Comparison of Erlang Capacity Models for Integrated Voice/Data CDMA System

By

Mr. Artit Wattanapruttipaisan

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
in Telecommunications Science
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Master Thesis Approval

Thesis Title	Comparison of Erlang Capacity Models for Integrated Voice/Data CDMA System
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ABSTRACT

In this paper, we present a research of comparison of 3 different resource managements models, Markov chain, Partial sharing, and Complete sharing, evaluated by Erlang capacity and number of subscribers supported by the system. The quality of service parameter, the call blocking probability is used in the analysis. The integration of 2 main services, voice and data, are the main specification modality of analysis in each model. Furthermore the effect of new standard, CDMA2000, and call blocking probability are considered. Finally the greater supportable size of voice/data services introduced by models and the cost of implementation are the factors that help service providers to decide for implementation.

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Chapter 1: Introduction

1.1 Overview

Nowadays wireless communication is gradually a part of people's life style, especially cellular mobile communication as we can see today, a lot of people use mobile phone. There are many cellular phone systems of both analog and digital, but the digital one is better and widely used for the current cellular phone system, especially in the developing countries. For example of the main widely used of the digital system in the present, are Global System for Mobile Communication (GSM), Digital AMPS and Code Division Multiple Access. With the rapid growth of number of users, the capacity is the main issue to take into consideration of each system. The two main cellular systems (GSM and CDMA), are the result of the development of the better efficiency in term of the number of users that system can support at the same time, hand off technique, interference, ... With the high competition in the world of cellular phone system, the smoothness of communication and many services such SMS (Short Messaging Service), MMS (Multimedia Messaging Service) or event WWW (World Wide Web) service and event now the new trend of using service concern more about graphic and video, are the strength point of marketing. And so, the systems to be used have direct impact on the growth of users, which in turn has implication on the limited resource and capacity of the operating systems themselves. For this work, we interested in CDMA2000 standard, which is the future kind of development of CDMA system.

1.2 Objective

Because of its many good points of CDMA especially in term of capacity, CDMA is very interesting to research. Until now, there are many studies that devote to the capacity of the CDMA system, which is defined as the maximum simultaneous number of user. For papers studying about the multimedia services in the DS-CDMA system, many devote to the control purpose of the system, but not estimating the supportable size of the system. And to estimate the capacity, there still are many ways to measure the system capacity such as peak load, Erlang capacity, and Erlang capacity seems to be the major of measurement of the capacity in integrated services (such voice and data) in CDMA system. Many models have been developed to find out the supportable size of integrated voice and data CDMA system by using the Erlang capacity as the measurement. And for me, the models of managing resources that effect directly to the supportable size of system are interesting. The problem is that many of them were introduced but not find out which model is better than the others yet, such in terms of its characteristics, strength and weak points of them. So the comparison is needed. Therefore, it is interesting to compare these models using the same set of input parameters. In this work we will investigate two main Erlang Capacity models for Integrated Voice, Data CDMA systems proposed in [4] and [6]. The Erlang Capacity will be calculated separately form each model using the CDMA 2000 standard. So that we can find out the suitable Erlang Capacity models of resource management for integrated voice and data in future CDMA systems.

So the main purposes of this thesis are as following:

- To characterize the nature of each model for managing the resource by Erlang capacity and number of subscribers that system is able to support
- The effect of the CDMA standards, IS-95 and CDMA2000, that are applied to each resource management model
- Comparing all models with the strength and weak points perspective

From this kind of researching, the result will help the service provider to apply to maintain the best of efficiency of system management and customer satisfaction purpose.

Chapter 2: Background and Survey of Related Works

2.1 Overview of Cellular CDMA

One of the most important concepts to any cellular telephone system is that of "multiple access", meaning that multiple, simultaneous users can be supported. In other words, a large number of users share a common pool of radio channels and any user can gain access to any channel (each user is not always assigned to the same channel). A channel can be thought of as merely a portion of the limited radio resource, which is temporary, allocated for a specific purpose, such as someone's phone call. A multiple access method is a definition of how the radio spectrum is divided into channels and how channels are allocated to the many users of the system. And nowadays many multiple access techniques are introduced [7], [10], [14].

2.1.1 Current Cellular Standards

Different types of cellular systems employ various methods of multiple access. The traditional analog cellular systems, such as those based on the Advanced Mobile Phone Service (AMPS) and Total Access Communications System (TACS) standards, use Frequency Division Multiple Access (FDMA). FDMA channels are defined by a range of radio frequencies, usually expressed in a number of kilohertz (kHz), out of the radio spectrum. With FDMA, only one subscriber at a time is assigned to a channel. No other conversations can access this channel until the subscriber's call is finished, or until that original call is handed off to a different channel by the system.

A common multiple access method employed in new digital cellular systems is Time Division Multiple Access (TDMA). TDMA digital standards include North American Digital Cellular (known by its standard number IS-54), Global System for Mobile Communications (GSM), and Personal Digital Cellular (PDC). TDMA systems commonly start with a slice of spectrum, referred to as one "carrier". Each carrier is then divided into time slots. Only one subscriber at a time is assigned to each time slot, or channel. No other conversations can access this channel until the subscriber's call is finished, or until that original call is handed off to a different channel by the system.

2.1.2 The CDMA Cellular Standard

With CDMA, unique digital codes, rather than separate RF frequencies or channels, are used to differentiate subscribers. The codes are shared by both the mobile station (cellular phone) and the base station, and are called "pseudo-Random Code Sequences." All users share the same range of radio spectrum. From using this technique, it offers the main advantage of low interference comes from the orthogonality of this code [5], [7], [8].

For cellular telephony, CDMA is a digital multiple access technique specified by the Telecommunications Industry Association (TIA), there are many standard nowadays such as W/CDMA, CDMA2000 and there is the old main one that we may be familiar with, which is IS-95. IS-95 systems divide the radio spectrum into carriers, which are 1,250 kHz (1.25 MHz) wide. CDMA standards support a frequency bandwidth of 1.25 MHz, wideband CDMA currently supports larger frequency bandwidths of 5, 10, and 15 MHz. Also for CDMA2000 it can offer channel bandwidth of 1.23, 5, 10, 15, 20 MHz wide.

One of the unique aspects of CDMA is that while there are certainly limits to the number of phone calls that can be handled by a carrier, this is not a fixed number. Rather, the capacity of the system will be dependent on a number of different factors. This will be discussed in later sections.

CDMA - Code Division Multiple Access

IS-95 uses a multiple access spectrum spreading technique called Direct Sequence (DS) CDMA. Each user is assigned a binary, Direct Sequence code during a call. The DS code is a signal generated by linear modulation with wideband Pseudorandom Noise (PN) sequences. As a result, DS CDMA uses much wider bandwidth than those used in other technologies. Wideband signals reduce interference and allow one-cell frequency reuse. There is no time division, and all users use the entire carrier, all of the time.

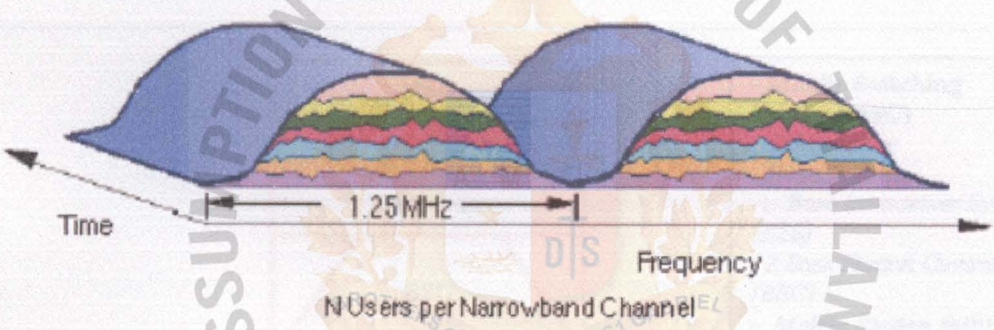


Figure 2-1. DS-CDMA

CDMA Technology

Though CDMA's application in cellular telephony is relatively new, it is not a new technology. CDMA has been used in many military applications, such as anti-jamming (because of the spread signal, it is difficult to jam or interfere with a CDMA signal), ranging (measuring the distance of the transmission to know when it will be received), and secure communications (the spread spectrum signal is very hard to detect).

CDMA is a "spread spectrum" technology, which means that it spreads the information contained in a particular signal of interest over a much greater bandwidth than the original signal. The standard data rate of a CDMA call is 9600 bits per second (9.6 kilobits per second). This initial data is "spread," including the application of digital codes to the data bits, up to the transmitted rate of about 1.23 megabits per second. The data bits of each call are then transmitted in combination with the data bits of all of the calls in the cell. At the receiving end, the digital codes are separated out, leaving only the original information, which was to be communicated. At that point, each call is once again a unique data stream with a rate of 9600 bits per second.

CDMA Implementation

Basic CDMA Architecture

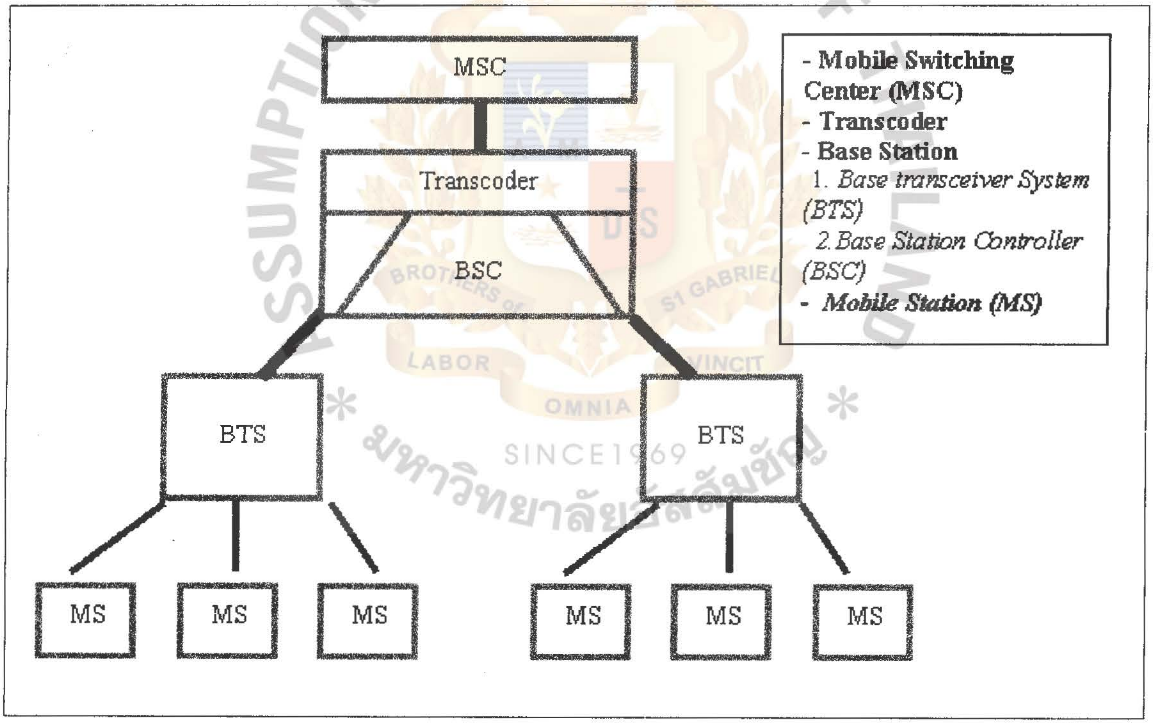


Figure 2-2. Basic CDMA Architecture

The basic architecture is shown in Fig. 2-2.

The main elements of basic CDMA architecture follows:

- Mobile switching center (MSC)

The MSC is an automatic system that interfaces the user traffic from the wireless network to the wire line network or other wireless network. The MSC functions as one or more of the following:

- Anchor MSC – the first MSC providing radio contact in a call.
- Border MSC – an MSC controlling BTSs adjacent to the location of a mobile station.
- Candidate MSC – an MSC that could possibly accept a call or a handoff.
- Originating MSC – the MSC directing an incoming call toward a mobile station.
- Remote MSC – the MSC at the other end of an intersystem handoff trunk.
- Serving MSC – the MSC currently providing service to a call.
- Tandem MSC – an MSC providing only trunk connections for a call in which a handoff has occurred.
- Target MSC the MSC selected for a handoff
- Visited MSC – an MSC providing service to the mobile station.

• Transcoder (XC)

The transcoder supports both voice coding (vocoder) and diversity reception. Diversity reception allows the transcoder to pick the "best" frame when multiple connections are established during a soft handoff. Diversity reception distinguishes CDMA technology from current digital technology.

The XC is responsible for the following:

- Distribution of speech/data on the forward traffic channel to all BTSs associated with a call. During a soft handoff, multiple BTSs are simultaneously assigned to the call. The XC selects the best speech/data frame from all BTSs associated with the call on the reverse traffic channel. This implies that signal quality characteristics of the speech/data frame are provided to the transcoder.

- Decode QUALCOMM code-excited linear prediction (QCELP) format, which is the CDMA speech-processing algorithm, to PCM format for voice frames sent on the reverse traffic channel. If the call is a data call, this task is bypassed.
- Decode PCM format to QCELP format for voice frames are sent on the forward traffic channel. If the call is a data call, this task is bypassed.
- Rate adapt voice frames to fully use the transmission bandwidth of the assigned terrestrial circuits. This task is bypassed for data calls.
- Rate adapt compressed voice PCM format into a circuit switched subrate channel on a DS0 facility. Compression uses the fact that voice activity is less than 100% of total duration. Typically, the actual voice activity is approximately 50%.
- Provide a control capability of inserting blank and burst or dim and burst signaling into the voice transmission on the forward traffic channel.

The transcoder is considered as a logical part of the BS, although the transcoder can be physically located at the BS, or at the MSC, or somewhere between the BS and the MSC.

- Base station (BS)

The base station terminates the radio path and connects to the mobile switching center. The base station is often segmented into the BTS and the BSC:

- Base transceiver system (BTS): The BTS consists of one or more transceivers placed at a single location and terminate the radio path on the network side. The GTS may be either co-located with a BSC or independently located.

  BTSs are uniquely identified by the cell global identification (CGI), which is composed of four components:

1. Mobile Country Code (MCC)
2. Mobile Network Code (MNC)
3. Location Area Code (LAC)
4. Cell Identity (CI)

- Base Station Controller (BSC): The BSC is the control and management system for one or more BTSs. The BSC exchanges messages with both the BTS and the MSC. Some signaling messages may pass through the BSC transparently.

• Mobile station (MS).

The MS terminates the radio path on the user side and enables the user to gain access to services from the network. The MS can be a stand-alone device or can have other devices (e.g., personal computers and fax machines) connected to it. The MS is not shown in Fig. 4.1, but the MS communicates with the BTS over the air interface.

CDMA Channels

CDMA uses the terms "forward" and "reverse" channels just like they are used in analog systems. Base transmit equates to the forward direction, and base received is the reverse direction. ("Forward" is what the subscriber hears and "reverse" is what the subscriber speaks.)

CDMA Forward Channels (Base Station to Mobile Station)

Pilot Channel

The pilot channel is used by the mobile unit to obtain initial system synchronization and to provide time, frequency, and phase tracking of signals from the cell site.

Sync Channel

This channel provides cell site identification, pilot transmit power, and the cell site pilot pseudo-random (PN) phase offset information. With this information, the mobile units can establish the System Time as well as the proper transmit power level to use to initiate a call.

Paging Channel

The mobile unit will begin monitoring the paging channel after it has set its timing to the System Time provided by the sync channel. Once a mobile unit has been paged and acknowledged that page, call setup and traffic channel assignment information is then passed on this channel to the mobile unit.

Forward Traffic Channel

This channel carries the actual phone call and carries the voice and mobile power control information from the base station to the mobile unit.

CDMA Reverse Channels

Access Channel

When the mobile unit is not active on a traffic channel, it will communicate to the base station over the access channel. This communication includes registration requests, responses to pages, and call originations. The access channels are paired with a corresponding paging channel.

Reverse Traffic Channel

This channel carries the other half of the actual phone call and carries the voice and mobile power control information from the mobile unit to the base station.

2.1.3 Capacity of Cellular CDMA System

Capacity

Capacity, for the simply meaning is just the number of simultaneous users that the system can support at the same time for unlimited period, we can say that 24 hours /day, 7 days/ week, 4weeks / month, 12 months/year and many years to eternity. For this description of capacity in this aspect, we can assume that if the system can support only 7 users at a time, we only can say that the capacity of this system is just 7 users/time (infinite time). We can imagine like the number of lanes in the road, if there are only 4 lanes on the road that means only 4 cars can use the road at the same time but different lane. However, in reality, none of any user will use the call for eternity, so the other aspect of measuring capacity, we used here is Erlang Capacity. What is the Erlang capacity? It is the capacity that measures in terms of the average number of simultaneous calls of users in reality. Since we investigate about CDMA system, for this system, it is interference-limited which means that the capacity and quality of the system are limited by the amount of interference power present in the band. When we talk about the capacity and quality here is defined as the perceived condition of a radio link assigned to a particular user; this perceived link quality is directly related to the probability of bit error, or bit error rate (BER).

For the CDMA system capacity that is discussed further, relates to the amount of user interference in the band. The actual capacity of a CDMA cell depends on many different factors, such as receiver demodulation, power-control accuracy, and actual interference power introduced by other users in the same cell and in neighboring cells. Before we discuss further about the effected factors to capacity of CDMA system, we learn about a link matric called E_b/N_o , or energy per bit per noise power density. For the quality of system, it refers about bit error, and the probability of bit error can present in term of a function of E_b/N_o. This quality can be related to the conventional signal-to-noise ratio (SNR) by recognizing that energy per bit equates to the average modulating signal power allocated to each bit duration, that is

$$E_b = ST \tag{1.}$$

Where

S = the average modulating signal power

T = Time duration of each bit

Because of bit rate R, is the inverse of bit Duration T.

$$R = 1/T$$

From (1.) we can re-write as

$$E_b = S/R$$

So, E_b/N_o is thus

$$E_b/N_o = S/(R*N_o) \tag{2.}$$

Where noise power density N_o, which is the total noise power N divides by the bandwidth W.

$$N_o = N/W \tag{3.}$$

Then we can have

$$E_b/N_o = (S/N) * (W/R) \tag{4.}$$

So from the equation (4.) energy per bit E_b/N_o relates to two factors, which are signal-to-noise ratio (S/N) of the link and the ratio of transmitted bandwidth W to bit rate R.

Note that the ratio W/R is known as the processing gain of the system.

For considering Reverse-link capacity, the mobile to base station link, we assume that the system possesses perfect power control that means at Base Station receiver, the received powers from all mobile users are equal.

From this, the SNR of one user can be written as

$$S/N = 1/(M-1) \tag{5.}$$

Where

M = the total number of users present in the band.

Note that this equation (5.) also ignores other sources of interference such as thermal noise. In CDMA, the total interference power in the band is equal to the sum of powers from the individual users. Therefore, if there are 7 users occupying the band, and each user is power-controlled to the same power level (perfect power control). Then the SNR experienced by any one user is 1/6.

From (5.) substitute into (4.), so we get

$$E_b/N_o = (1/(M-1)) * (W/R) \tag{6.}$$

$$M-1 = (W/R) / (E_b/N_o) \tag{7.}$$

If M is large, then

$$M \approx (W/R) / (E_b/N_o) \tag{8.}$$

From this equation (8.) is effectively a model that describes the number of users a single CDMA cell can support. This single cell is omidirectional and has no neighboring cells, and the users are transmitting 100 % of that time.

From equation (8.), we can analyze that

$M \alpha W/R$ and

$M \alpha 1/(E_b/N_o)$

Note: α is "proportional to"

So to increase capacity (M), W/R must be high while the E_b/N_o must be low.

Effect of Loading

In reality, there are many cells in a CDMA cellular or PCS system. Loading is the interference from the other cells. For example, a particular cell A is bordered by other CDMA cells that are supporting other users. Although these other users from other cells are power-controlled by their respective home cells, the signal powers from these other users constitute interference to cell A. Therefore, cell A is said to be loaded by users from other cells.

So, from equation (6.) is modified to account for the effect of loading.

$$E_b/N_o = (1/(M-1)) * (W/R) * (1/1+\eta) \tag{9.}$$

Where

η = the loading factor, between 0 % and 100 %

Note that the inverse of the factor $(1+\eta)$ is known as frequency reuse factor F; that is

$$F = 1/(1+\eta) \tag{10.}$$

So, the frequency reuse factor is ideally 1 in the single-cell case ($\eta = 0$). In multicell case, as the loading η increase, the frequency reuse factor corresponding decrease.

Effect of Sectorization

The interference from other users in other cells can be decreased if the cell in question is sectorized. Instead of having an omidirectional antenna, which has an antenna pattern over 360 degrees, cell A can be sectorized to 3 sectors so that each sector is only receiving signals over 120 degree. In effect, a sectorized antenna rejects interference from users that are not within its antenna pattern. This arrangement decreases the effect of loading by a factor of approximately 6. This factor is called sectorization gain λ.

$$\lambda = \int_0^{2\pi} I(\theta)d(\theta) / \int_0^{2\pi} [G(\theta)/G(0)]I(\theta)d\theta \tag{11.}$$

Where

$G(\theta)$ = the horizontal antenna pattern of the sector antenna.

$G(0)$ = the peak antenna gain, which assumed to occur at boresign ($\theta = 0$)

$I(\theta)$ = the received interference power from users of other cells as a function of θ.

The integrals in equation (11.) are evaluated from 0 to 360 degrees. This equation computes the exact sectorization gain, which depends heavily on the antenna gain of the antenna used, as well as on the spatial distribution and distance of interfering users in other cells.

Note that in reality λ is typically around 2.5 for 3-sector configured systems and 5 for 6-sector configured systems. So for equation (9.) is thus modified to account for the effect of sectorization:

$$E_b/N_o = (1/(M-1)) * (W/R) * (1/1+\eta)*\lambda \qquad (12.)$$

Effect of voice activity

From the previous equation (12.), assumes that all users are transmitting 100 % of the time. In practice, the vocoder used by the IS-95 system is transmitting at a variable rate, which means that the output rate of the vocoder is adjusted according to a user's actual speech pattern. For example, the user is not speaking during part of conversation, the output rate of the vocoder is lowered to prevent power from being transmitted unnecessarily. The effect of this variable-rate vocoding is the reduction of overall transmitted power and hence interference. By employing variable-rate vocoding, the system reduces the total interference power by this voice-activity factor. Thus, equation (12.) is modified to account for the effect of voice activity:

$$E_b/N_o = (1/(M-1)) * (W/R) * (1/1+\eta)*\lambda*(1/V) \qquad (13.)$$

Where

V = the voice activity factor

Note that the effect of voice activity is to reduce the denominator, or the interference portion of the equation.

Solving (13.) for M yields

$$M = 1 + [((W/R) * (1/1+\eta)*\lambda*(1/V)) / (E_b/N_o)] \tag{14.}$$

If M is large, then

$$M \approx ((W/R) * (1/1+\eta)*\lambda*(1/V)) / (E_b/N_o) \tag{15.}$$

From the above equation, we can analyze that effect of each factor on the CDMA capacity (M);

$M \alpha$ W and λ

$M \alpha$ $1/R$, $1/(E_b/N_o)$, $1/(1+\eta)$, and $1/V$

Note: α is proportional to

So we can conclude that CDMA capacity will increase when W (bandwidth) increase or λ (sectorization gain) increase and vice versa. In addition, the factors that effect inversely with the CDMA capacity can conclude as following:

CDMA capacity will decrease if E_b/N_o , η or V is smaller value and vice versa.

Power Control

Power control is essential to the smooth of a CDMA system. Because all users share the same RF band through the use of PN codes, each user looks like random noise to other users. The power of each individual user, therefore, must be carefully controlled so that no one user is unnecessarily interesting with others who are sharing the same band. The inequity of SNR (signal-to-noise ratio) of each user in the same cell is known as near-far problem. Power control is implemented to overcome the near-far problem and to maximized capacity. Power control is where the transmit power from each user is controlled such that the received power of each user at the base station is equal to one other.

Conclusion of capacity

Capacity is defined as the total number of simultaneous users the system can support. CDMA system capacity can be described via the amount of user interference in the band. The actual capacity of a CDMA cell depends on many different factors, such as receiver demodulation, power-control accuracy, and actual interference power introduced by other users in the same cell and in neighboring cells. For reverse link in CDMA system is often the limiting link in terms of capacity. Reverse link is the mobile to base station.

The effected factors to capacity

- Capacity, or number of simultaneous users, is directly proportional to the processing gain of the system (W/R).
- The link requires a particular E_b/N_o (Energy per bit per noise power density) to attain an acceptable BER and ultimately an acceptable frame error rate (FER). Capacity is inversely proportional to the required E_b/N_o of the link. The lower the required threshold E_b/N_o, the higher the system capacity.
- Capacity can be increased if one can decrease the amount of loading, interference introduced by users in the neighboring cell, from users in adjacent cells.
- Sectorization (λ) increases system capacity. For example, a six–sector cell would have more capacity than a three-sector cell.
- Capacity is maximized when the received powers of all users are equal at the base station.

For the following section, it concentrates on traffic engineer, the process of provisioning communication circuit for a given service area, at the base station level as related to CDMA system.

2.1.4 CDMA Traffic

Traffic Intensity

Traffic is measured in term of traffic intensity. Traffic intensity is commonly measured in the unit of ***Erlang***. An Erlang defined as the average number of simultaneous calls.

Erlang = Avg. no. of simultaneous calls

= Total usage during a time interval / Time Interval (16.)

For example, assume that the base station logs the number of active calls on a second-by-second basis. For 10-sec interval.

The traffic intensity (the average number of simultaneous calls) is

[(14 calls)(2 sec) + (13 calls)(4sec) + (12calls)(2 sec) + (15 calls)(2 sec)] / 10 sec

= 13.4 Erlang

Note that the numerator is the total usage during this measurement interval (10 sec), and that total usage during this measurement interval is 134 (13.4 * 10) sec.

Because most network management system measure usage during 1 hour intervals, and Erlang is sometimes referred to as 60 minutes or 1 hour of usage.

Grade of Service

The term of blocking probability is often used interchangeably with grade of service.

Blocking probability (Hard Blocking): the probability that a call is blocked due to no channel available.

Blocking probability (Soft Blocking): the probability that a call is blocked due to the interference level is above the predetermine threshold due to the exceed of users.

Load

Offered load: the amount of traffic load offered by user to network.

Carried load: the amount of traffic load that network handles (actually carried by network).

The offered load, during the time interval can be estimated by the following equation:

$$\text{Carried load} = (\text{offered load}) * (1 - \text{Blocking Prob}) \tag{17.}$$

$$\text{Offered load} = (\text{carried load}) / (1 - \text{Blocking Prob}) \text{ or} \tag{18.}$$

$$= \lambda/\mu \tag{19.}$$

where

$\lambda =$ the Poisson arrival rate of λ calls/sec.

$1/\mu =$ the exponential call service time of $(1/\mu)$ seconds/call.

Note: Calls arrive according to the Poisson process. This implies that the time between call arrivals is exponentially distributed. For this to be strictly true, a user whose call is blocked cannot immediately retry.

Mathematical Models

Erlang-B is widely used mathematical model that describe the relationship among the blocking probability (grade of service), offered load (demand), and number of channel.

Erlang-B model

Erlang-B assumes that blocked are cleared and the caller are tried again later. So the caller whose call is blocked does not immediately re-originate the call.

The blocking probability $P_{(blocking)}$, or grade of service, according to the Erlang-B model, is given by

$$P_{(blocking)} = (P^c/C!) \,/ \sum_{i=0}^{C} (P^i/i!) \tag{20.}$$

Where

C: number of channel

P: the offered load

2.1.5 Voice & Data Integration

Voice Traffic Characteristics

- Require real time delivery – no delay
- Tolerate higher error rate than data

Data Traffic Characteristics

- No need for real time delivery – discontinuous transmission
- Require very low error probability

The data call is similar in nature to a voice call, barring the data rate and the activity duration. [6]

Simultaneous Voice and Data

The CDMA system will support the simultaneous transmission of voice and data. The two digital streams will be multiplexed on a frame-by-frame basis with voice being given priority over data to maintain voice quality. As higher data rate channels, data throughput will increase. Several modes of operation including turning on and off voice service during a data call or adding data to a voice call in progress will be supported. Speech statistic shows that a user in a conversation typically speaks between 40 % and 50 % of the time [17].

2.2 Literature Reviews

2.2.1 Capacity Analysis of an Integrated Voice and Data CDMA System [6]

In this paper, the researcher introduced an approach for evaluating the Erlang capacity of a single carrier CDMA system with voice and data users with different bit rates.

They also provided more specific for analyzing the capacity, which limited by the old conventional one that does not cover for the more services. Such as before, only voice service provided so the QoS (Quality of service) that take into account for analysis is Outage Probability, traditionally the capacity of system determined by this [12] and many approaches use it [9]. But for new coming service, data service, has the different characteristics compared to voice service. To use only one standard of measure such Outage Probability, which set as the fixed value for all types of traffic, seems not enough to cover for 2 distinguish services and the outcome of the analysis will not give the suitable result for the real situation. Also to adapt the results from this kind of analysis is not suitable. So they introduced additional measure to deal with these 2 kinds of service, voice and data, a call Blocking Probability, for this they can study different grade of service for different types of calls.

Capacity is calculated for reverse link.

There are 2 steps of capacity calculation as following:

1. Determine the trunking capacity or number of active user (or some books or journals refer to the number of channels). By this capacity, they use the Outage Probability for calculation.
2. Determine the Erlang Capacity for CDMA system by using the Erlang-B model and generalized-Erlang model in [1]. The result from the previous step, number of users, will be taken into account to find out the Erlang Capacity.

For this analysis, call blocking probability is the major factor to deal with capacity.

For this approach, they assumed the same outage probability for both types of calls (voice and data), but the call blocking probability is different between the two types of calls.

The interesting point of this paper is the method to find out the capacity by Erlang capacity models. They use 2 models for determining capacity, which are Erlang-B model and generalized-Erlang model.

I. System Models

1.) Voice-Only System model

For this part, they introduce about the outage probability for the CDMA reverse link; outage occur when total collection of users introduce an amount of interference density, I_o, exceeds the background noise level, N_o, by an amount $1/\eta$.

$I_o > N_o$

$I_o - N_o = 1/\eta$

For the single cell voice-only system, outage occur when

$$\sum_{i=1}^{k} \alpha_i E_i > (W/R)(1-\eta) \qquad (1.)$$

Where

K = the number of admitted users in the system

α_i = a binary random variable that denoted the activity factor for the i_{th} user

E_i = SIR for the i_{th} user

Note: $E_i = E_b/I_o$ is the received energy-per-bit to total interference density.

W = bandwidth

R = bit-rate of active user

In their paper, they fix scope as ideal case of fixed SIR targets and perfect power control, in reverse link and single cell.

2.) Call model for voice and data

Now two types of calls are active in the system, voice calls and data calls. How to separate these two call types. The calls can be identified by their data rates (R), activity factor (α), and E (E_b/I_o) requirements.

The following parameters are used:

- α_v, α_d = activity factor for voice and data users respectively
- R_v, R_d = bit rate (in kbps) of voice and data users when active respectively
- Ev, Ed = required E_b/I_o for voice and data calls respectively

They specify the value of these parameters as following; the activity factor for voice calls (α_v) is typically around 0.4 , the channel bit rate of voice (R_v) is 9.6 kbps or 14.4 kbps. Also assume that the data calls once accepted in the system, contract a fixed peak rate (this is in fact a circuit switched data call, but with activity factor less than 1). From this paper, they also said that in fact the data call is similar in nature to a voice call, barring the data rate and the activity duration. There are periods of silence and activity while the data call is in progress.

Next section is concerned about the method to determine the system capacity. They also introduce separately the capacity for call types.

II. Capacity of reverse link CDMA

To perform capacity analysis, there are 2 stages.

First stage, determine the number of available ("Virtual") trunks from a circuit switching perspective. And second stage, determines the Erlang capacity from the numbers of virtual trunks.

1.) Trunking capacity

Virtual trunks are not determined by the number of hardware channel elements available in a CDMA base station, but the number of available virtual trunks, or reverse link capacity is determined by the outage probability. Outage for CDMA reverse link occurs when the total received power from user is such that the required E_b/I_o cannot be met.

$$N_b \approx [((W/R) / E_t) + 1] / (1+f) \quad (2.)$$

Where

N_b = the total number of users active simultaneously

The number of virtual trunk is calculated by

$$N = \max \{ I: \text{such that} \sum_{K=Nb}^{I} \binom{I}{K} \alpha^k (1-\alpha)^{I-k} \leq P_o\} \quad (3.)$$

Where

α = activity factor of call

Then we find the Erlang capacity by using the result of Trunking capacity.

Note: for instant of trunking capacity of 2 services and their relationship also derived in the form of formulas described in [2], [7].

2.) Erlang capacity

They use the Erlang-B formula

$$P_b = (e^N / N!) / (\sum_{k=0}^{N} e^k/k!) \quad (4.)$$

Where

e = Erlang capacity

N = the number of trunk

P_b = call blocking probability

Note: Also mention to the generalized-Erlang model in [1].

Conclusion

- It is beneficial to share the reverse link bandwidth between voice and data calls rather than dedicating some portion of the bandwidth for voice and allocating the remaining bandwidth to the data calls.
- Once data and voice calls are sharing dynamically the available bandwidth, the purposed method provides the service provider with the mean to differentiate voice from data calls by providing lower blocking probability to the voice calls.
- Data calls with higher bit rates (and hence higher quality of service) consume more bandwidth than calls with the same average rate but with lower peak bit rate.

Benefit and Drawback

Benefit

- This paper introduces the suitable method, call blocking probability with different grade of service, of calculating the capacity of CDMA system with many types of services, voice and data. This gives the more reliability to find out the result that comes from the procedure that close and suitable to the real business system.
- They introduced the other interested Erlang capacity model such introduced in [1].

Drawback

- They introduced the Erlang capacity analysis for dynamic sharing model from [1], which is the main model that use for research but mention to it just few descriptions.

2.2.2 Analysis of Erlang Capacity for the Multimedia DS-CDMA Systems [4]

For this paper, the researchers presented an analytical approach for evaluating the Erlang Capacity of multimedia DS-CDMA systems supporting the multi-class services (voice and data) with different transmission rates, bit error rates, traffic activity factors in the reverse link and also find the maximum current number of users which also refer in [7], [8], [15], [16]. The number of concurrent users of the corresponding service groups (voice and data) is modeled as a K-dimension Markov chain. And the Erlang Capacity for multimedia DS-CDMA system will be found based on a K-dimension M/M/m loss system, which extend from [11] that for voice service only. For this paper, they also rely on IS-95 type DS-CDMA system, supporting voice and data services, and the capacity bounds of the maximum current number of users was used for call admission strategy which depicted in conjunction with the 2-dimensional Markov chain. Finally, they apply the channel reservation scheme to increase the total system Erlang Capacity.

There are 2 steps of capacity calculation as following:

1. Find out the system capacity (number of active concurrent users).
2. Find out the Erlang capacity for a given call admission strategy.

The detail of 2 major parts is described in the following section.

1. The System Capacity for the Multimedia DS-CDMA Systems

This multimedia system covers various service groups classified by different quality (E_b/N_o) requirement, information bit rate and traffic activity factor. The system capacity bound of DS-CDMA system supporting K service groups in the reverse link is expressed as:

$$N_i\alpha_i\,(\overline{E_b/N_o})_{i\text{-req}}\,R_i \;+\; \sum_{j=1,\,j\neq i}^{K} N_j\alpha_j\,(\overline{E_b/N_o})_{j\text{-req}}\,R_j \;\leq$$

$$W\,(1/(1+f))\,10^{(Q\text{-}1(\beta))/10)\,\sigma x\,-0.012\sigma x\sigma x} \qquad (1.)$$

Where

W = the allocate frequency bandwidth

N_i = the number of active user of the i-th service group

α_j = the activity factor

$(E_b/N_o)_{i\text{-req}}$ = the require (E_b/N_o)

R_i = information bit rate (i = 1, … ,K)

f = the allocated frequency bandwidth

(1/(1+f)) = the average value of frequency reuse factor

Q^{-1}= the inverse Q-function

σ_X = standard deviation of the receive SIR (Signal to Interference Ratio)

β% = the required system capacity

Note: $10^{(Q\text{-}1(\beta))/10)\,\sigma x\,-\,0.012\,\sigma x\sigma x}$ indicates the effect of imperfect power control error and the required system reliability β% on the system capacity where the imperfect power control error is represented by the standard deviation of received SIR σ_X .

From this equation, we can conclude that the given system resource W is exhausted by two factors; frequency reuse factor, and the standard deviation of the received SIR. In addition, a set of possible admissible states (n_1, n_2, n3, … , n_k) is determined in the range that the sum of the effective bandwidth of active users of each service group does not exceed the total system effective bandwidth.

2. Erlang Capacity for the Multimedia DS-CDMA System

First they assume the system to be considered, is characterized by following:

1.) The calls of the j-th service group in the home cell are generated as a Poisson process with arrival rate λ_j and arrival rate is homogeneous.

2.) CAC rule: A call request is blocked and cleared from the system if its acceptance would move the state out of the admissible region. Otherwise, a call request is accepted.

3.) If a call is accepted, then it remains in the cell of its origin for a holding time that has a Poisson distribution with the mean holding time $1/\mu_j$ where holding time is homogeneous and independent of the other holding time and of the arrival process.

If (n_1, n_2, n3, ... , n_k) denote a state and represent the number of concurrent users of K service groups, the system is modeled as a K-dimension Markov chain.

To find out the Erlang capacity, the formula express as

$$B_i = 1 - G(R\text{-}Ae_i) / G(R) \qquad (2.)$$

Where

B_i = the call blocking probability

G(R) = the normalizing constant calculated on the S(R)

G(R-Ae_i) = the normalizing constant calculated on the S(R-Ae_i) with respect to the traffic of the I-th service group

The following Figure depicts the state transition diagram in the case that the system supports two services groups (voice and data traffics), by given the offered traffic loads of voice and data.

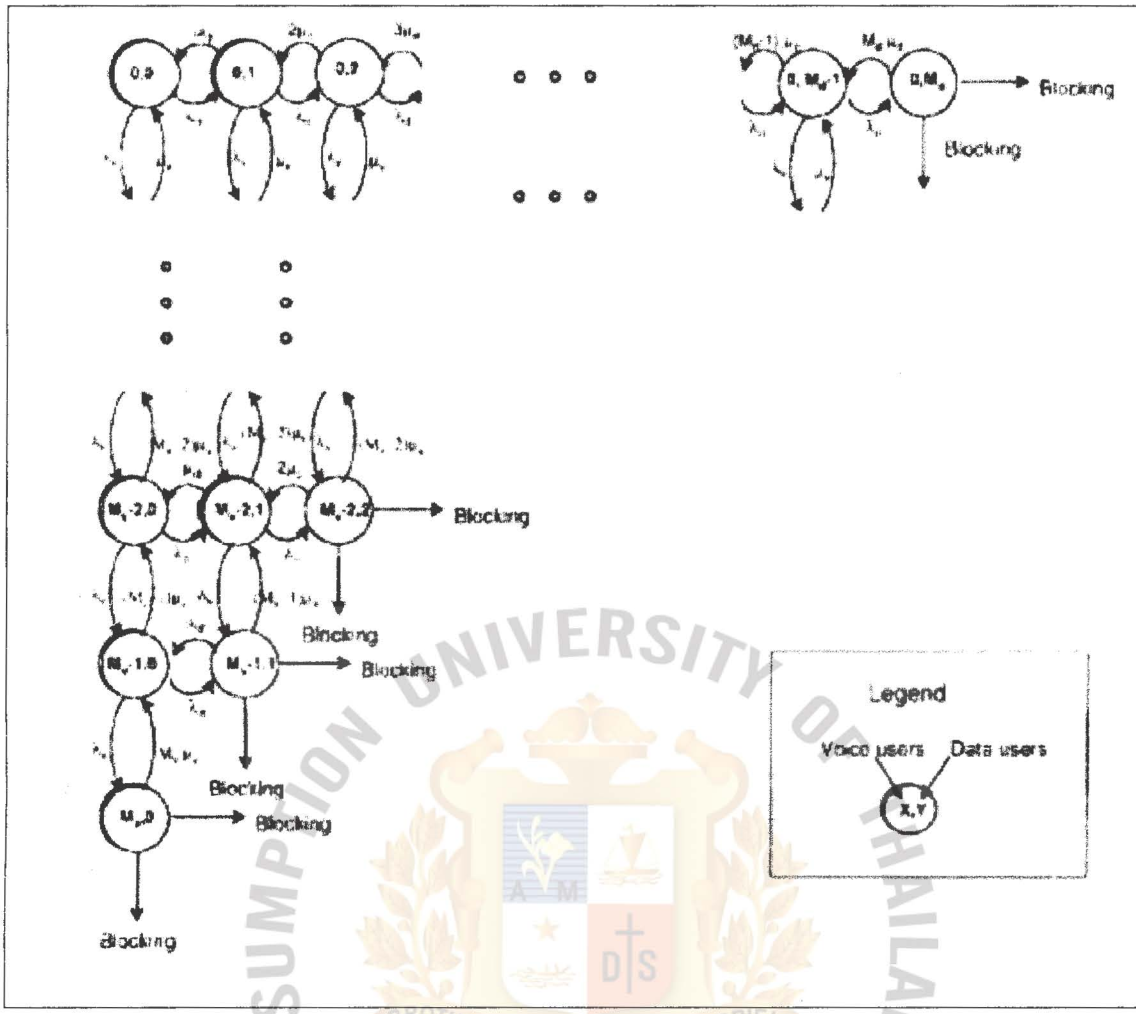


Figure 2-3. The state transition diagram

Conclusion from Experiment

- Data user has more impact on the voice users because the effective bandwidth of data was larger than that of voice.
- The system Erlang Capacity could be increased by properly reserving the channel for the prioritized call.

Benefit and Drawback

Benefit

- This paper also introduces the suitable method, call blocking probability with different grade of service, of calculating the capacity of CDMA system with many types of services, voice and data. This gives the more reliability to find out the result that comes from the procedure that close and suitable to the real business system.
- They introduced the method to analyze the CDMA system capacity by using K-dimension M/M/m loss system with K-dimension Markov Chain model.

Conclusion

From the first paper, introduce one of resource management model in [1]. However there are interested sharing models of resource management in [1] to do researching and compare with the main one introduced in the last paper, Markov chain model. Also with the new standard, CDMA2000, some effects must happen and valued to do researching.

Chapter 3: Experimental Investigation

3.1 Block Diagram

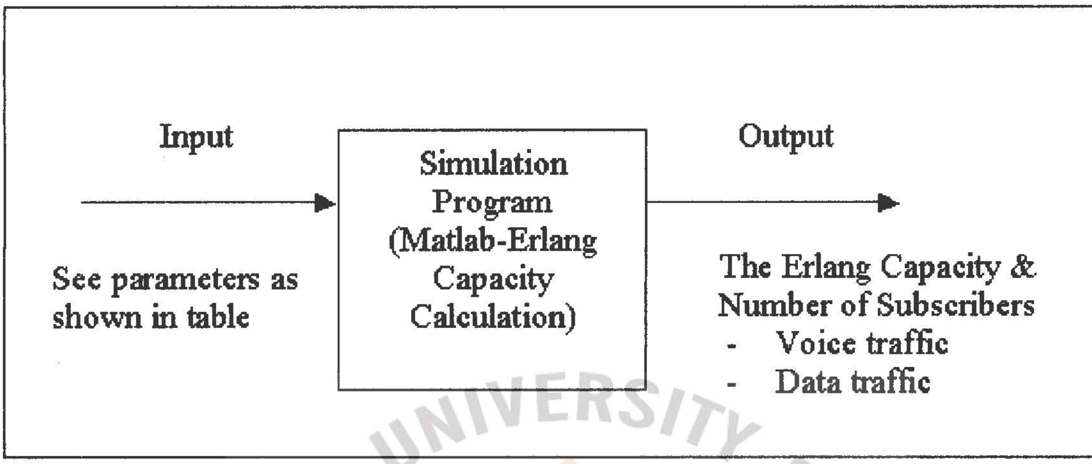


Figure 3-1. Block Diagram of scope of work

3.2 Scenario of testing

From the literature review, there are two main models of resource management, which directly effect to the supportable size of the CDMA system base on different ways. Both of them consider the two main services, which are voice and data. The first one uses resource sharing model, which also separates into 2 sub-models, partial sharing and complete sharing [1], but the other uses K-dimension Markov chain model [4]. To perform the comparison of these models, the same input is needed.

The input parameters of those two papers are mostly based on the DS-CDMA system, IS-95 in this work. The suitable input parameters for the future, which is CDMA2000 standard, will be used.

Parameter	Symbol	Value
Bandwidth	W	5, [10,15,20] MHz
Voice rate	R_v	9.6 kbps
Data rate	R_d	64, [144,384] kbps
Required E_b/N_o for voice traffic	$(E_b/N_o)_{v\text{-}Req}$	7 dB
Required E_b/N_o for data traffic	$(E_b/N_o)_{d\text{-}Req}$	10 dB
Voice traffic activity factor	α_v	3/8
Data traffic activity factor	α_d	0.125
Frequency reuse factor	1/(1/f)	0.7
Blocking probability of voice	$P_{b\text{-voice}}$	5%, (10%, 20%, 30%, 40%)
Blocking probability of data	$P_{b\text{-data}}$	1%, (10%, 20%, 30%, 40%)

Table 3-1. Parameters for CDMA2000 system supporting voice and data service

Note: For this standard, use Bandwidth = 5 MHz and Data Rate = 64 kbps in the experimental.

Parameter	Symbol	Value
Bandwidth	W	1.25 MHz
Voice rate	R_v	9.6 kbps
Data rate	R_d	8 kbps
Required E_b/N_o for voice traffic	$(E_b/N_o)_{v\text{-}Req}$	7 dB
Required E_b/N_o for data traffic	$(E_b/N_o)_{d\text{-}Req}$	10 dB
Voice traffic activity factor	α_v	3/8
Data traffic activity factor	α_d	0.125
Frequency reuse factor	1/(1/f)	0.7
Blocking probability of voice	$P_{b\text{-voice}}$	5%, (10%, 20%, 30%, 40%)
Blocking probability of data	$P_{b\text{-data}}$	1%, (10%, 20%, 30%, 40%)

Table 3-2. Parameters for IS-95 CDMA system supporting voice and data service

What to compare?

- The K-dimension Markov chain model in [4]
- The sharing models, Partial Sharing and Complete Sharing, in [1]

What to calculate?

- Calculate the acceptable offer traffic load of voice and data in the reverse link to maintain a call Blocking probability for voice < $P_{b\text{-voice}}$ and call Blocking probability for data < $P_{b\text{-voice}}$ and finally, find out the number of subscribers that system can support.

How to calculate?

- Programming by Matlab R12 Version 6.0.0.88
- Input the parameters as shown in tables (IS-95 and CDMA2000 standards)
- Analyze output in term of Erlang capacity and number of subscribers

3.3 Experimental Model

3.3.1 Trunking Capacity for 2 types of calls

There are 3 different resource management models to determine the trunking capacity or in other word, channels for both types of call, voice and data.

3.3.1.1 K-dimension Markov chain model

$$N_i\alpha_i\,(\overline{E_b/N_o})_{i\text{-req}}\,R_i \;+\; \sum_{j=1,\,j\neq i}^{K} N_j\alpha_j\,(\overline{E_b/N_o})_{j\text{-req}}\,R_j \;\leq$$

$$W\,(1/(1+f))\,10^{(Q\text{-}1(\beta))/10)\,\sigma x\,-0.012\sigma x\sigma x} \qquad (1.)$$

[4-Koo, Ahn, Lee, 1999]

Where

W = the allocate frequency bandwidth

N_i = the number of active user of the i-th service group

α_j = the activity factor

$(E_b/N_o)_{i\text{-req}}$ = the require (E_b/N_o)

R_i = information bit rate (i = 1, … ,K)

f = the allocated frequency bandwidth

(1/(1+f)) = the average value of frequency reuse factor

Q^{-1}= the inverse Q-function

σ_x = standard deviation of the receive SIR (Signal to Interference Ratio)

$\beta\%$ = the required system capacity

Note: $10^{(Q-1(\beta))/10)\,\sigma x - 0.012\,\sigma x \sigma x}$ indicates the effect of imperfect power control error and the required system reliability $\beta\%$ on the system capacity where the imperfect power control error is represented by the standard deviation of received SIR σ_x . Respect to the other 2 models evaluate by perfect power control, so we also assume perfect power control for this model, then $10^{(Q-1(\beta))/10)\,\sigma x - 0.012\,\sigma x \sigma x}$ assumed to be 1.

So, we can derive the above formula with respect to 2 services, voice and data, and standard, IS-95 and CDMA2000 standards. The formula show as following

$$(N_v \alpha_v (E_b/N_o)_{v\text{-}req} R_v) + (N_d \alpha_d (E_b/N_o)_{d\text{-}req} R_d) \leq W\,(1/(1+f)) \qquad (2.)$$

[4-Koo, Ahn, Lee, 1999]

Where

N_v = Number of voice channel

N_d = Number of data channel

3.3.1.2 Partial Sharing model

For IS-95 Standard

$$\left.\begin{array}{l} N_v = 38,\ N_d \leq 24 \text{ (Dedicate for data service)} \\ N_v = -0.4\,N_d + 47,\ 24 < N_d < 87 \text{ (Sharing for both services)} \\ N_v = [0\ldots 12],\ N_d = 87 \text{ (Dedicate for voice service)} \end{array}\right\} \quad (3.)$$

[1-Kaufman, 1981]

For CDMA2000 Standard

$$\left.\begin{array}{l} N_v = 138,\ N_d \leq 12 \text{ (Dedicate for data service)} \\ N_v = -3N_d + 174,\ 12 < N_d < 43 \text{ (Sharing for both services)} \\ N_v = [0\ldots 45],\ N_d = 43 \text{ (Dedicate for voice service)} \end{array}\right\} \quad (4.)$$

[1-Kaufman, 1981]

Where

N_v = Number of voice channel

N_d = Number of data channel

Note: approximately 33% of voice resource and 28% of data resource are dedicated

3.3.1.3 Complete Sharing model

For IS-95 Standard

$$\left.\begin{aligned} N_v &= -0.276\,N_d + 38,\ N_d \le 87 \\ N_v &= 0.161 N_d,\ N_d \le 87 \end{aligned}\right\} \quad (5.)$$

[1-Kaufman, 1981]

For CDMA2000 Standard

$$\left.\begin{aligned} N_v &= -2\,N_d + 138,\ N_d \le 43 \\ N_v &= 1.21 N_d,\ N_d \le 43 \end{aligned}\right\} \quad (6.)$$

[1-Kaufman, 1981]

Where

N_v = Number of voice channel

N_d = Number of data channel

Note: the turning point of sharing resource (change to degradation of data resource) between 2 services is around 37% out of the voice resource.

3.3.2 Erlang Capacity Calculation

Erlang-B formula

$$P_b = (e^N / N!) / \left(\sum_{k=0}^{N} e^k/k!\right) \quad (7.)$$

Where

e = Erlang capacity

N = the number of trunk

P_b = call blocking probability

From the previous section, trunking capacity calculation, we will get each valid of N_v, number of voice channel, and N_d, number of data channel. So to find out the Erlang capacity, by applying each valid (N_v,N_d) pair with the desired call blocking probability for each type of calls.

3.3.3 Number of Subscribers Calculation

To evaluate the number of voice and data subscribers that can be supported in the CDMA system.

For voice calls, we assumed that each subscriber generates a typical 0.015 Erlangs in the busy hour. For data calls, we also assume that each subscriber generates about 1/3 Erlangs [6]. So now we can find out the number of subscribers of each type of call by dividing the Erlang capacity value from the above model by this assumed value of each type of calls.

Chapter 4: Presentation and Discussion Result

4.1 Markov Chain Model

IS-95 Standard

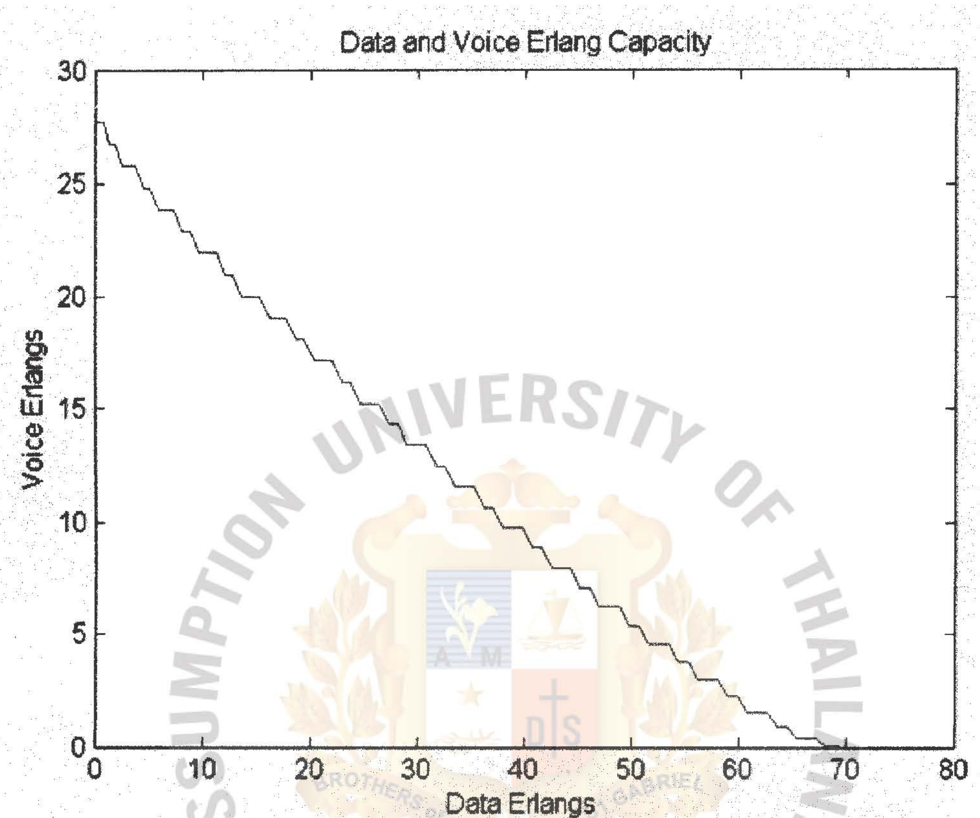


Figure 4-1. The Voice and Data Erlang Capacity of Markov chain model for IS-95 Standard (5% call blocking probability for voice and 1% for data)

For this Figure 4-1, we can see that the more voice Erlang capacity, the less data Erlang capacity and vice versa. It shows that both voice and data Erlang capacity are the inversely proportional to each other. And for number of both voice and data subscribers also shows in the same way that while the supportable number of one type of subscribers is increased, the drop of the other type also increase as shown in the Figure 4-2.

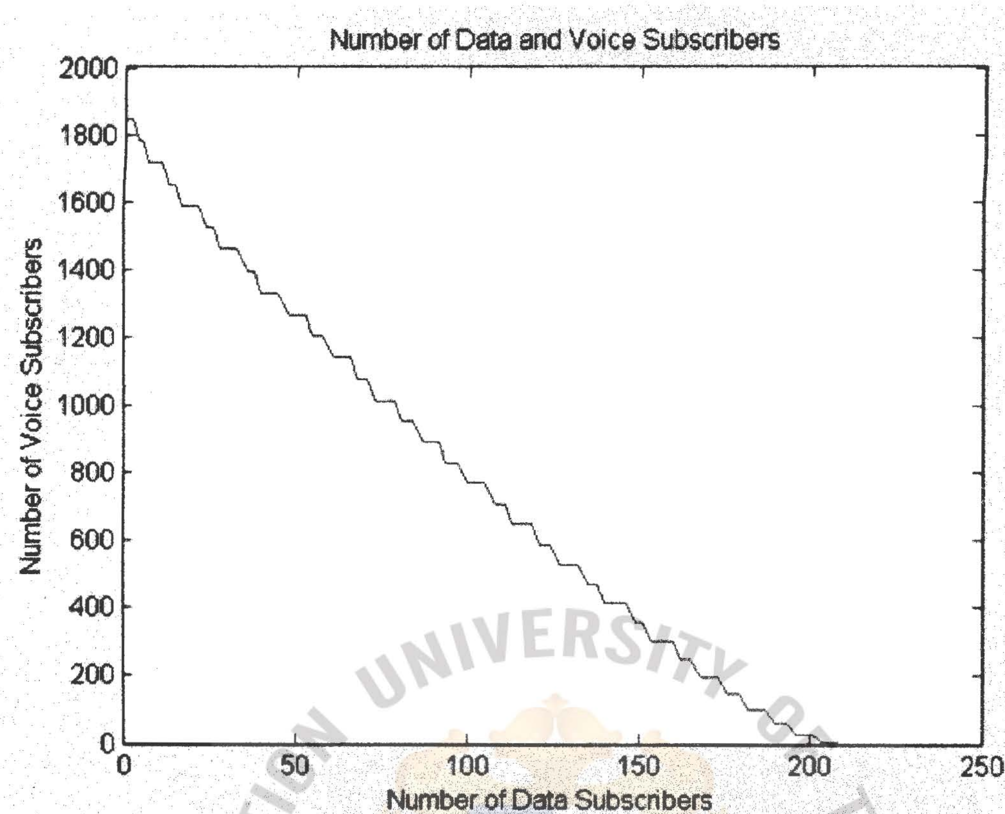


Figure 4-2. The Number of Voice and Data Subscribers of Markov chain model for IS-95 Standard (5% call blocking probability for voice and 1% for data)

CDMA2000 Standard

For the following Figure 4-3. and Figure 4-4 of the CDMA2000 standard, the characteristic of system capacity in term of Erlang capacity or number of subscribers is the same as with those IS-95 standard. The figures are shown in the section below.

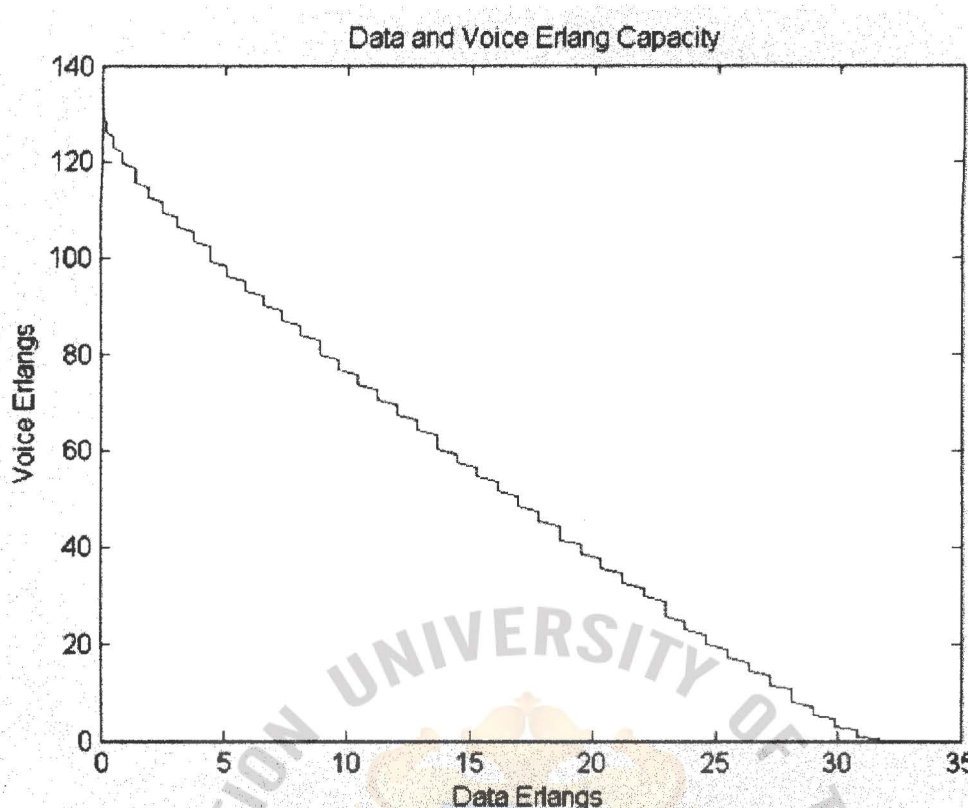


Figure 4-3. The Voice and Data Erlang Capacity of Markov chain model for CDMA2000 Standard (5% call blocking probability for voice and 1% for data)

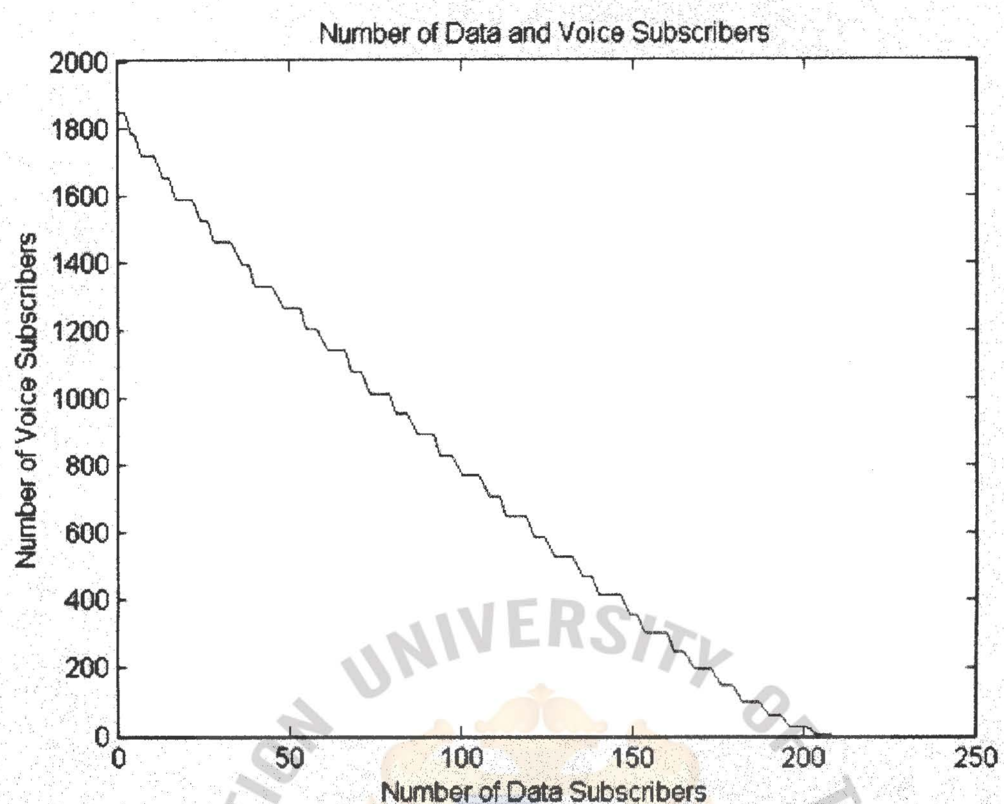


Figure 4-4. The Number of Voice and Data Subscribers of Markov chain model for CDMA2000 Standard (5% call blocking probability for voice and 1% for data)

IS-95 Vs CDMA2000 Standard

For IS-95, it is obvious that the difference of effect to the supportable size of system for data service is much more than the voice service. In contrast with CDMA2000, the voice service is supported much greater than data service, Figure 4-5. The reason behind this, comes from the effect of Bandwidth and data rate. From the view of voice service, it is clear that only Bandwidth factor is the main factor that introduces the effect to the supportable size of system. With the higher Bandwidth, the more supportable for voice service, since Bandwidth of IS-95 is 1.25 MHz while 5 MHz for CDMA2000. However in the view of data service, which obviously decrease of the supportable size by IS-95 to CDMA2000 standard. Because of the much higher data bit rate that improve for the new standard as CDMA2000 for the greater quality such that from 8 kbps in IS-95 to 64 kbps in CDMA2000. From this point, we can conclude that the data rate has more effect than Bandwidth to support the system capacity.

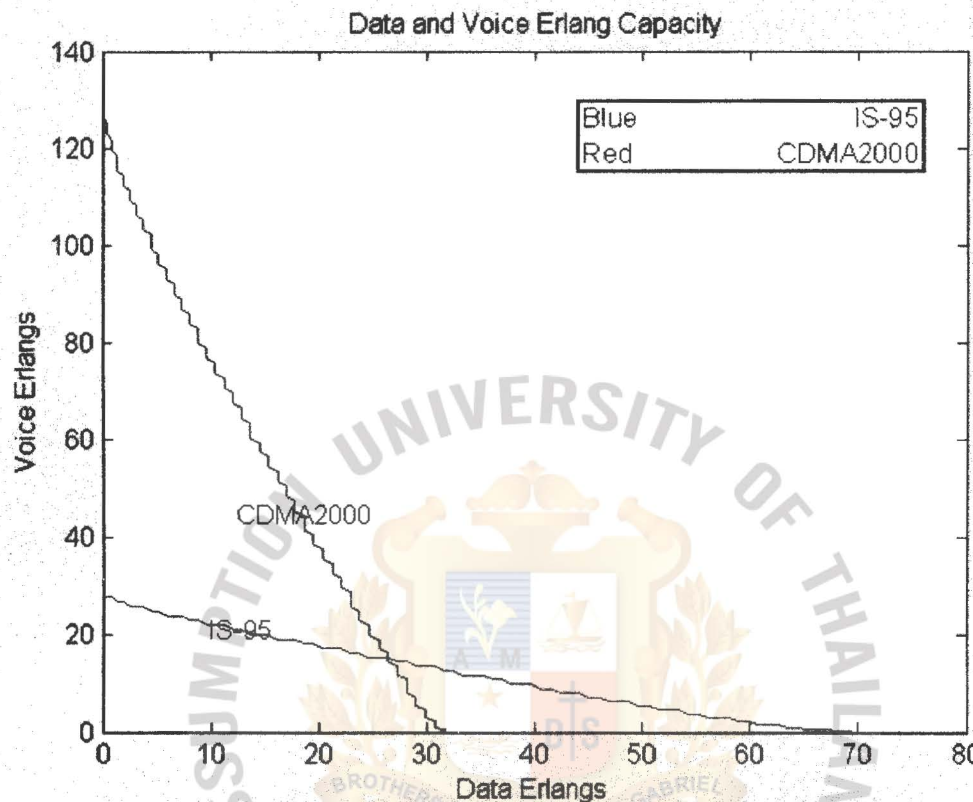


Figure 4-5. The Voice and Data Erlang Capacity of Markov chain model for IS-95 Vs CDMA2000 Standards

(5% call blocking probability for voice and 1% for data)

Let's see in the view of subscriber, Figure 4-6 shows that while the number of voice subscribers increase with a lot of quantity the quality is still the same, voice bit rate is the same for both types of service which is 9.6 kbps. But the number of data subscribers decrease by the increasing of data bit rate, however with the higher bit rate, subscribers will get more satisfaction by the better quality of service in term of file transfer delay, this is the sign of data play the important activity in future use such graphic or event video service which consume great quantity of data.

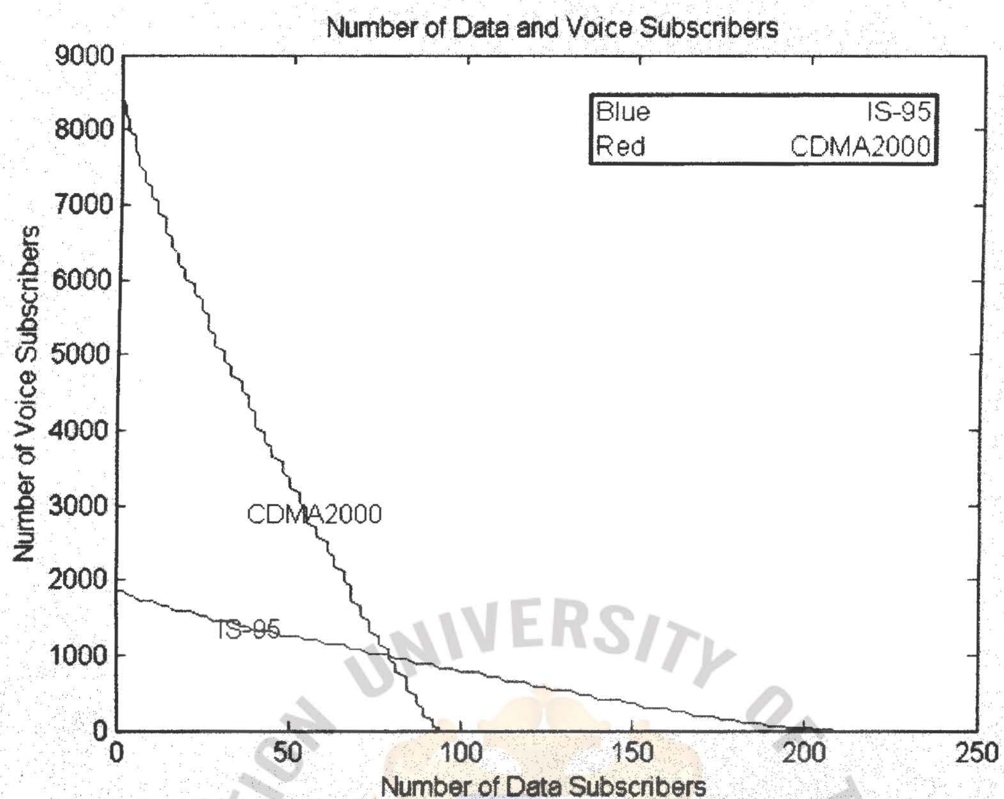


Figure 4-6. The Number of Voice and Data Subscribers of Markov chain model for IS-95 Vs CDMA2000 Standards

(5% call blocking probability for voice and 1% for data)

Various call Blocking probability

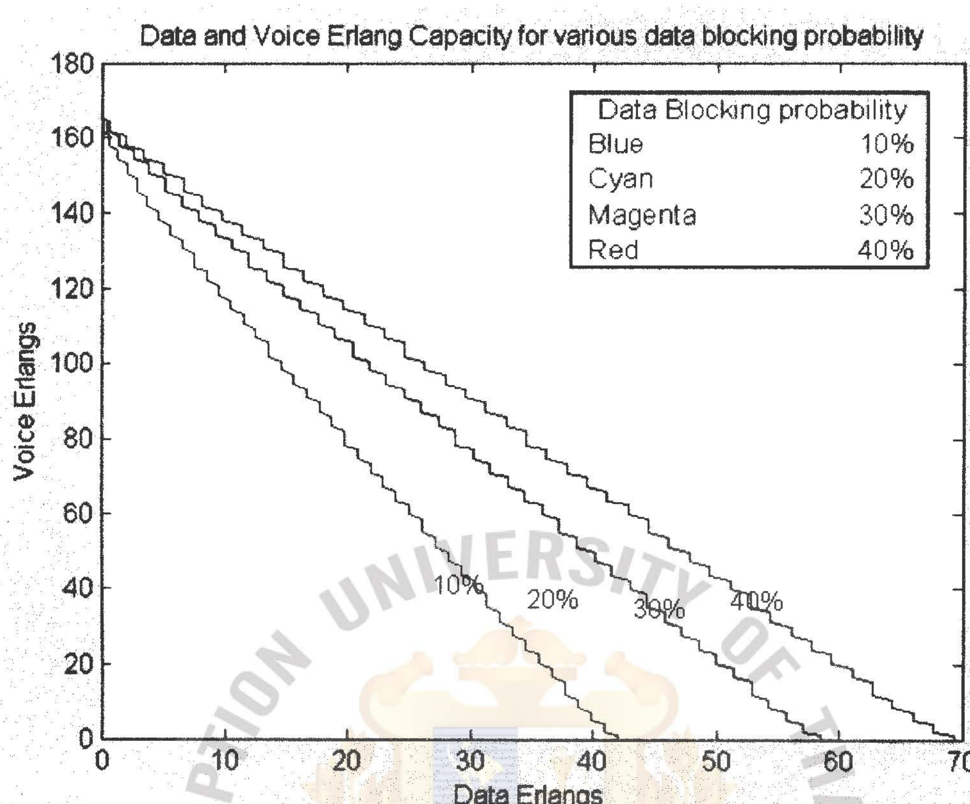


Figure 4-7. Voice and Data Erlang capacity of Markov chain model for various data blocking probability, CDMA2000 Standards (Constant voice blocking probability 20%)

From Figure 4-7, it is obvious that the higher data call blocking probability, the more Erlang capacity of data service, however the maximum of voice Erlang capacity is still the same, because of the constant of call blocking probability of voice. It is clear that the blocking probability increase, the more system capacity.

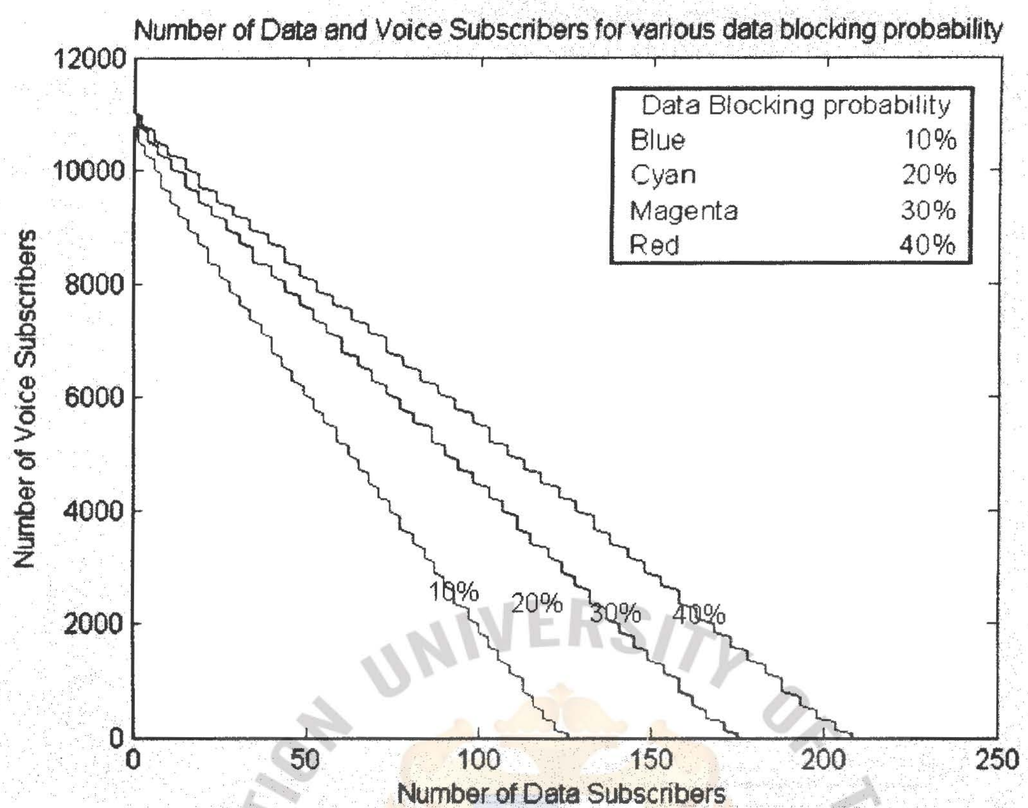


Figure 4-8. The Number of Voice and Data Subscribers of Markov chain model for various data blocking probability, CDMA2000 Standards (Constant voice blocking probability 20%)

We are also able to consider in the view of subscribers, as shown in Figure 4-8, if we want to support more data subscribers, data call blocking probability is a must to increase but the trade of quality of data service, the ability of using resource by subscribers, need to take into account. But for this model, the interesting point happen for voice service that is with the higher data blocking probability, at the same supportable size of data call such that 100 data subscribers, the supportable size of voice call is increase such that 1900, 3200, 4300, 5400 voice subscribers, it shows that the supportable size for voice increases while the quality of voice service is the same, since the constant of probability of voice.

For service provider can apply this analysis, to consider for the benefit of data service which come with trade of in term of quality of that subscribers will be able to use the resource, but only benefit for voice service. They may switch the probability for the suitable circumstance such that while voice service is more required by subscribers and data service still less, the switch to higher blocking probability may adapt to improve the supportable size of voice and because of lower data subscribers the drawback of this effect will be regardless.

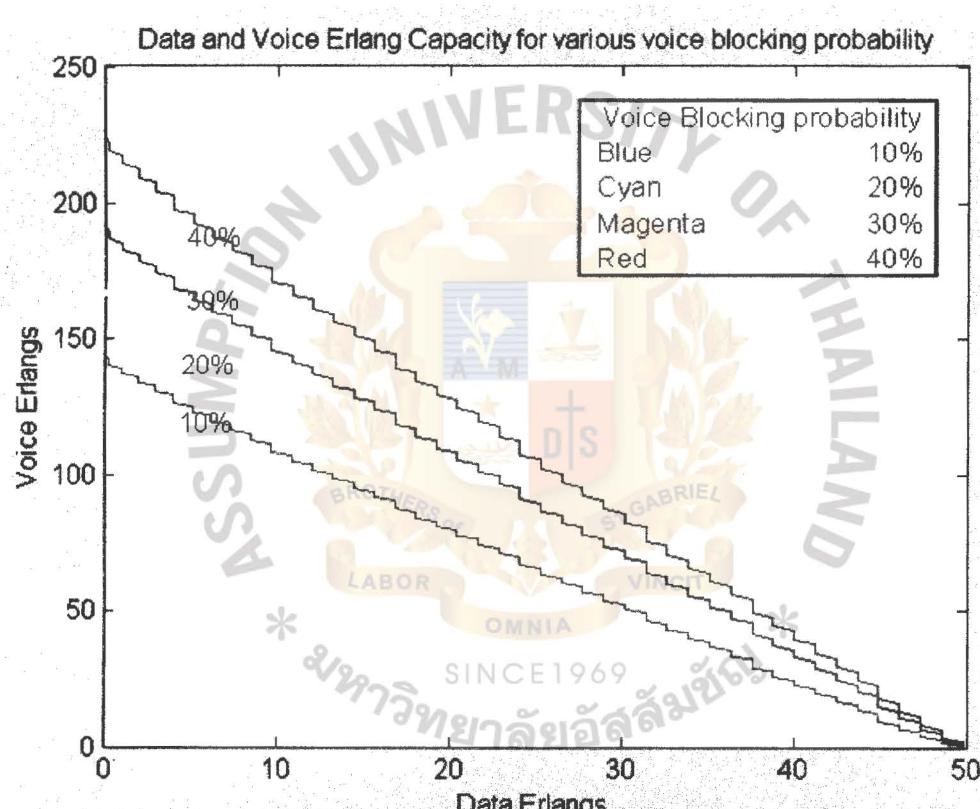


Figure 4-9. Voice and Data Erlang capacity of Markov chain model for various voice blocking probability, CDMA2000 Standards (Constant data blocking probability 20%)

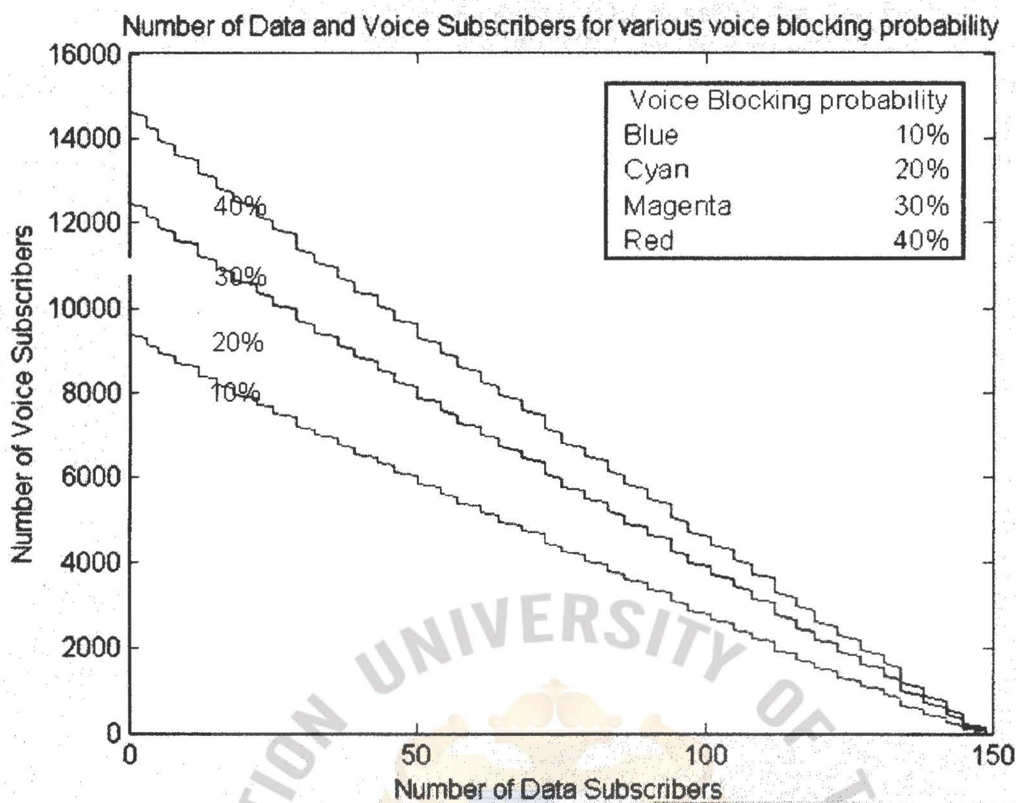


Figure 4-10. The Number of Voice and Data Subscribers of Markov chain model for various voice blocking probability, CDMA2000 Standards (Constant data blocking probability 20%)

From Figure 4-9 and 4-10, show the effect of voice blocking probability instead of data blocking probability already mentioned in Figure 4-7 and Figure 4-8. The effect also gives the same pattern the same as the effect of data blocking. We can shortly conclude that while increasing the voice probability, the more supportable size of voice service is introduced, it is obvious for benefit but also trade off with voice quality of service in term of the availability of resource usage by subscribers. Back to data service view, it is benefit that the higher voice blocking probability, at the same supportable size of voice call, the supportable size of data call increases, it shows that the supportable size for data increases while the quality of data service is the same, since the constant of probability of data.

For service provider can apply this analysis, to consider for the benefit of voice service, which come with trade off in term of quality of service in term of the availability of resource usage by subscribers but only benefit for data service. They may switch the probability for the suitable circumstance such that while data service is more required by subscribers and voice service still less, the switch to higher blocking probability may adapt to improve the supportable size of data and because of lower voice subscribers the drawback of this effect will be regardless.

By the way, the suitable point of call blocking probability of voice and data that service provider want to use for each circumstance, the effect of each other need to be balanced to enhance system capacity.

4.2 Partial Sharing Model

IS-95 Standard

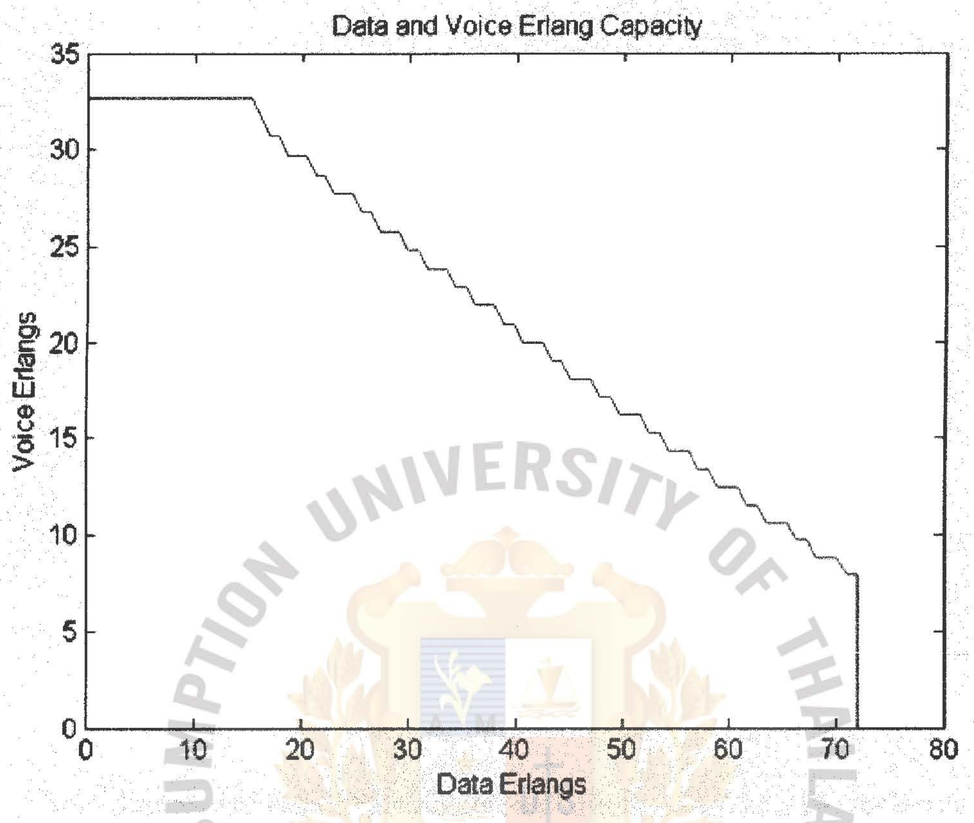


Figure 4-11. The Voice and Data Erlang Capacity of Partial Sharing model for IS-95 Standard (5% call blocking probability for voice and 1% for data)

For the Figure 4-11, we can see that the system guarantee for the minimum of supportable size for each type of services, voice and data. It shows that at the maximum support of voice Erlang capacity, the system maintain some portion of data Erlang capacity to be supported in system and vice versa, at the maximum support of data Erlang capacity, the system also maintain some portion of voice Erlang capacity. And for the rest that out of guarantee by system, it will be shared between both 2 services by inversely proportional to each other. It also shows this characteristic in the view of subscribers as shown in the Figure 4-12.

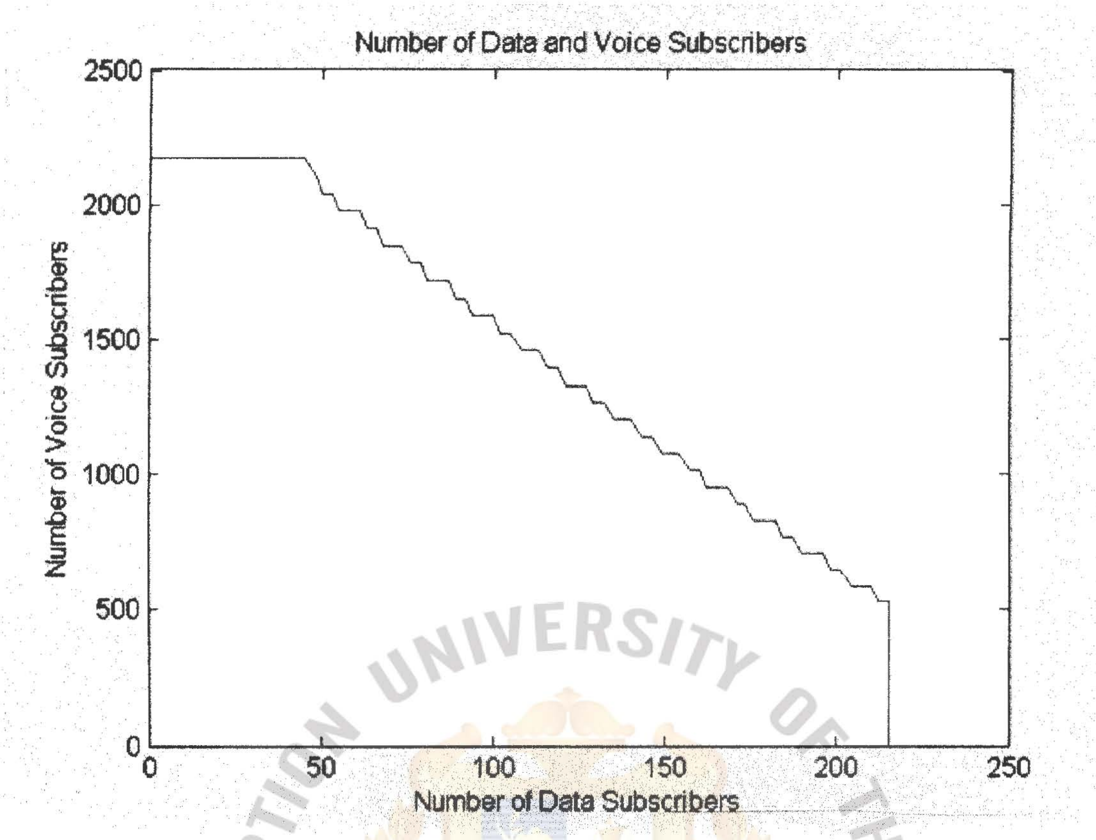


Figure 4-12. The Number of Voice and Data Subscribers of Partial Sharing model for IS-95 Standard (5% call blocking probability for voice and 1% for data)

CDMA2000 Standard

For the following Figure 4-13. and Figure 4-14. of the CDMA2000 standard, the characteristic of system capacity in term of Erlang capacity or number of subscribers is the same as with those IS-95 standard. The figures are shown in the following section.

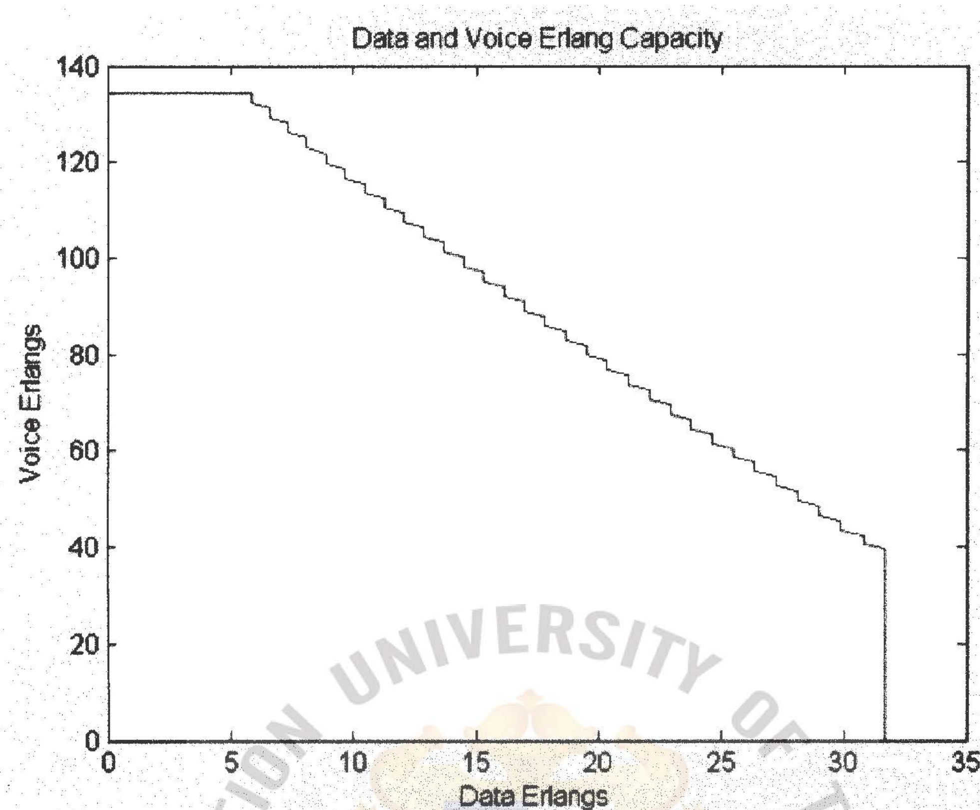


Figure 4-13. The Voice and Data Erlang Capacity of Partial Sharing model for CDMA2000 Standard (5% call blocking probability for voice and 1% for data)

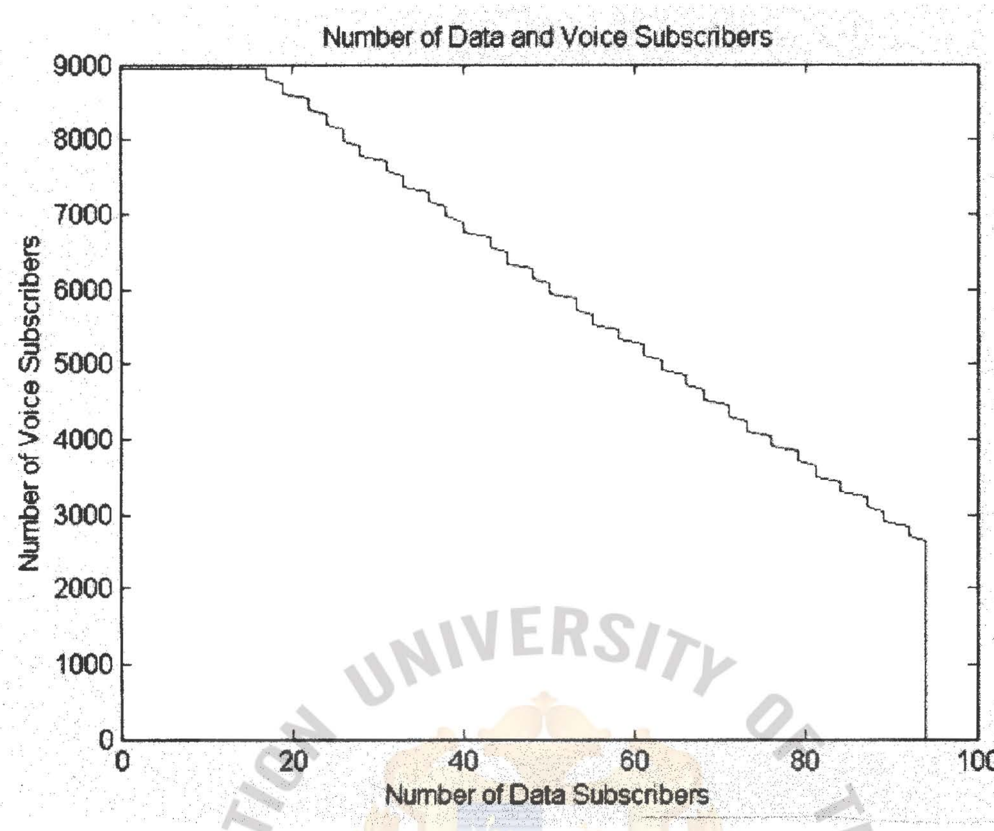


Figure 4-14. The Number of Voice and Data Subscribers of Partial Sharing model for CDMA2000 Standard (5% call blocking probability for voice and 1% for data)

IS-95 Vs CDMA2000 Standard

For IS-95, it is obvious that the difference of effect to the supportable size of system for data service is much more than the voice service. In contrast with CDMA2000, the voice service is supported much greater than data service, as shown in Figure 4-15. and Figure 4-16. The effect of different standard shows the same result the same as the previous model.

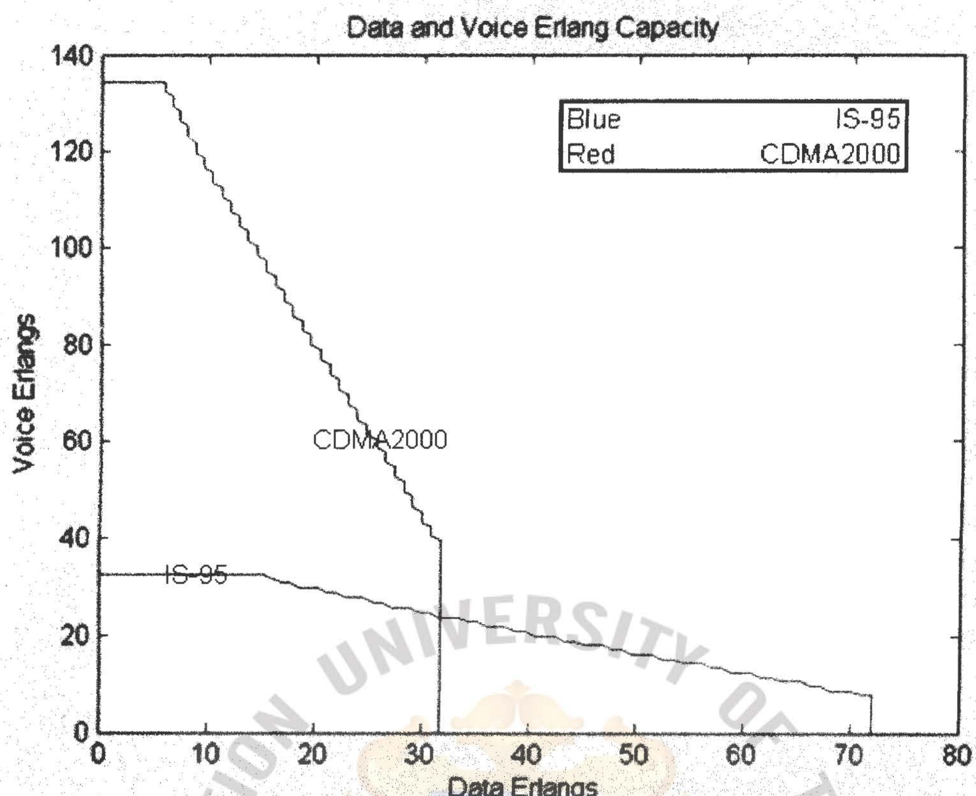


Figure 4-15. The Voice and Data Erlang Capacity of Partial Sharing model for IS-95 Vs CDMA2000 Standards

(5% call blocking probability for voice and 1% for data)

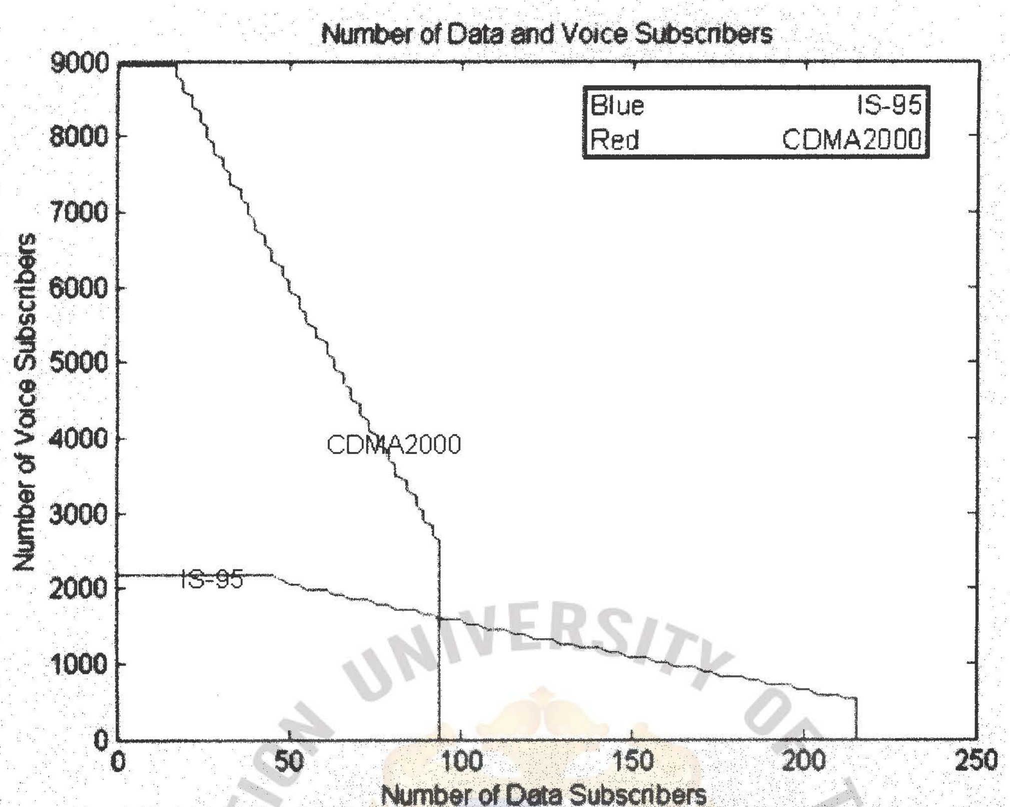


Figure 4-16. The Number of Voice and Data Subscribers of Partial Sharing model for IS-95 Vs CDMA2000 Standards

(5% call blocking probability for voice and 1% for data)

Various call Blocking probability

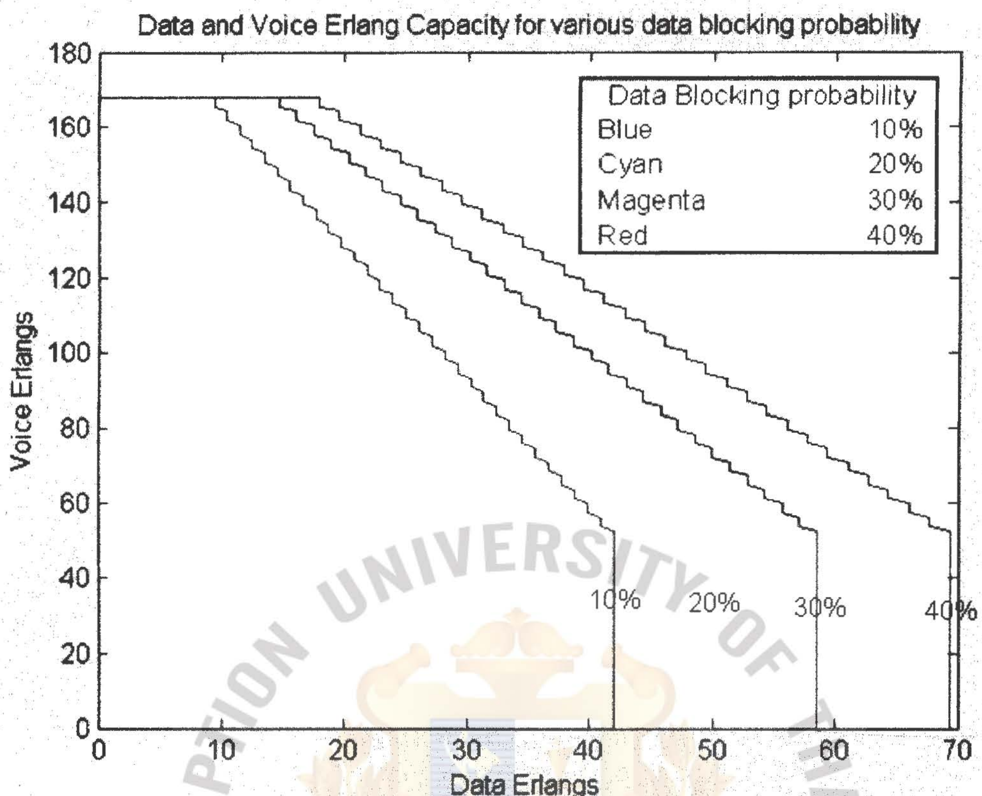


Figure 4-17. Voice and Data Erlang capacity of Partial Sharing model for various data blocking probability, CDMA2000 Standards (Constant voice blocking probability 20%)

From Figure 4-17, it is obvious that the higher data call blocking probability, the more Erlang capacity of data service and also minimum of supportable size for data service, however the maximum of voice Erlang capacity is still the same included with the same of the minimum of supportable size for voice service as well, because of the constant of call blocking probability of voice.

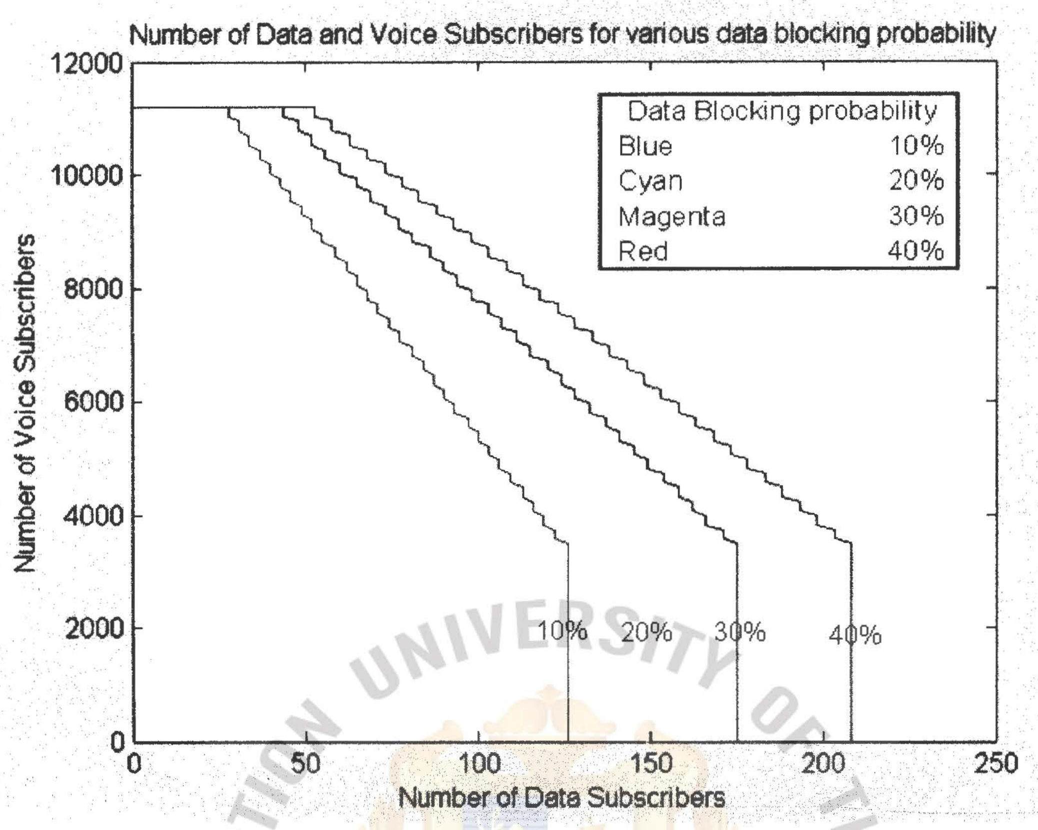


Figure 4-18. The Number of Voice and Data Subscribers of Partial Sharing model for various data blocking probability, CDMA2000 Standards (Constant voice blocking probability 20%)

The other point of view, number of subscribers, shown in Figure 4-18, if we want to support more data subscribers, data call blocking probability is a must to increase but the trade of quality of data service, the ability of using resource by subscribers, need to take into account. But for this model, the interesting point happens for voice service that is with the higher data blocking probability, at the same supportable size of data call, the supportable size of voice call is increased with more voice subscribers, it shows that the supportable size for voice increases while the quality of voice service is the same, since the constant of probability of voice. This fact is as same as the experiment for the previous model.

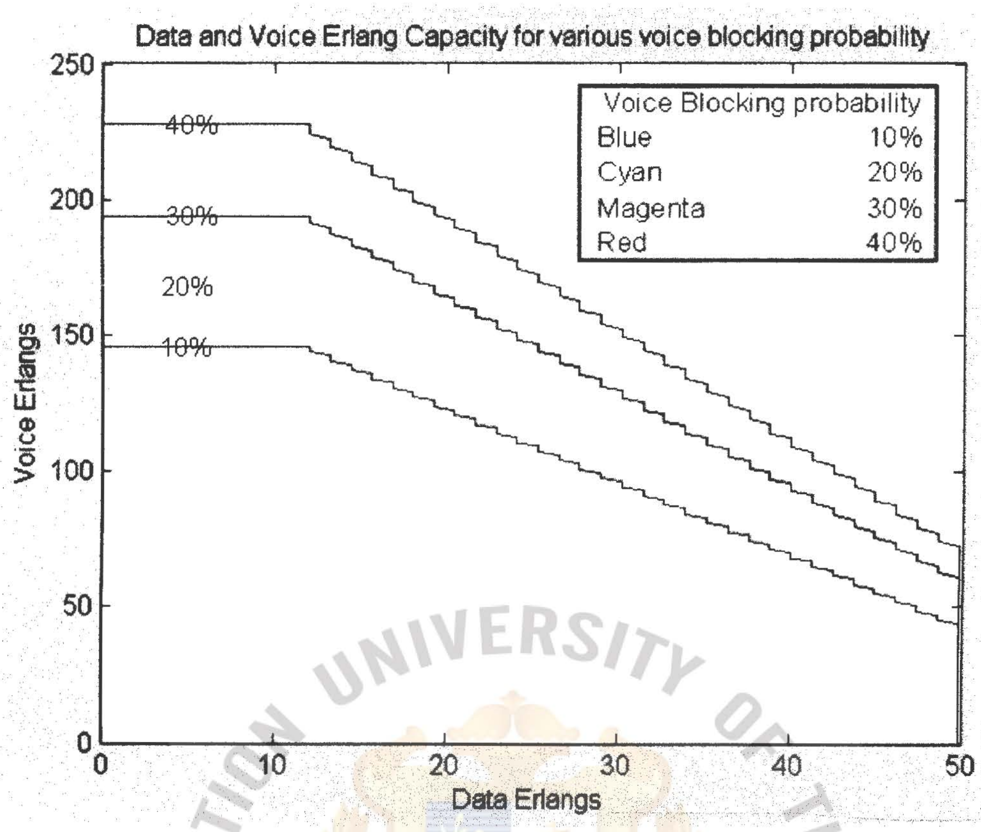


Figure 4-19. Voice and Data Erlang capacity of Partial Sharing model for various voice blocking probability, CDMA2000 Standards (Constant data blocking probability 20%)

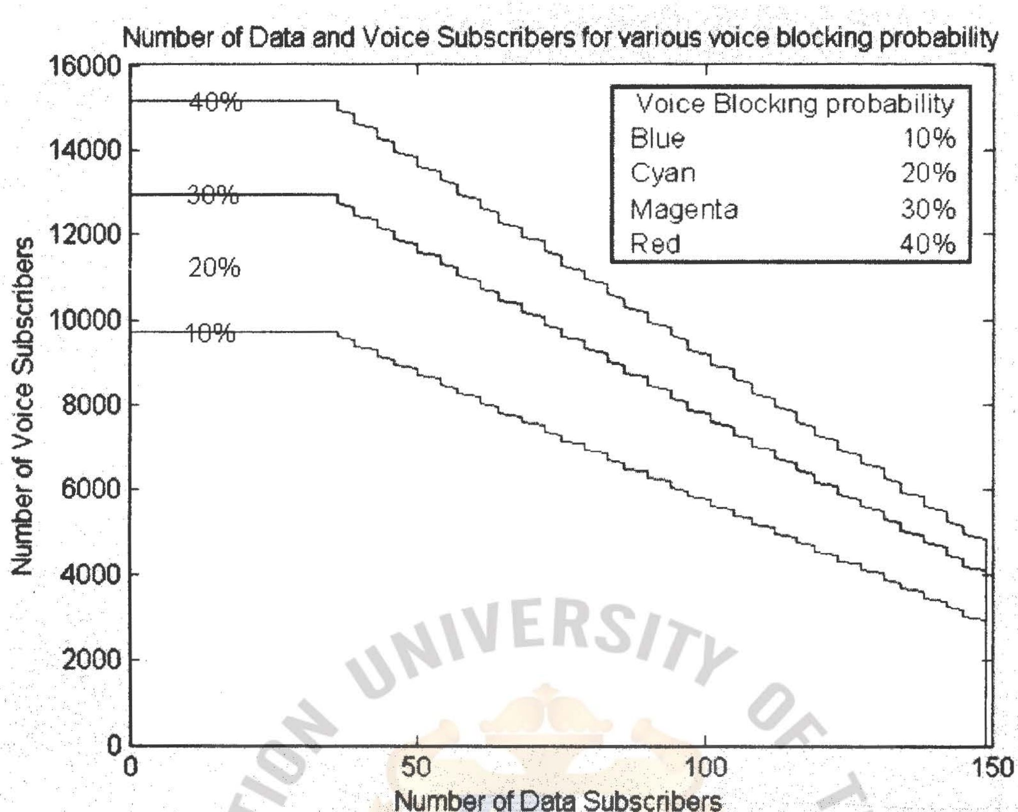


Figure 4-20. The Number of Voice and Data Subscribers of Partial Sharing model for various voice blocking probability, CDMA2000 Standards (Constant data blocking probability 20%)

From Figure 4-19 and 4-20, show the effect of voice blocking probability instead of data blocking probability already mentioned in Figure 4-17 and Figure 4-18. The effect also give the same pattern as same as the effect of data blocking. We can shortly conclude that while increasing the voice probability, the more supportable size of voice service and also the minimum of supportable size for voice service, are introduced, while the maximum of supportable size and minimum of supportable size for data service are still the same. It is obvious for benefit but also trade off with voice quality of service in term of the availability of resource usage by subscribers. Back to data service view, it is a benefit that the higher voice blocking probability, at the same supportable size of voice call, the supportable size of data call is increased, it shows that the supportable size for data increases while the quality of data service is the same, since the constant of probability of data.

For service provider can apply this analysis, the same as the mention in the previous model.

4.3 Complete Sharing Model

IS-95 Standard

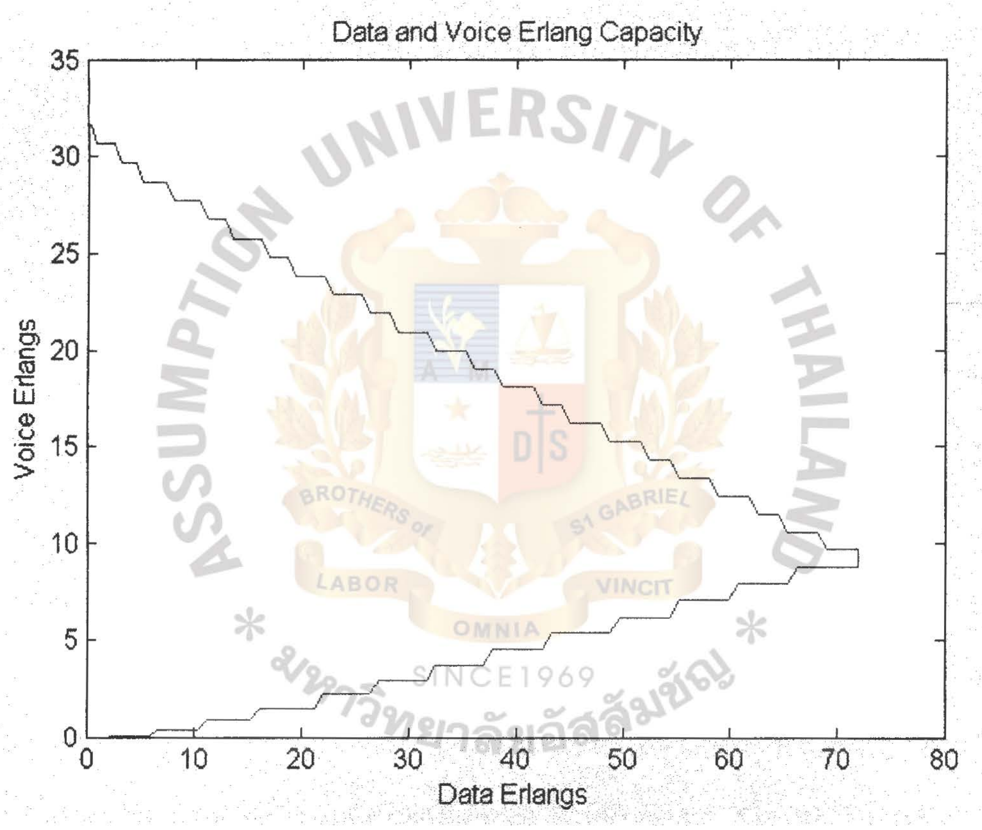


Figure 4-21. The Voice and Data Erlang Capacity of Complete Sharing model for IS-95 Standard (5% call blocking probability for voice and 1% for data)

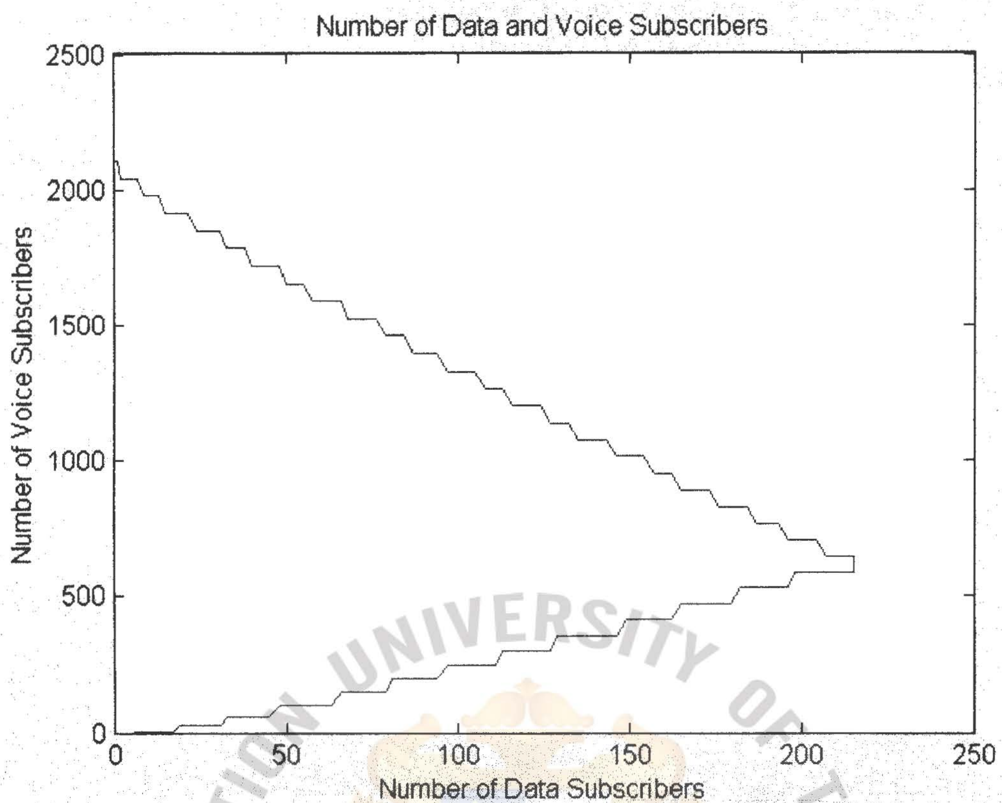


Figure 4-22. The Number of Voice and Data Subscribers of Complete Sharing model for IS-95 Standard (5% call blocking probability for voice and 1% for data)

For the Figure 4-21, we can see that at the one of service, here is voice, is guaranteed by system to support with the minimum boundary, however the maximum boundary has to decrease as the proportion of minimum boundary when increasing. Or in other words, while supportable size of one service is increasing, the other service is still supporting with at lease the specific supportable size. As we see that, while data Erlang capacity is increasing, the minimum voice Erlang capacity is changing to increasing with the reducing of the maximum voice Erlang capacity until reaching at the specific point of voice Erlang capacity when the maximum data Erlang capacity is met. We can also see in the supported subscribers view as shown in Figure 4-22, while number of data subscribers is increasing, the maximum number of voice subscribers gradually drop but also the minimum number of voice subscribers also gradually increase. From this we can also conclude that the minimum supportable size of system is given to the more priority service such voice in this. At the maximum boundary, it occupies by voice while the minimum boundary occupies by data. Also it seems to fix channel for voice already.

CDMA2000 Standard

For the following Figure 4-23. and Figure 4-24. of the CDMA2000 standard, the characteristic of system capacity in term of Erlang capacity or number of subscribers is the same as with those IS-95 standard. The figures are shown below.

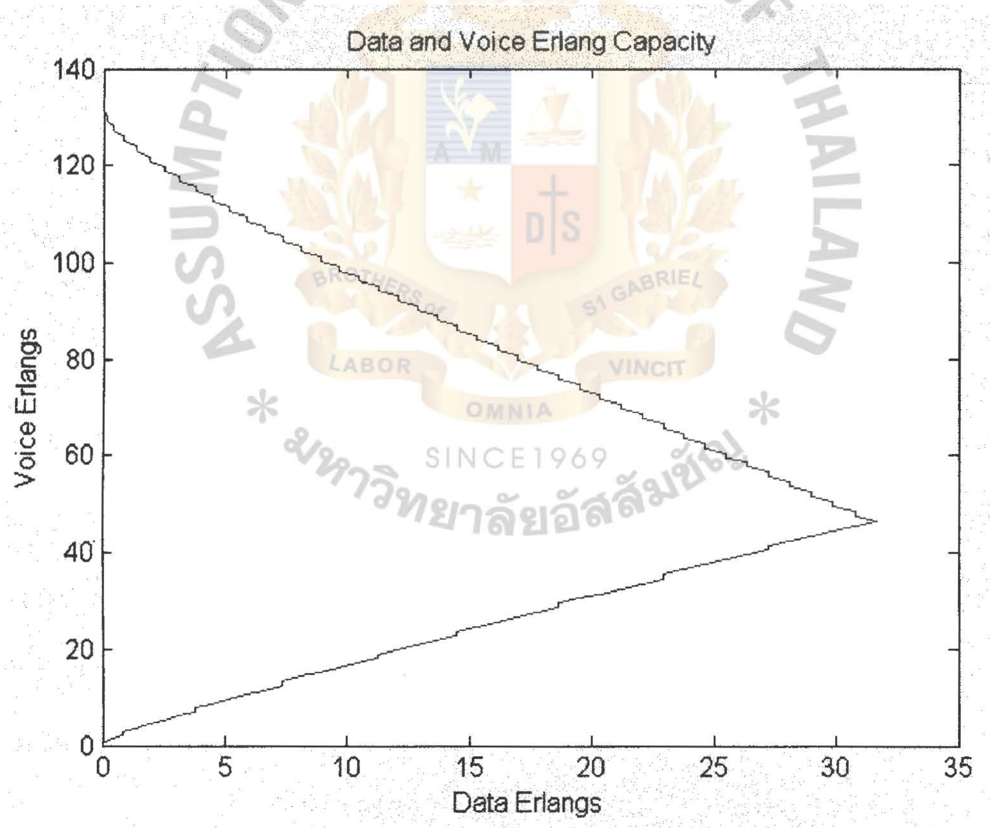


Figure 4-23. The Voice and Data Erlang Capacity of Complete Sharing model for CDMA2000 Standard (5% call blocking probability for voice and 1% for data)

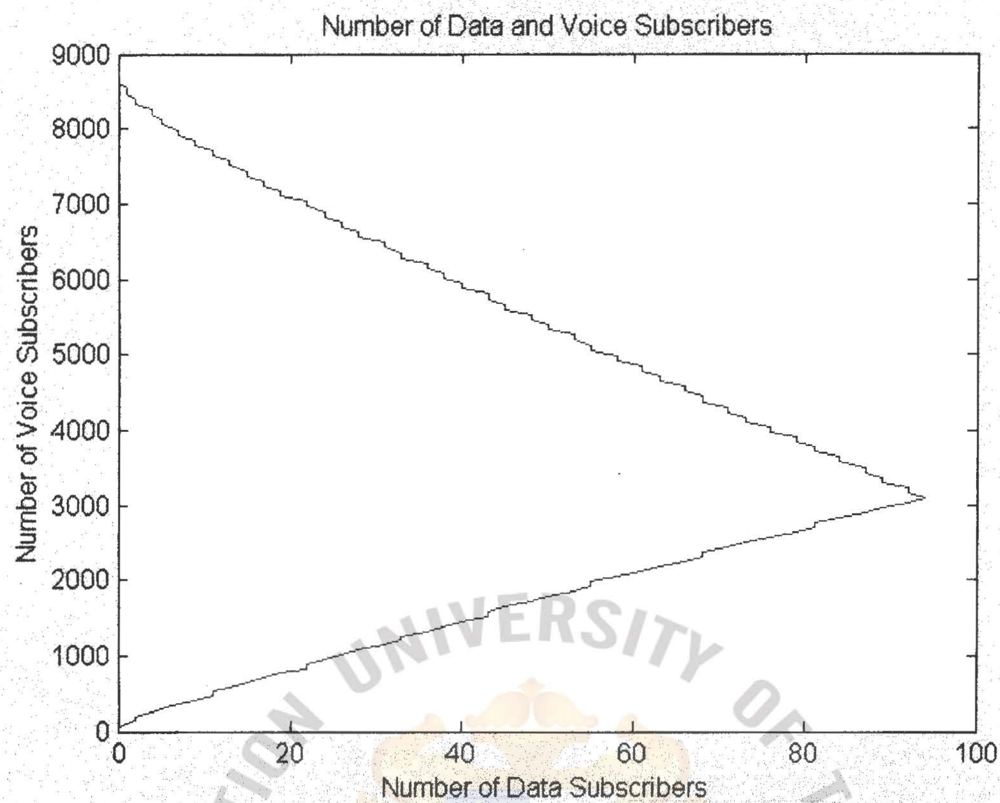


Figure 4-24. The Number of Voice and Data Subscribers of Complete Sharing model for CDMA2000 Standard (5% call blocking probability for voice and 1% for data)

IS-95 Vs CDMA2000 Standard

For IS-95, it is obvious that the difference of effect to the supportable size of system for data service is much more than the voice service. In contrast with CDMA2000, the voice service is supported much greater than data service, as shown in Figure 4-25. and Figure 4-26. The effect of different standard show the same result the same as the 2 previous models.

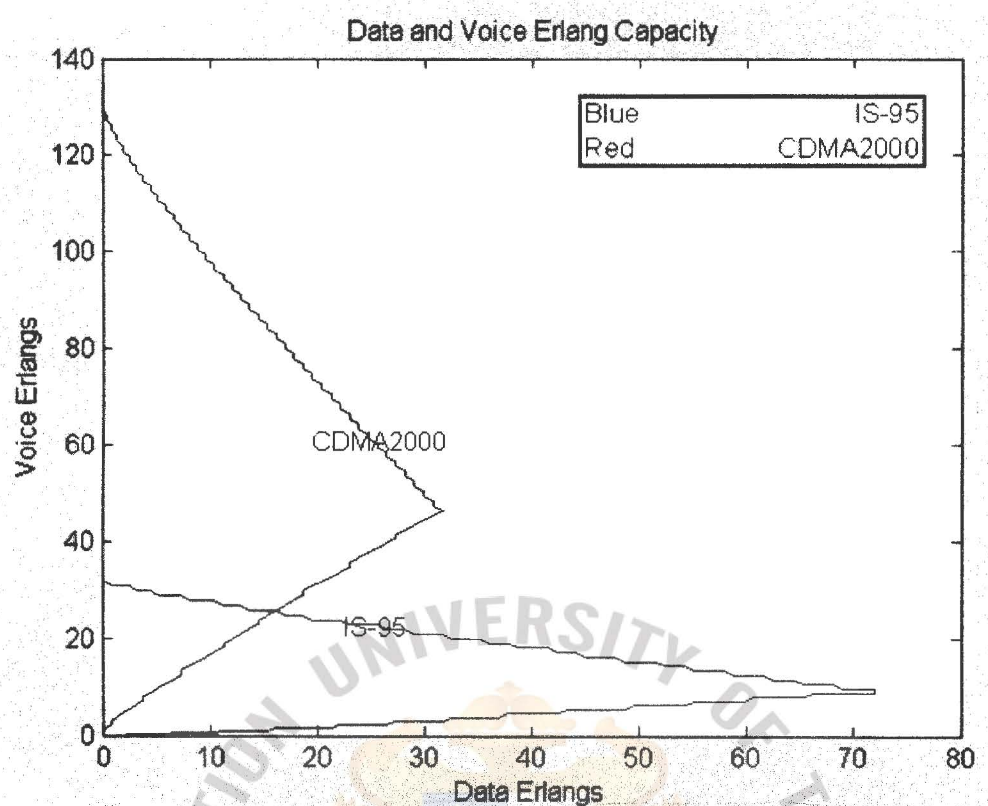


Figure 4-25. The Voice and Data Erlang Capacity of Complete Sharing model for IS-95 Vs CDMA2000 Standards

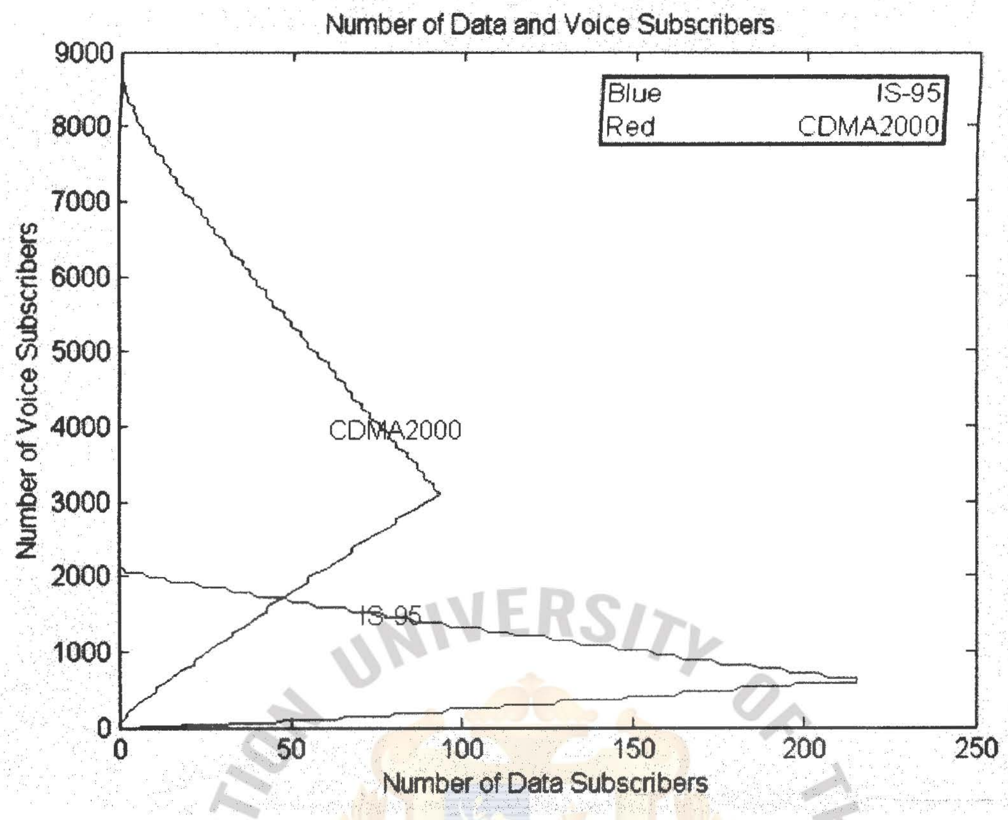


Figure 4-26. The Number of Voice and Data Subscribers of Complete Sharing model for IS-95 Vs CDMA2000 Standards

(5% call blocking probability for voice and 1% for data)

Various call Blocking probability

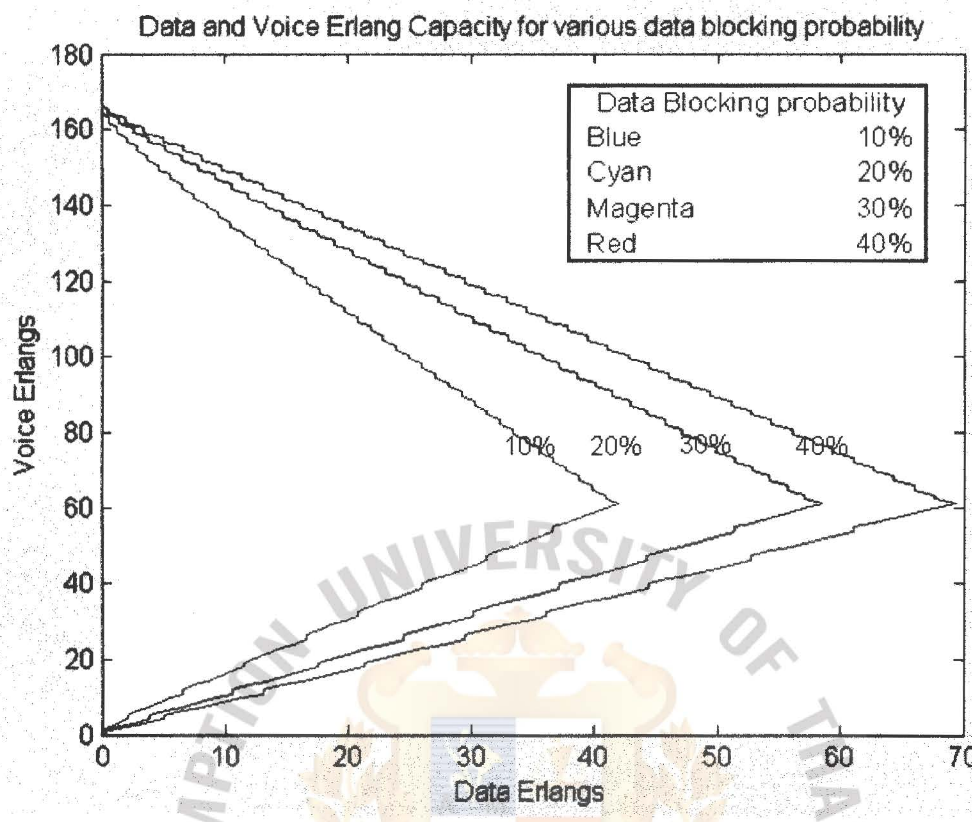


Figure 4-27. Voice and Data Erlang capacity of Complete Sharing model for various data blocking probability, CDMA2000 Standards (Constant voice blocking probability 20%)

From Figure 4-27, it is obvious that the higher data call blocking probability, the more Erlang capacity of data service and the higher of range between the maximum and the minimum voice Erlang capacity boundary that system supports, higher maximum boundary and lower minimum boundary, however the maximum of voice Erlang capacity is still the same, because of the constant of call blocking probability of voice. From this point, the higher maximum boundary of supportable size for voice service means that the higher supportable size for voice service. However, with the lower minimum boundary supportable size for voice service, it also implies that the minimum guarantee for support voice service is also lower. And this seems to be trade off for each other.

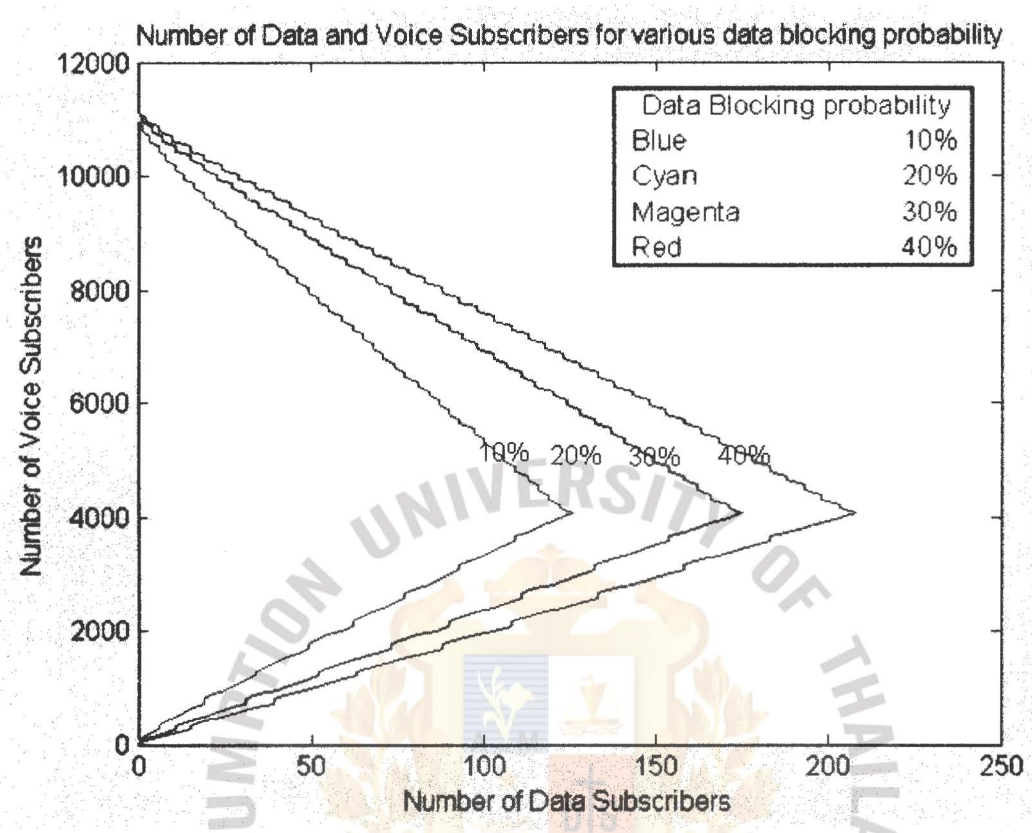


Figure 4-28. The Number of Voice and Data Subscribers of Complete Sharing model for various data blocking probability, CDMA2000 Standards (Constant voice blocking probability 20%)

In other point of view, number of subscribers, shown in Figure 4-28, if we want to support more data subscribers, data call blocking probability is a must to increase but the trade of quality of data service, the ability of using resource by subscribers, need to take into account. But for this model, the interesting point happen for voice service that is with the higher data blocking probability, at the same supportable size of data call, the supportable size of voice call is increased with more voice subscribers but it is also trade off with the lower guarantee of minimum supportable size of voice subscribers, while the quality of voice service is the same, since the constant of probability of voice. Such for this, at the same supportable size of data call such that 100 data subscribers, the supportable size of voice call is increased at the maximum supportable side such that 5300, 6100, 7000, 7600 but also the decrease at the minimum supportable side such 3300, 2800, 2300, 1900.

For service provider can apply this analysis, to consider for the benefit of data service which come with trade off in term of quality of that subscribers will be able to use the resource, but benefit for voice service with higher supportable size, also comes with the lower guarantee of minimum supportable size.

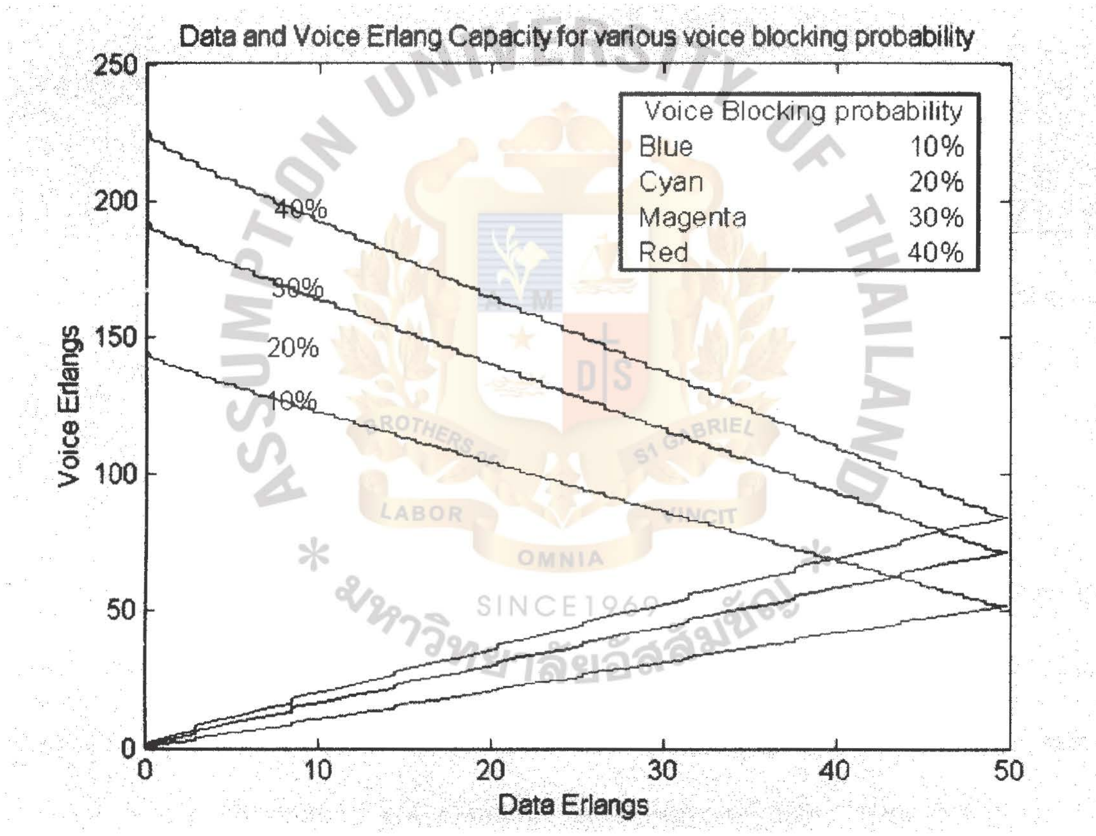


Figure 4-29. Voice and Data Erlang capacity of Complete Sharing model for various voice blocking probability, CDMA2000 Standards

(Constant data blocking probability 20%)

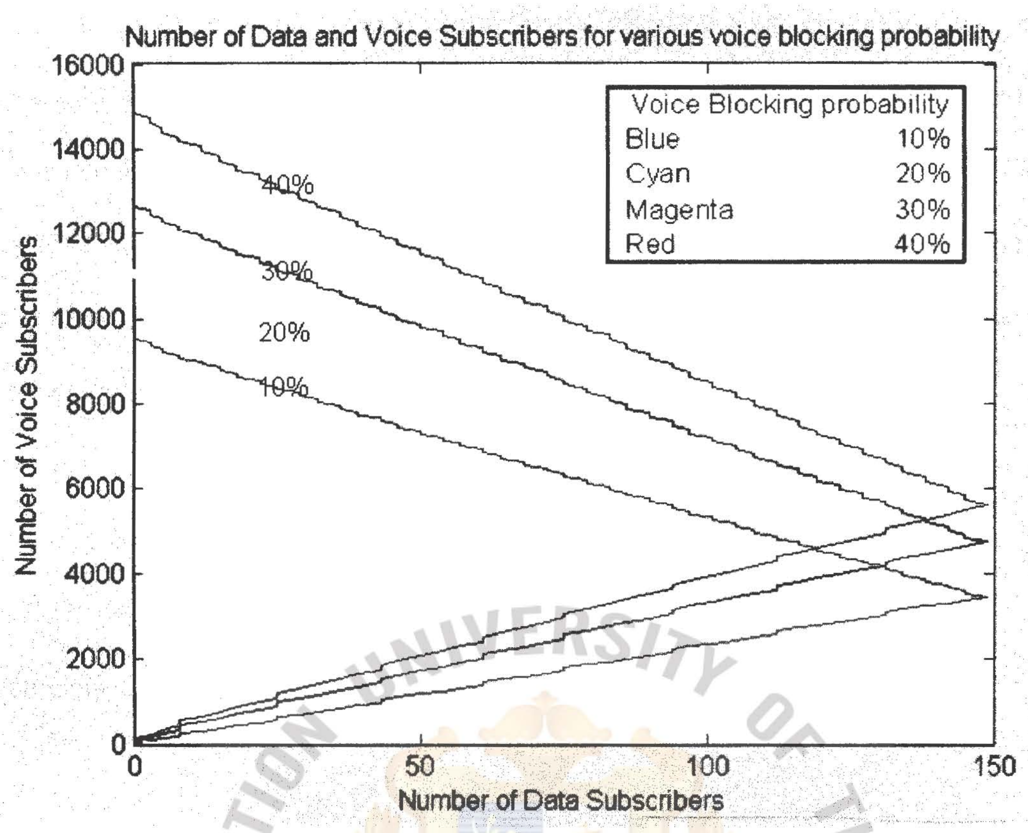


Figure 4-30. The Number of Voice and Data Subscribers of Complete Sharing model for various voice blocking probability, CDMA2000 Standards (Constant data blocking probability 20%)

From Figure 4-29, it is obvious that the higher voice call blocking probability, the more Erlang capacity of voice service, higher maximum boundary and also higher minimum boundary, however the maximum of data Erlang capacity is still the same, because of the constant of call blocking probability of data. From this point, the higher maximum boundary of supportable size for voice service means that the higher supportable size for voice service. Also the higher minimum boundary supportable size for voice service, it also implies that the minimum guarantee for support voice service is also increased. In other point of view, number of subscribers, shown in Figure 4-30, if we want to support more voice subscribers in term of maximum and minimum supportable, voice call blocking probability is a must to increase but the trade off quality of voice service, the ability of using resource by subscribers, need to take into account. There is also interesting for data service that is with the higher voice blocking probability, at the same supportable size of voice call, the supportable size of data call is increased with more data subscribers, at the maximum supportable size for voice service. But less data subscribers, at the minimum supportable size for voice service.

For service provider can apply this analysis, to consider for the benefit of voice service which come with trade off in term of quality of that subscribers will be able to use the resource, but for data service with higher supportable size at the maximum boundary and minimum boundary of voice service.

4.4 Comparison of 3 different Models

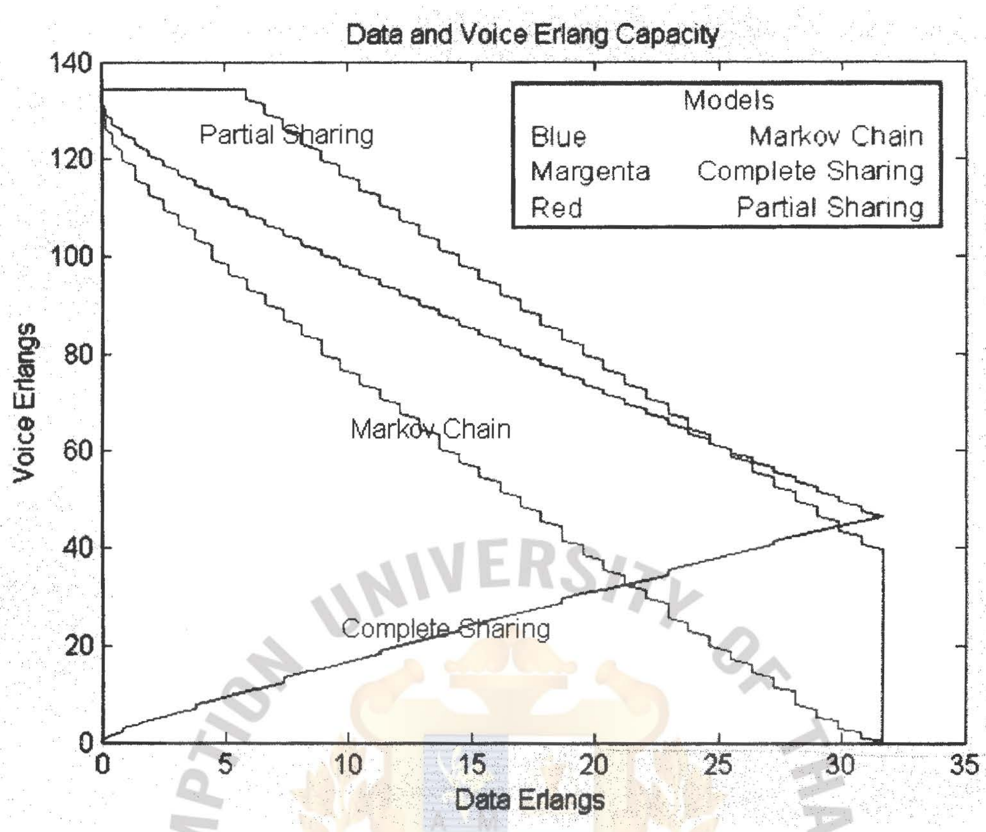


Figure 4-31. Voice and Data Erlang capacity of 3 different models for CDMA2000 Standards (5% call blocking probability for voice and 1% for data)

From Figure 4-31 and Figure 4-32, for all 3 models are in the same system environment, but the difference are shown for each characteristic of models. First, we point out the characteristic of each model. The maximum resource are clearly to be the same, now we can see that the first model, Markov chain, the data and voice Erlang capacity are inversely proportion to each other, the more voice Erlang capacity, the less data Erlang capacity and vice versa. And for the second model, Partial Sharing model, the system guarantee the minimum of supportable size for each service at the maximum using resource by the other service, then in the part of out of the guarantee resource, the share between both 2 services is allowed by inversely proportional to each other. For the last model, complete sharing model, it breaks into

2 parts, maximum boundary side and minimum boundary side. For the maximum boundary side, the voice and data Erlang capacity is proportion to each other, while inverse proportion between 2 services at the minimum boundary side.

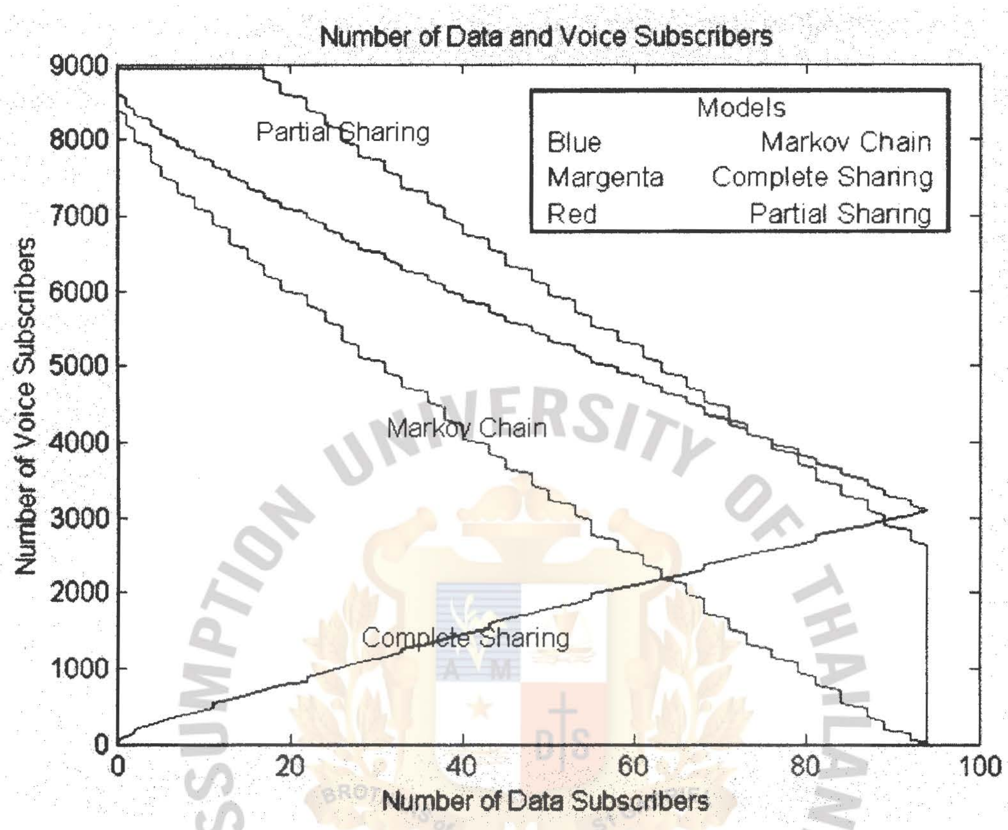


Figure 4-32. The Number of Voice and Data Subscribers of 3 different models for CDMA2000 Standards (5% call blocking probability for voice and 1% for data)

Now let us analyze the strength and weak point of each model. For the first model, its strength point is that simply algorithm, which mean inexpensive cost of implementation, but also show the weak point that no priority policy for specific type of service and the supportable size such Erlang capacity for each services seems that lower utilization than the rest 2 models. For the Partial sharing model, it is obvious for the strength point that it almost introduces the most supportable size of system rather than the other 2 models and it still guarantees the minimum of supportable size for each service while one of service reach the maximum support. It implies that the priority of service can be applied via this specification. And the weak point of this model is the more complex algorithm that may cost a lot budget to implement and manage. The last model, complete sharing, the strong point is that it clearly shows that one service has the most prioritize, which will dominate the other service, that means the activity of one service will control directly to the activity of other service, which is also a weak point and other weak point is the more complexity of algorithm. Note: for the comparison of 3 different models show the same way of result for both standards, IS-95 and CDMA2000.

Chapter 5: Conclusions and Recommendations

Many models have been developed to find out the supportable size of integrated voice and data CDMA system by using the Erlang capacity as the measurement. The models of managing resources, which effect directly to the supportable size of system, are introduced where the new standard is also used for the best efficiency.

In this work, we presented an analytical of performance for resource management models in term of Erlang capacity with the effect of new standard that applied, CDMA2000. This work introduces 3 models, Markov chain, Partial sharing, and Complete sharing, The environment setting for reverse link of multimedia CDMA system which concern with 2 main services, voice and data. Through the numerical example, we can briefly conclude that each model can increase more supportable size for each model by the increasing of call blocking probability of that specific service. While the new standard, CDMA2000, that applied with each model instead of the old one, IS-95, shows that the higher of supportable size for voice service, however the lower of supportable size of data service but better quality in term of file delay transfer, which is suitable for the trend of using service for nowadays especially data service. Finally the models that seem to be the best than the others is Partial sharing, with criteria by supportable size, capacity of voice/data subscribers, most of all the supportable size, it introduced the greater capacity than the other 2 models.

The interested extended worked from this, is the call admission control algorithm that is able to improve the efficiency of system in term of supportable size, because of it is directly correspondent to the call blocking. And the research of forward link is also interesting.

Bibliography

1. Bloaking J.S. Kaufman., *"Shared Resource Environment"*, IEEE Transactions on Communications, vol. Com-29, no.10, October 1981.

2. Hanly S.V., *"Information Capacity of RadioNetworks"*, PhD thesis Universoty of Cambridge, 1993.

3. Kelly F., *"Loss networks"*, The Annals of Applied Probability, vol.1, pp.319-378, 1991.

4. Koo Insoo, JeeHwan Ahn, Jeong-A Lee, and Kiseon Kim, *"Analysis of Erlang Capacity for the Multimedia DS-CDMA Systems"*, IEICE Trans. Fundamentals, Vol.E82-A, No.5, pp. 849-855, May 1999.

5. Mandayam N. and J. Holtzman, *"Analysis of a simple protocol for short message data service in an integrated voice/data CDMA system"*, IEEE Proc. MILCOM, pp.1160-1164, 1995.

6. Matragi Wassim and Sanjiv Nanda, *"Capacity Analysis of an integrated Voice and Data CDMA System"*, IEEE VTC'99 Spring, pp. 1658-1663, 1999.

7. Sampath, A. P. Sarath Kumar, and J.M. Holtzman, *"Power Control and Resource Management for a Multimedia Wireless CDMA System"*, In PIMRC'95, Toronto, Canada, September 1995.

8. Sampath A., N. Mandayam, and J. Holtzman, *"Analysis of an access control mechanism for data traffic in an integrated voice/data wireless CDMA system"*, IEEE Proc. VTC, pp.1448-1452, 1996.

9. Sampath A., N. Mandayam, and J. Holtzman, *"Erlang Capacity of a Power Controlled Integrated Voice and Data CDMA System"*, VTC, 1997.

10. Sasaki A., M. Mizuno, S. Samperi, F. Watanabe, H. Sasaoka, M. Hata, and K. Honama, *"Standardization activities on FPLMTS radio transmission technology in Japan"*, IEICE Trans. Fundamentals, vol.E79-A, no.12, pp.1938-1946, 1996.

11. Viterbi A. and A. Viterbi, *"Erlang capacity of a power controlled CDMA system"*, IEEE J. Sel. Areas Commun., vol.11, no.6, pp.892-900, 1993.

12. Viterbi A.J., *"CDMA, Principles of Spread Spectrum Communication"*, Addison-Wesley, 1995.

13. H. Walke Bernhard, *"Mobile Radio Networks: Networking and Protocols"*, Wiley, 1999.

14. Wu J. and R. Kohno, *"Wireless multi-media CDMA system based on transmission power control"*, IEEE Proc. PIMRC, pp.36-40, 1995.

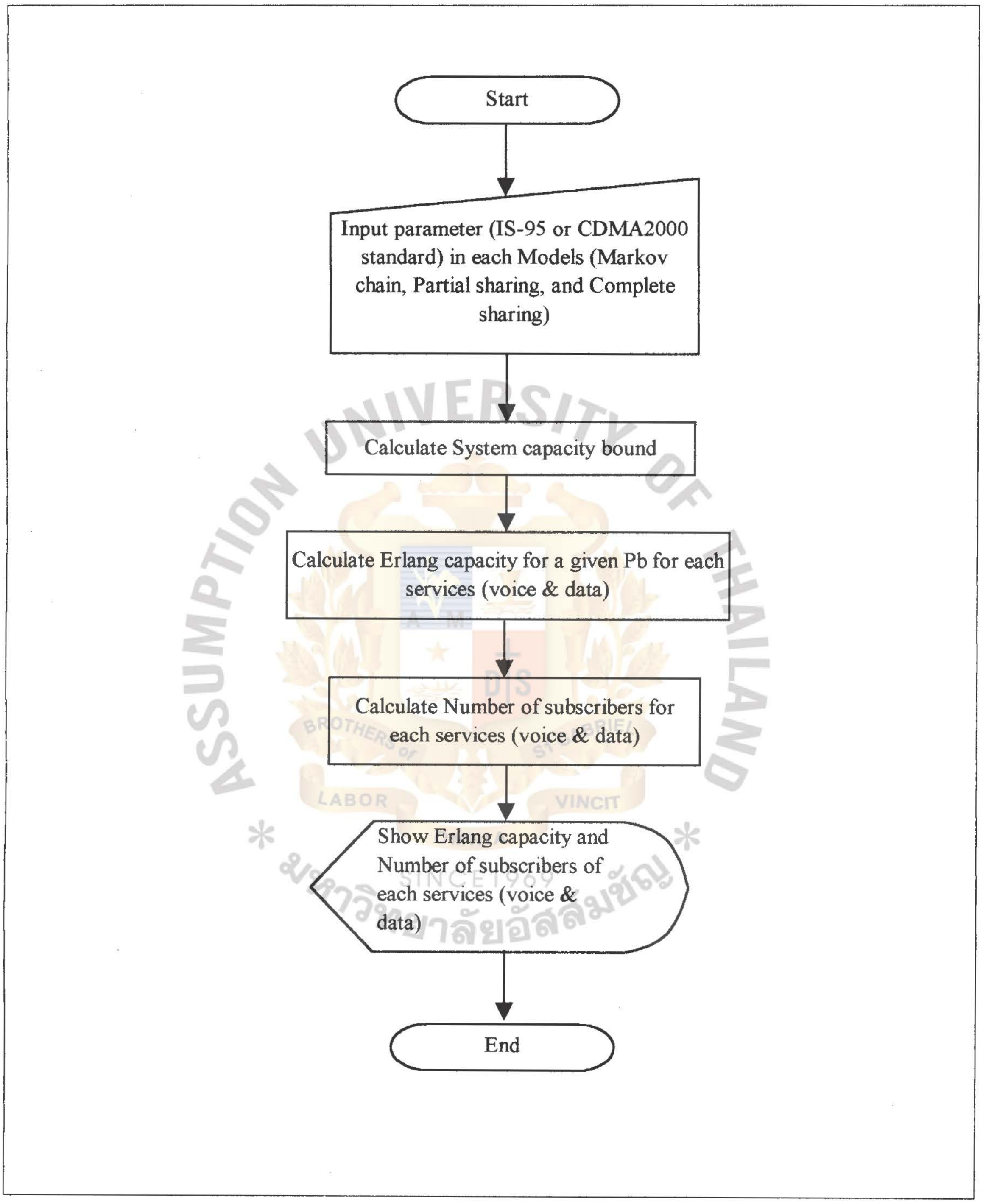
15. Yang J., Y. Choi, J. Ahn, and K. Kim, *"A capacity plane of CDMA system for multimedia traffic"*, IEE Electronics Letters, vol.33, no.17, pp.1432-1433, 1997.

16. Yang J., H. Seo, A. Ahmad, and K. Kim, *"A generalized capacity formula for the multimedia DS-CDMA system"*, APCC'97, pp.46-50, 1997.

17. Yang Samuel C., *"CDMA RF System Engineering"*, Artech House, 1998.

Appendix A. Source code

Programming Flowchart



1.Markov Chain Model

IS-95 Standard

See attached CD-ROM: MarkovModel_IS95.m

CDMA2000 Standard

See attached CD-ROM: MarkovModel_CDMA2k.m

2.Partial Sharing Model

IS-95 Standard

See attached CD-ROM: PartialSharingModel_IS95.m

CDMA2000 Standard

See attached CD-ROM: PartialSharingModel_CDMA2k.m

3.Complete Sharing Model

IS-95 Standard

See attached CD-ROM: CompleteSharingModel_IS95.m

CDMA2000 Standard

See attached CD-ROM: CompleteSharingModel_CDMA2k.m

Example: source code of Markov Chain model for CDMA2000

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%% Erlang Capacity: K-dimension markov chain Model for CDMA2000%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%% Step 1. Find System capacity bound
%%%%%%%%%%% Step 2. Find Erlang capacity for a given Pb
%%%%%%%%%%% Step 3. Find Number of subscribers
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%% Input Parameter %%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%======================== CDMA-2000 Standard =========================
% W        5          MHz  (Bandwidth): 5,10,15,20 MHz
% Rv       9.6         kbps  (Voice rate)
% Rd       64          kbps  (Data rate): 64, 144, 384 kbps
% Ev       7          db    (Required Eb/No or (Eb/Io) for Voice traffic)
% Ed       10          db    (Required Eb/No or (Eb/Io) for Data traffic)
% (1/(1+f))   0.7            (Frequency reuse factor)
% Pbv      0.05             (Blocking probability of voice)
% Pbd      0.01             (Blocking probability of data)
% AlpV     3/8  (Should not be 1)(Voice traffic activity factor)
% AlpD     0.125 (Should not be 1)(Data traffic activity factor)
%--------------------------------------------------------------------------------------------------------------

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear;
pack;

%=================================================================
%================= Step 1. Find System capacity bound ====================
%=================================================================
% Step 1.1 Find maximum Nd & Nv
% Step 1.2 Find N: each pair (Nv,Nd) in the range of maximum of Nv and Nd
```

```
%================ Formula ================================
%  Nv*AlpV*Ev*Rv + Nd*AlpD*Ed*Rd <= W*((1/(1+f)))  ------------ (1)
%  Nv <= [W*((1/(1+f))) - (Nd*AlpD*Ed*Rd)] / (AlpV*Ev*Rv) ----- (2)
%  Nd <= [W*((1/(1+f))) - (Nv*AlpV*Ev*Rv)] / (AlpD*Ed*Rd) ----- (3)
%  Note: Nv is no. of voice channel (virtual channel)
%        Nd is no. of data channel (virtual channel)
%=========================================================

%*************************************************************************
%*************** Step 1.1 Find maximum Nd & Nv *****************
%*************************************************************************
% maximum of Nv when Nd = 0
% So maximum no. of Nv is
% maxNv = fix([(W*rf)-0]/(AlpV*Ev*Rv))--- (1)
% maximum of Nd when Nv = 0
% So maximum no. of Nd is
% maxNd = fix([(W*rf)-0]/(AlpD*Ed*Rd))--- (2)
%*************************************************************************

%******************* Variable declaration **************************
rf = 0.7;  % Frequency reuse factor (1/(1+f))
W  = 5000; % Bandwidth (5,10,15,20) MHz
Rv = 9.6;  % Voice rate (9.6 kbps)
Rd = 64;   % Data rate (64, 144, 384 kbps)
Ev = 7;    % Required Eb/No or (Eb/Io) for Voice traffic (7 db)
Ed = 10;   % Required Eb/No or (Eb/Io) for Data traffic (10 db)
AlpV  = 3/8; % Voice traffic activity factor
AlpD  = 0.125; % Data traffic activity factor
%*************************************************************************

% Find maximum Nv (Integer number)
maxNv = fix([(W*rf)-0]/(AlpV*Ev*Rv));% Nbd = 0
% Find maximum Nd (Integer number)
maxNd = fix([(W*rf)-0]/(AlpD*Ed*Rd));% Nbv = 0
```

```
% Show result value
disp('Step 1.1 Find maximum Nd & Nv');
disp('maxNv is');
disp(maxNv); % 138
disp('maxNd is');
disp(maxNd); % 43

%*******************************************************************************************
%** Step 1.2 Find N: each pair (Nv,Nd) in the range of maximum of Nv and Nd **
%*******************************************************************************************
%========================= Formula =====================
%  Nv*AlpV*Ev*Rv + Nd*AlpD*Ed*Rd <= W*((1/(1+f))) --- (1)
%  No. of voice channel is
%  Nv = [W*((1/(1+f))) - (Nd*AlpD*Ed*Rd)] / (AlpV*Ev*Rv) --- (2)
%  No. of data channel is
%  Nd = [W*((1/(1+f))) - (Nv*AlpV*Ev*Rv)] / (AlpD*Ed*Rd) --- (3)
%======================================================
%*******************************************************************************************

aNv = []; % inital array for keep each Nv data
aNd = []; % inital array for keep each Nd data

% Check mximum of Nv and Nd value, then loop through the larger value for finding the small value
if maxNd > maxNv
 % Find Nv for a given Nd
  for Nd= 0:maxNd % Loop through array of Nd (aNd)
    %get Integer number of Nv for the given Nd
    Nv = fix([(W*rf)-(Nd*AlpD*Ed*Rd)]/(AlpV*Ev*Rv));
   % Keep data into array
    aNd = [aNd,Nd]; %add new Nd data into array
    aNv = [aNv,Nv]; %add new Nv data into array
  end
else % maxNd <= maxNv
 % Find Nd for a given Nv
  for Nv= 0:maxNv % Loop through array of Nv (aNv)
```

```
    %get Integer number of Nd for the given Nv
     Nd = fix([(W*rf)-(Nv*AlpV*Ev*Rv)]/(AlpD*Ed*Rd));
   % Keep data into array
     aNd = [aNd,Nd]; %add new Nd data into array
     aNv = [aNv,Nv]; %add new Nv data into array
   end
end

% Show result value
disp('Step 1.2 Find Nb: each pair (Nbv,Nbd) in the range of maximum of Nbv and Nbd');
disp('aNd');
disp(aNd);
disp('aNv');
disp(aNv);

%************************************************************************************************
%*********************************** Step 2. Find Erlang Capacity ***********************************
%************************************************************************************************
% For each service(Voice & Data)
% Step 2.1 Find the co-efficient of equation
% Step 2.2 Solve equation (from 2.1) to find out Erlang Capacity(e)
%====================== Formula ====================================
% Pb = [(e power N) / N!)]/ the sum of (e power K)/K! from K = 0 to N --- (1)
% Pb * N! * Y - e^N = 0 , where Y = the sum of (e power K)/K! from K = 0 to N --- (2)
%==================================================================
%************************************************************************************************

%****************** Variable declaration ***************
Pbv = 0.05; % Blocking probability of voice
Pbd = 0.01; % Blocking probability of data
%***********************************************************

%***********************************************************
%******************* For Voice Service *****************
%***********************************************************
```

```
%*****************************************************************************************************
%************************ Step 2.1 Find the co-efficient of equation **************************
%*****************************************************************************************************
%======================== Formula ==========================
% equation: Pb * N! * Y - e^N = 0 , where Y = the sum of (e power K)/K! from K = 0 to N
% 1. get the co-efficient value of this part (Pb * N! * Y) by (Pb * N! / K!)
% 2. get the co-efficient value of equation by -1 out of the co-efficient of e^N from(1)
%====================================================
%*****************************************************************************************************


%For aNv
disp(size(aNv,2)); %Show array size of aNv (keep as 1 row , many columns)
aErlangV = []; % re-initial the array for keeping Erlang value of Type-Voice
for i=1:size(aNv,2) % Loop through array of Voice channel
  disp(i);
  N=aNv(i); % get each value from array at the index i
  disp(N);
  aCF = []; % re-initial the array for keeping the co-efficient of e^N
  for j=N:-1:0 % Loop from power N to 0 (N, N-1,N-2,...,0)
   %1. calculate co-efficient of equation for this part (Pb * N! * Y) by (Pb * N! / K!)
   cf = Pbv * factorial(N) / factorial(j); % Find co-efficient value of e^N
   aCF = [aCF,cf]; % adding new co-efficient value into array

%    Show value for checking
%    disp('Co-Efficient of the power of ');
%    disp(j);
%    disp('is');
%    disp(cf);
%    disp('array value');
%    disp(aCF);
  end

  % 2. get the co-efficient value of equation by -1 out of the co-efficient of e^N from(1)
  % create the equation: Pb * N! * Y - e^N = 0
  % from the previous, we get the coefficient value of (Pb * N! / K!)
```

```
  % cf. of e^N - e^N
   aCF(1) = aCF(1) - 1; % the first array is the co-efficient of e^N
  % from array: aCF, contain the co-efficient of e power N, N-1, N-2,..., 0 (the last value of array)


   %Show result
   disp('Equation');
   disp(aCF);

%*********************************************************************************************
%************** Step 2.2 Solve equation to find out Erlang Capacity(e) ***************
%*********************************************************************************************


  disp('Result value of Erlang');
  Erlang = roots(aCF); % Solve equation for finding the result, result will keep in 1 row, many columns
  disp(Erlang); % Show result of equation

  % Keep Erlang result into array
   aSize = size(Erlang,1); % keep size of result array
   if aSize < 1
     Erlang(1,1) = 0; % Result not available, keep as 0 due to no. of channel is 0
   end

   %Show result
   disp('Keep Erlang Value');
   disp(Erlang(1,1));
   aErlangV = [aErlangV,Erlang(1,1)]; % add new result into array
   disp('Erlang Collection');
   disp(aErlangV);
   disp('Find Next Erlang');
end

%*********************************************************
%****************** For Data Service ****************
%*********************************************************
```

```
%*******************************************************************************************************
%************************** Step 2.1 Find the co-efficient of equation *************************************
%*******************************************************************************************************
%======================== Formula ======================================
% equation: Pb * N! * Y - e^N = 0 , where Y = the sum of (e power K)/K! from K = 0 to N
% 1. get the co-efficient value of this part (Pb * N! * Y) by (Pb * N! / K!)
% 2. get the co-efficient value of equation by -1 out of the co-efficient of e^N from(1)
%=====================================================================
%*******************************************************************************************************


%For aNd
disp(size(aNd,2)); %S how array size of aNv (keep as 1 row , many columns)
aErlangD = []; % re-initial the array for keeping Erlang value of Type-Data
for i=1:size(aNd,2)% Loop through array of Data channel
  disp(i);
  N=aNd(i); % get each value from array at the index i
  disp(N);
  aCF = []; % re-initial the array for keeping the co-efficient of e^N
  for j=N:-1:0 % Loop from power N to 0 (N, N-1,N-2,...,0)
    %1. calculate co-efficient of equation for this part (Pb * N! * Y) by (Pb * N! / K!)
    cf = Pbd * factorial(N) / factorial(j); % Find co-efficient value of e^N
    aCF = [aCF,cf]; % adding new co-efficient value into array
%     disp('Co-Efficient of the power of ');
%     disp(j);
%     disp('is');
%     disp(cf);
%     disp('array value');
%     disp(aCF);
 end
  % 2. get the co-efficient value of equation by -1 out of the co-efficient of e^N from(1)
  % create the equation: Pb * N! * Y - e^N = 0
  % from the previous, we get the coefficient value of (Pb * N! / K!)
  % cf. of e^N - e^N
   aCF(1) = aCF(1) - 1; % the first array is the co-efficient of e^N
  % from array: aCF, contain the co-efficient of e power N, N-1, N-2,..., 0 (the last value of array)
```

```
 %Show result
  disp('Equation');
  disp(aCF);

%*****************************************************************************************************
%************** Step 2.2 Solve equation to find out Erlang Capacity(e) ****************
%*****************************************************************************************************

  disp('Result value of Erlang');
  Erlang = roots(aCF); % Solve equation for finding the result, result will keep in 1 row, many columns
  disp(Erlang);% Show result of equation

%    disp('size(Erlang,1)');
%    disp(size(Erlang,1));

  % Keep Erlang result into array
   aSize = size(Erlang,1); % Keep size of result array
   if aSize < 1
     Erlang(1,1) = 0; % Result not available, keep as 0 due to no. of channel is 0
   end

  % Show result
   disp('Keep Erlang Value');
   disp(Erlang(1,1));
   aErlangD = [aErlangD,Erlang(1,1)]; % add new result into array
   disp('Erlang Collection');
   disp(aErlangD);
   disp('Find Next Erlang');
end


%disp('aNv');
%disp(aNv);
%disp('aNd');
```

```
%disp(aNd);


%Show Erlang value for voice
 disp('Erlang of Voice');
 disp(aErlangV);
%Show Erlang value for data
 disp('Erlang of Data');
 disp(aErlangD);


%**********************************************************************
%****************** Step 3. Find Number of Subscriber ************
%**********************************************************************
%Assume that each subscriber generate in busy hour
%For voice call
% - each subscriber generates 0.015 Erlangs
%For data call
% - each subscriber generates 1/3 Erlangs
%================== Formula ==================
% Number of subscribers
% Voice subscribers: Voice Erlang / 0.015
% Data subscribers :  Data Erlang / (1/3)
%=========================================
%**********************************************************************


aSubscriberV = []; % re-initial the array for keeping no. of Subscribers for Type-Voice
aSubscriberD = []; % re-initial the array for keeping no. of Subscribers for Type-Data

VE = 0.015; % Erlang capacity for each voice subscriber
DE = 1/3; % Erlang capacity for each data subscriber

% Find No. of Voice subscriber
for i=1:size(aErlangV,2)% Loop through array of Data Erlang
  S = fix(aErlangV(i)/ VE); %Find no. of voice subscribers
  aSubscriberV = [aSubscriberV,S];% adding new subscribers value into array
```

```
end

% Find No. of Data subscriber
for i=1:size(aErlangD,2)% Loop through array of Data Erlang
   S = fix(aErlangD(i)/ DE); %Find no. of voice subscribers
   aSubscriberD = [aSubscriberD,S];% adding new subscribers value into array
end

%Show Subscribers value for voice
 disp('Subscriber of Voice');
 disp(aSubscriberV);
%Show Subscribers value for data
 disp('Subscriber of Data');
 disp(aSubscriberD);
```

Appendix B. Erlang Capacity Result

1.Markov Chain Model

IS-95 Standard

See attached CD-ROM: 3Models-Erlang95.xls

CDMA2000 Standard

See attached CD-ROM: 3Models-Erlang2k.xls

2.Partial Sharing Model

IS-95 Standard

See attached CD-ROM: 3Models-Erlang95.xls

CDMA2000 Standard

See attached CD-ROM: 3Models-Erlang2k.xls

3.Complete Sharing Model

IS-95 Standard

See attached CD-ROM: 3Models-Erlang95.xls

CDMA2000 Standard

See attached CD-ROM: 3Models-Erlang2k.xls

Appendix C. Subscribers Result

1.Markov Chain Model

IS-95 Standard

See attached CD-ROM: 3Models-Sub95.xls

CDMA2000 Standard

See attached CD-ROM: 3Models-Sub2k.xls

2.Partial Sharing Model

IS-95 Standard

See attached CD-ROM: 3Models-Sub95.xls

CDMA2000 Standard

See attached CD-ROM: 3Models-Sub2k.xls

3.Complete Sharing Model

IS-95 Standard

See attached CD-ROM: 3Models-Sub95.xls

CDMA2000 Standard

See attached CD-ROM: 3Models-Sub2k.xls