Interference Power Measurement in Outdoor/Indoor Environment

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This paper describes the interference power measurement experiment on STICS. It aims to understand the interference power toward satellite caused by from terrestrial terminal located at outdoor/indoor environment. The experimental system consists of IMT-2000 cellular phone terminal, Continuous Wave (CW) transmitter, and pseudo satellite. We have conducted the experiment at the office building area and the residential area to obtain fundamental data effective for interference evaluation of STICS.

1 Introduction

To realize effective frequency sharing in the Satellite/Terrestrial Integrated mobile Communication System (STICS)[1], interference levels between satellite and terrestrial channels must be understood as accurately as possible. There are four links that may involve interference (uplink and downlink for satellite and terrestrial systems). As an example, Figure 1 shows a mode of possible interference schematically, in which a satellite uplink suffers interference from the transmit wave emitted by dual mode terminals used in terrestrial communication.

In view of a possible situation in which a great number of terminals operate in the terrestrial links, a non-negligible level of interference to satellite links must be assumed to take place, making this interference path a major challenge toward frequency sharing. Note, that the figure illustrates a case in which both the terrestrial and satellite systems share the same frequency for their uplinks (normal mode). This study places focus on this mode.

Let us look a bit further into the frequency sharing scheme for the uplinks of terrestrial and satellite systems. STICS presupposes the use of around 100 satellite beams to cover Japan and its exclusive economic zone (Figure 1 shows one of these beams). The uplink and downlink bandwidth (30 MHz) are each divided into multiple sub-bands, and these sub-bands are allocated to the satellite beams described above in a multi-color fashion, enabling the satellite system to reuse frequencies efficiently. Based on these settings, the satellite and terrestrial systems share frequencies using the following method: a sub-band f_1 is allocated to a satellite beam, and a terrestrial cell located outside the beam uses the same sub-band f_1 (see Fig. 1). For further reduction of the interference level to the satellite system, placement of a spatial guard band surrounding the satellite is under review, within which the terrestrial system is unable to use the sub-band, f_1.

There are a number of terrestrial terminals that operate using the same frequency. In normal mode, as described above, the satellite receives aggregate interference from all of these terminals, which must be correctly evaluated. In this situation, the interference levels the satellite perceives are not uniform depending on the usage environment in which each terrestrial terminal is located (the interference level varies depending on such factors as transmission power and attenuation along the propagation path from the terrestrial terminal to the satellite).

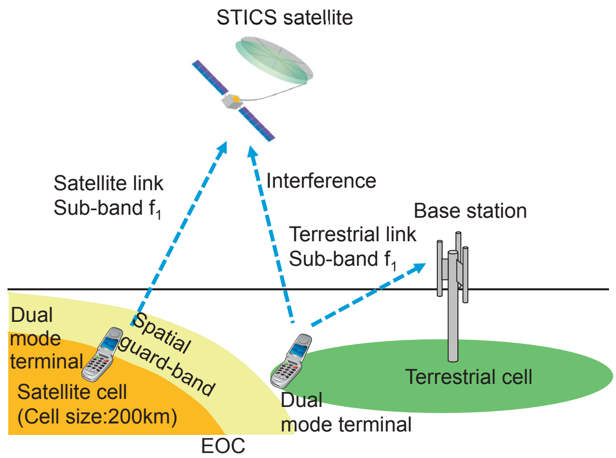


Fig. 1 Interference path to STICS satellite uplink (normal mode)

Therefore, to evaluate terrestrial-satellite interference levels accurately in STICS, the evaluation method must reflect characteristics of two distinct propagation paths respectively associated with terrestrial mobile communication and satellite mobile communication. The method should also reflect various conditions in place in the usage environment. Figure 2 is a schematic representation of the effects the terrestrial terminals may have on the interference level to the STICS satellite. Possible factors include: geological features around the call site, distance/positional relation from the base station, and distribution density of base stations. Among them, geological features around the call site provide irregular variations superposing on the interference level of the line-of-sight path.

Assuming the use of an IMT-2000 cellular phone system on the terrestrial side, the latter factors—distance/positional relation from the base station—cause variations of terminal transmission power from one call site to another (an effect caused by transmit power control). Experimental vehicles, mounted with an IMT-2000 cellular phone, have travelled around the country, and the distributions of wide area transmission power have been published both in the USA[2] and Japan[3].

Against this backdrop, the objective of this study is to clarify the interference level variations caused by the former factor—geological features around the call site. Key determinants that affect such variations include the local position of the call-site (open-air or in-door) and types of features around it. Normally, a terrestrial-satellite propagation path is designed with consideration given only to the shielding effect of nearby features. However, this approach (terrestrial-satellite propagation model[4]–[9]) is not applicable as it is to the STICS system, because, considering the interference from terrestrial terminals, the transmission power of the terrestrial terminals is not constant. Especially, the transmission power increases if the terminal is operating indoors. An estimate from a statistical survey indicates that mobile phones are used predominantly indoors. Thus, difference in interference levels between indoor and outdoor usage is an important factor for upgrading the accuracy of interference evaluation. Quantitative data is needed. In addition, types of nearby features (office buildings, conventional homes, etc.) can give rise to variations in interference levels, making it necessary to assign appropriate factors to each type of features.

Against this backdrop, NICT has conducted simulations[10][11] to gather quantitative data experimentally regarding the differences of interference effects in STICS—i.e. the effect a terrestrial terminal can have on the satellite. One focus of these simulations was clarifying differences between indoor and outdoor calls. For these simulations, a new experiment system was set up consisting of a mobile station (equivalent to the terrestrial terminal in STICS) that carries an IMT-2000 mobile phone and CW (continuous wave) transmitter, and a pseudo satellite station (simulated STICS satellite) located at an elevated position. Two typical ambient surroundings were selected—a business district[10] and a residential area[11]—for conducting experiments and interference level evaluation. The objective of this report is to provide readers with a general overview of the outdoor/indoor interference simulations. It also includes detailed descriptions of the experiment system configuration and measurement results, as well as discussions on the environment-dependent nature of interference—business district and residential area.

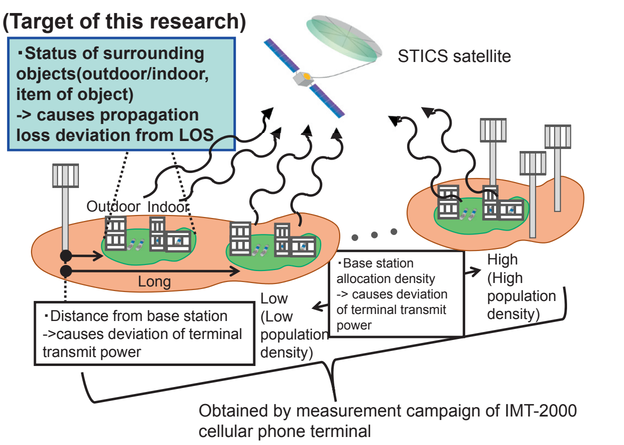


Fig. 2 Factors affecting interference levels (from terrestrial terminals to STICS satellite)

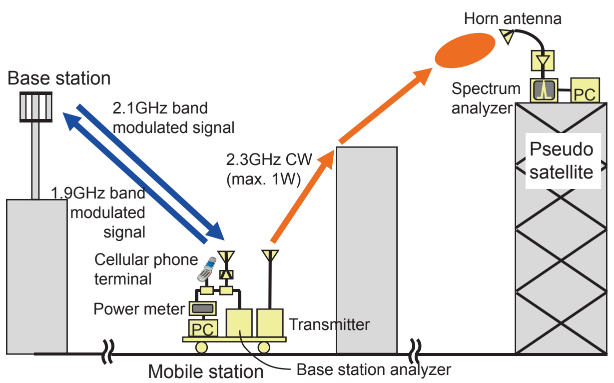


Fig. 3 Schematic configuration of the experimental system

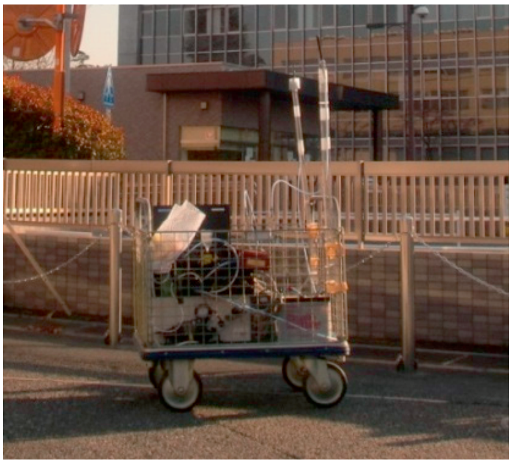
2 Experimental system

Interference power received by the STICS satellite can be separated into two dissimilar components: transmission power from terrestrial terminals, and propagation loss along the path from terrestrial terminals to the satellite. The objective of the experiment is to measure characteristic values of these components experimentally. In concrete terms, a power meter is used to measure transmission power from an IMT-2000 cellular phone (transmission power from a terrestrial terminal). For terrestrial-satellite propagation loss evaluation, a pseudo satellite set up in an elevated position was used to receive a signal sent out from a CW transmitter (a surrogate terrestrial terminal).

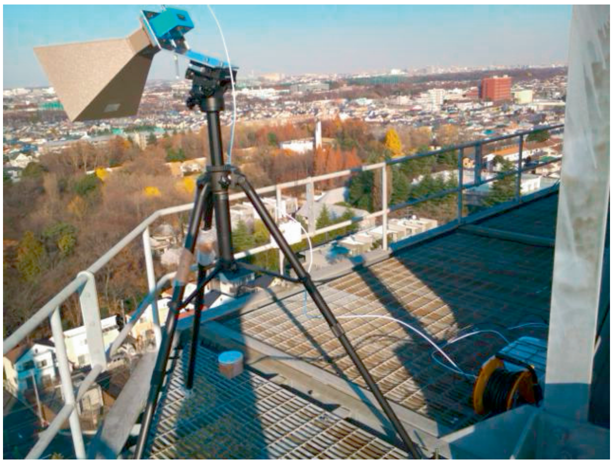
Figure 3 shows the outline of the experimental system. The system consists of a mobile station and pseudo satellite. The mobile station consists of a transmit power measuring system for mobile phones, a base station pilot signal measuring system, and a CW transmitter system. The former two systems share a set of external antennas.

This sharing of the same antennas enables the two systems to use a common band-pass filter to suppress wraparound of the signal from the CW transmitter. The transmission wave from a mobile phone (1.9 GHz band) is split into two streams by a hybrid coupler: one is fed to a power meter and the measurements are recorded on a PC, and the other is fed to the external antenna for transmission. Transmission power calculation of the mobile phone involves insertion loss correction between the mobile phone and external antenna. Signals from the base station (2.1 GHz band), received by the external antenna, are fed to the base station instrument (area tester) and measurements are recorded on an RSCP (Received Signal Code Power) basis.

The transmitter passes the continuous wave signal (2.355 GHz, max. 1W) to the external antenna for transmission. The instruments in the pseudo satellite, set up at an elevated location, receive the CW with a horn antenna (half-power beam width 30°) and amplify it for spectrum analysis. Analyzed data is recorded on a PC. Figure 4 shows the external appearances of the mobile station and pseudo satellite. All of the instruments of the mobile station are mounted in a carrier for ease of changing locations, which is powered by carrier-mounted batteries or from an external source via a cable reel. The pseudo satellite's horn antenna, with its amplifier unit, is set up in an open terrace of an iron tower used for testing (the figure shows the setup configuration of the horn antenna). Conditions for measurements are summarized in Table 1. In the experiment, the mobile station moved around while gathering several items of data simultaneously—transmission power of the mobile phone, received power at the pseudo satellite, and received power of base station pilot signals. The recorded data was calibrated before calculating median values for section-by-section evaluation.



(a) Mobile station



(b) Pseudo satellite

Fig. 4 External view of the experimental system

Table 1 Measurement conditions

Item		Specification
Mobile station – base station	Cellular phone terminal	IMT–2000 cellular phone, 1.9GHz band
	Transmit antenna	External antenna (directivity: omni–directional in horizontal plane, gain: 4dBi, polarization: vertical)
	Transmit antenna height	1.5m
Mobile station – pseudo satellite	Transmitter	Continuous wave, 2.335GHz, max. 1W
	Transmit antenna	directivity: omni–directional in horizontal plane, gain: 2dBi, polarization: vertical
	Transmit antenna height	1.5m
	Receive antenna	Horn antenna (half–power beam width: 30°, gain: 16.6dBi, polarization: vertical)
	Receive antenna height	50m(Office building area), 150m(residential area)

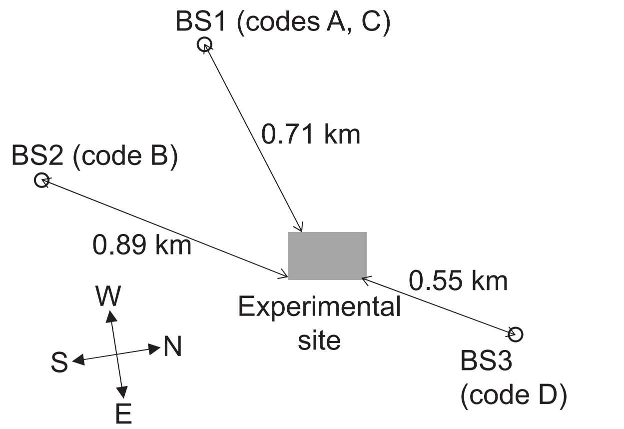


Fig. 5 Positional relations between the experiment site and nearby base stations

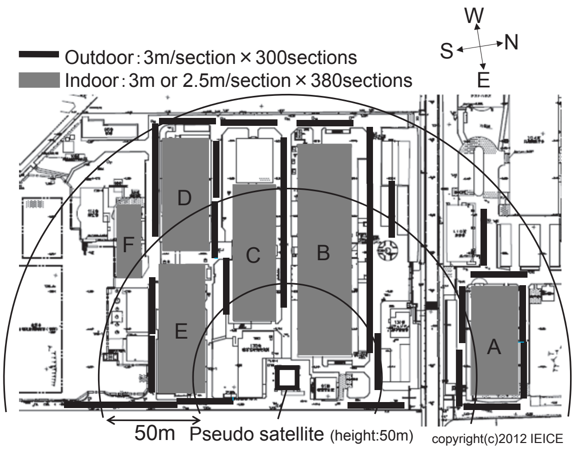


Fig. 6 Ranges for measurements

Table 2 General outline of experiment environment

	Item	Condition
Experimental environment	Experimental site	Street and indoor in office building area
	Surrounding base stations	Maximum intensity recorded in code A, BS1 in Figure 5 for over 90% sections
	Measurement section	Outdoor: 3 m, Indoor: 3 m/2.5 m
	Number of sections	Outdoor: 300, Indoor: 380
	Sampe points/section	50 - 60 points
	Horizontal distance between measurement section and pseudo satellite	22 m - 146 m
	Elevation angle between measurement section and pseudo satellite	18° - 66°

	Bld.	Type	Floors	Measured floor	Room (number/section)		Corridor (section)
Building for indoor measurement	A	Office bld. (concrete)	4	1F	1	12	29
				4F	1	12	17
	B	Office bld. (concrete)	4	1F	1	6	46
				4F	3	36	33
	C	Office bld. (concrete)	4	1F	1	6	8
				4F	1	6	6
	D	Office bld. (concrete)	4	2F	1	6	26
				3F	1	4	20
	E	Office bld. (concrete)	4	2F	3	24	36
				3F	3	19	10
	F	One-storied (concrete)	1	1F	1	12	6

3 Experiments in business district

3.1 Experiment environment

A typical communication environment includes business districts: the premises of NICT Koganei Headquarters (Koganei City, Tokyo) were selected as an exemplary location, and indoor and outdoor experiments were conducted in December 2010. Figure 5 shows positional relationships of the experiment site and nearby base stations. Note that the figure shows only the three base stations, among others, that transmit the top-four strongest pilot signal codes (A–D) in all of the measurement areas (correspondence between the pilot signal code and base station was determined by searching nearby base stations, whereby RSCP strength, measured using base station instruments, was used as the decision criterion). As the code A of BS1 showed maximum strength in terms of RSCP in more than 90% of the whole area, BS1 was chosen, for simplicity's sake, as the opposing base station in the entire measurement area. Figure 6 shows locational relationships of measurement sections in the experiment site, and Table 2 summarizes an outline of the measurement environment.

3.2 Experimental results

Figure 7 shows the histograms of mobile phone EIRP measurements for indoor and outdoor calls. The horizontal axis indicated EIRP for one channel (5 MHz). The range of EIRP for indoor calls is wider than that for outdoor calls, with notable difference in maximum values and shift of the average to a high EIRP zone. As summarized in Table 3 below, cellular phone EIRP statistics for indoor calls are higher—11 dB in terms of average, and 7 dB in terms of median—than those for outdoor calls. Higher EIRP for indoor calls can be attributed to building entry loss. For example, the indoor compartments that exhibited low EIRP (≦-30 dBm/5 MHz) include a room and a corridor directly facing the base station (BS1) through windows (low building entry loss), and those compartments with high EIRP (≧0 dBm/5 MHz) lie on the far side of the building from BS1 (large building entry loss).

Figure 8 shows a histogram of CW power received by the pseudo satellite, which is sent from the transmitter. The data has been corrected for distance attenuation caused by

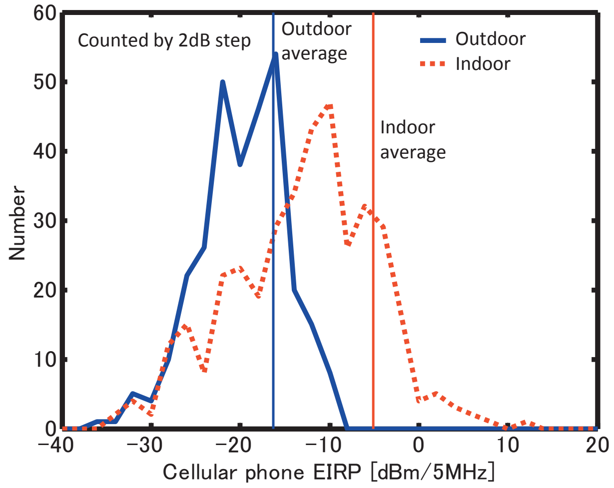


Fig. 7 Histogram of cellular phone EIRP measurements

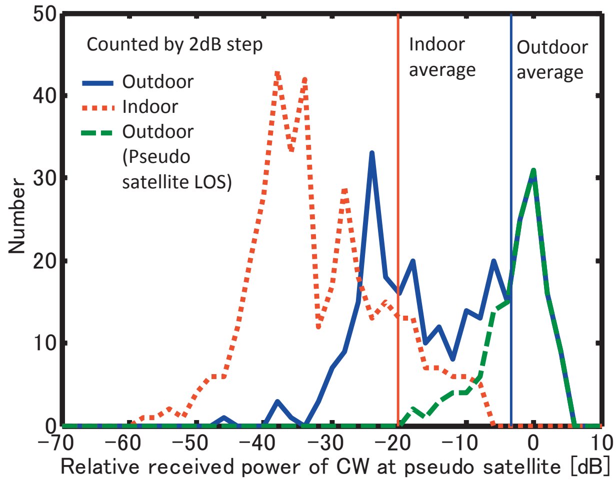


Fig. 8 Histogram of CW power received by the pseudo satellite: relative values against those obtained in line-of-sight conditions

Table 3 Summary of experiment results

Item	Cellular phone EIRP		CW relative received Power at pseudo satellite		Estimated interference power of cellular phone transmit power	
Unit	dBm/5MHz	dBm/5MHz	dB	dB	dB	dB
Environment	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor
Average	-16.3	-5.1	-3.4	-20.1	-3.5	-13.4
Median	-18.3	-11.0	-11.3	-33.1	-15.9	-28.0
Maximum	-8.1	12.8	5.8	-6.4	8.6	2.5
Minimum	-35.0	-32.9	-44.3	-57.1	-51.9	-54.0
Sections	300	380	299*	360*	299*	360*

*Unsuccessful measurement sections removed

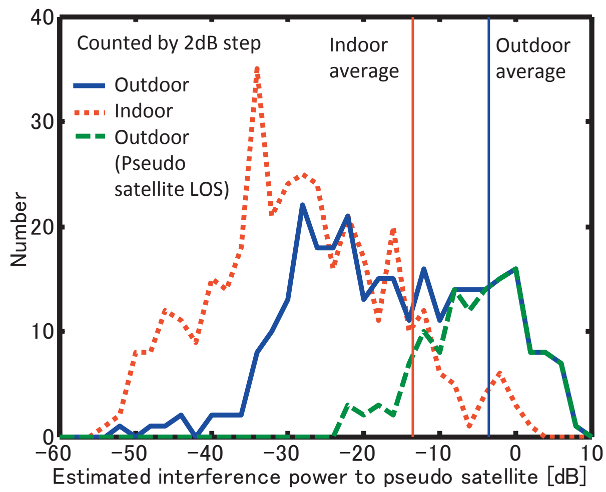


Fig. 9 Histogram of estimated relative interference power (transmission from mobile phones)

path differences between the pseudo satellite and measurements sections. The horizontal axis represents the relative power against the average received power of 130 sections in which the outdoor mobile station moves within the line-of-sight area from the pseudo satellite. Contrary to the case with mobile phone EIRP, indoor calls produce smaller received power than those of outdoor calls.

The differences are: 17 dB in terms of average, and 22 dB in terms of median. The two peaks seen in the outdoor-call histogram represent two distinctive situations: communication blocked by buildings and communication in line-of-sight space (for, reference, the histogram shown in dotted line represents outdoor, line-of-sight communication).

What the measurement results described above tell us is the fact that CW power received by the pseudo satellite becomes smaller when the transmitter is placed indoors than in the case of outdoor transmission, and the magnitude of this change is greater than the rise of cellular phone EIRP (indoor call over outdoor call). The reason for this can be ascribed to angle of elevation: the angles of elevation are larger in mobile-to-pseudo satellite communications than in mobile-to-base station communications, resulting in heavier building entry loss in the former mode.

Figure 9 shows a histogram of estimated relative interference power received by the pseudo satellite as plotted against each mobile station location. From this figure, it can be seen that the relative interference power is smaller for indoor calls than for outdoor calls. Although the indoor/outdoor disparity is diminished by the boosted transmission power to compensate path attenuation to the pseudo satellite, the path attenuation still outweighs the boosted transmission power, resulting in smaller interference power in indoor calls. In concrete terms, the differences are 10 dB (average) and 12 dB (median). These values indicate, in terms of average power, that one outdoor terminal gives rise to interference power equivalent to those from 10 indoor terminals. When we calculate relative values against the cases in which the outdoor terminals lie in line-of-sight from the pseudo satellite, the average values become -4 dB (outdoor) and -13 dB (indoor), and the medians become -16 dB and -28 dB, respectively.

To include location-dependent variations (indoor/outdoor) of interference power received by the STICS satellite into interference evaluation for higher accuracy, these values should be used to correct terminal transmission power for each location (separately acquired). Table 3 summarizes the results described so far.

4 Experiments in residential area

4.1 Experiment environment

We chose the vicinities around JR Ichikawa Station as a typical residential area, and conducted experiments in December 2011. Two two-story wooden apartment buildings were used as the measurement sites (mobile stations) and a pseudo satellite station was set up in a tower building with 150 m height. The cellular phones received signals from four nearby base stations. These base stations were searched based on the RSCP strength measured by measuring instruments for the base station. Measurements at mobile stations were carried out at three indoor locations—two rooms (one on the first and another on the second floor in the wooden apartment building A), and a ground room in the wooden apartment building B)—as well as nearby outdoor area. The wooden apartment building A is surrounded by residential houses and characterized by a relatively large mobile station to base station distance. The room on the second floor had a good line-of-sight path both to the base station and pseudo satellite station. The first floor room in the building B was located a short distance away from nearby residential houses, and near the base station. It had, although on the first floor, a good line-of-sight path both to the base station and pseudo satellite station. Conditions of the experiment environment are summarized in Table 4.

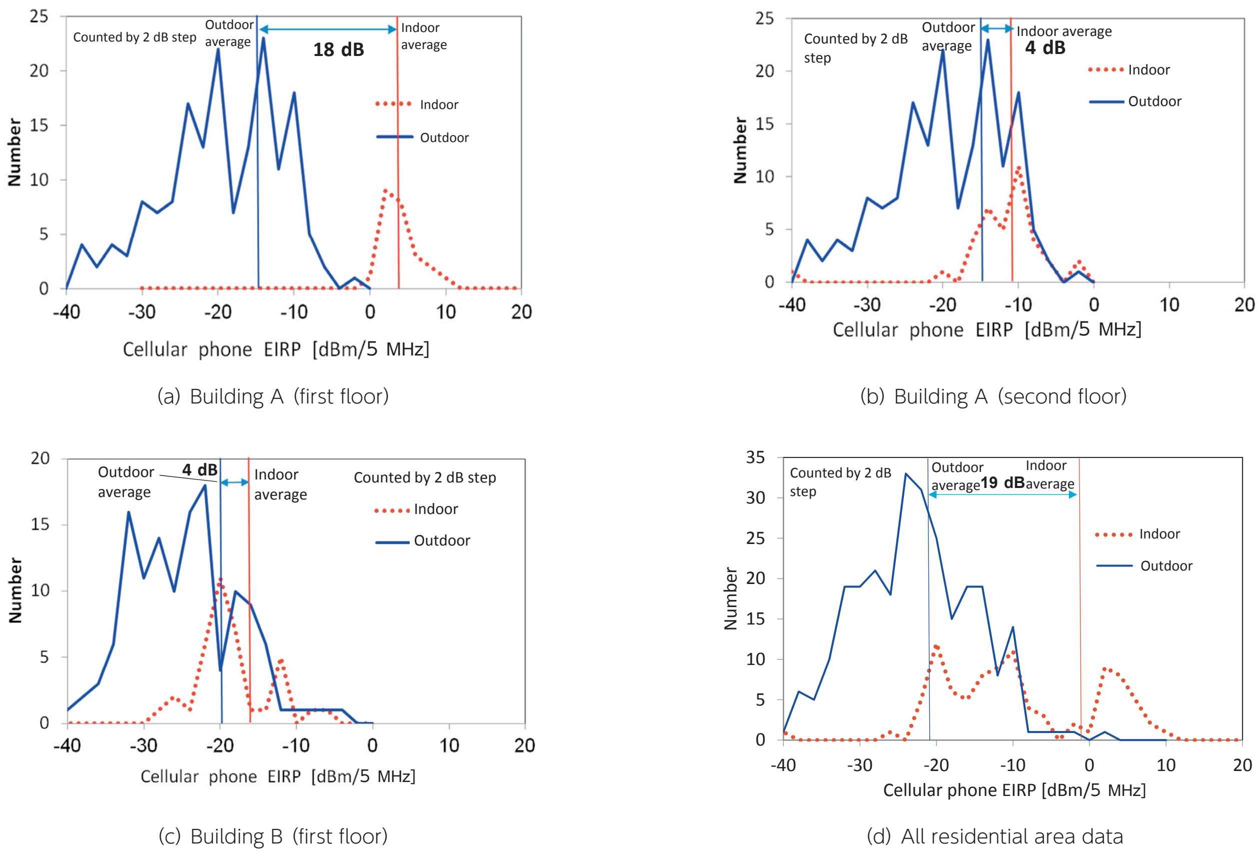
Table 4 General outline of experiment environment

<table>
<tr><td rowspan="8">Experimental environment</td><td colspan="3">Item</td><td colspan="3">Condition</td></tr>
<tr><td colspan="3">Experimental site</td><td colspan="3">Street and indoor in residential area</td></tr>
<tr><td colspan="3">Surrounding base stations</td><td colspan="3">Distance between section and nearest base station：
Around 200 m (A)、around 60 m (B)</td></tr>
<tr><td colspan="3">Measurement section</td><td colspan="3">Outdoor：3 m, Indoor：2–3 m</td></tr>
<tr><td colspan="3">Number of sections</td><td colspan="3">Outdoor：299, Indoor：98</td></tr>
<tr><td colspan="3">Sampe points/section</td><td colspan="3">50–60 points</td></tr>
<tr><td colspan="3">Horizontal distance betw een measurement section and pseudo satellite</td><td colspan="3">Around 200 m (A)
Around 190 m (B)</td></tr>
<tr><td colspan="3">Elevation angle betw een measurement section and pseudo satellite</td><td colspan="3">More than 30°</td></tr>
<tr><td rowspan="4">Building</td><td>Bld.</td><td>Type</td><td>Floor s</td><td>Measur-ed floor</td><td colspan="2">Room
(number/section)</td></tr>
<tr><td rowspan="2">A</td><td rowspan="2">Apartment (Wooden)</td><td rowspan="2">2</td><td>1F</td><td>1</td><td>24</td></tr>
<tr><td>2F</td><td>1</td><td>37</td></tr>
<tr><td>B</td><td>Apartment (Wooden)</td><td>2</td><td>1F</td><td>1</td><td>37</td></tr>
</table>

4.2 Experimental results

Figure 10 shows the histograms of mobile phone EIRP measurements for indoor and outdoor calls. The horizontal axis indicates EIRP for one channel (5 MHz). On the whole, EIRP shows higher values for indoor calls than for outdoor calls. High EIRP data from the building A's first floor (see Fig. 10 (a)) can be ascribed to two factors: the building is far away from the base station, and, as the experiment room is located in the central part of the building, signal propagation was shielded by the neighboring rooms that lie in the direction to the base station. Reduction of EIRP was observed on the second floor of the building A (see Fig. 10 (b)) presumably because of better line-of-sight enjoyed by upper floor rooms. The first floor of the building B showed low EIRP (see Fig. 10 (c)) despite its low position. This can be ascribed to its small distance from the base station and relatively good line-of-sight. Figure 10 (d) shows cumulative data from all three locations. On average, indoor EIRP was higher than outdoor EIRP by 19 dB. In comparison with the measurements in the business district as described in Section **3**, indoor EIRP in the residential area (-2 dBm on average) was comparable or slightly larger than that obtained in the business district (-5 dBm on average).

Figure 11 shows a CW power histogram received by the pseudo satellite (transmitted from mobile stations). The data is corrected for distance attenuation caused by path differences between the pseudo satellite and each measurement section. Contrary to the case with mobile phone EIRP, indoor calls produce smaller received power than those of outdoor calls. The two peaks seen in the outdoor call histogram represent two distinct environments: one blocked by buildings, and the other with a good line-of-sight path. In contrast to the measurements in the business district (see Section **3**), higher reception levels were observed in indoor usage in wooden buildings, which indicates that indoor operations in wooden buildings are assumed to produce larger interference levels to the



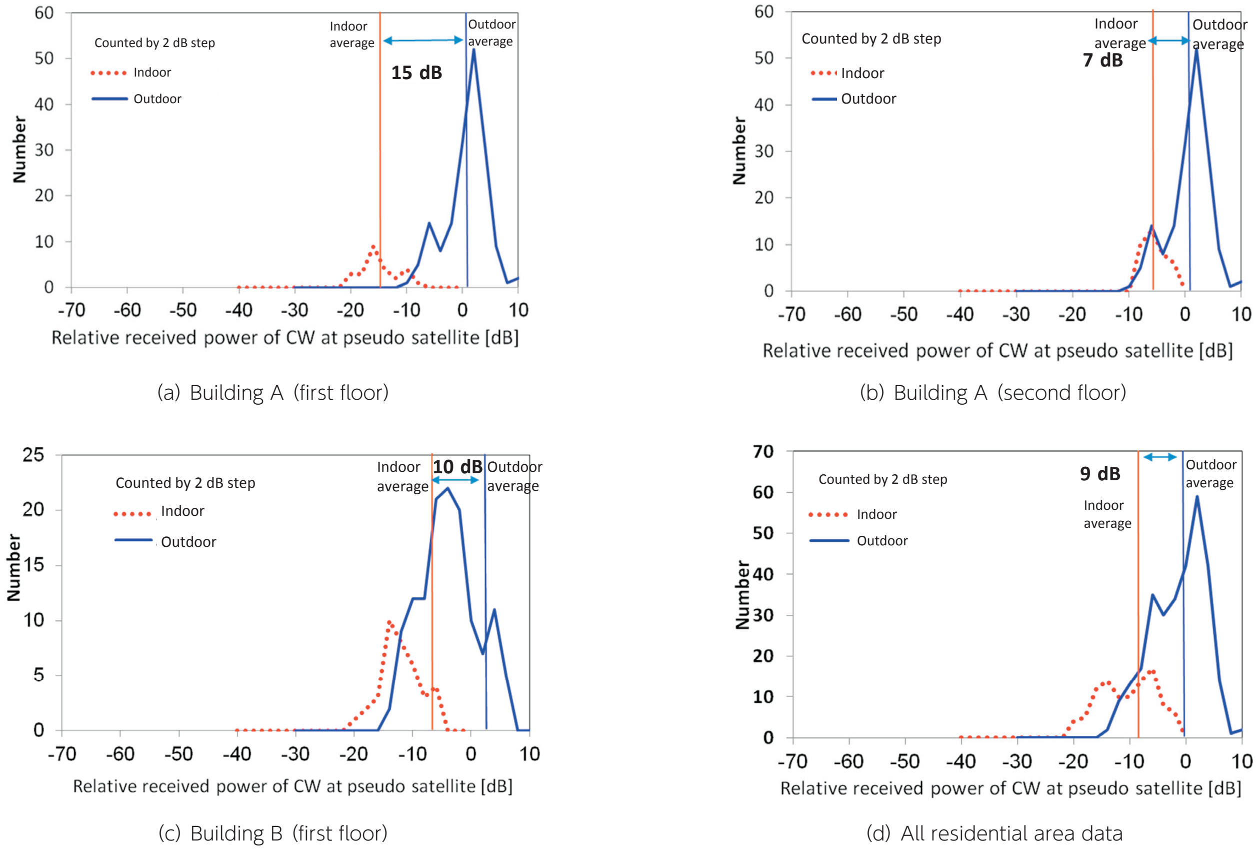
(a) Building A (first floor)

(b) Building A (second floor)

(c) Building B (first floor)

(d) All residential area data

Fig. 10 Histogram of measured cellular phone EIRP



(a) Building A (first floor)

(b) Building A (second floor)

(c) Building B (first floor)

(d) All residential area data

Fig. 11 Histogram of CW power received by the pseudo satellite: relative values against those obtained in line-of-sight conditions satellite.

The results described up to here can be summarized as: when used in a residential area, mobile phone EIRP is higher in indoor calls than in outdoor calls, and the signal level received by the pseudo satellite is higher in outdoor calls than in indoor calls.

When compared with the results obtained in the business district experiments, indoor calls inside a wooden building produce comparable or greater interference levels than those produced by indoor calls from an office building.

5 Conclusion

In this study, we conducted a series of simulation experiments to evaluate the levels of interference the STICS satellite may suffer from due to the emission from terrestrial terminals. These simulations were conducted in a business district and residential area (indoor and outdoor) for the purpose of obtaining quantitative data that explain call-mode dependency—i.e. indoor and outdoor calls—of the interference level. A mobile station equipped with an IMT-2000 cellular phone and CW transmitter was operated in the simulations: transmission power of the IMT-2000 cellular phone was measured, and a pseudo satellite located in a high position measured CW signal to evaluate propagation loss along the path connecting the mobile and pseudo satellite station. The results of the measurements conducted in several locations in a business district—indoor of reinforced concrete buildings and outdoor in the vicinity of it—revealed that the magnitude of the decrease of CW signal power received by the pseudo satellite measured by indoor calls compared with that measured by outdoor calls is larger than the magnitude of increase of cellular phone EIRP measured by indoor calls compared with that measured by outdoor calls. The results indicate, in terms of simplified estimate of relative interference power, that indoor calls showed smaller values than those of outdoor values. The measurement results obtained from the experiments conducted in the residential area indicate that the calls from indoor rooms of wooden buildings give rise to equal or greater interference to the satellite than from the indoor calls in the business district. These results represent a set of useful basic data for accurate evaluation of the interference level in STICS.

6 Acknowledgments

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