppression by MIMO verification test results

MIMO configuration	Interference suppression at FSS station
Intra-sector	18.1 dB
Inter-sector	14.7 dB
Inter-site	14.8 dB

Table 2 Effect of interference suppression by sector-disabling verification test results

	All-sector area	Sector center area
Sector A	6.9 dB	8.2 dB
Sector B	7.5 dB	8.1 dB

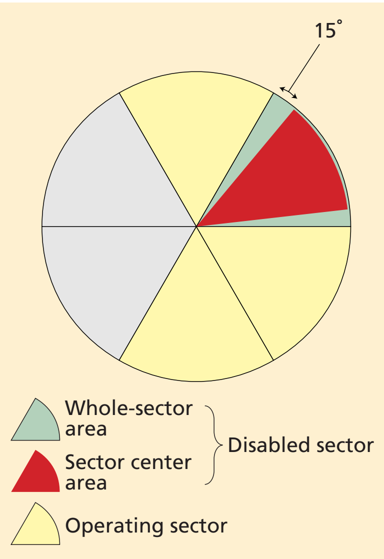

Figure 6 Measurement areas for tests of effect of interference suppression by sector disabling

Figure 7 Received power distribution measured in field test

6. Conclusion

In this article we have described the main results obtained by a study group conducted as a technical examination service of MIC, Japan, to which NTT DOCOMO has actively contributed for the smooth introduction of IMT-Advanced.

In the future, we plan to contribute a part of these results to related meetings of the ITU-R and to continue study on the developing areas of spectrum-sharing technology.

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*13 **Local oscillator**: A device generating a continuous wave signal with a fixed frequency, incorporated into each transmitter and receiver.

*14 **TPC**: A technology which adaptively adjusts transmitter power in order to satisfy a target condition. In this article, it refers to controlling transmission power such that the power received at the interfered-with station is under a predetermined threshold.

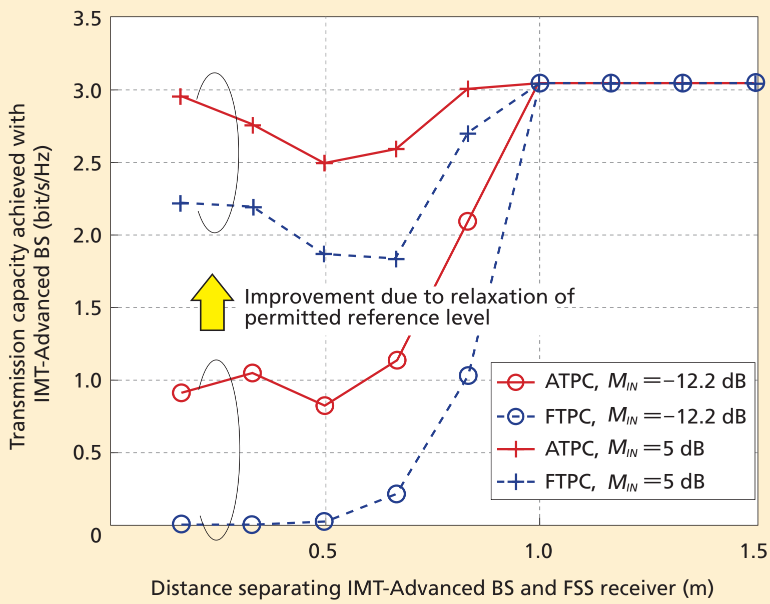

Figure 8 Transmission capacity achieved with IMT-Advanced

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