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Forward Link Power Allocation and Capacity of IMT-2000 System

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Abstract

This paper discusses solutions for forward link power allocation based on 3GPP(FDD) standardization reports and which meet the required Eb/No of forward link channels. In addition, the forward link user capacity in a mixed service environment. Cell coverage is induced from the user capacity solutions using the urban propagation model.

In an urban macrocell environment, the forward link user capacity turns out to be roughly 29 and 3, respectively, for voice and data service (144 kbps) at a distance of 1 km, and in an urban microcell environment, the user capacity turns out to be roughly 14, 4, and 2, respectively, for voice and two data services (144 kbps, 384 kbps) when the cell radius is 0.2 km.

1. Introduction

In the 3rd generation mobile communication system, CDMA(Code Division Multiple Access) is adopted to support variable data rates and high capacity. 3GPP standardization reports show that there are various channels in the forward link of IMT-2000, that is DP(Dedicated Physical)CH, PCCP(Primary Common Control Physical)CH, SCCP(Secondary Common Control Physical)CH, CPI(Common Pilot)CH and etc.[1] Since these forward link channels are simultaneously transmitted by the base station using orthogonal code multiplexing, they share the same link power budget gain and loss parameters. However, since each channel has different data rate and SNR requirement, the base station should transmit each type of channel with different power level to meet those requirements. In addition, there are various services in IMT-2000 system, which have different QoSs, so that transmitter power level and forward link capacity vary according to the ratio of each services. Thus, the analysis on the forward link power allocation and capacity is needed for an efficient cell planning. In the analysis, various services which have different QoS requirements are considered.

This paper is organized as follows. In section 2, a method for forward link power allocation of IMT-2000(FDD) system based on 3GPP specification is presented. In section 3, the forward link capacity is derived based on the analysis of section 2. In section 4, analyzed results assuming various scenarios are derived. Finally, conclusions are made in section 5.

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2. Forward Link Power Allocation

In the forward link of 3GPP system, the different channels are transmitted simultaneously by the base station, but they have different data rates and different required Eb/No. Thus base station should transmit each type of channel at a different power level to meet these requirements. In this section, forward link power allocation method is analyzed.

2.1 Total transmission Power

Total forward link power is denoted as

$$P_{total} = P_{CPICH} + P_{PCCPCH} + P_{SCH} + N_s P_{SCCPCH} \tag{1}$$

where P_{CPICH}, P_{PCCPCH}, P_{SCCPCH}, P_{AICH}, P_{PICH} means the transmission power of each physical channel. P_{DPCH_total} is the power of all DPCHs and N_s is the number of SCCPCH.

Since SCH is not orthogonal with the other forward link channels and transmitted during first 10% of each slot, SCH is not considered in this analysis. Also, AICH and PICH, which is for Acquisition and Paging Indication respectively, are not considered, because their effects on the total transmit power are negligible. As a result, total transmission power in the forward link can be arranged as follows.

$$P_{total} = P_{CPICH} + P_{PCCPCH} + N_s P_{SCCPCH} + P_{DPCH\_total} \quad (2)$$

2.2 Eb/No Requirements

As mentioned above, CPICH, PCCPCH, SCCPCH, DPCH are considered in the analysis. Relation of transport channels to physical channels is as follows:

BCH in transport layer is mapped to PCCPCH, PCH and FACH to SCCPCH, DCH to DPCH, respectively [1], whereas CPICH is not mapped to any transport channel.

The received Eb/No of CPICH can be denoted as

$$\left(\frac{E_b}{N_0}\right)_{CPICH} = \frac{P_{CPICH} / L_T(R)}{N_m + I_T} \cdot \left(\frac{W}{R_b}\right)_{CPICH} \quad (3)$$

where SCPICH and PCPICH are the transmitted and the received CPICH power, respectively. $L_T(R)$ indicates the transmission loss. N_0 is the thermal noise power spectral density and N_m is the noise power at the mobile receiver. I_T is the effective noise power of the received forward link interference. R_b is bit rate and W is the transmission bandwidth. In the above equation for Eb/No, all parameters such as pilot, TPC, TFCI, CRC, tail, repetition, and channel coding are calculated as overhead.

The PCH and the FACH can be mapped to the same or to separate SCCPCH. In the analysis, we assume that the PCH and the FACH are mapped to separate SCCPCH, denoted as SCCPCH1(PCH), SCCPCH2 (FACH).

The received Eb/No's of BCH, PCH, FACH and DCH are derived using the same manner.

In equation (3), I_T is common to all forward link physical channels and can be spilt into same-cell interference ISC and other-cell interference IOC. Assuming transmission power of all base stations is equal, I_T can be written

$$I_T = I_{SC} + I_{OC} = (K_{same} + K_{other})S = K_f S \quad (4)$$

where K_{same} is the orthogonality factor of the forward link(K_{same} =0 means that all the forward link channels are perfectly orthogonal). K_{other} is a factor to define other cell interference power. In this analysis, K_{same} = 0.4/0.06 (macro/micro), K_{other} = 2.5 dB(value at the cell edge) are used [2,3]. Thus, the value of K_f becomes 2.1778/1.838 (macro/micro).

2.3 Forward link Power Allocation

The total transmission power in the forward link of eq. (2) is rearranged as follows:

$$P_{total} = P_{CPICH} + P_{PCCPCH} + P_{SCCPCH1} + P_{SCCPCH2} + K_{DPCH} M \alpha_f P_{DPCH} \quad (5)$$

Since all users are not in the cell edge, transmission power of DPCHs for users near to the base station can be decreased through power control. K_{DPCH} in above equation is the factor to consider this power control effect. Assuming that users are distributed uniformly distributed over area and propagation power law is 3 or 4, K_{DPCH} =0.3~0.4 would be reasonable. Adding the margin term, 0.5-0.6 is a reasonable value [2].

By replacing I_T in eq. (3) with eq. (4), the received Eb/No of CPICH becomes

$$\left(\frac{E_b}{N_0}\right)_{CPICH} = \frac{P_{CPICH}}{N_m L_T(R) + K_f P_{total}} \cdot PG_{CPICH} \geq \rho_{CPICH} \quad (6)$$

where ρ is the required Eb/No and PG_{CPICH} is the processing gain of CPICH.

From eq. (5) and (6), we can obtain eq. (7).

$$P_{CPICH}\left(\frac{PG_{CPICH}}{K_f \rho_{CPICH}} - 1\right) - (P_{PCCPCH} + P_{SCCPH1} + P_{SCCPC2} + K_{DPCH} M \alpha_f P_{DPCH}) \geq \frac{N_m L_T(R)}{K_f} \quad (7)$$

Inequality means that the received Eb/No has some margin over required Eb/No. Equations for PCCPCH, SCCPCH1, SCCPCH2 and DPCH can be attained as the same manner for CPICH. Assuming that there are no margins, the solutions for the forward link transmission power are obtained through some calculations.

(8)

$$Z = 1 - k_f \left(\frac{\rho_{CPICH}}{PG_{CPICH}} + \frac{\rho_{BCH}}{PG_{BCH}} + \frac{\rho_{PCH}}{PG_{PCH}} + \frac{\rho_{FACH}}{PG_{FACH}} + K_{DPCH} M \alpha_f \frac{\rho_{DCH}}{PG_{DCH}} \right)$$

3. Forward Link Capacity

3.1 Asymptotic capacity

The amount of forward link power increases to infinite at a certain value of M, the number of users. This behavior can be interpreted in terms of a limit to the forward link user capacity. Assuming that there is no power limit, forward link asymptotic capacity can be attained as follows.

For each channels forward link power to be positive, the following restriction must be applied to the denominator.

$$Z = 1 - k_f \left(\frac{\rho_{CPICH}}{PG_{CPICH}} + \frac{\rho_{BCH}}{PG_{BCH}} + \frac{\rho_{PCH}}{PG_{PCH}} + \frac{\rho_{FACH}}{PG_{FACH}} + K_{DPCH} M \alpha_f \frac{\rho_{DCH}}{PG_{DCH}} \right) > 0 \quad (9)$$

By exchanging inequality to equality and solving for M, asymptotic forward link capacity(M_∞) is obtained.

$$M_\infty = \frac{PG_{DCH}}{K_{DPCH} \alpha_f \rho_{DCH}} \times \left[\frac{1}{k_f} - \frac{\rho_{CPICH}}{PG_{CPICH}} - \frac{\rho_{BCH}}{PG_{BCH}} - \frac{\rho_{PCH}}{PG_{PCH}} - \frac{\rho_{FACH}}{PG_{FACH}} \right] \quad (10)$$

Eq. (10) denotes the upper bound on the forward link capacity.

3.2 Power limited capacity

Since transmission power of the base station (P_{max}) has a limit, the capacity of the forward link is obtained when the total transmission power equals the maximal power. In this case, by substituting the transmission power of each channel, the total transmission power in eq. (5) can be denoted as

$$P_{total} = P_{max} = \frac{N_m L_T(R) \left(\frac{\rho_{CPICH}}{PG_{CPICH}} + \frac{\rho_{BCH}}{PG_{BCH}} + \frac{\rho_{PCH}}{PG_{PCH}} + \frac{\rho_{FACH}}{PG_{FACH}} + K_{DPCH} M \alpha_f \frac{\rho_{DCH}}{PG_{DCH}} \right)}{1 - k_f \left(\frac{\rho_{CPICH}}{PG_{CPICH}} + \frac{\rho_{BCH}}{PG_{BCH}} + \frac{\rho_{PCH}}{PG_{PCH}} + \frac{\rho_{FACH}}{PG_{FACH}} + K_{DPCH} M \alpha_f \frac{\rho_{DCH}}{PG_{DCH}} \right)} \quad (11)$$

Solving above eq. (11) for M, forward link capacity, $M(P_{max})$, can be obtained.

$$M(P_{max}) = \frac{PG_{DCH}}{K_{DPCH} \alpha_f \rho_{DCH}} \times \left[\frac{P_{max}}{N_m L_T(R) + K_f P_{max}} - \frac{\rho_{CPICH}}{PG_{CPICH}} - \frac{\rho_{BCH}}{PG_{BCH}} - \frac{\rho_{PCH}}{PG_{PCH}} - \frac{\rho_{FACH}}{PG_{FACH}} \right] \quad (12)$$

When multiple services are considered, forward link capacity, $M(P_{max})$, is

$$M(P_{max}) = \frac{1}{K_{DPCH} \cdot X} \times \left[\frac{P_{max}}{N_m L_T(R) + K_f P_{max}} - \frac{\rho_{CPICH}}{PG_{CPICH}} - \frac{\rho_{BCH}}{PG_{BCH}} - \frac{\rho_{PCH}}{PG_{PCH}} - \frac{\rho_{FACH}}{PG_{FACH}} \right] \quad (13)$$

where $X = \sum \alpha_{fi} r_i \rho_i / PG_{DCH\_i}$ · r_i is ratio of users using i-*th* service to the total users, ρ_i and PG_{DCH_i} is the required Eb/No and processing gain of i-*th* service, respectively.

4. Results

Parameters used in the scenarios are listed in table 1. Fig. 1 depicts the variation of required channel transmitter power according to the number of users in the macro cell environment, where the transmission loss $L_T(R) = 130$ dB and only voice service are assumed. From the figure, more power is needed as the number of users increases. When M approaches about 70, required powers abruptly increases and all the forward link channels cannot meet the requirements when the number of users exceeds 74.

The forward link capacity when all the active users use voice service (12.2 kbps) in the macro cell is shown in Fig. 2. From the asymptotic capacity, we can see that the number of users where the transmission power increases abruptly in Fig. 1 is the upper bound of a user capacity. The power limited capacity in Fig. 2 shows that when the transmission loss is about 110-120 dB there are little differences between the cases with maximum transmission power of 1W, 5W, 10W. This means that forward link capacity can be maintained using relatively small transmission power according to the propagation condition and the cell size.

Fig. 3 and Fig. 4 depict the user capacity with various services. Non-Line of Sight model of COST-231(Walfisch-Ikegami) is used as an urban propagation model. Parameters used in the scenarios are listed in table 2[3].

Fig. 3 shows that forward link capacity in the urban macro cell environment is about 29 and 3, respectively for the voice and the data service at the distance of 1km. In Fig. 4, forward link capacity in the urban micro cell environment is about 14, 4, and 2, respectively for the voice and the data services (144kbps, 384 kbps), when the cell radius is 0.2km. In both cases, total user capacity decreases rapidly as the number of users using high rate services increases. So, it is desirable that high rate services be mapped to micro cell.

[Table 1] Parameters for IMT-2000 forward link analysis

Parameter	Value
Antenna Gain	MS:0 dBi, BS:11 dBi
Log Normal Fade Margin	10 dB
Power Control	Perfect
Noise Figure	9 dB
Receiving Bandwidth	3.84 MHz
Noise Power	-99 dBm
Maximum Transmission Power	43 dBm/33 dBm (macro/micro)
User Distribution	Random and Uniform
Information rate	CPICH: 30kbps BCH: 15kbps PCH,FACH: 48kbps DCH: 12.2/144,384kbps (Voice/Data)
Required Eb/No	Macro cell CPICH: 7 dB BCH: 7 dB PCH: 4dB FACH: 4dB DCH: 9 dB/5 dB (12.2/144 kbps) Micro cell CPICH: 6 dB BCH: 6 dB PDH: 3 dB FACH: 3 dB DCH: 6.5 dB/4 dB/3 dB (12.2/144/384 kbps)
α_f	0.4/1 (Voice/Data)
K_{DPCH}	0.5
k_f	2.178/1.838 (Macro/Micro)

[Table 2] Parameters for Fig. 3 and 4

Parameter	Value	
	Macro	Micro
Voice:data:data(12.2:144:384 kbps)	9:1:0	7:2:1
BS Antenna Height	30 m	10 m
MS Antenna Height	1.5 m	1.5 m
Nominal Height of Building Roofs	20 m	20 m
Building Separation	40 m	40 m
Width of Street	20 m	20 m
Angle of Incident wave	90 °	90 °

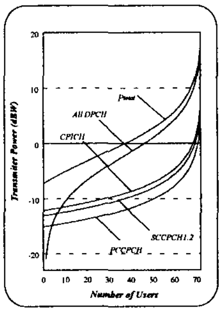

Fig 1. Required channel power vs number of users

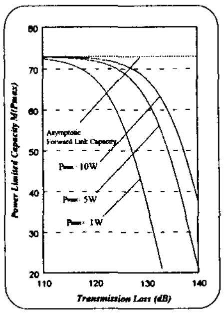

Fig 2. User capacity vs transmission loss

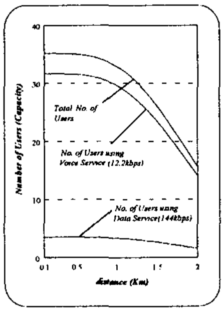

Fig 3. User capacity vs cell radius (macro)

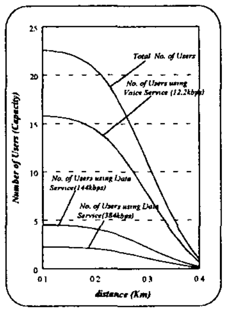

Fig 4. User capacity vs cell radius (micro)

5. Conclusions

In this paper, the forward link user capacity is derived by using the solutions of forward power allocation. In addition, features of capacity related to required channel power, transmission loss and cell radius are shown. These results show that IMT-2000 system with a mixed service environment should carefully allocate its forward link power to obtain a proper user capacity and consider the ratio of service to be served and user density for optimal cell planning.

References

[1] 3rd Generation Partnership Project(3GPP) Technical Specification

[2] J.S.Lee , "CDMA System Engineering Handbook", Artech House Publishers, 1998.

[3] Almgren, M., Bergstrom, L. Frodigh, M., Wallstedt K., "Channel Allocation and Power Settings in a Cellular System with Macro and Micro Cells Using the Same Frequency Spectrum", Proceedings of VTC96, Atlanta, USA, April/May 1996, pp.1150-1154