Radio Engineering Technology

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Radio engineering technology is necessary for maximizing the effectiveness of capital investment when constructing a radio network for a mobile communications system. Improving this technology enables optimization of the radio network and more flexible response to changes in the system requirements. Radio engineering technology is used in the design, tuning, operation, and maintenance of radio networks. This paper introduces and explains methods for designing Long Term Evolution systems and presents results obtained in field trials conducted to evaluate their performance.

1. Introduction

An important aspect of building mobile communications systems is to use equipment efficiently, particularly to minimize the number of base stations. Effective application of radio engineering technology is thus needed to optimize the capacity and coverage of base stations. Although the technology is based on theory, it has also become established through the accumulation of know-how obtained through testing of mobile communications systems as they have become more sophisticated. This technology is used not only for designing radio networks but also for constructing, optimizing, operating, and maintaining them.

In this paper, we first introduce and explain three radio-network design processes related to Long Term Evolution (LTE) systems and then present example results from field trials conducted to evaluate their performance.

2. Radio network design

Radio network design consists of three processes: channel design, dimensioning, and base station placement.

1) Channel design

Channel design is the process of calculating the cell radius and transmission power required to obtain the desired radio channel quality.

2) Dimensioning

Dimensioning is the process of determining, on the basis of the channel design and base station capacity, the optimal base station configuration and the number of base stations required within the service area to satisfy the target traffic parameters.

3) Base station placement

Base station placement is the process of effectively placing base stations on an electronic map and determining the required antenna parameter values, both done on the basis of the dimensioning results.

Details and methods for each of these processes are explained below.

2.1 Channel design

2.1.1 Design detail

Channel design is the process of calculating, on the basis of the performance of the base station and terminal equipment, the cell radius and transmission power at the points of transmission and reception to obtain the radio channel quality (i.e., block error rate [BLER] and signal-to-interference-and-noise ratio [SINR]) required for communication. In addition to base station and terminal equipment performance, the base station configuration and radio-wave propagation environment are also taken into consideration. Some of the channel design parameters can be freely selected while others, such as frequency, maximum transmission power, and occupied frequency bandwidth, are regulated by radio law.

2.1.2 Design method

Estimation of the required margins is an important aspect of channel design. Errors here can result in problems when actually transmitting radio signals from the base stations, such as coverage holes (areas where the radio signal does not reach) or unnecessarily high transmission power.

Channel design is done using a link budget. An example of a link budget for a downlink channel is shown in **Table 1**. Using a link budget simplifies channel design, regardless of differences in application environments (radio-wave propagation, area partitioning, base-station antenna height, etc.) or customer requirements (quality of service [QoS], traveling speed, transmission speed, etc.). Using the same approach for designing the uplink channels enables the capacity of uplink and downlink channels to be balanced.

2.2 Dimensioning

2.2.1 Design detail

Dimensioning is the process of calculating the number of base stations required in the service area on the basis of the channel design and base station capacity (average cell throughput, which equals the total throughput for all subscribers using the cell at a given time) and of allowing for flexibility in increasing the number of subscribers while planning for installation of additional base stations and other equipment.

LTE systems use various methods to increase system capacity in addition to dividing

Table 1
Downlink channel link-budget example.

Factor	Description	Unit	Value	Note
1	Center frequency	MHz	1862.4	
2	Bandwidth	MHz	5.0	
3	Base station maximum transmit power	dBm	40.0	Per antenna system
4	Base station antenna gain	dBi	16.0	Including feeder losses
5	Shadowing margin	dB	8.7	Standard deviation = 8 dB; location rate = 90%
6	Handover gain	dB	2.9	Standard deviation = 8 dB; location rate = 90%
7	Transmission losses through buildings	dB	8.0	
8	Other cell interference margin	dB	5.3	
9	Mobile station antenna gain	dBi	0.0	
10	Mobile station receiver noise figure	dB	7.0	
11	Thermal noise power density	dBm/Hz	–173.8	
12	Thermal noise power	dBm	–99.8	= 10*$\log_{10}$([F2]*10^6) + [F10] + [F11]
13	Required receiver SINR	dB	5.0	For downlink channel throughput of 5 Mb/s
14	Receiver sensitivity	dBm	–94.8	= [F12] + [F13]
15	Maximum allowed propagation loss	dB	131.7	= [F3] + [F4] – [F5] + [F6] – [F7] – [F8] + [F9] – [F14]
16	Cell radius	km	0.72	COST231-Hata Model

areas into sectors with all base stations using the same frequencies, including use of a scheduler function, a fractional frequency reuse (FFR) function, and an adaptive modulation scheme. As a result, the concept of base station capacity is more complex than with earlier systems.

2.2.2 Design method

1) Scheduler function

The scheduler function allocates resources in accordance with the QoS classes of the services being used by subscribers. Possible schemes include MAX C/I, which preferentially allocates resources to the users requiring the highest channel quality, and proportional fair, which allocates time fairly to all users and resources to all users depending on instantaneous changes in channel quality. Each scheme has advantages and disadvantages. For example, the average cell throughput is higher with MAX C/I, but some subscribers may not be allocated any resources. The scheduling function is selected on the basis of parameters such as the number of simultaneously connected subscribers and the maximum throughput.

Simulation under certain conditions has shown that slightly higher average throughput can be obtained by applying MAX C/I when user throughput for all subscribers is below a relatively small value and by applying proportional fair when users with throughput above the threshold are being serviced.

2) FFR function

The FFR function is a frequency reuse scheme for increasing user throughput for subscribers at the edge of a cell. Subscribers are divided into two groups: those near the center and those near the edge. Subscribers near the center use the same frequency band, and frequency reuse is not executed. Subscribers away from the center (near the edge) reuse a frequency band different from that of the adjacent cells. Different frequency bands are allocated to each of the three cells served by a base station to avoid signal interference from adjacent cells and are changed as necessary.

Simulation has shown that, by giving a certain offset power to frequency bands used by subscribers at the cell edge, it is possible to decrease interference from other cells and to increase user throughput for subscribers at the edge by approximately 20%, with almost no degradation in average cell throughput.

3) Adaptive modulation schemes

Adaptive modulation schemes are used to increase user throughput by switching among modulation schemes and coding rates on the basis of radio channel quality. Maximizing the cell radius is preferable when only a small number of subscribers are being accommodated, but simulation results have shown that the average throughput of a cell tends to drop as the cell radius is increased even if the maximum user throughput does not change. Thus, a good balance in designing the cell radius and average cell throughput is needed. Under certain conditions and with a bandwidth of 5 MHz, an average cell throughput of 10 Mb/s on the downlink and 4 Mb/s on the uplink can be achieved.

4) Sector configuration schemes

Base station sectors can be configured using a large-zone scheme with three sectors or a small-zone, omni (directional) scheme. We investigated the characteristics of these schemes through simulation. We compared the number of base stations required with each scheme for service areas with the same number of subscribers uniformly distributed. The results showed that the small-zone scheme required more base stations, but a system could be configured using less equipment. Note that for implementation, it is also necessary to consider factors such as securing additional base station sites for expansion and the cost of adding transmission lines and other auxiliary equipment.

There are also various possible ways to introduce a system over a span of several years.

They include prioritizing control of the initial investment by first installing base stations in important areas and adding stations as traffic increases and prioritizing control of the final investment by anticipating the final base station configuration and installing all of the stations but with the minimum amount of equipment from the beginning.

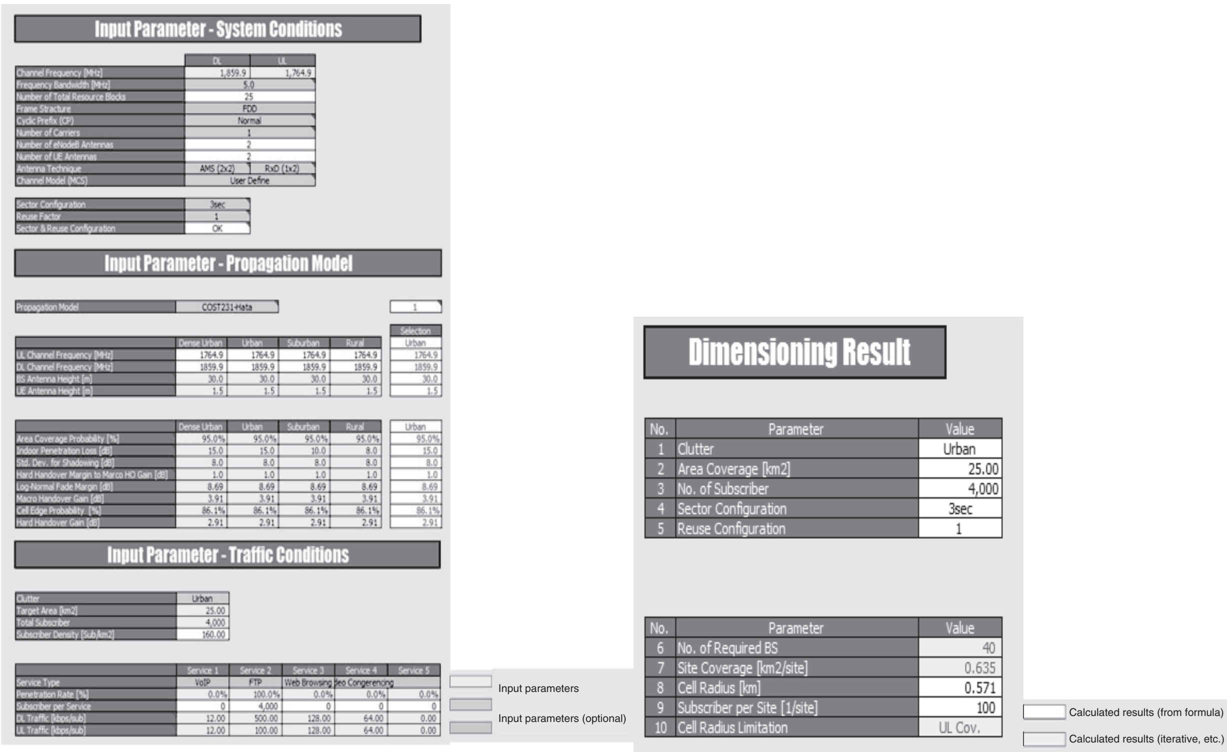
For efficient design, we have created our own (Fujitsu Communications) dimensioning tool. Example inputs and outputs are shown in **Figure 1**. The input parameters are the system requirements (channel frequency, bandwidth, antenna system, number of sectors, etc.), the radio wave propagation model, and the traffic conditions; the outputs are the number of base stations required and the area covered per base station. This tool enables differences in parameters, such as throughput, for different base station configurations (omni vs. 3-sector vs. 6-sector) to be checked, so the base station configuration can be adjusted to suit each location.

2.3 Base station placement

2.3.1 Design detail

Base-station placement is the process of effectively placing base stations on an electronic map and involves computing beforehand the base-station design parameters, such as the antenna parameters (type, direction, tilt angle, height) and the base-station transmission power, evaluating the suitability of the system configuration, and reducing the amount of optimization and other work in the actual environment after the base stations have been installed.

This design can be done using commercial base-station placement simulators and electronic maps, but using accurate data alone does not yield simulation results that match the actual environment. The results of design method



(a) Input parameters (b) Output parameters

Figure 1
Example I/O parameters for dimensioning tool.

verification through field trials must be reflected-back on the final design.

2.3.2 Design method

1) Design using electronic maps

Since the mechanisms of radio-wave propagation (diffraction, reflection, transmission, etc.) are complex, researchers have recently begun studying design methods that use 3D mapping data. Although these methods can improve the design accuracy for areas where there are dense concentrations of buildings and for other specific types of areas, there are areas where they cannot improve the accuracy. Conversely, design methods that use 2D mapping data are not able to increase local design accuracy because they make corrections using statistical margins that reflect the actual environment. They can, however, improve the accuracy of the design for the overall area, so we select the design method to use on the basis of where it is applied.

2) Design for large-scale urban areas

In cases when there are a large number of base stations, such as large-scale urban areas, base-station placement design work can be very complex. The cost in terms of personnel and time can be high, particularly to tune a system to its optimal state. We thus need an algorithm to adjust the antenna parameters automatically. Such an algorithm would sequentially adjust the antenna parameters for each base station to obtain the maximum reception power and SINR. Convergence depends on the initialization of the antenna parameters.

Convergence on an optimal state requires a method for initializing the antenna parameters to values that do not depend on the base station order.

3) Adjusting antenna tilt angle

Selecting the antenna emission characteristics and adjusting the antenna parameters, particularly the antenna tilt angle, is very important in suppressing interference caused to other cells. Setting the antenna tilt angle too high causes interference in the downlink of other cells, and setting it too low reduces the propagation distance, potentially resulting in failed handovers or null spots. Antenna tilt-angle tuning methods use lower tilt angles for cases such as hot spots, where terminals are not expected to move as much, and higher angles where they move more dynamically, to achieve SINR values above the threshold for successful handovers, and adjust for channel quality over the whole cell.

4) Designing energy saving functionality

Base station placement also takes into account functions that control the overall system dynamically. The energy saving (ES) function is one such function. It adjusts the operating state of base stations (e.g., which stations are operating, their transmission powers) on the basis of the amount of subscriber traffic to optimize power consumption of the overall system. This function cannot be implemented by simply controlling base station functions. During base-station placement design, the operational state in ES mode must be designed to ensure coverage is expanded to reach other operating cells.

3. Performance evaluation in a field trial

Design methods studied and established theoretically were tested in field trials to evaluate their performance. The trials were conducted in a residential area with a radius of about 1.2 km, near the Fujitsu Kawasaki plant in Nakahara ward of Kawasaki City. Example results are presented below.

1) Radio wave propagation model correction

It is essential to understand the radio wave propagation model when designing a mobile communications network. Such models depend on the frequency band, application area, and other factors. We first selected a propagation model suitable for the trial area. We then received transmission signals from a base station at a mobile terminal and measured the propagation losses. Next, we fine-tuned the model using 2D map data, propagation loss offset values for each land-use classification, and standard deviations for shadowing. **Figure 2** shows the relationship between the received signal level and the distance traveled (from the base station). The measured values correspond relatively well with the results from station placement simulation after correction using the radio wave propagation model, validating the correction method.

2) Throughput characteristics

The adaptive modulation schemes used in LTE systems increase throughput by adjusting the rank (spatial multiplexing) and modulation and coding schemes in accordance with radio channel quality. **Figure 3(a)** shows the relationship between throughput and average SINR for the downlink (DL), and **(b)** shows the same relationship for the uplink (UL). The dotted

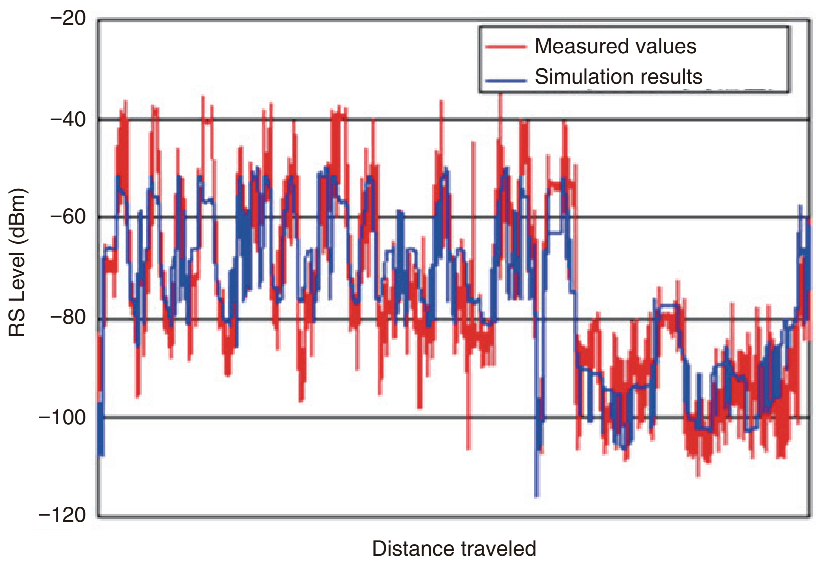
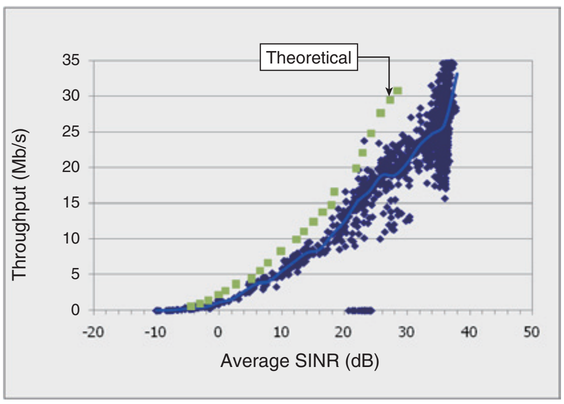
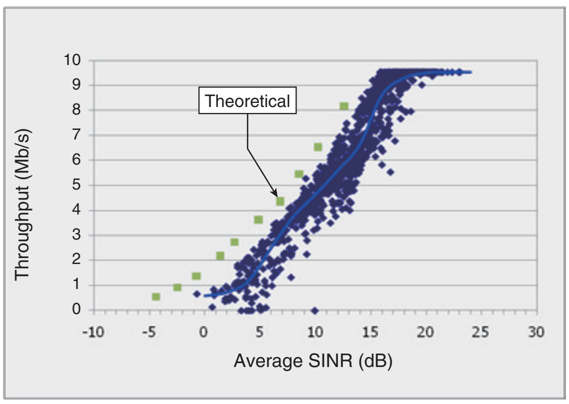


Figure 2
Comparison of measured values and simulation results for received signal (RS).



(a) Downlink (DL) channel



(b) Uplink (UL) channel

Figure 3
Relationship between throughput and average SINR.

lines show theoretical values. For the downlink, multiple-input multiple-output (MIMO) began functioning from an SINR of about 18 dB, and a maximum throughput of about 35 Mb/s at 5 MHz was achieved in a location where multipath effects were present. The average cell throughput was over 10 Mb/s on the downlink, validating the channel design method.

Refer to the paper entitled "Field Trial for LTE Mobile Network System," in this issue for details regarding the field trials.

4. Conclusion

In this paper, we have introduced and explained design processes for radio engineering technology and presented results obtained in field trials conducted to evaluate their performance. We conclude with a summary and discussion of future developments.

1) Simulation using 3D map data and automatic optimization algorithms improved the design accuracy for a radio network, particularly the channel design, dimensioning, and base station placement. Using 3D mapping data, we can simulate building shadows and other propagation conditions more accurately, but somewhat more consideration was given to propagation losses than necessary over the entire area. Over wider areas, accurate base-station placement design is possible even when using 2D mapping data.
2) We were able to reproduce field-test radio propagation phenomena in base-station placement simulations. We plan to develop methods needed for developing indoor systems, i.e., ones for checking indoor propagation characteristics and determining the power of signals leaking in from outdoor systems. This will establish a base-station placement design technology for indoor installations.

The design processes for radio engineering technology introduced in this paper are essential for designing radio networks for LTE systems, which are part of our societal infrastructure. Fujitsu will continue studying related methods and contributing to the design and construction of optimal systems.

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