Transmit Power Measurement of Terrestrial Cellular Phone

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In the research of Satellite/Terrestrial Integrated Mobile Communications System, it is important for the system design to estimate the interference power level caused by terrestrial system to satellite system. We have carried out the transmit power measurement of the existing terrestrial cellular phone in order to obtain fundamental data dedicated to the interference level evaluation. A transmit power measurement system has been developed to be mounted to the experimental vehicle. Statistical data effective for interference level evaluation was obtained by the measurement campaign of the transmit power in the regions with various population densities in Japan.

1 Introduction

In recent years, the role of mobile communication services in society, primarily in the form of mobile phones, has been increasing. Particularly in the case of mobile phones, their ease-of-use and increased high level of functioning has stimulated discussion of their use, too, in disaster prevention, reduction, and management. However, in the case of terrestrial-based transmission systems, there is, for example, the problem of vulnerability to damage from disaster[1]. What is more, special measures are necessary for those out of transmission range, such as residents in suburban areas, ships at sea in coastal regions, and persons engaged in mountain climbing.

In order to find solutions to these issues, research and development of an integrated and complementary satellite and terrestrial network has been in progress in different countries around the world. These systems are referred to as “ATC” (Ancillary Terrestrial Component)[2] in the United States and “CGC” (Complementary Ground Component)[3] in Europe.

In Japan, research and development is underway for technology that combines terrestrial and satellite communication systems and enables communication while sharing the same frequency band. Called the Satellite/Terrestrial Integrated mobile Communication System (hereafter, “STICS”)[4], the shared frequency band is expected to have a Mobile Satellite Service (MSS) band of uplink 1980–2010 MHz and downlink 2170–2200 MHz.

As indicated in Fig. 1, in the common frequency-sharing STICS system, radio frequency interference occurs between terrestrial and satellite communication systems. The configuration of the transmission device for STICS is still undecided, but if a system similar to that of mobile devices, using the adjacent IMT2000 band, is employed, mobile device output power will fluctuate due to terrestrial transmit power control, and the interference level to the satellite will also fluctuate at the same time. The impact from this interference level becomes an important parameter for constructing the system by, for example, determining the number of lines it can accommodate[5]. Until now, there has been only one example overseas dealing with the measurement of cellular phone transmit power that specifically addresses the interference level’s impact on the satellite system[6]. In Japan, even the level of transmit power while the device is in operation is not yet clear. In this experiment, a cellular phone transmit power measuring device

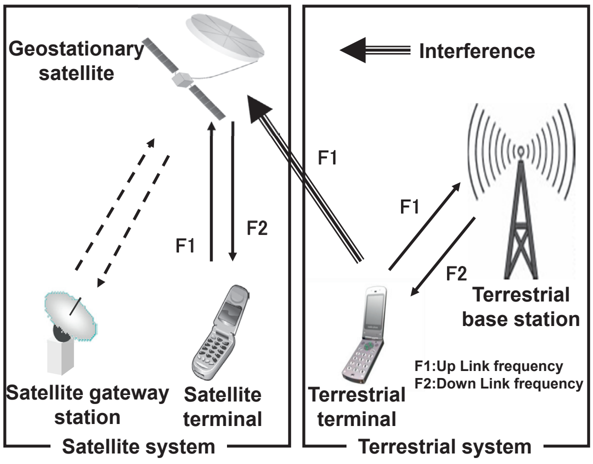

Fig. 1 Conceptual diagram of the interference path in STICS

was developed[7] in order to measure transmit power in various regions of Japan with differing radio frequency environments such as urban and suburban areas. A travelling experiment was conducted using this device to measure transmit power throughout the various parts of the Kanto region[8], as well as wider areas including regions with low population density[9]. Below is an overview of the experiment and the measurement results.

2 Experiment method

2.1 Overview of the measurement system

Figure 2 is a function block diagram of the measurement system employed in the cellular phone transmit power experiment. The premise of the experiment was that the device be mounted on a vehicle, with a GPS compass fixed on the front section of the roof, an external antenna inside a radome in the mid-section of the roof, and an external unit with a human head phantom and video camera. The vehicle was equipped inside with a cellular phone, which was the transmission source, an RF unit, a power meter, a spectrum analyzer, and a computer that controlled these devices and recorded data.

Transmitted power from the cellular phone to the external antenna was controlled at the base station. Both the output power and output frequency were measured by the power meter and the spectrum analyzer via a coupler, and the data was recorded on the computer, which was controlling the devices.

It may also be possible to ascertain transmit power from a cellular phone by measuring the power radiated from the phone's internal antenna with the external monitoring antenna; but, in the case of CDMA phones, it is difficult to distinguish the targeted transmit power output from that coming from other cellular phones, so in this experiment the above method was employed so that the transmit power from the subject device can be reliably isolated and measured.

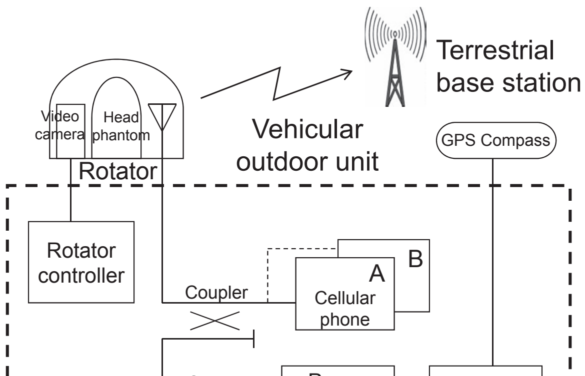

Fig. 2 Functional block diagram of the measurement system

2.2 Main specifications and external appearance of the measurement system

Table 1 shows the main specifications of the measurement device. In this experiment, we measured output from a W-CDMA cellular phone that was using the IMT-2000 system. Frequency and power value were measured every 100 ms while the vehicle was in motion, and the resulting data was collected and then statistically processed to calculate averages and distribution, etc., which were then shown as transmit power distribution. At the same time, measurements such as latitude, longitude and altitude were taken from the GPS compass mounted on the vehicle roof, and, using this in conjunction with the vehicle navigation software, we were able to establish a measurement route with a high degree of accuracy.

The measurement vehicle and the external unit are shown in Fig. 3. The output from the cellular phone is transmitted from the external antenna, but in order to create a usage situation that is close to real-life, the external antenna was fixed near a phantom with a shape and electromagnetic permittivity level similar to that of a human head, as can be seen in Fig. 3 (b).

3 Measurement experiment

3.1 Overview of the measurement experiment

With the objective of acquiring the mean transmission output of one cellular phone, which is receiving transmit

Table 1 Main specifications of the measurement device

Item	Performance
Measured frequency	2 GHz band
Measurement items	Transmit power, frequency, position, time, surrounding image
Measured power range	-30～+30 dBm
Measured power resolution	+/- 0.01 dB
Measured power accuracy	+/- 0.2 dB
Measured position error	0.5 m (DGPS), 2.5 m (single point)
Measuring interval	below 100 ms
Successive measuring time	more than one day

(a) Measurement vehicle

(b) Outside appearance of the external unit

Fig. 3 Outside appearance of the measurement vehicle and the external unit

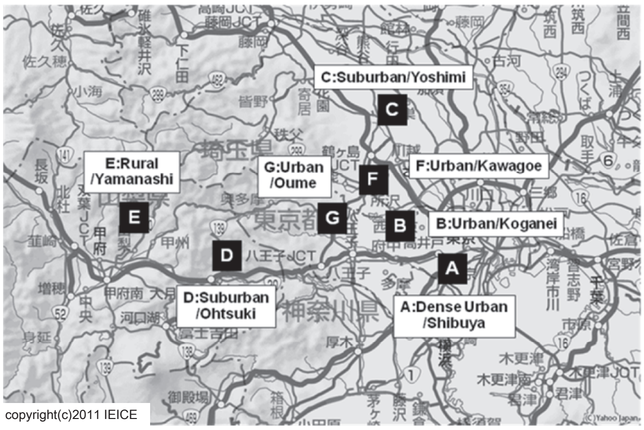

Fig. 4 Measurement areas (seven areas in Kanto)

Fig. 5 Example of measurement area and course route (Koganei City, Tokyo)

power control from a base station, we drove through regions with different population densities while measuring the transmission output. In the experiment, mean transmission was measured in three ways: by selecting and measuring separate areas and circular course routes in the Kanto region based on population density; by measuring while driving longitudinally through the Kanto region; and, measuring while driving through wider areas including low population-density areas (i.e. Hokkaido and the Kumano Sea coastal area).

3.2 Measurements in selected areas and course routes

In this experiment, as indicated in Fig. 4, seven areas of different population density were selected—from dense urban areas to rural areas (in Tokyo: Shibuya-ku, Koganei City and Oume City. In Saitama Prefecture: Kawagoe City and Yoshimi-machi. In Yamanashi Prefecture: Otsuki City and Yamanashi City). A course route of around six to nine kilometers was fixed for each area taking into consideration the distribution density of mobile base stations.

Figure 5 is the course route for Koganei City, Tokyo. The vehicle drove around the route multiple times taking measurements. A large amount of sample data was collected and processed statistically.

This measurement was conducted for two cellular phone carriers (Company A and Company B). One example of the measurement result is indicated in Fig. 6, which shows a histogram of the cellular phone's transmit power for Koganei City. In the case of Company A, mean transmit power was −5.4 dBm, and the mode value was −12.3 dBm.

A graph comparing the mean transmit power measured in each area with the population density of each municipality is shown in Fig. 7. The mean transmit power for both Companies A and B was within the region of +7 dBm maximum and −10 dBm minimum, and in high population density areas (1,000 people/km^2), the mean was around −5 dBm or less. According to IMT2000 standards, terrestrial mobile phones have a 2 GHz band that is capable of transmitting +24 dBm maximum[10], but from these results,

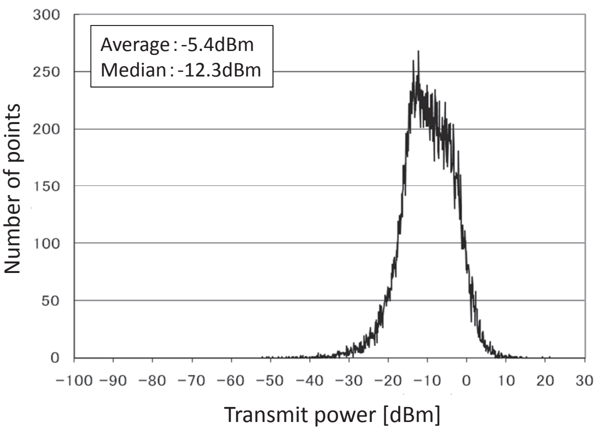

Fig. 6 Example of transmit power measurement results (Koganei City, Tokyo)

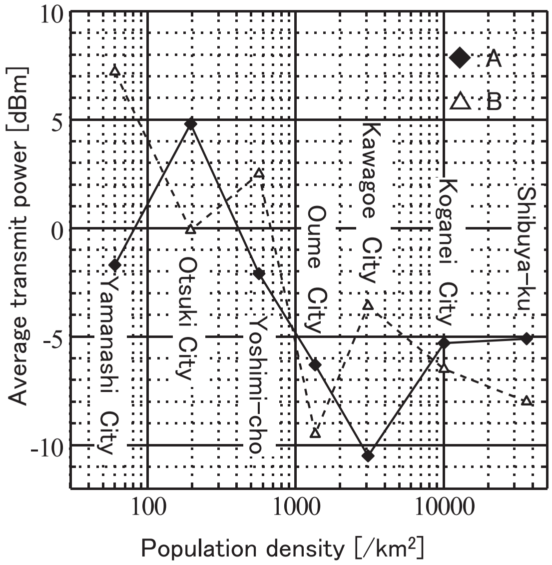

Fig. 7 Mean transmit power in relation to population density in each municipality

it has become clear that actual transmissions are made at very low power output levels.

Furthermore, the mean transmit power of both Companies A and B tends to be inversely proportional to population density—the same trend seen with measurements taken in the US.

3.3 Longitudinal measurements for the Kanto region

Measurements from a vertical cross-section of the Kanto region were taken with the objective of collecting a large amount of sample data. Areas of both high and low population density were covered.

Furthermore, the route was chosen in order to overlap with a ground validation measurement experiment using an aircraft[11], which was carried out during the same period. The route started in Yokosuka City in Kanagawa Prefecture, and travelling in a northern direction, passed urban areas of Tokyo to reach Kanuma City in Tochigi Prefecture, as seen in Fig. 8.

Fig. 8 Kanto region longitudinal ground-travel route

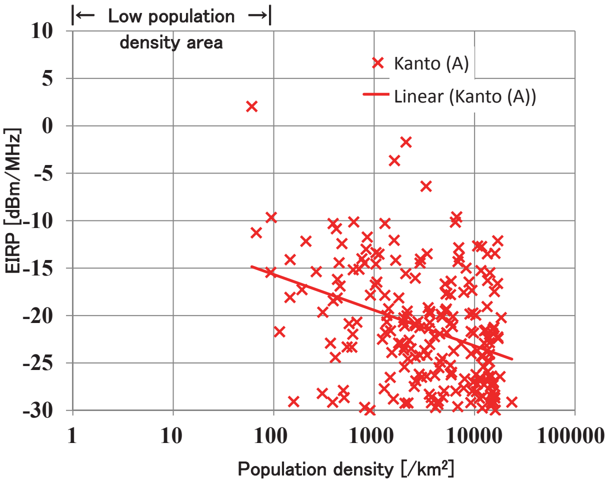

Fig. 9 Correlation diagram for third-level mesh population density vs. mean transmit power (Kanto region)

In this experiment, the route was divided into third-level meshes (approx. 1 km by approx. 1 km) defined latitudinally and longitudinally under the standard Japanese geographical location mesh code system[12]. We then calculated and compared for each mesh the mean transmit power and population density data measured while

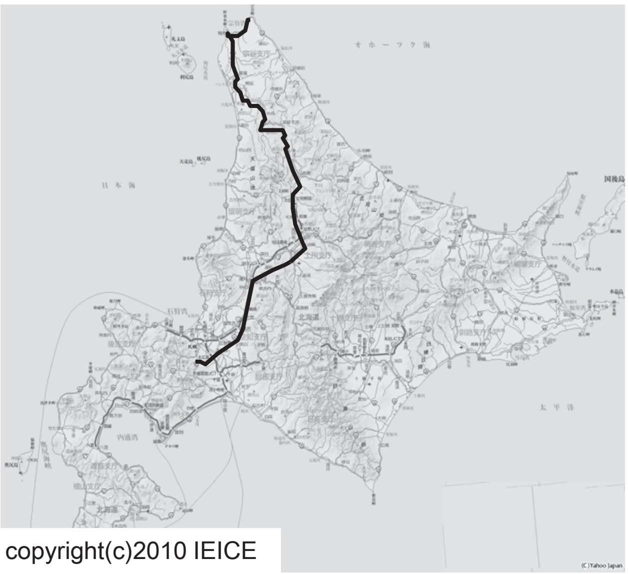

Fig. 10 Hokkaido area longitudinal ground-travel route

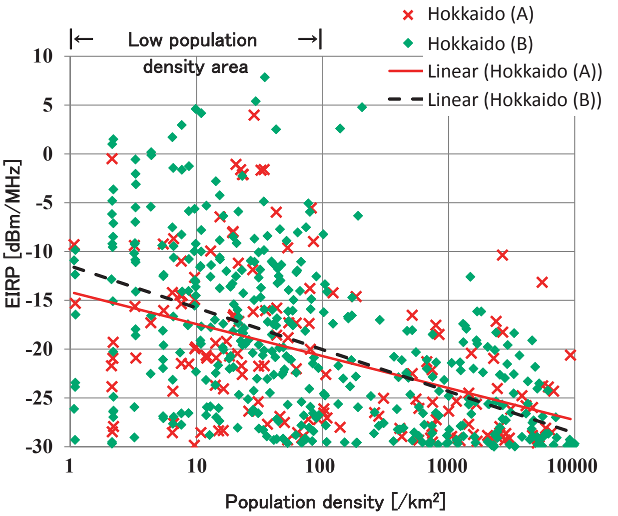

Fig. 11 Correlation diagram for third-level mesh population density vs. mean transmit power (Hokkaido area)

travelling through those meshes. Regarding Company A, third-level mesh sample data from 226 locations was taken, and a correlation diagram of population density and mean transmit power is shown in Fig. 9. The vertical axis for correlation diagrams for Fig. 9 onward have been normalized so that the axis gives the transmit power per unit bandwidth [dBm/MHz].

The straight line in the center is an approximate regression line using the least-squares method, and this indicates that although there is a lack of uniformity regarding the relationship between population density and distribution of data acquisition, a general negative trend can be detected. This trend is also seen in **3.1** and is also in accordance with the results of Reference [6].

Fig. 12 Kumano Sea coastal area ground-travel route

3.4 Longitudinal measurements for Hokkaido

In the Kanto experiment, not enough data was collected from low population density areas.

Therefore, in order to secure accurate measurements of 2 GHz-band output from a wide range of population density areas, measurements were conducted for a vertical cross-section of Hokkaido for Company A and Company B cellular phones. The route is indicated in Fig. 10. Using Company A's cellular phone, the experiment started in Soya, headed south, passing Asahikawa, and ending in Sapporo; at which point we switched to Company B's cellular phone, and the same route was taken in reverse, heading north from Sapporo back to Soya. 2 GHz-band sample data was collected from 155 locations for Company A and 428 locations for Company B. A correlation diagram comparing population density and mean EIRP can be seen in Fig. 11. A large amount of uniformly distributed data was collected from a wide range of population density areas, including low population density areas, and the regression lines for Companies A and B appear very similar.

3.5 Longitudinal measurements for the Kumano Sea coastal area

In addition to the longitudinal measurements taken in Hokkaido, in order to collect supplementary data from different areas with widely varying population density, we selected a route from Komaki City in Aichi Prefecture, via the Nagoya inner city area, to Kumano Sea Coast on the east side of the Kii Peninsula, as indicated in Fig. 12. This

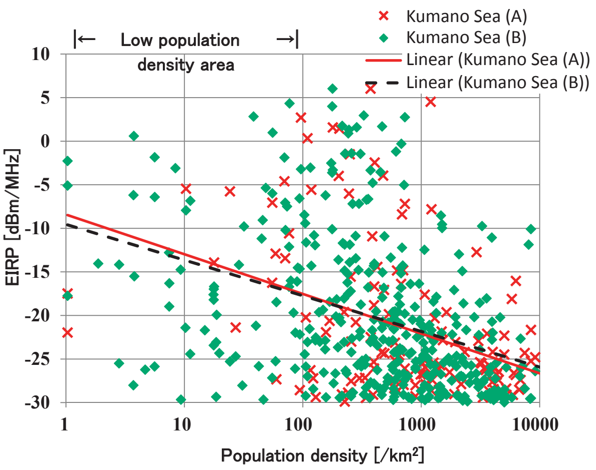

Fig. 13 Correlation diagram comparing third-level mesh population density and mean transmit power (Kumano Sea)

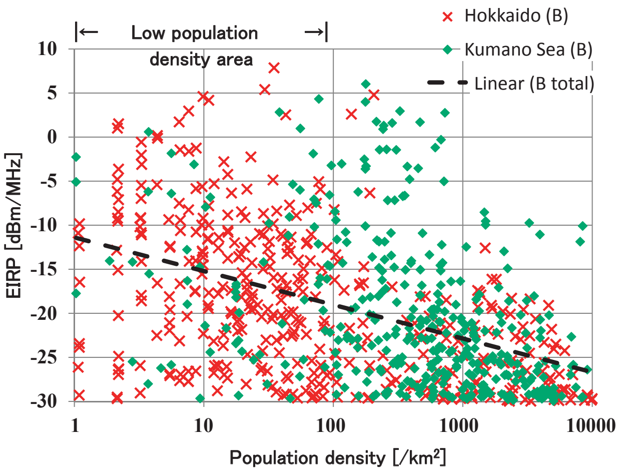

Fig. 14 Correlation diagram comparing mean EIRP and population density

area is also subject to an aerial ground validation measurement experiment using an aircraft, which will be carried out at a later date. Both Company A and Company B's cellular phones were used in this travelling experiment. Using Company A's cellular phone, the experiment started from Komaki City, and heading south, passed Shima and reached Shiono-misaki—at which point we switched to Company B's phone, and the same route was taken, heading north from Shiono-misaki back to Komaki City. 2 GHz-band sample data was collected from 138 locations for Company A and 374 locations for Company B.

The correlation diagram comparing population density and mean EIRP is given in Fig. 13. The regression lines for both companies appear to be almost the same. For Company B, relatively uniformly distributed data was collected, but for Company A, much of the data collected in low population density areas was outside of the 2 GHz range. Due to this, only 16 examples of sample data were collected in these low population density areas of less than 100 persons/km^2.

3.6 Observation

In these experiments, data showing the correlation between population density and mean EIRP was successfully collected from a wide variety of population density areas, from 1 to 10,000 persons/km^2 (applies to 99.7% of the national territory). Taking into consideration this population density of 1 to 10,000 persons/km^2, Company B yielded a greater amount of uniformly distributed data. Therefore, a correlative regression line was constructed using the data collected for Company B in the Hokkaido and Kumano Sea experiments (a total of 802 points of data) for Equation (1).

$$P=-0.38 \times (10\log_{10}N) - 11.38 \qquad (1)$$

P : mean EIRP [dBm/MHz]
N : population density [person/km^2]

As shown in Fig. 14, population density of 1 to 10,000 persons/km^2 applies to 99.7% of Japan.

Thus, it appears that it is possible to estimate—based on the values seen in the regression line, which were taken from the measurement data collected from a wide range of population density areas—reference values for output from cellular phones: i.e., the output which is a source of radio frequency interference from the variously densely populated areas throughout Japan.

4 Conclusion

The output level of terrestrial-based cellular phones, which is the key for evaluating interference levels on the STICS satellite-based transmission system, was measured in various locations with consideration to the correlative relationship with population density in many different areas covering almost all of Japan. From this evaluation experiment, it was found that the transmission output level of cellular phones has a proportionally inverse relationship with population density, and we were able to draw a regression line that gives reference values indicating output levels derived from a large quantity of measurement data that also includes low population density regions. This makes it possible to estimate, on a per region-basis, interference levels being emitted from areas with varying population density, and reference data was obtained for use in evaluating nationwide STICS system interference levels.

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