Calculation of Spectral Efficiency for Estimating Spectrum Requirements of IMT-Advanced in Korean Mobile Communication Environments

Woo-Ghee Chung, Euntaek Lim, Jong-Gwan Yook, and Han-Kyu Park

In this paper, we analyze the algorithm of the methodology developed by ITU for the calculation of spectrum requirements of IMT-Advanced. We propose an approach to estimate user density using traffic statistics, and to estimate spectrum efficiencies using carrier-to-interference ratio distribution and capacity theory as well as experimental data under Korean mobile communication environments. We calculate the IMT-Advanced spectrum requirements based on the user density and spectral efficiencies acquired from the new method. In the case of spectral efficiency using higher modulation and coding schemes, the spectrum requirement of IMT-Advanced is approximately 2700 MHz. When applying a 2×2 multiple-input multiple-output (MIMO) antenna system, it is approximately 1500 MHz; when applying a 4×4 MIMO antenna system, it is approximately 1050 MHz. Considering that the development of new technology will increase spectrum efficiency in the future, the spectrum requirement of IMT-Advanced in the Korean mobile communication environment is expected to be approximately 1 GHz bandwidth.

Keywords: Spectral efficiency, spectrum requirements, IMT-Advanced.

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I. Introduction

The design objective of next generation mobile communication systems is to support a peak bit rate up to 100 Mbps with high mobility and up to 1 Gbps with low mobility. The International Telecommunication Union (ITU) has required spectrum requirement estimations for next generation mobile communication services in order to meet the above objective in preparation for the World Radiocommunication Conference 2007 (WRC-07). Also, the ITU has produced a new version of reports on market analysis and radio aspect analysis for the future development of IMT-2000 and IMT-Advanced.

In the past, estimation of the spectrum requirements for wireless applications has been considered as a framework focusing on a single system and market scenario as given in [1]. With the convergence of mobile and fixed telecommunications and multiple network environments as well as supporting attributes such as seamless inter-working between different complementary access systems, as described in [2], the application of such simple approaches is no longer suitable.

The methodology in [1] was based on 2G and IMT-2000 technology networks. For this methodology, the model of service delivery is a voice-based traffic architecture including a short message service (SMS) with some higher data rate services characterized by a simple peak traffic model. An estimation of the spectrum required to carry the projected traffic for 2005 and 2010 was developed in [3] using [1]. As indicated in [2], the majority of future traffic will shift from speech-oriented communications to multimedia communications. Internet protocol (IP)-based traffic will play a dominant role in the future. For this reason, networks and systems must be designed to economically transfer packet data.

The methodology in [1] treats each environment and service independently, so that the peak traffic for each service within each environment is merely added together to obtain the total traffic volume. The recommendation in [1] does not take into account the fact that some services are interrelated with others. Therefore, the traffic statistics for multiple services should be combined, at least in some cases.

Therefore, to estimate the spectrum requirements, ITU has developed a new spectrum calculation methodology, which allows for the consideration of spatial and temporal correlations among variable telecommunication services, taking into account the market requirements and network deployment scenarios. Moreover, it is also important to analyze the effects of market related and technology related input parameters on the new methodology of the spectrum requirement calculation.

The input parameters of a new spectrum calculation methodology are market parameters such as user density, mean service bit rate, and mobility classes; distribution of traffic to radio access technology groups (RATGs) and radio environments, such as cell area; and radio parameters such as guard band, spectral efficiencies, and so on. Among the above input parameters, the variation of the spectrum requirements due to user density and spectral efficiencies is large; therefore, the method used to choose the value of user density and spectral efficiencies is very important.

In this paper, we present our analysis of an algorithm of the methodology developed by ITU for the calculation of spectrum requirements of IMT-Advanced. We propose an approach to estimate user density using traffic statistics, and spectrum efficiencies using carrier-to-interference ration (CIR) distribution and capacity theory as well as experimental data under Korean mobile communication environments. We calculate the IMT-Advanced spectrum requirements based on the user density and spectral efficiencies acquired from the new method.

The remainder of this paper is organized as follows. Section II presents an overview of the spectrum calculation methodology. In section III, the simulation parameters are presented and an approach to choose the value of user density and spectrum efficiencies are proposed. Section IV reports the simulation results, and finally, the proposed method and some results are summarized in section V.

II. Spectrum Requirement Calculation Methodology by ITU-R

The spectrum requirement calculation methodology is designed to accommodate a wide variety of applications. The market expectations for wireless communications services in 2010, 2015, and 2020, which are found in [4] from the basis for all considerations concerning IMT-Advanced networks. This report predicts the required communication capacities for uplink and downlink operations of mobile users within IMT-2000 and IMT-Advanced.

The spectrum requirement calculation methodology takes a technology-neutral approach in its technical studies of radio access techniques and uses the classifications of RATGs presented in [5]. The spectrum calculation methodology requires technical parameters to characterize the different RATGs as inputs into the spectrum calculations. Using the RATGs approach, the technical considerations for spectrum estimation can be easily conducted without referring to the detailed specifications of the radio interfaces of either existing or future mobile systems. The technical considerations include the RATG definitions and radio parameters associated with the RATGs which are used in different steps of the methodology. These radio technology aspects and values for radio parameters, such as spectral efficiency, have been considered and are described in [5]. The generic flow chart for the calculation methodology is shown in Fig. 1 [6].

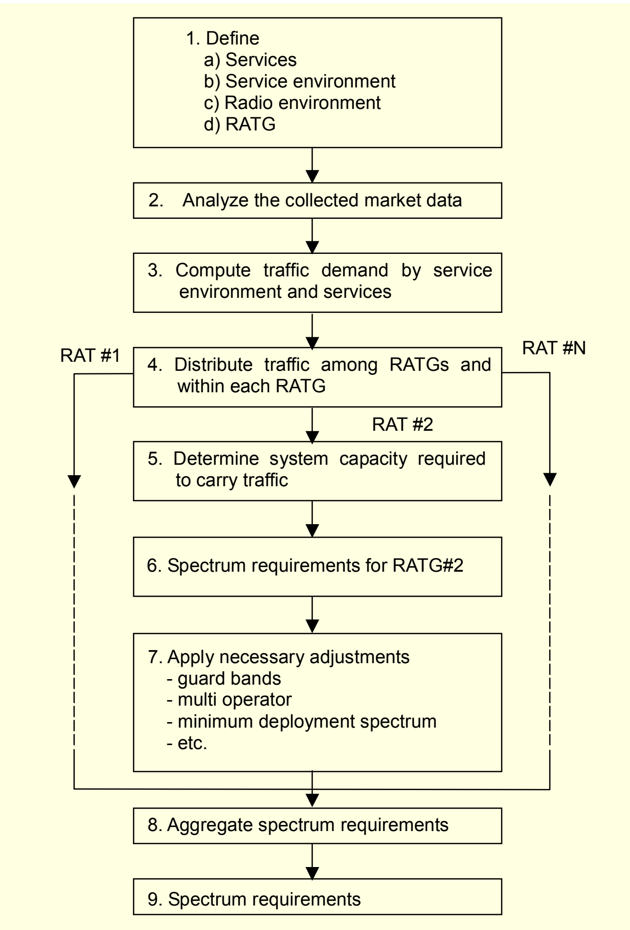

Fig. 1. Flow chart for a generic spectrum calculation methodology.

1. Definitions

First, all necessary categorizations and associated input parameters for the spectrum calculation methodology are defined. A service category (SC) is a service type (ST) with an associated traffic class (TC) as shown in Table 1.

Service environments (SE) are defined as a combination of service usage pattern and teledensity. Table 2 shows the identification of service environments.

Radio environments (RE) are defined to reflect different types of wave propagation phenomenon. Typical radio environments are macro cells, micro cells, pico cells, and hotspot areas. Both radio access technology (RAT) and RATGs are also defined in this step. The RATGs suggested by ITU are the following:

- RATG #1: pre-IMT systems and IMT-2000 and its enhancements
- RATG #2: IMT-Advanced
- RATG #3: existing Radio LANs and their enhancements
- RATG #4: digital broadcasting systems and their enhancements

Table 1. Service categories.

	Conversational	Streaming	Interactive	Background
Super high multimedia	SC 1	SC 6	SC 11	SC 16
High multimedia	SC 2	SC 7	SC 12	SC 17
Medium multimedia	SC 3	SC 8	SC 13	SC 18
Low-rate data & low multimedia	SC 4	SC 9	SC 14	SC 19
Very low-rate data	SC 5	SC 10	SC 15	SC 20

Table 2. Service environments.

<table>
<tr><th>Teledensity / Service usage pattern</th><th>Dense urban</th><th>Suburban</th><th>Rural</th></tr>
<tr><td>Home</td><td>SE1</td><td>SE4</td><td rowspan="3">SE6</td></tr>
<tr><td>Office</td><td>SE2</td><td rowspan="2">SE5</td></tr>
<tr><td>Public area</td><td>SE3</td></tr>
</table>

2. Market Data Analysis

This step analyzes the market data, which may be obtained from [4]. The market data can be collected with the use of questionnaires sent to subjects outside of ITU [7]. The collected market data should be categorized and calculated in order to obtain the market attributes.

3. Traffic Computation

Step 3 of Fig. 1 is the computation of the traffic load of different service categories for different service environments at different time intervals. This is necessary due to the temporally and regionally varying nature of traffic.

4. Traffic Distribution

The traffic load obtained in the previous step will be distributed to the possible RATGs and radio environments. Figure 2 depicts the traffic distribution process. It can be calculated mathematically by multiplying the traffic load obtained in step 3 to distribution ratio $\xi_{m,n,rat,p}$, which represents the distribution ratio for service category *n* for RATGs (*rat*) in service environment *m* and radio environment *p*.

5. System Capacity

The required system capacity must be calculated separately for the uplink and downlink operations. For circuit switched services, the required capacity is calculated by a multidimensional Erlang-B formula [8], while for packet-switched services the required capacity is calculated using the M/G/1 non-preemptive priority queuing model [9]. Equation (1) shows that separately calculated capacity requirements must be combined:

$$C_{rat,p,ps} = C_{rat,p,ps,UL} + C_{rat,p,ps,DL},$$
$$C_{rat,p,cs} = C_{rat,p,cs,UL} + C_{rat,p,cs,DL}, \tag{1}$$

where $C_{rat,p,ps}$ is the required system capacity for RATGs (*rat*) in service environment *m* and radio environment *p*; the subscripts *ps* and *cs* are packet switching and circuit switching, respectively; and *UL* and *DL* represent the uplink and downlink operations, respectively. Following this, the capacity requirement for packed switching and circuit switching is calculated as

$$C_{rat,p} = C_{rat,p,ps} + C_{rat,p,cs}. \tag{2}$$

6. Spectrum Requirements for Each RATG

In step 5, the spectrum requirement for each RATG is calculated. The spectrum requirement for each *rat*, in service environment *m* and radio environment *p* is obtained from

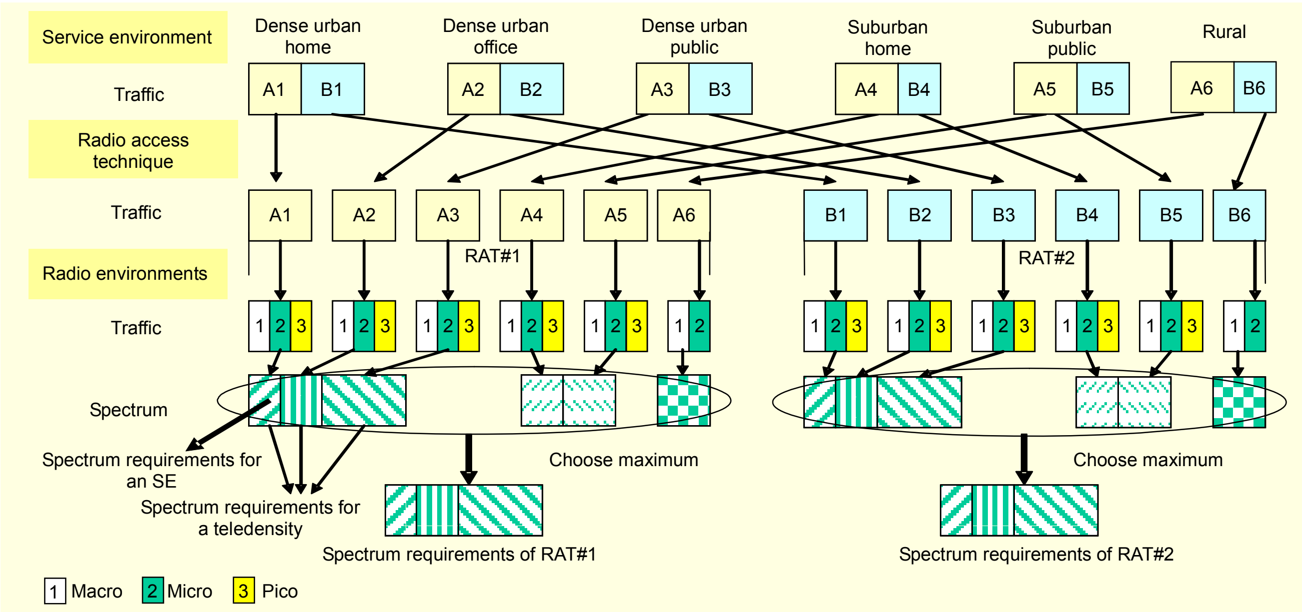

Fig. 2. Traffic distributions among service and radio environments and RATGs.

$$f_{m,rat,p} = \frac{C_{m,rat,p}}{\eta_{m,rat,p}}, \tag{3}$$

where $f_{m,\ rat,\ p}$ denotes the m-th row vector of the spectrum requirement matrix of $f_{rat,\ p}$; η is spectral efficiency; $f_{rat,\ p}$ is defined as the sum of spectrum requirements for service environments existing in the same teledensity; and F_{rat} is defined as the sum of spectrum requirements for each radio environment *p*.

7. Necessary Adjustments

Adjustments are made taking into account the minimum spectrum requirements for network deployment, the necessary guard bands, and the impact of the number of operators explained in [6].

8. Aggregation of Spectrum Requirements

In the final step, the spectrum requirements are aggregated over time intervals and teledensity environments. It is important to note that the maximum value of the spectrum requirements in time and teledensity must be selected because the spectrum requirement is time dependent. With a flexible spectrum usage (FSU) possibility between RATGs, the aggregate spectrum demand for the RATGs that support an FSU can be calculated in this step. Without an FSU, $F_{d,rat}$ denotes the maximum spectrum requirements over time *t* and teledensity *d* for *rat*.

$$F_{d,rat} = \max_t (F_{d,t,rat}) \tag{4}$$

With the FSU possibility between RATGs, the aggregate spectrum demand for the RATGs that support the FSU is calculated by summing the spectrum demands of each RAT separately for each teledensity:

$$F_{d,rat} = FSU_{marg} \times \sum_{rat \in (FSURATs)} F_{d,t,rat} \;. \tag{5}$$

III. Approach to Estimate User Density and Spectrum Efficiencies

1. Simulation Parameters

The input parameters for the spectrum requirement calculation can be categorized into either market related parameters or technology related parameters. The general market related and technology parameters can be obtained from [10]. For simulation we established the input parameters except user density and spectral efficiency using [10].

The general parameters used in the simulation are shown in Table 3. The traffic load for service categories #1 (SC#1) to SC#10 is circuit switched, and the traffic load for SC#11 to SC#20 is packet switched. The blocking probability for the circuit switched traffic is set to 0.01. In RATG#1, pre-IMT systems and IMT-2000 and its enhancements are included; in RATG#2, IMT-Advanced systems are included (namely, new mobile access and new nomadic/local area wireless access). RATG#2 is more efficient than RATG#1 in using the spectrum resources; therefore, the traffic load distribution ratio between RATG#1 and RATG#2 is an important parameter in the spectrum requirement calculation. The traffic distribution ratio

Table 3. Main simulation parameters.

Parameter	Value
Service category	SC#1–10 (circuit) SC#11–20 (packet)
Service environment	SE#1–6
Distribution ratio	RATG#1 42% RATG#2 58%
Radio environment	RE#1–4
Mean packet size (byte)	1500 (SC #11–15) 540 (SC#16–20)
2nd moment of packet size ($byte^2$)	4500000 (SC#11–15) 583200 (SC#16–20)
Mean packet delay (s)	0.04 (SC #11–15) 0.4 (SC #16–20)
Blocking probability	0.01 (SC#1–10)

(proposed by ITU) between RATG#1 and RATG#2 is 42% to 58% [10]. We used the values proposed by ITU because no deeper market study has been implemented in Korea.

2. Market Parameters

The number of users in the market data cannot exceed the population density in the market. If the reference population density is well-known, we can perform a rounding process for the maximum value of the market data for each service. Let x_i denote the reference population density of teledensity *i*, and p_s^j denote the maximum value of user data estimated by ITU for a service *s* in the service environment *j* [4]. Then, $\sum_{j\subset i} p_s = x_i$ for the service category with the highest penetration rate. For example, voice services are likely to be saturated in the near future; therefore, the sum of the number of voice users over all service environments within teledensity *i* is set to x_i.

We estimated the population density of each environment in Korea as follows [11]. First, we selected Seoul with a dense urban teledensity and estimated the population density of the potential mobile subscribers using the operator traffic data and the following formula:

$$\text{Potential user density (Persons/km}^2) = \frac{\text{Busy hour call access(BHCA) per base station}}{\left\{\begin{matrix}(\text{Average BHCA per user})\times(\text{Area per cell})\\ \times(\text{Service penetration})\end{matrix}\right\}}, \quad (6)$$

where

$$\text{Service penetration} = \frac{\text{Numner of subscribers in Seoul}}{\text{Population density in Seoul}}.$$

The population density of Seoul is estimated as 272,661 persons per km^2, which is divided into 156,311 per km^2 in-building, 110,050 per km^2 pedestrian, and 6,300 per km^2 in-vehicle. The 272,661 persons per km^2 is a reference number of the population density for dense urban teledensity. The saturation of service penetration is 90%; therefore, user density is 272,661 × 0.9 = 245,395.

We used the voice and SMS services denoted by SC#5 in the DNR M. [IMT.METH] as reference services. In 2015, the projected urban density has a maximum number of at-home users of 119,330, in the office of 246,841, and in the public service environment of 166,892. Therefore, the total population density in a dense urban area is 533,063, but the reference number of the population density is equal to 245,395; therefore, we can easily regard the appropriate user density portion to be less than 46%.

3. Spectral Efficiency

The spectral efficiency matrix needs to be estimated for each RATG area. The area spectral efficiency of each RATG in each radio environment can be estimated using an average spectrum efficiency, which is determined by taking into account the propagation characteristics, interference considerations, typical deployment scenarios, and technical requirements for technical characteristics.

Figure 3 shows the overall procedure of the spectral efficiency calculation method. The parameters described in each step (represented by boxes) indicate the parameters necessary to calculate the output of each step.

In the first stage of the spectral efficiency calculation procedure, all parameters that can affect the CIR distribution are incorporated into the CIR distribution function. The propagation model and radio parameters, such as frequency, reuse factor, and duplex schemes that affect the interference mechanism of the system should be reflected in the CIR distribution. Examples of this procedure were introduced in [12] and [13]. The purpose of the second stage is to obtain the basic spectral efficiency without advanced technologies such as MIMO. The modulation function associated with the CIR value and bandwidth will be defined prior to this stage. It represents a mapping function of the modulation and coding rate from the received CIR to transmission rate given the bandwidth and required bit error rate (BER). Usually, for a system level simulation test for present systems, modulation performances are obtained by a link level simulation, which requires a more detailed specification of the RATGs, but provides realistic values of RATGs. In the third stage, advanced technologies are applied as multipliers. Advanced technologies such as multiple-input multiple-output (MIMO) technologies can improve the system level throughput and conventional values of the improvement ratio can be

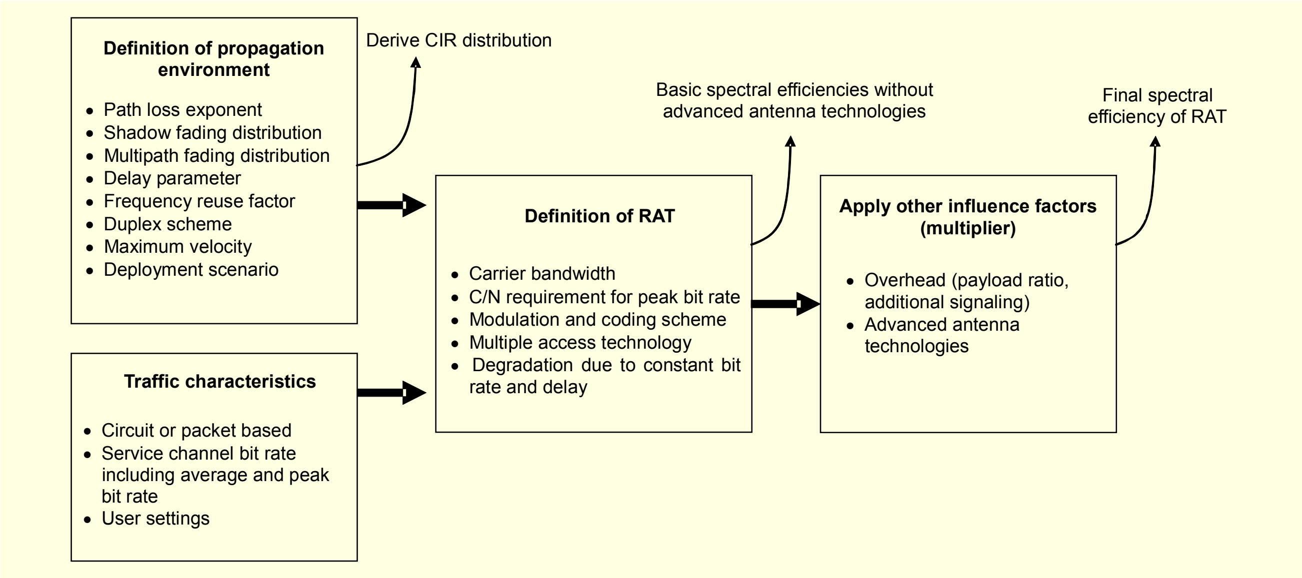

Fig. 3. General procedure processor for spectral efficiency calculator.

obtained by the application of the technologies to currently existing systems.

The basic formula for spectral efficiency (η) is defined as

$$\eta = P \cdot R_{av} \cdot G / BW, \tag{7}$$

where η is spectral efficiency (bps/Hz/Cell), P is the peak data rate (bps), R_{av} is the modulation and coding scheme (MCS) average factor, G is other gain from advanced technologies, and BW is the channel bandwidth.

The CIR distribution can be obtained from channel models considering different frequency bands, user mobility, frequency reuse factors, and cell radius, assuming a uniform distribution of users in a cell. It can be provided by a numerical calculation or a computer simulation.

From this formula, the spectral efficiency of a system is calculated by a simple product of each parameter, which is assumed to be estimated separately on an average basis. The main advantage of such a modular formulation is that each value can be calculated simply and some values of statistical information from past experiences are reused. The peak data rate in the formula is the target data rate of the new capabilities of IMT-Advanced. As shown in [2], 100 Mbps under a mobile environment and 1 Gbps under a stationary environment are regarded as target data rates. The MCS averaging factor is defined as the normalized average achievable data rate of a user in a cell compared with the peak rate. When the MCS is applied, the data rate can be adjusted to coincide with the channel condition, which is quantized by the received CIR of a user.

Each value of the above formula can be calculated as follows:

1) If the modulation orders with coding rates are denoted as $r_1, r_2, \cdots, r_n$, where r_1 is the highest modulation order with a coding rate and P is defined as the peak data rate, then the data rate for a user with a modulation order r_i can be calculated as $(r_i/r_1)\cdot P$. In addition, the required CIR value is denoted as cir_i, corresponding to a modulation order with the coding rate r_i, while keeping the frame error rate (FER) value below a predefined threshold. Table 4 is an illustrative example of mapping between CIR distribution and an MCS with a maximum data rate of P.

2) In a cell, the MCS average factor is defined as

$$R_{av} = \sum_i \frac{r_i}{r_1} \cdot \mathrm{prob}\left(cir_i \le CIR < cir_{i-1}\right). \tag{8}$$

3) The MCS average factor, taking into account user distribution and channel conditions within a cell, needs to be estimated by a computer simulation:

$$\sum_i P \cdot \frac{r_i}{r_1} \cdot \mathrm{prob}\left(cir_i \le CIR < cir_{i-1}\right). \tag{9}$$

However, such a simulation method usually requires technical details. Alternatively, if the technical details are not available, it can be calculated by realistic values.

4) For the application of advanced antenna technologies such as MIMO technologies, spectral efficiency will increase proportionally to the number of antennas used, but it may not necessarily be linear. Thus, we must also evaluate the gain of the MIMO technology on an average basis. The final spectral efficiency η is given by

$$\eta = P \cdot R_{av} \cdot G_M / BW, \tag{10}$$

Table 4. Mapping between CIR distribution and MCS for spectral efficiency calculation.

CIR distribution Prob(cir_i ≤CIR<cir_{i-1})	Modulation order and coding scheme		Data rate per symbol	Achievable rate
prob(cir_9 ≤CIR<cir_8)	QPSK,1/12	r_9	1/6	P × 1/30
prob(cir_8 ≤CIR<cir_7)	QPSK, 1/6	r_8	1/3	P × 1/15
prob(cir_7 ≤CIR<cir_6)	QPSK, 1/3	r_7	2/3	P × 2/15
prob(cir_6 ≤CIR<cir_5)	QPSK, 2/3	r_6	4/3	P × 4/15
prob(cir_5 ≤CIR<cir_4)	16QAM, 1/2	r_5	2	P × 2/5
prob(cir_4 ≤CIR<cir_3)	16QAM, 2/3	r_4	8/3	P × 8/15
prob(cir_3 ≤CIR<cir_2)	16QAM, 3/4	r_3	3	P × 3/5
prob(cir_2 ≤CIR<cir_1)	64QAM, 2/3	r_2	4	P × 4/5
prob(cir_1 ≤CIR)	64QAM, 5/6	r_1	5	P

Note: 1. Data rate per symbol = (modulation order) × (coding rate)
2. Achievable rate = P×(data rate per symbol)/(maximum data rate per symbol)

Table 5. MCS level for WiBro systems with different channel models.

Modulation	Coding rate	Required CIR (dB)				
		Ped-A, 3 km/h	Ped-A, 10 km/h	Ped-B, 3 km/h	Ped-B, 10 km/h	Veh-A, 60 km/h
QPSK	1/12	–3.95	–3.8	–3.9	–3.9	–3.9
QPSK	1/6	–1.65	–1.4	–1.5	–1.45	–1.45
QPSK	1/3	1.5	2.1	1.6	1.65	1.65
QPSK	1/2	4.3	5.3	4.25	4.3	4.4
QPSK	2/3	7.95	9.4	7.9	8	8.15
16QAM	1/2	9.3	10.15	9.25	9.35	9.5
16QAM	2/3	13.1	14.6	13.2	13.5	13.65
16QAM	3/4	15.8	17.7	16.7	16.5	15.7
64QAM	2/3	18.45	19.7	18.2	18.4	19.2
64QAM	5/6	24.8	27.2	24.4	24.7	27.5

where G_M is the gain obtained from the MIMO technology at a certain channel condition and BW is channel bandwidth.

The above method to estimate realistic spectral efficiency is applied only to RATG2 (IMT-Advanced) not to be developed because the spectral efficiency of RATG1 can be estimated using commercialized systems (such as HSDPA and so on). The IMT-Advanced system is being developed and the specifications of IMT-Advanced system have not been decided. The WiBro system is neither the RATG1 system nor the RATG2 system. The WiBro system uses OFDM multiple access, up to 64 QAM MCS, and the ITU propagation channel model. It does not yet use MIMO technology in commercialized systems. If the IMT-Advanced system uses OFDM multiple access, up to 64 QAM, and a MIMO system, the spectral efficiency of the proposed IMT-Advanced system can be estimated simply and realistically by using the realistic performance of the WiBro system with OFDM multiple access up to 64 QAM. Therefore, only the performance of the current WiBro system is used to estimate the realistic spectral efficiency of RATG2 (IMT-Advanced system). Other systems applying up to 64 QAM MCS and OFDM can be used to estimate the realistic spectral efficiency of RATG2.

Table 5 shows a modulation table of various channel models which have been applied to WiBro systems, a type of 802.16e system commercialized in Korea [14]. In Table 5, the CIR values required for each modulation order with coding rates are given for each channel model.

The peak rate of the WiBro system is defined as 30 Mbps and the channel bandwidth as 9 MHz. This data rate can be achieved when a user is very close to a base station (BS); thus, his received CIR is high enough to employ the highest order of modulation and coding rate. The MCS averaging factor is estimated at approximately 0.6 compared with the peak data rate. This value was calculated by a system level simulation. The cell radius used in the simulation was assumed to be 400 m. As a consequence, the spectral efficiency of the WiBro system is estimated as 30×0.6/9= 2 bps/Hz/cell (for downlink).

The capacity in bits per second per Hertz of an [M, N] MIMO link is given by

$$C = B\log_2(1_N + r\mathbf{H}\mathbf{H}^H / M), \qquad (11)$$

where B is the bandwidth, I_N is the N by N identity matrix, r is the average signal-to-noise ratio (SNR), and $\mathbf{H}$ is an M by N matrix whose (m, n)th element is a complex amplitude between the m-th transmitter and n-th receiver [15]. We have assumed a perfect channel state of information at the receiver In other words, the entries of matrix $\mathbf{H}$ are known precisely. In a rich scattering environment, the entries in $\mathbf{H}$ are independent and identically distributed complex Gaussian random variables. If M=N, the capacity of an orthogonal MIMO channel approaches

$$C = BM\log_2(1+r). \qquad (12)$$

IV. Simulation Results

In this section, the spectrum requirements according to spectrum efficiency are simulated. Table 6 shows the spectral efficiencies resulting from the conditions of the WiBro system with only MCS up to 64 QAM and up to a 5/6 coding rate. In addition the spectral efficiencies of a WiBro + MIMO (2×2) system and a WiBro + MIMO (4×4) system are shown.

Figure 4 and Table 7 present the spectrum requirements per

Table 6. Spectral efficiencies resulting from the conditions of various systems.

		Macro cell	Micro cell	Pico cell	Hot spot
MCS only	RATG#1	0.4	0.4	0.7	1
	RATG#2	1.7	2	2.6	4.3
MCS+ MIMO(2×2)	RATG#1	0.4	0.4	0.7	1
	RATG#2	3.4	4	5.1	8.6
MCS+ MIMO(4×4)	RATG#1	0.4	0.4	0.7	1
	RATG#2	6.9	8	10.3	17.1

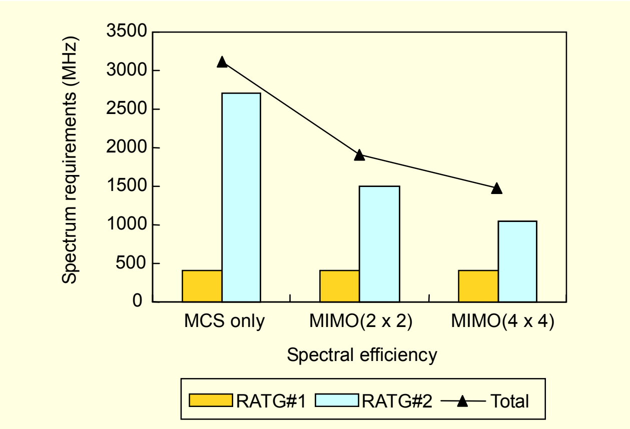

Fig. 4. Spectrum requirements according to spectrum efficiencies.

Table 7. Simulation result.

	MCS only	MCS + MIMO (2×2)	MCS + MIMO (4×4)
RATG#1 (MHz)	420	420	420
RATG#2 (MHz)	2700	1500	1050
Total (MHz)	3120	1920	1470

RATG and the total spectrum requirements under the conditions of systems with and without MIMO technology.

The spectrum requirement for MCS only is over 3 GHz bandwidth. The spectrum requirement for MCS plus MIMO (2×2) decreases to approximately 1.92 GHz bandwidth. Finally, the spectrum requirement for MCS plus MIMO (4×4) is approximately 1.47 GHz bandwidth. Considering the development of new technology to increase spectrum efficiency in the future, it can be concluded that the spectrum requirement for IMT-Advanced can be approximately 1 GHz bandwidth.

V. Conclusions

In this paper, we analyzed the algorithm of the methodology developed by ITU for the calculation of spectrum requirements of IMT-Advanced. We proposed an approach to estimate user density considering traffic statistics and spectrum efficiencies using CIR distribution and capacity theory and experimental data under Korean mobile communication environments. Furthermore, we calculated the IMT-Advanced spectrum requirement based on the user density and spectral efficiencies acquired from the new method.

In the case of spectrum efficiency using higher modulation and coding schemes, the spectrum requirement of IMT-Advanced is approximately 2700 MHz; additionally when applying MIMO (2×2), it is approximately 1500 MHz and when applying MIMO (4×4), it is approximately 1050 MHz. Since the development of new technology will increase spectrum efficiency in the future, the spectrum requirement of IMT-Advanced in the Korean mobile communication environment is expected to be approximately 1 GHz bandwidth based on user density considering traffic statistics and spectrum efficiencies using CIR distribution, capacity theory, and experimental data under Korean mobile communication environments.

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