System Load Estimation for IMT-2000 in Multi-user Multi-service Environment

J.H. Kim*†, Y.H. Bae**, B.S. Min*, and D.W. Tcha*‡

* Graduate School of Management, KAIST(Korea Advanced Institute of Science and Technology)

207–43, Cheongryangri-Dong, Dongdaemun-Gu, Seoul, 130–012, Korea

Phone: +82–2–958–3377, Fax: +82–2–958–3376

** Access Network Laboratory, Korea Telecom

17 Woomyun-dong, Seocho-gu, Seoul, Korea

Phone: +82-2-526-5214

ABSTRACT

The IMT-2000 system provides diversified functionalities as compared with the existing mobile phone systems. Through considerable enhancements in lower layer, multistage multiplexing, and common channel accessing, simultaneous multiple services for multiple users can be supported. Traffic patterns generated by users vary, consuming system resources in different ways. To economically design a wireless network, a new system load estimation method has to be developed, the resulting value of which may be used as one of the most important decision criteria. In this paper, we propose a new method to calculate a system load, especially the wireless channel load, in multi-user multi-service environment, based on which key system design criteria are presented.

KEYWORDS

Capacity Planning, CDMA, IMT-2000, UMTS, System Load

1. Introduction

The voice only service has been migrated to the multimedia services supported by IMT-2000 including web

---

† Presenter

‡ Corresponding author: tchadw@sorak.kaist.ac.kr (with CC to kimtim@kgsm.kaist.ac.kr)

browsing, file transfer, e-mail, etc.. These heterogeneous service classes and high data rates are to be treated with enhanced multiplexing schemes and more complicated media access control which characterizes the IMT-2000 air interface. A particular point to note in the air interface is that due to varying sizes and arrival patterns of multimedia packets, a dual mode transmission scheme is supported therein either via a common channel or via a dedicated channel. The common channel is typically used for short infrequent packets, mostly downstream. The dedicated channel is usually for transmission of a long sequence of packets. These complicated characteristics on channel requirements makes the planning and design of the IMT-2000 wideband CDMA system quite different from the one of the traditional mobile communication systems. Each service is with its own traffic characteristics, which has not fully been investigated in wireless environment. The heterogeneity of the IMT-2000 service classes makes it undesirable to simply employ the CDMA erlang capacity estimation method developed for homogeneous voice traffic[1]. A study particularly drawing our attention is that by Ishikawa et al. [2], which views a cellular CDMA system as a resource limited system, not as an interference limited system, and conducts its capacity planning. Following their approach, we first describe the wideband CDMA system for IMT-2000 service as resource limited system, and then obtain its system capacity of the maximum possible number of simultaneous users supported.

The paper is organized as follows. In section 2, we describe a wideband system model as a resource limited system and calculate its trunking capacity. IMT-2000 services are classified, and their characteristics are listed in section 3. In section 4, we define the transmitting power limit as a resource limit and develop power-balancing constraints. The multi-user multi-service environment of IMT-2000 is described and a numerical example of capacity analysis based on the power balancing constraint is illustrated in section 5. Finally given are concluding remarks and some hints of future works.

2. System Model Description

As the first step to view the system as a limited resource, we develop the concept of trunking capacity that has not been seen in the research community regarding it as an interference limited system. But calculating the number of trunk channels itself requires the use of interference limit concept. Note that the number of trunk channels has been used as a resource measure for the environment of homogeneous traffic only

2.1. Trunking Capacity

With I_0 and I_{other} respectively defined as the acceptable maximum total interference and interference from other cells, the following inequality has to be met for communication quality,

$$\frac{E_b(K-1)}{pg} + N_0 + I_{other} \le I_0, \tag{1}$$

where K, E_b, N_0 and pg denote respectively the number of active (ON) users in the same cell, bit energy, thermal noise power density, and processing gain. The processing gain can be seen as W/R in the CDMA system, where W is spread-spectrum bandwidth and R is data rate. The first term of the left hand side of the inequality means the own cell interference. Then the inequality means the summation of the own cell interference, background noise (i.e. N_0) and total other cell interference cannot exceed the required interference level. Without loss of generality, the background noise N_0 can be replaced by ηI_0, where the typical value for η is 0.1. Also, I_{other} can be substituted for $f \cdot \frac{E_b(K-1)}{pg}$, where f is the ratio of other to own cell interference. Then inequality (1) can be transformed as

$$K \le \frac{W}{R} \cdot \left(\frac{E_b}{I_0}\right)^{-1} \cdot \frac{1-\eta}{1+f} + 1 \tag{2}$$

The K means the maximum number of active users using the homogeneous service class in one cell. The value of K can be calculated relatively easily if the associated parameter values are known. For example, in case of the IS-95 based voice service, $W = 1250$ kHz, R =9.6 kbps, W / R is 21dB, E_b / I_0 have to be 7dB to achieve BER < 10^{-3}, f =0.6, and $\eta = 0.1$. From inequality (2), $K \le 15.6$, implying that K, the maximum number of active users using voice service in one cell, is 15. Namely, the trunking capacity for voice traffic can be calculated via inequality (2).

2.2 . Trunking Capacity accounting for Activity Factor and Outage

Matragi and Nanda [3] derived the maximum number (of the same type) of users' calls as follows. Let N be the maximum number (of the same type) of users' calls that can be supported in a cell, such that the cases of outage, i.e., the number of simultaneously busting users, exceeds K with probability less than BP. Typical values for BP are in the range of 0.01 – 0.1. It is easy to show that N is given by

$$N = \max\{I : \text{such that} \sum_{k=K}^{I} \binom{I}{k} \alpha^k (1-\alpha)^{I-k} \le BP\} \tag{3}$$

where α is the activity factor of the cell.

3. Service Classification

In contrast to the traditional mobile communication system, the IMT-2000 system can support all imaginable services conceptually. The wide bandwidth of 5 MHz and the high speed chip rate of 3.84 Mcps serve the physical data rate of maximum 2 Mbps. The MAC layer makes admission control to the common resource (i.e. channel), supporting both the traditional circuit mode and the packet mode taken in Internet. The exponential increasing of Internet renders the packet type data traffic the most important kind far exceeding all other kinds of traffic.

3.1. Service Classification for IMT-2000

Among a number of classes of packet type data transmission services, those key ones offered as the basic services are listed below

- Voice telephony

- Streaming (Video on Demand, Audio on Demand)
- Data Transfer (FTP)
- E-mail
- Web

The characteristics of the listed services are summarized in table 1.

	Average Data Rate	Degree of channel occupancy	Symmetry	Average Duration	Transmission Type	Expected main using channel type
Voice telephony	8 ~ 13kbps	Medium	Symmetric	180s	Circuit	Dedicated
VoD	384kbps	High	Asymmetric	N/A	Circuit	Dedicated
AoD	128kbps	High	Asymmetric	N/A	Circuit	Dedicated
Data transfer	384kbps	Low	Asymmetric	485s	Packet	Dedicated /Common
E-mail	32kbps	Low	Asymmetric	0.55s	Packet	Dedicated /Common
Web	384kbps	Low	Asymmetric	500s	Packet	Dedicated /Common

Table 1. Basic Service Characteristics

Notes.

- The Degree of channel occupancy means the qualitative measure of activity factor.
- Traffic load of asymmetric services is concentrated on downlink.
- Data transfer model is cited from the ITU 8/1 task group report [4].
- Average size of e-mail is 2kbytes and e-mail can be transmitted at any data rate if delay is allowed.
- Average page size of web is 79kbytes, 9kbytes one text page and 14kbytes five images.

3.2 Downlink Capability of UMTS

To get the actual data rate of each service class, we examine the air interface characteristics. There are two major air interface standards for IMT-2000. One is cdma2000, the North American standard, and the other is UMTS, the European one. cdma2000 adopts the multi carrier (MC) technique for wideband transmission, where raw data is spread into times of 1.25MHz bandwidth. Contrastingly, UMTS use direct spread (DS) spectrum for wideband. It is known that the capability of two standards is only slightly different. But UMTS-DS has recently gained more popularity over cdma2000 among large service operators. So we use those parameter values of UMTS-DS for our purpose throughout the paper, which are listed below.

- Bandwidth: 5MHz
- Chip rate: 3.84Mcps
- Maximum physical data rate: 2Mbps
- Spreading factor: 4 ~ 256
- Channel coding: convolution code 1/3, 1/2or turbo code 1/3
- Radio frame length: 10ms

- Number of slots per radio frame: 16

The source packet or frame (Level 3 data, such as IP datagram), to be transmitted, have to be processed by both Radio Link Control (RLC) and Media Access Control (MAC) layers. In each of two layers, some overheads are added to the raw frame for identification, transmission warranty and data type categorization, etc.. The physical layer further processes these encapsulated frames for data redundancy. Also performed is rate matching to put these frames into fixed format (Refer to [5] for more details). Table 2 shows the resulting figures of data transmissions for those key services.

	# of Bits per Frame	Spreading Factor	Channel Bit Rate	Average Duration
Voice telephony	960	124	64k	180s
VoD	19,968	4	2,048k	N/A
AoD	9,728	8	1,024k	N/A
Data transfer	19,968	4	2,048k	485s
E-mail	2,240	32	256k	0.55s
Web	19,968	4	2,048k	500s

Table 2. Eventual rates for UMTS-DS transmissions

4. Power Allocation for Each Service Class

4.1. Capacity Calculation for Each IMT-2000 Service

This section is to calculate the trunking capacity of each homogeneous service class with the aforementioned parameter values including the activity factor and the outage probability in function (3). Further parameters are specified below.

- E_b / I_0 Requirement for voice and streaming traffic: 7dB
- E_b / I_0 Requirement for data traffic: 12dB
- f : 0.6
- η : 0.1
- W : 5000kHz
- R : Channel bit rate specified table 2

Table 3 shows the trunking capacity of each individual service.

Services	Voice Telephony	VoD	AoD	Data Transfer	E-mail	Web
Trucking Capacity	9.77	1.27	1.55	1.09	1.69	1.09

Table 3. Trunking Capacity of Homogeneous Services

Now, both the activity factor and the blocking probability are taken into account to render the following revised trunking capacity for each service.

	Average Activity Factor	Trunking Capacity with Activity Factor and Blocking Probability	Trunking Capacity divided by Average Activity Factor
Voice telephony	0.400	13	24.43
VoD	1.0000	2	1.27
AoD	1.0000	2	1.55
Data transfer	0.0026	5	419.23
E-mail	1.0000	2	1.69
Web	0.0160	2	68.13

Table 4. Trunking Capacity with Activity Factor and Blocking Probability

Notes.

- The average activity factors are derived from the ratio of actual transmitting time to total session time.
- There is no consideration for duration time. The calculated capacity has to be normalized with unit duration time in multi service environment.
- Blocking probability is assumed at 0.01.

The results in table 4 shows that the 5MHz bandwidth may not be sufficient for high rate – high density multimedia services. Note the level of increase in overhead at the MAC, RLC and physical layers, sacrificed for the safe transmission and efficient media access control

4.2. Power Allocation in Downlink

Most of high rate – high density services place asymmetrically heavy loads to downlinks. The transmitting power is set equal over all downlink channels for the same service. Some previous studies assume that the transmitting power is proportional to the channel data rates. But in this paper, we simply set the power at

$$P_i = \frac{P_{\max}}{N_i} \quad (4)$$

where $P_{\max}$ is the maximum available total power for the downlink in one cell, and N_i is the estimated maximum number of type i trunking channels that can be obtained from function (3). Then, P_i is the minimum power level of type i downlink channel to guarantee a sufficient level of QoS.

5. Capacity Analysis for Multi-User Multi-Service Environment

5.1. Multi-User Multi-Service Environment

To estimate the system capacity in a multi-service environment, we introduce a unified system load measure for IMT-2000 services. The traditional CDMA system capacity measure of the erlang capacity, since can be applied only for homogeneous services, is not adequate for the co-existence environment of heterogeneous services. For that, we consider the following power balancing constraints

$$\sum_{i}\sum_{j=1}^{N_i} P_i \le P_{\max} \tag{5}$$

where i is the index of service classes, and P_i, N_i and $P_{\max}$ are as given in section 4.2. Inequality (5) arises from that the total power consumption of all heterogeneous services in a cell should not exceed the predefined threshold. Since P_i is the minimum required power level of type i service, the capacity of a cell can be expressed as the sum of active users , or active individual services in the cell. When a single user is with two or more services simultaneously, we can view this specific person as two or more individual persons are with his own service. In this case, the average activity factor would be lowered than the case of single service only.

5.2 Numerical Example of Capacity Analysis based on Power Balancing Constraint

We provide a numerical example of capacity analysis based on inequality (5) in this section. There are six service classes and we assume that the predefined power threshold, $P_{\max}$ is 3000mW. From table 4 and the predefined power threshold, we can calculate the power consumption of each individual session. The minimum required power levels of Voice, VoD, AoD, Data Transfer, E-mail and Web are respectively 230mW, 1500mW, 1500mW, 600mW, 1500mW, 1500mW in each active state. So inequality (5) can be rewritten as

$$230N_{voice} + 1500N_{vod} + 1500N_{aod} + 600N_{data} + 1500N_{e-mail} + 1500N_{web} \le 3000 \tag{6}$$

Any possible combination of $\{N_i\}$ can be a capacity of IMT-2000 system for multi service classes in a single cell.

6. Conclusion and Future Works

The IMT-2000 system can provide all imaginable services through enhanced physical layer capability and MAC/ RLC functions. The main services are multi media services requiring packet transmission. For system capacity planning, an appropriate capacity measure has to be figured out. The traditional erlang capacity estimation for the CDMA system is not adequate for the co-existing environment of heterogeneous service classes. For the purpose of finding a unified measure that can quantify a system load of each service class, we first estimate the maximum number of trunking channels satisfying the interference limit constraints. Considering additionally the activity factor of each single service and the blocking probability, the real characteristics of IMT-2000 services are analyzed to give rise to the maximum number of simultaneous users who use homogeneous services. Finally we suggest a inequality constraint for the co-existing environment of heterogeneous services.

For more accurate capacity estimation, we need to examine the probabilistic aspects of each service. Also we need to consider service duration times. We suggest only a 'snapshot' of capacity planning. To apply for real system construction, capacity estimation within a specified period is needed. We leave capacity analysis in view of time domain and identification of probabilistic aspects of services for future works.

REFERENCES

1. Viterbi A.M. and Viterbi A.J.(1993). Erlang Capacity of a Power Controlled CDMA System. IEEE Journal on SAC. Vol. 11, No 6. 892 – 900
2. Ishikawa Y. and Umeda N. (1997). Capacity Design and Performance of Call Admission Control in Cellular CDMA Systems. IEEE Journal on SAC. Vol. 15, No 8. 1627 – 1635
3. Matragi W. and Nanda S. (1999). Capacity Analysis of an Integrated Voice and Data CDMA system. IEEE VTC Spring 1999, 1658 – 1663
4. Draft New Report ITU-R M. [IMT-SPEC] Spectrum Requirements for IMT-2000. ITU-R Task Group 8/1 Report
5. 3GPP Technical Specification 25 series