A NEW METHODOLOGY FOR ESTIMATING THE SPECTRUM REQUIREMENTS WITH DATA TRAFFIC

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Abstract: In this paper, we present a new methodology for estimating the spectrum requirements of next generation mobile network with multimedia data traffic. In order to fully reflect the characteristics of mobile multimedia data traffic in the spectrum requirement estimation, we take senven factors into account: self-similarity of the data traffic, the layered structure of the data traffic, asymmetry of the data traffic between uplink and downlink, engineered capacity considering QoS, regional simultaneous FA increase, uneven traffic pattern among base stations, and handoff traffic overhead.

1 INTRODUCTION

Recently, along with the introduction of various mobile access technologies, spectrum demand has been rapidly increased. Therefore, an efficient allocation of spectrum is becoming a principal issue. In order to properly allocate spectrums to service providers, we have to determine how much spectrum is required for specific applications. Predicting the spectrum requirement appropriately is essential for the operators to guarantee the pre-defined quality of service (QoS) and also helps the government to license the proper number of service providers.

This study analyzes the existing studies on data traffic, and presents core factors that must be taken into consideration for spectrum requirements estimation in mobile network with data traffic.

Well-known methodologies for spectrum requirement estimation for mobile services include the Rec. ITU-R M.1390 (1999) and the Report ITU-R M.2023 (2000), which designed especially for IMT-2000. These approaches are based on a circuit-switching model, which mostly assumes voice traffic. However, it is known that data traffic has a self-similarity characteristic unlike voice traffic (Crovella, M. E, 1997) (Leland, 1994). Therefore, data traffic cannot be modeled accurately with Poisson process or Busy Hour Session Attempts (BHSA), which have been widely used for voice traffic modeling.

Furthermore, it is known that the self-similarity produces longer queue length and delay (Grossglauser M. 1999) (Stallings, 1998). Hence, this characteristic should be taken into account when the service (system) capacity is calculated. This paper adopted the "engineered capacity," which reflects the QoS in calculating the system capacity.

We assumed a " regional simultaneous FA increase" in order to avoid possible deterioration of service quality due to hard handoff.

In the ITU-R model, the frequency efficiency of a region is assumed to be constant in calculating the spectrum requirement (ITU-R, 1999) (ITU-R, 2000). However, the frequency efficiency of a region is not constant, and this non-constant characteristic should be considered in spectrum requirement estimation.

The paper is organized as follows. In Section 2, we examine ITU-R's methodology and its limitation.

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In Section 3, we describe the key factors in detail. In Section 4, we propose a new methodology for estimating spectrum requirements, and the conclusion follows in Section 5.

2 ESTIMATING THE SPECTRUM REQUIREMENTS IN ITU-R

There have been many studies for estimating the spectrum requirement for mobile networks with data traffic such as IMT-2000 and WiBro. Well-known methodologies include the Rec. ITU-R M.1390 (1999) and the Report ITU-R M.2023 (2000), which designed especially for IMT-2000. These approaches are based on a circuit-switching model, which mostly assumes voice traffic.

ITU-R M.1390 considers the BHSA for estimating the Erlang traffic per user, assuming that call arrival follows the Poisson Process, and using exponential distribution model for session holding duration. As the traffic for data services is bursty, the activity factor must be taken into consideration. For measurment of QoS, the Erlang-B formula representing the call cut-off probability is used. Moreover, the transmission rate of service channel is set to average sector throughput, which is a physical capacity. The spectral efficiency per cell assumes equal for all cells. ITU-R M.1390 uses the method described above to determine the final spectrum requirements (ITU-R, 1999).

ITU-R M.2023 determines the spectrum requirements for IMT-2000 based on the Erlang-C model under the assumption that traffic follows the Poison Process with consideration given to BHSA.

However, it is known that data traffic has a self-similarity characteristic unlike voice traffic (Leland, 1994). Therefore, data traffic cannot be modeled accurately with Poisson process or BHSA, which have been widely used for voice traffic modeling.

Furthermore, it is known that the self-similarity produces longer queue length and delay (Stallings, 1998). Hence, this characteristic should be taken into account when the service (system) capacity is calculated.

3 KEY FACTORS IN ESTIMATING THE SPECTRUM REQUIREMENTS

3.1 Characteristics of Data Traffic

3.1.1 Self-Similarity of Data Traffic

Many studies have reported that data traffic has self-similarity (Crovella, M. E, 1997) (Leland, 1994). The self-similarity of traffic implies that the present traffic pattern has been influenced by past traffic (Leland, 1994) (Willinger W, 1998). Because of the self-similarity, data traffic cannot be modeled by a Poisson process, which assumes that the current state is independent of the past states. And the BHSA also does not fit well for modeling data traffic. ITU-R M.2023, however, did not consider self-similarity because the spectrum requirement of IMT-2000 was estimated by using the Erlang-C model, which assumes Markovian call arrivals and holding times.

In this paper, self-similarity of data traffic is considered in spectrum requirement estimation because future mobile service will deliver much data traffic as well as voice traffic.

3.1.2 Layered Characteristic of Data Traffic

A typical traffic model used for the Internet has a layered traffic structure of packet, packet call, and a session layer appear (TR45.5, 1998). It also shows the asymmetry of traffic flow between uplink and downlink.

ITU-R M.2023 used the “activity factor” in order to obtain Erlang traffic in modeling such layered traffic. However, this scheme does not model data traffic accurately because the Erlang model works well for voice traffic. In order to alleviate this discrepancy, a heuristic approach such as the simulation approach was introduced (Yong-Joo Chung, 2003).

3.2 Engineered Capacity Considering QoS

In estimating the spectrum requirement, average sector throughput has been widely used as the physical layer capacity (ITU-R, 1999). However, the average sector throughput usually does not take into consideration QoS issues such as delay. For example, delay variation over utilization for voice and data traffic (with self-similarity) is shown in Figure 1 (Stallings, 1998). In order to handle the data traffic in estimating the spectrum requirements, we need to consider the "engineered capacity," which takes delay into consideration

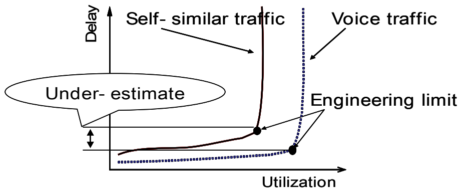

Figure 1: Delay of Self-similar Traffic over Utilization.

3.3 FA Increase Scheme

An example of WiBro spectrum allocation is shown in Figure 2 (MIC, 2004). The unit of spectrum allocation is called the frequency assignment (FA).

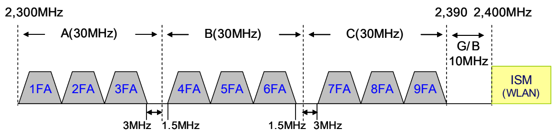

Figure 2: WiBro Spectrum Bands.

We assumed a "regional simultaneous FA increase" in order to avoid the possibility of hard handoff. The rationale for a "regional simultaneous FA increase" is as follows. When the number of FAs for each cell is not the same in a region, a hard handoff may occur if a different FA is assigned to the mobile terminal during handoff. A disconnection during a hard handoff, however, would deteriorate the QoS. We therefore assumed that all the FAs of base stations are extended by the same number (simultaneously) when the number of overloaded base stations in a "handoff region" exceeds a threshold.

3.4 Uneven Traffic Pattern among Base Stations

Figure 3 shows a sample distribution of the offered load of base stations in a region. The offered load varies because of the differences in subscriber mobility, subscriber density, and the users' dispositions.

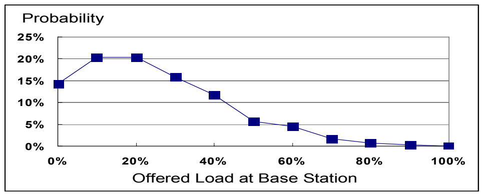

Figure 3: Offered Load at Base Station.

The fact that the offered load varies for the base station implies that spectral efficiency is not fixed for each base station even if service properties are equal. In this paper, the uneven traffic pattern among base stations is considered to obtain the regional operation ratio.

3.5 Handoff Traffic Overhead

Traffic overhead due to handoff in the CDMA system is known to be about 30% of the total traffic. It is noted that the TDMA or FDMA system may also generate handoff overhead traffic in some cases. In this paper, we considered the handoff overhead in the estimating spectrum requirements.

4 PROPOSED MODEL

The new model for estimating the spectrum requirements of a mobile network with multimedia data traffic is proposed. The symbols used in the model are summarized in Table 1.

Table 1: Symbols for the Proposed Model.

N	Number of local subscribers
h	Handoff traffic rate
U , D	Uplink, Downlink
$T_S(\cdot)$	Traffic per subscriber (uplink/downlink)
$T(\cdot)$	Total traffic in a region (uplink/downlink)
$r(\cdot)$	Share of base stations(BS) (Ratio of physical capacity over engineered capacity)
S	Total number of sectors of BS in a region
$C_A(\cdot)$	Average sector throughput of BS (physical capacity)
$C_Q(\cdot)$	Engineered capacity of BS considering QoS
$C(\cdot)$	Total engineered capacity of BS in a region (uplink/downlink)
m	Base station capacity margin
$A(\cdot)$	Regional operating ratio (uplink/downlink)
f	Standard value for capacity increase

The total uplink or downlink traffic in a region is determined by the number of users, traffic per user, and handoff rate:

$$T(i) = NT_S(i)(1+h), \quad i = U, D \qquad (1)$$

The total engineered capacity of the base stations in a region is defined as the product of the engineered capacity of a base station and the total number of sectors.

$$C(i) = SC_Q(i)(1-m), \quad i = U, D \qquad (2)$$

In Eq (2), m is used for the marginal capacity of the base station, and for the engineered capacity of base stations considering the QoS, $C_Q(\cdot)$ is expressed as follows:

$$C_Q(i) = r(i)C_A(i), \quad i = U, D$$

From Eqs (1) and (2), the regional operating ratio, $A(i)$ is defined as follows:

$$A(i) = T(i)/C(i), \quad i = U, D \qquad (3)$$

The regional simultaneous FA increase method can be expressed as:

If $A(U) \geq f$ or $A(D) \geq f$, increase the regional FA

If we assume that traffic is uniformly distributed for each base station and the loads are the same, f becomes one. However, as shown in Figure 3, the load is not the same for all base stations. Therefore, the uneven pattern of traffic distribution in a region makes f less than one.

Following the above process, the required number of FAs in a region can be calculated. It is noted that the spectrum required for a specific service should be chosen as the maximum value among all regional spectrum requirements.

5 CONCLUSIONS

In this paper, we investigated key factors that may affect the estimating of spectrum requirements of next generation mobile network with multimedia data traffic. First, the self-similarity and layered structure of data traffic was considered. Characteristics of data traffic were reflected via simulations. And the asymmetry of data traffic between uplink and downlink was considered to include both types of traffic. Second, engineered capacity based on the QoS (e.g., delay) was used as the system capacity. Third, we assumed a “regional simultaneous FA increase” in a region in order to avoid the possibility of deterioration of service quality. Fourth, uneven traffic patterns among base stations in a region were considered, and finally handoff overhead traffic was taken into consideration.

The next study will be showed some numerical examples of the proposed methodology applied to communication technologies. In addition, we need to study in more detail how each of the parameters will change when the individual service environment such as service type and characteristics changes.

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