On the Carrier Spacing for Mobile Multimedia Systems

Een Kee Hong, Sang Hyuck Yun, and Jeong Geun Kim

Abstract: **Previous approaches to sizing the carrier spacing for voice-oriented cellular systems have been based on the outage requirement. However, such a design paradigm needs to be changed as the performance of most upcoming cellular systems employing adaptive modulation and coding (AMC) techniques is more sensitive to throughput than outage. In this paper, we propose a novel approach to determining the carrier spacing which is based on a throughput criterion. The proposed method reflects well the characteristics of throughput-sensitive cellular systems that transport multimedia traffic. Numerical results show that our approach requires less carrier spacing, thus leading to more efficient spectrum utilization.**

Index Terms: **Adjacent channel interference, adaptive modulation and coding (AMC), carrier spacing.**

I. INTRODUCTION

Introducing a new wireless service on a specific frequency band requires a careful consideration on its possible disruption to other wireless services on neighboring frequency bands. A common technique to minimize such disruption is providing a sufficient spacing between the carrier frequencies. Since the carrier spacing determines spectral efficiency as well as the level of interference, it must be carefully chosen prior to deployment of the systems. Tighter carrier spacing causes increased interference whereas over-dimensioned carrier spacing incurs less interference at the expense of scarce spectrum.

In previous studies, the minimum coupling loss (MCL) technique has been widely used to determine both minimum frequency separation and interference distances [1], [2]. However, the MCL method assumes the worst case interference scenario that rarely occurred, thus giving too conservative results. In order to take into account more realistic conditions, some studies relied on the system level simulation methodology in which all the detailed characteristics of cellular environment and interference are reflected [1]. In [2], the system level simulation was also used to determine the frequency allocation of the IMT-2000 system. Common to these works [1], [2] is the use of the outage criterion to calculate the proper carrier spacing for the voice-oriented cellular systems.

As the service paradigm in cellular communication systems rapidly shifts from voice to multimedia, a new methodology for determining the optimum carrier spacing needs to be studied in the context of multimedia services. Recently proposed cellular systems, capable of transporting multimedia traffic, mostly use the adaptive modulation and coding (AMC) scheme to achieve higher data rates [3]. In those systems link adaptation is carried out by the AMC scheme with the transmission power fixed. In particular, the impacts of interference in those systems are manifested in terms of throughput degradation rather than the outage. That is, as the amount of interference increases, the level of modulation and coding scheme (MCS) becomes directly lowered yielding lower throughput while the link connectivity can still be maintained without the outage. In fact, the outage indicates only whether the link connectivity is maintained or not, but it may not be a good metric in selecting the carrier spacing for the recent throughput-sensitive cellular systems.

In this paper, we propose a new methodology for calculating the carrier spacing that gives the maximum throughput for throughput-sensitive cellular systems. In the previous approaches, the interference from neighboring bands put more mobile stations into outage, consequently reducing the capacity. In our approach, the impacts of adjacent channel interference lead to, in contrast, throughput degradation. In our approach system, throughput of the single operator is obtained by first summing the data rates of individual mobile stations whose data rate is absolutely determined by the MCS level. Then the adjacent channel interference is introduced and the system throughput is calculated again. Following this procedure we obtain the optimum carrier that maximizes the normalized throughout to the required bandwidth. Extensive simulations were performed to achieve the reliable system level simulation results.

The rest of the paper is organized as follows. In Section II, we give a brief overview of the adjacent channel interference (ACI). Simulation methodology is presented in Section III. Numerical results are reported in Section IV followed by concluding remarks.

II. ADJACENT CHANNEL INTERFERENCE

ACI refers to unwanted transmission power that leaks from adjacent bands due to imperfectness of the spectrum mask. The ACI is a very critical system parameter in that co-existence performance of the systems on adjacent channels heavily depends on it. In 3GPP [6], the notion of adjacent channel protection (ACP) is first introduced for the analysis of ACI. The ACP is a function of adjacent channel leakage power ratio (ACLR) and adjacent channel selectivity (ACS). The ACP is the ability to suppress the interference and is required if a fraction of interference from adjacent channels interferes with the intended signal. The ACLR is the ratio of the transmitted power to the power measured after a receiver filter in the adjacent RF channel. The ACS is a measurement of a receiver's ability to receive a signal at its assigned channel frequency in the presence of a modulated signal in the adjacent channel. The ACS is the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent channel frequency.

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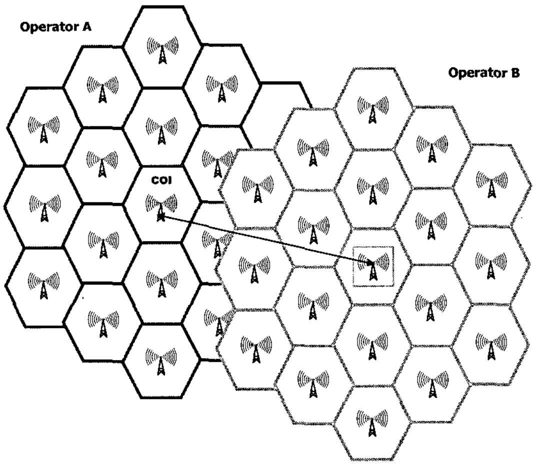

Fig. 1. Cellular structure model.

The relation among ACP, ACLR, and ACS is given by

$$\mathrm{ACP} = \frac{1}{\frac{1}{\mathrm{ACLR}} + \frac{1}{\mathrm{ACS}}}. \tag{1}$$

For the sake of simplicity, the effect of ACS is neglected in (1) and the following simplified equation will be used throughout this paper.

$$\mathrm{ACP} = \mathrm{ACLR}. \tag{2}$$

III. SIMULATION METHODOLOGY

IMT-2000 system, widely accepted for the study of carrier spacing, is modeled in our simulation. Its wide acceptance enables us to easily compare our approach against the previous ones. Our simulation assumes the IMT-2000 system that transports throughput-sensitive multimedia traffic. We also focus on the downlink and the carrier spacing issues associated with it because of its dominance in terms of traffic amount. We follow the method of calculating carrier spacing between two operators described in [1] and [5]. Snap-shop simulation approach is used in which simulation is repeatedly carried out for sufficient times to obtain the proper results.

A. Cellular System Modeling

2-tier macro cell is shown in Fig. 1 and each cell has a hexagonal structure with radius R. We assume that the distance between two operators' base stations is equal to cell radius because it is the worst case in FDD-FDD macro cell coexistence simulation scenario [5]. The users are randomly distributed in each cell.

B. Propagation Model

Macro cell propagation model is applicable to the test scenarios in urban and suburban areas outside the high rise core where the buildings are of nearly uniform height. The pathloss in such environment is given by

$$\begin{aligned} L &= 40(1 - 4 \times 10^{-3} h_{\mathrm{BS}}) \log_{10}(R) \\ &\quad -18 \log_{10} h_{\mathrm{BS}} + 21 \log_{10}(f) + 80 \text{ dB} \end{aligned} \tag{3}$$

where R is the separation between base station (BS) and mobile station (MS) in kilometers, and f is the carrier frequency of 2000 MHz. h_{BS} is the BS antenna height, in meters, measured from the average rooftop level. The BS antenna height is fixed at 15 meters above the average rooftop (h_{BS} = 15 m). Once L is obtained from (3), log-normally distributed shadowing ($\log F$) with standard deviation of 10 dB is added to produce the pathloss, which is given by

$$\mathrm{Pathloss}_{macro} = L + \log F. \tag{4}$$

C. Power Control

The IMT-2000 FDD system uses the inner-loop power control scheme in the downlink [8]. The MS generates the transmit power control (TPC) commands to control the transmit power of BS and sends them in the TPC field of the uplink dedicated physical control channel (DPCCH). After receiving the k-th TPC command, UTRAN adjusts the current downlink power $P(k-1)$ to a new power $P(k)$ according to the following expression.

$$P(k) = P(k-1) + P_{\mathrm{TPC}}(k) + P_{bal}(k) \qquad \text{(dB)} \tag{5}$$

where $P_{\mathrm{TPC}}(k)$ is the k-th power adjustment by the inner loop power control, and $P_{bal}(k)$ is a correction term according to the downlink power control procedure for balancing radio link powers towards a common reference power. $P_{\mathrm{TPC}}(k)$ is given by

$$P_{\mathrm{TPC}}(k) = \begin{cases} +\Delta_{\mathrm{TPC}} & \text{if } \mathrm{TPC}_{est}(k) = 1 \\ -\Delta_{\mathrm{TPC}} & \text{if } \mathrm{TPC}_{est}(k) = 0. \end{cases} \tag{6}$$

In this paper, $P_{bal}(k)$ is neglected for simplicity.

Each user estimates SIR from the downlink channel using the following equation.

$$SIR_{DL} = \frac{G_p \cdot S}{\alpha I_{\mathrm{own}} + I_{\mathrm{other}} + N_0} \tag{7}$$

where S is the power of received signal, G_p is processing gain, I_{own} is intra-cell interference, I_{other} is interference from other cells, α is the orthogonal factor, and N_0 is thermal noise.

Thermal noise is calculated for 4.096 MHz bandwidth by assuming 9 dB system noise figure. Thus, thermal noise power is equal to -99 dBm. I_{own} is the total amount of power that is allocated to other users within a same cell and it determines the amount of intra-cell interference with an orthogonal factor α. The orthogonality is not maintained among multi-path signals because the multipath signals are not received synchronously. In this paper, the orthogonal factor is set to 0.4 as in [2]. In the multi-operator case, I_{other} also includes the interference from the adjacent operators.

Once SIR estimation on (7) is finished, each user generates the power control command. System outages occur in case the target E_b/N_0 (SIR) of the user is not achieved after a sufficient iteration of power control.

D. Interference from Adjacent Operators

Interference from the other operators on adjacent bands needs to be modeled properly for determination of optimum carrier spacing. We assume that every BS of other operators transmits

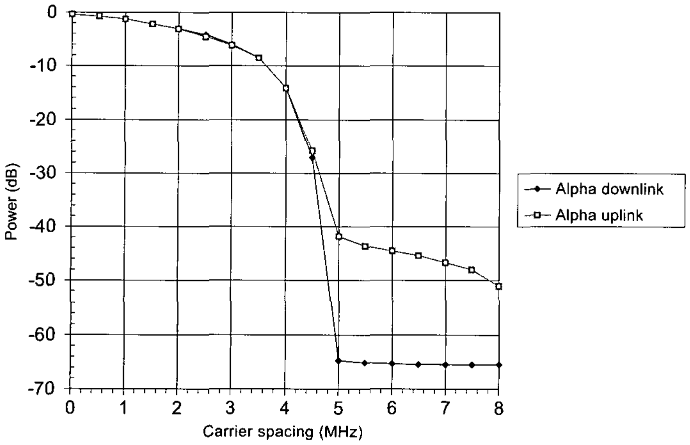

Fig. 2. Relationship between ACP and carrier spacing.

the maximum power without power control. The interferers in downlink are the BSs with fixed location. Of course, every BS performs the power control to distribute the power to each user but the total power that causes the other cell interference is the sum of the distributed powers. The downlink power control contributes the distribution of power to each user but has little impact on the total amount of interference. Thus, in this paper, the interfering system is assumed to transmit the maximum power allocated to BS. However, in victim system, the power control should be carried out because the power control determines the receiving power of each user. In two-tier cellular structure used in our simulation, 19 BSs of adjacent operator cause the ACI and the amount of ACI is determined by the distance between victim and interfering BS, spectrum mask, and carrier spacing.

E. Adjacent Channel Protection

ACI occurred from the other operators is determined by ACP. Thus, the relationship between ACP and carrier spacing plays an important role in the calculation of guard band. The most widely used curves to express it, in both the uplink and downlink, are those produced by the Alpha concept group as shown in Fig. 2 [1].

F. System Outage Criterion

Now, we describe how to evaluate the capacity of single operator with outage criterion. First, we construct cells and locate BSs at the center of each cell. The MSs are randomly distributed. The MSs in the cell of Interest (COI) are set up with initial power given as a parameter. We also generate the geometry information between the MSs and the BS. Next the MSs of COI estimate the SIR by using (7) and perform power control to achieve target SIR. The MS is considered to be in the outage if the estimated SIR of MS, after a sufficient iteration of power control, is below the target SIR. The number of MSs in COI is continuously increased until the system outage is equal to 5% (i.e., approximately 95% of MSs reaches their target). At that point the system capacity is defined as the number of MSs. For multi-operator case, the whole process is the same as single operator case, except that ACI is added.

Table 1. SINR thresholds for MCS.

Thresholds (dB)	Modulation and code rate	Throughput (Mbps)
−1.9	QPSK 1/4	1.2
1.25	QPSK 1/2	2.4
4.5	QPSK 3/4	3.6
6.5	16-QAM 1/2	4.8
10.2	16-QAM 3/4	7.2
14	64-QAM 5/8	9.0
16.2	64-QAM 3/4	10.8

Table 2. System level simulation parameters.

Parameters	Value
Simulation type	Snapshot
Number of snapshots	> 1000
Number of PC steps per snapshot	> 150
Cell structure	2-tier hexagonal cell
Step size of PC, Δ_{TPC}	1 dB
Noise power	−99 dBm
Maximum BTS power	43 dBm
Power control range	25 dB
Orthogonal factor, α	0.4
Cell radius R	1 km
SIR target	4.5 dB (without diversity)
Data rate	144 kbps
Base station shift	1 km (worst case)

G. System Throughput Criterion

The evaluation procedure for the capacity with throughput criterion is similar to that of outage criterion, except the metric for calculating carrier spacing is now throughput instead of outage. In throughput-sensitive cellular systems considered in this work, the link adaptation is mainly performed by AMC instead of power control. As the received SIR varies, the MCS level is changed and the system throughput is accordingly determined by these MCS levels. The MCS table used in our simulation is shown in Table 1 [3]. In the throughput criteria, the MCS level is changed depending on the amount of ACI that is directly related to carrier spacing .

IV. SIMULATION RESULTS

Parameters of IMT-2000 FDD/FDD coexistence scenario defined in [5] are used in our simulation and are listed in Table 2.

A. Outage Criterion

The carrier spacing based on outage criterion is obtained as described earlier in Section III-F. First, the capacity of single operator is calculated. Next, the ACI whose amount is determined by carrier spacing is applied and the capacity is derived again. The capacity of single operator with the outage requirements is shown in Fig. 3. The results show that the capacity of COI is about 190 at 5% outage criterion. In case the multiple operators are present, the effect of additional ACI needs to be incorporated. For that case, the relative capacity and normalized capacity are shown in Table 3 and Fig. 4.

ACI capacity is the relative capacity to the capacity of single operator when the ACI exists. The relative number of channels is the number of relative channels that can be accommodated within a given bandwidth, ignoring edge effects [2]. This is

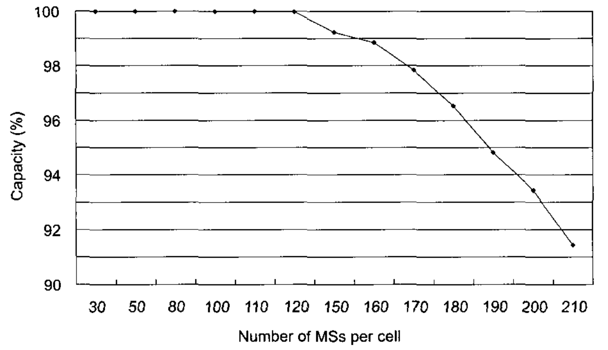

Fig. 3. IMT-2000 FDD single operator capacity.

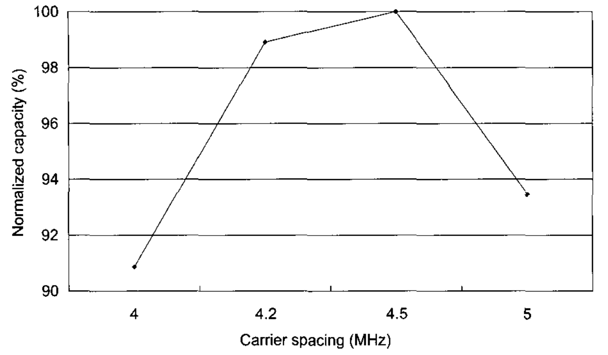

Fig. 4. Normalazed capacity versus carrier spacing.

Table 3. Outage criteria IMT-2000 FDD/FDD coexistence scenario carrier spacing calculation.

Carrier spacing (MHz)	ACP (dB)	ACI capacity (%)	Relative # of channels	Percent capacity	Normalized capacity (%)
4	14	77.37	25.0	19.34	90.87
4.2	20	88.42	23.8	21.05	98.9
4.5	28	95.79	22.22	21.29	100.0
5	65	99.47	20.0	19.89	93.46

the inverse of the carrier spacing (expressed as a percentage). Percent capacity is the ACI capacity multiplied by relative number of channels. Normalized capacity is obtained by dividing the individual percent capacities by the highest percent capacity obtained in that particular guard band scenario. In this way, the normalized capacity for the best carrier spacing is always 100% [2].

From the simulation results for the outage criterion in Table 3 and Fig. 4, it can be seen that the optimum carrier spacing between IMT-2000 FDD/FDD downlink systems is 4.5 MHz. In contrast, the optimum carrier spacing for the uplink in IMT-2000 FDD/FDD systems turned out to be 5 MHz [2]. The ACP of downlink as shown in Fig. 2 is larger than that of uplink and the less carrier spacing is obtained in downlink.

B. Throughput Criterion

Carrier spacing on throughput criterion is obtained as follows. Similar to the outage case, the system throughput of single operator is first obtained. This throughput is calculated by summing all of transmission data rates that is determined by MCS level.

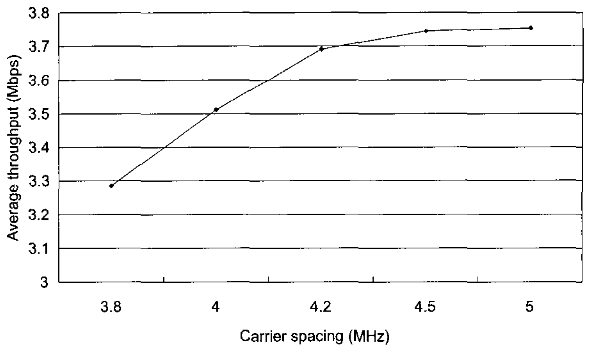

Fig. 5. Average throughput versus carrier spacing.

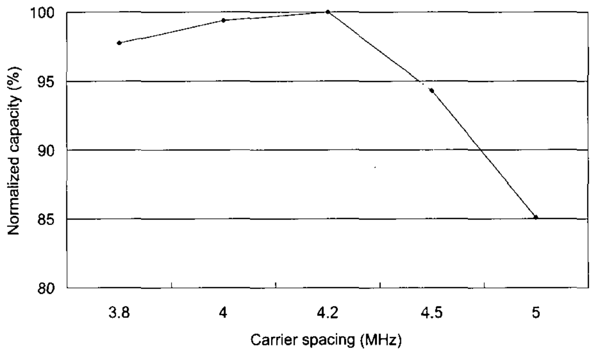

Fig. 6. Normalized capacity versus carrier spacing.

Table 4. Carrier spacing calculation result based on throughput criteria.

Carrier spacing (MHz)	ACP (dB)	ACI capacity	Relative # of channels	Capacity	Normalized capacity
3.8	11	87.17	26.32	22.94	97.76
4	14	93.27	25.0	23.32	99.36
4.2	20	98.23	23.8	23.39	100.0
4.5	28	99.59	22.22	22.13	94.3
5	65	99.84	20.0	19.99	85.09

Then, the ACI whose amount is determined by carrier spacing is considered and the capacity based on throughput is derived again. By considering this capacity, ACI, total bandwidths occupied by two operators, and guard bandwidth, we can obtain the optimum carrier spacing as in the outage case.

Fig. 5 shows the average throughput as a function of carrier spacing. As the carrier spacing increases, the throughput increases because of reduced interference. Relatively higher incremental rate is observed by 4.2 MHz, but the average throughput eventually saturates to 3.75 Mbps after 4.2 MHz. The optimum carrier spacing based on throughput criterion is listed in Table 4 and shown in Fig. 6.

The simulation results in Fig. 6 are different from that of outage criterion in Fig. 5. With throughput criterion, the simulation results show that 4.2 MHz is the optimum carrier spacing between two operators of IMT-2000 FDD/FDD downlink system. In the outage criterion, we just differentiate whether the MS is in outage condition or not. In contrast, the throughput is highly sensitive to the MCS level directly related to ACI in throughput criterion.

V. CONCLUSION

In this paper, we propose a novel technique of calculating the optimum carrier spacing based on the throughput criterion. We compare our approach against the previous approaches based on the outage criterion. Numerical results show that our approach requires less carrier spacing, consequently providing more efficient spectral utilization. As the next generation wireless communication systems move faster toward transporting throughput-sensitive multimedia traffic, our methodology will become a useful tool in calculating the optimum carrier spacing for those systems.

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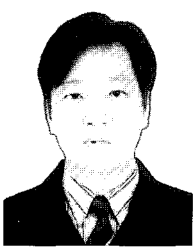

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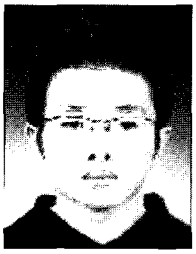

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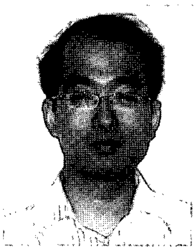

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