Development of the Base Station Controller and Manager in the CDMA Mobile System

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CONTENTS

ABSTRACT

The base station (BS) in the CDMA Mobile System (CMS) connects calls through the radio interface and is designed to provide mobile subscribers with high quality service in spite of mobile subscribers' motions. The BS consists of multiple base station transceiver subsystems (BTSs), a base station controller (BSC) and a base station manager (BSM). This paper is concerned with the BSC and the BSM. The BSC is located between the BTSs and the mobile switching center (MSC) connected with the public network, and is responsible for controlling mobile calls from and to mobile subscribers via the BTSs. The BSM provides operator-interfaces per the BS and takes responsibility of operation and maintenance (OAM) of the BS. Design of the BSC is based on two module types: functional module and unit module. The functional module is used to support new services easily and the unit module to increase the system capacity economically. Both modular types are easily achieved by inserting the corresponding modules to the system. Particularly, in order to efficiently support the soft handover which is one of CDMA superior advantages, the BSC adopts a large high-speed packet switch connecting up to 512 BTSs, and thus mobile subscribers can be provided with soft handover in high probability. The BSM is based on a commercial workstation to support OAM functions efficiently and guarantee high reliability of the functions. The BSM uses graphical user interface (GUI) for efficient OAM functions of the BS.

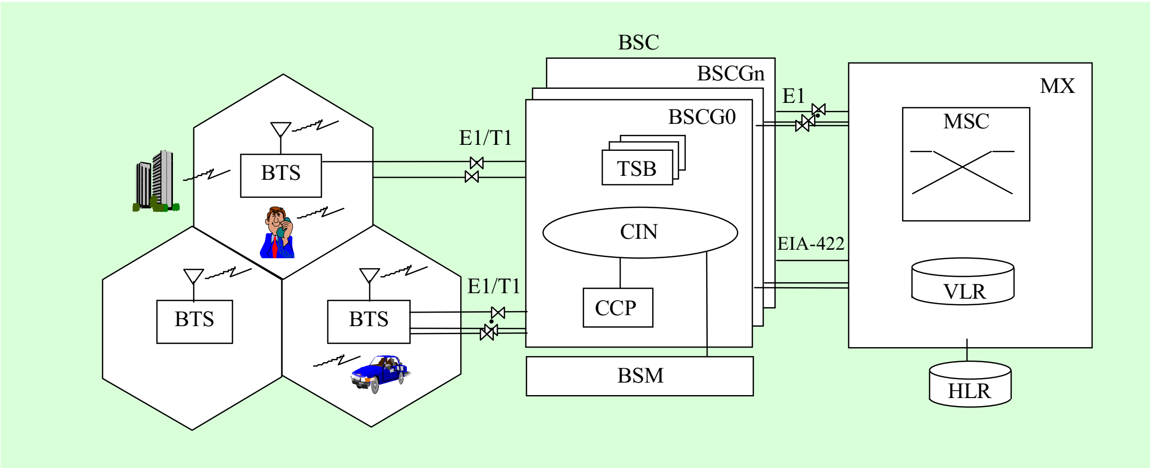

Fig. 1. CDMA Mobile System.

I. INTRODUCTION

The CDMA Mobile System (CMS) is designed to provide various services to mobile subscribers. Figure 1 shows the CMS architecture. The basic CMS consists of a base station (BS), a mobile exchange (MX) and a home location register (HLR). The BS is interfaced to mobile stations over the air and to the MSC through trunks. The BS consists of three subsystems: base station tranceiver subsystem (BTS), base station controller (BSC) and base station manager (BSM). The BTS is located in the cell sites and provides radio interfaces. The BSC controls mobile traffic and the BSM manages the BS including the BTS and the BSC [1], [2]. We describe the design concept, the architecture, and functions of the BSC and the BSM.

In the BSC design, we adopt a distributed architecture and a modular technique to handle system capacity and new services easily. The BSC is composed of three modules: the CDMA interconnection network (CIN), the transcoder and selector bank (TSB), and the call control processor (CCP) [1]. Each module is composed of distributed units which are interfaced to loosely coupled packet messages. The BSC can be configured flexibly and economically by adding the module units. To provide a continuous connection during handover, the soft handover method is adopted in the BSC.

The CIN adopts a large high-speed packet switch with low delay to take advantage of modular growth of capacity and to extend the soft handover area to many cell sites. The CIN switches traffic and control messages among TSBs, CCPs, BSM and BTSs. The TSB consists of two parts: selector and transcoder. The selector takes the best traffic messages from two or three BTSs during soft handover, controls mobile call procedure, and handles outer loop power on the reverse link and closed loop power on the forward link. The transcoder encodes traffic codebook excited linear prediction (CELP) data transferred from the selector into PCM data for the fixed network, and vice versa. The CCP controls the registration procedure, mobile calls and handovers. It also manages resources used in the BSC. The call processing software in the CCP consists of configuration data depending on the cell sites and programs controlling mobile subscribers.

Operator interface is necessary for efficient system operation. The BSM is designed to provide easy operation, administration, and maintenance methods to operators of the BS. The visual display and audible tone are organized to provide ease of use by the operators. The BSM is composed of a commercial workstation and a man-machine interface that serve a wide variety of the BS configurations. Graphical user interface (GUI) provides a very flexible external interface to the operators [1].

This paper is composed as follows. In Section II, we discuss the BSC design objectives. Section III proposes the BSC architecture and its implementation. The BSC is designed by modular techniques and distributed concepts. Section IV describes the BSC application, which handles mobile calls, handovers, and transmission power. In Section V, we explain the BSM which handles operation and management functions of the BS and provides the user interface to the BS operator. This paper is concluded in Section VI.

II. DESIGN OBJECTIVES

Design objectives are modular growth, easy upgrade of services, large soft handover area, reliability, and easy operation and maintenance of the BS.

i) Modular structure
The BSC is designed by utilizing a modular technique and distributed architecture. Each component is connected to the loosely coupled interconnection packet switch. By simply adding each component, the BSC can economically achieve modular growth.

ii) Functional distribution
The BSC is decomposed into CIN, TSB, and CCP by the functional distribution concept. The CIN switches traffic and control messages among the BTSs located in the cells and each module of the BSC. The TSB communicates with MSs through the BTSs. The CCP controls mobile calls and handovers in cooperation with TSBs, BTSs, and MSC. The BSM is designed to operate and manage the BS. The services are easily upgraded by adding or changing some parts of the functions of distributed components.

iii) Large high-speed packet switch
The traffic messages between the MS and the selector of BSC should be processed within 20 ms. During a soft handover, a selector has connection with the MS through two or three BTSs. To increase the possibility of soft handover when the MS travels, the BSC must

have direct connections with as many as possible BTSs. So a high-speed packet switch with large scale is required for a large soft handover area. The traffic channel capacity is 23,000 traffic channels from 512 BTSs.

iv) Synchronization of traffic messages
Soft handover is possible by the synchronization of traffic messages between BTSs and BSC. During the soft handover, the traffic messages from the MS via two or three BTSs should arrive within the same time interval of 20 ms. The selector selects a traffic message by referring to sequential order and a quality metric included in the traffic message during the demodulation procedure at the BTS. The BSC and BTSs synchronize the traffic messages between them using global positioning system (GPS) receivers.

v) Frame staggering
The CIN connects the TSBs through EIA-422 interface and the BTSs through T1/E1 trunks. Since there are finite number of trunks between BSC and BTSs, queuing delay of traffic messages is inevitable. To alleviate the effect of queuing delay, frame staggering, which distributes the traffic messages with the staggered time interval (1.25 ms), is used between the traffic channel element of BTS and the selector of BSC.

vi) Fault tolerance
Failures can cause call drop or system down. The BSC should not be down for more than the specified time accumulation. To prevent the system from going down, major parts of hardware are duplicated by the active-and-standby scheme. When a major failure occurs in the active side, the standby side takes over the tasks of the active side.

vii) Operation and maintenance
The BS must be properly operated and managed for efficiently controlling the radio mobile network. The BSM is responsible for the maintenance and administration of the BS. It operates on a commercial workstation to provide easy hardware availability and offers graphical user interface to provide user friendly working environments.

III. BASE STATION CONTROLLER ARCHITECTURE

The BSC has a distributed architecture in which each equipment is connected to the CIN. It is functionally decomposed into CIN, TSB and CCP. The CIN switches traffic and control message packets among TSBs, CCPs, BSM and BTSs. The CCP is an embedded processor which controls mobile calls in the BS. The TSB processes traffic messages from a mobile and sends them to the MSC. It also processes traffic data from the MSC and sends them to a mobile subscriber [1].

The BSC connects the BTSs with T1/E1 trunks. Traffic and control messages are

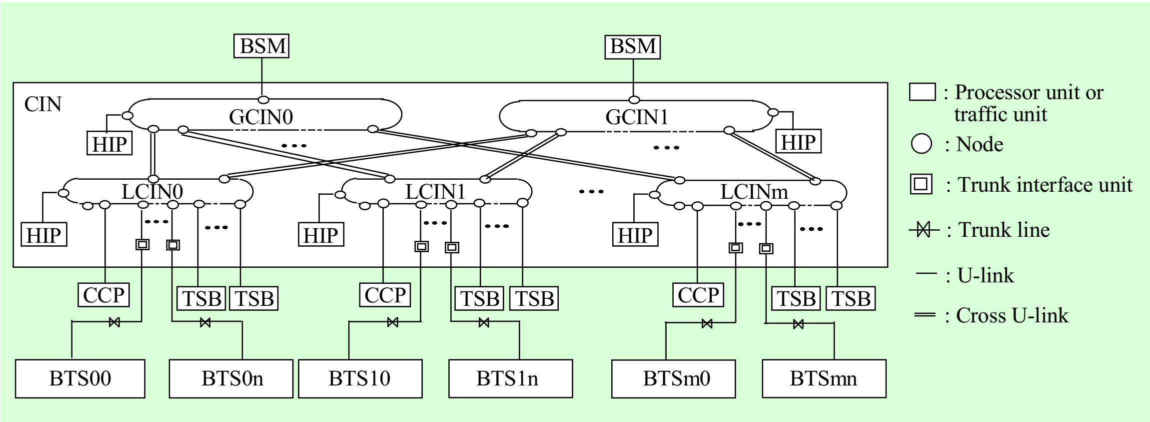

Fig. 2. CDMA interconnection network architecture.

transmitted through them. The BSC and MX are connected by two different paths: E1 trunks for traffic data and EIA-422 for control messages. Figure 1 shows the structure and interface of the CMS including BTS, BSC and MX.

1. CDMA Interconnection Network

The CIN is a high-speed packet switch which switches HDLC frame packets forming traffic and control messages in the BSC. Its throughput is 320 Mbps. Connectivity, transmission delay, expandability, reliability, and capacity are considered in the system design. In this section, we describe CIN architecture, the bus arbitration method, and the address structure and routing algorithm.

A. CIN Architecture

The CIN has a hierarchical architecture with partial mesh topology as shown in Fig. 2. The CIN consists of local CINs (LCINs) and global CINs (GCINs).

A GCIN provides message paths between distributed LCINs and distributes message loads. The GCIN connects up to 12 LCINs and a BSM with EIA-422 and it is cross-duplicated to ensure reliability. The LCIN connects up to 48 BTSs through T1/E1 trunks. It also connects 32 TSBs and a CCP. The whole CIN network is built from several CIN units.

Figure 3 shows the structure of the CIN unit. The high-performance interprocessor communication processor (HIP) is a network manager which performs several maintenance functions such as configuration management, status management, fault management, duplication control, and self-diagnosis for a reliable operation of the CIN unit. It is duplicated for its own reliability and operates in active or stand-by mode.

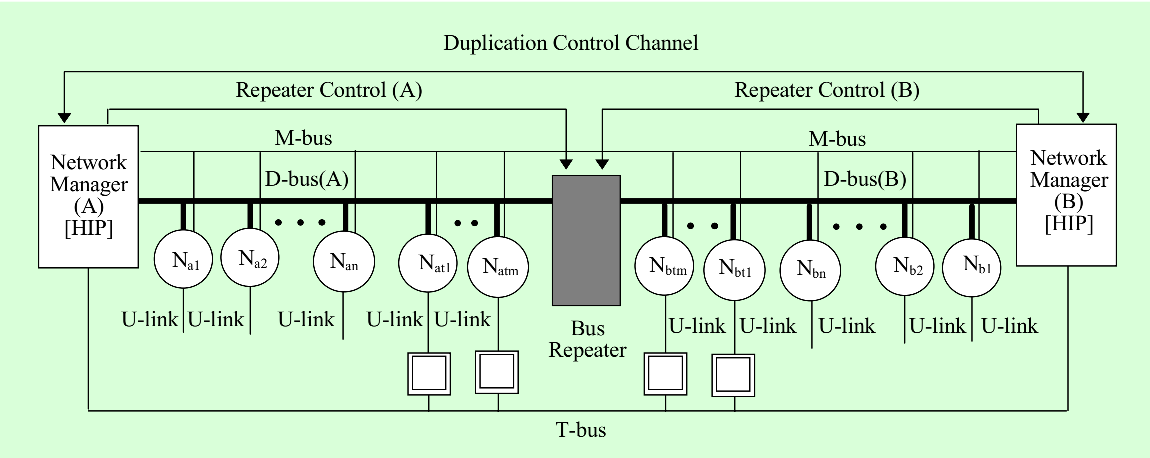

Fig. 3. Structure of the CIN unit.

The nodes N_{a1}, $\cdots$, N_{an} switch message packets. They are duplicated and operate in pairs with N_{b1}, $\cdots$, N_{bn} to prevent a message from being lost due to faults. They connect the CCP, TSBs, BSM and trunks through U-links, and trunks connect the BTSs through the trunk interface. The nodes use the D-bus for transmission and reception of message packets. The D-bus has a triple modular redundancy scheme in which it selects the majority of occurrences for a high reliability. The D-bus operates in either an extended mode or an independent mode. A bus repeater controls the operation modes of the D-bus and is controlled by the HIP. The U-link is a serial path which connects the CCP, TSBs, and BSM with a speed of up to 10 Mbps. The trunk interface unit transmits messages between the node and the distributed BTS. The status of the trunk interface devices is monitored by the HIP through the T-bus. The M-bus provides maintenance paths between the HIP and the nodes. The HIP administrates the status of each node periodically through the M-bus.

B. Bus Arbitration

Transmission collisions must be avoided when nodes transmit messages to the D-bus. Also the waiting time of the messages in queue must be short. The proposed two-phase bus arbitration scheme, reservation phase and transmission phase, satisfies the above requirements. The arbitration scheme uses a round-robin scheme operating with two virtual tokens, a reservation token and a transmission token. It operates as follows. While the ith node seizes the transmission token and transmits messages to the bus, the reservation token turns around to the $(i+1)$th, $(i+2)$th, $\cdots$, jth, $\cdots$, nth node until finding a node that has messages to transmit. If there are messages in the jth node, the reservation token stops at that node. The jth node seizes the transmission token when the ith node has finished the transmission of messages, and it transmits messages. This scheme reduces switch-over time between nodes and average waiting time in a message queue. It enhances the performance of the D-bus.

Figure 4 shows the result of simulation, where round-robin and two-phase bus arbitration schemes are compared. Average waiting time of a message queue abruptly increases to 243.5 μs at 2,000 frames/sec in round-robin, but does not for the two-phase bus arbitration.

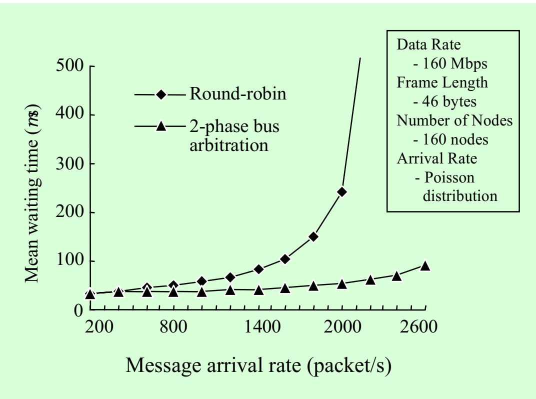

Fig. 4. Average waiting time to message arrival rate.

C. Node Address Structure and Routing

The node address structure is designed with consideration of the maximum configuration of the BSC and to provide both point-to-point and multicasting communications. Figure 5 shows the bit-oriented node address structure. The routing applied to the CIN is the self-routing without software controls.

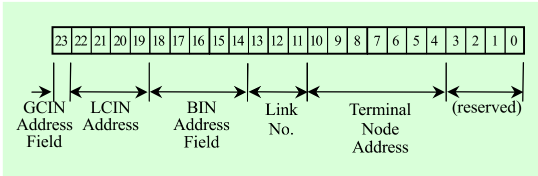

Fig. 5. Node address structure.

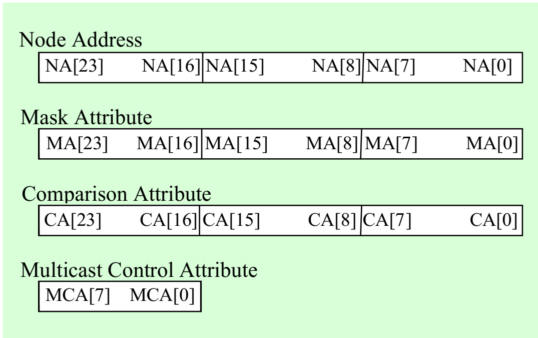

Fig. 6. Structure of address attributes for routing.

Figure 6 shows structure of address attributes. Each node has a unique node address (NA [23:0]) and three attributes–a mask attribute (MA [23:0]), a comparison attribute (CA [23:0]) and a multicasting control attribute (MCA [7:0])–for routing. The mask attribute masks bits in the node address, and the corresponding bits are ignored when the frame address of received message packet is examined. The comparison attribute discriminates between local and gateway nodes. Its bits are set for gateway nodes and reset for local nodes. They are valid when the corresponding bits of the mask attribute are not set. The multicasting control attribute classifies the group of units and supports multicasting. The proposed routing control algorithm is as follows. If the comparison attribute bits are set and the corresponding bits of the node address and those of the frame address are not the same, the corresponding bits of the comparison result are set. If the comparison attribute bits are reset and the corresponding bits of the node address and those of the frame address are the same, the corresponding bits of the comparison result are set. When all bits of the comparison result are set, the message packet is received at the node.

2. Transcoder and Selector Bank

The TSB executes two major functions. The first is a transcoding function that converts the variable rate QCELP vocoding data to the μ-law PCM and vice versa. The second is a selection of traffic message packets from the BTSs during soft handover. For these functions, it is composed of two kinds of printed board assembly: the selector and transcoder interface board assembly (SXIA) and the selector and transcoder board assembly (SXOA). The SXIA receives data from the BTS through the CIN and converts the data into a proper format. It contains trunk interface functions that reformat PCM between the ST-buses and the E1 connections (to and from MSC). The SXOA contains several DSPs. The selector executes the basic functions such as call setup and call tear down, handover and power control. The transcoder is implemented with a digital signal processor (DSP) which has a maximum speed of 40 mega instructions per second (MIPS). The clock generation and distribution device (CKD) receives the reference clock from the GPS and distributes it to the selector and transcoders of the TSB. Traffic messages between the selector/transcoder and the traffic channel element (TCE) in the BTS are synchronized by the GPS clock. This section describes the structure and function of the TSB.

A. TSB Structure

The TSB is connected to the CIN through a U-link interface and to the MSC through trunks on SXIA. Figure 7 shows the architecture of the TSB.

The TSB receives PCM data from the MSC. A transcoder in the TSB encodes PCM data to QCELP data, and then the traffic messages of HDLC frame packet including QCLEP data are transmitted to a mobile through the CIN according to 20 ms timing tick. The TSB also receives traffic messages from a mobile through the CIN, and the transcoder decodes QCELP data to the μ-law PCM code, and then transmits them to the MSC.

B. Selector and Transcoder Interface

The SXIA is responsible for control and maintenance of selectors and transcoders up to 60 channels. It performs flow control of traffic messages and control messages, and exchanges the messages with the selector. Figure 8 is a block diagram of the SXIA,

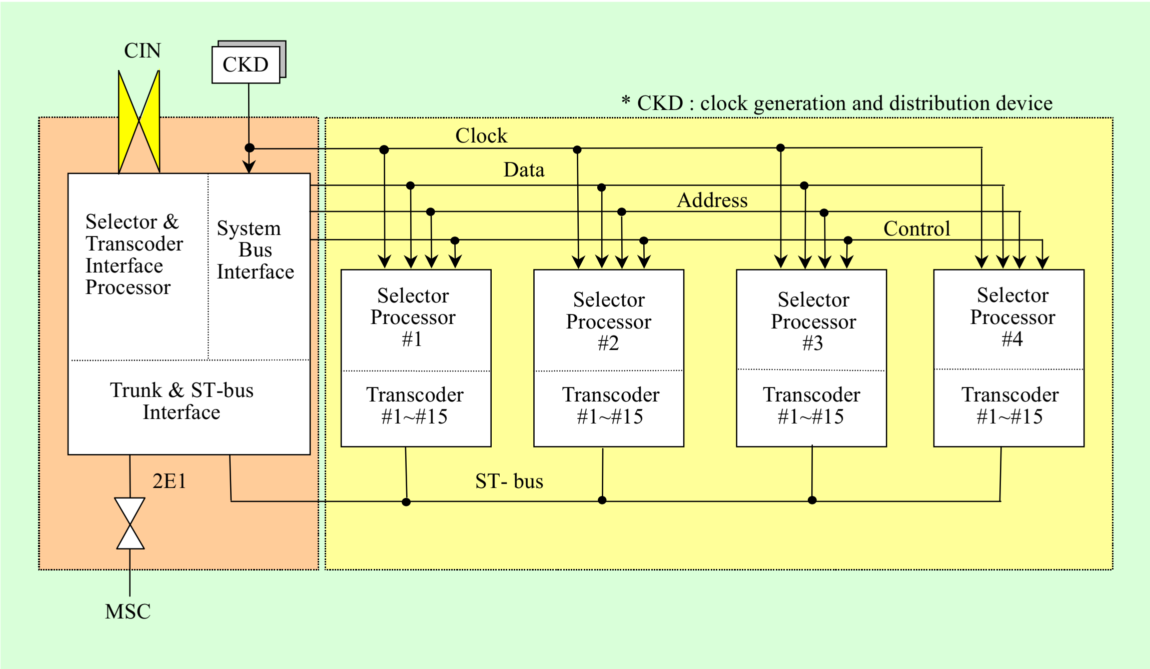

Fig. 7. TSB structure.

which is located between the CIN and the SXOAs.

The selector and transcoder interface device consists of several functional modules. The processor module provides the control and interface to the other blocks on the device. The CIN interface module contains the HDLC controller for interfacing with the CIN using HDLC protocol at 2.048 Mbps. The HDLC controller receives the packet messages from the CIN and extracts the packet data. After analyzing its destination address, it distributes packet data to the SXOAs through the serial path. The trunk and ST-bus interface module receives decoded traffic data from the transcoder with μ-law PCM code. It transmits them to the MX through two E1 trunks. The ST-bus, a PCM subhighway with 2.048 Mbps, shares PCM code with 30 transcoding DSPs in two SXOAs.

C. Selector and Transcoder

The selector and transcoder has the functions such as traffic control, power control and transcoding [3]-[5]. It is composed of several modules shown in Fig. 9. The system bus provides a data interface between the processor modules in SXOA and SXIA through the back plane. The processor module contains a single-chip microprocessor and peripheral circuits [6]. All the traffic and control messages to the SXOA are

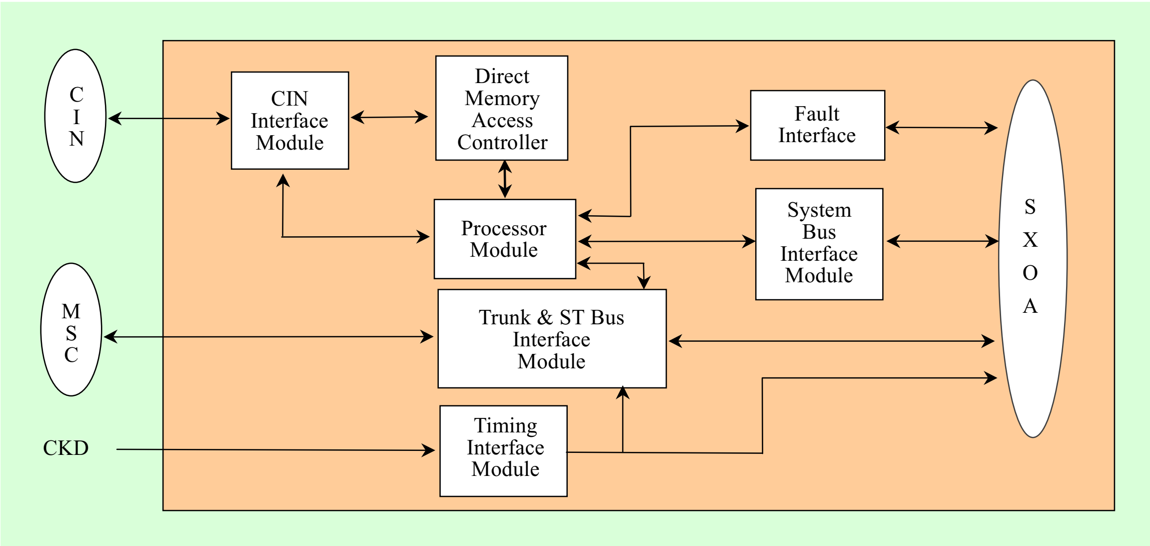

Fig. 8. Block diagram of selector and transcoder interface device.

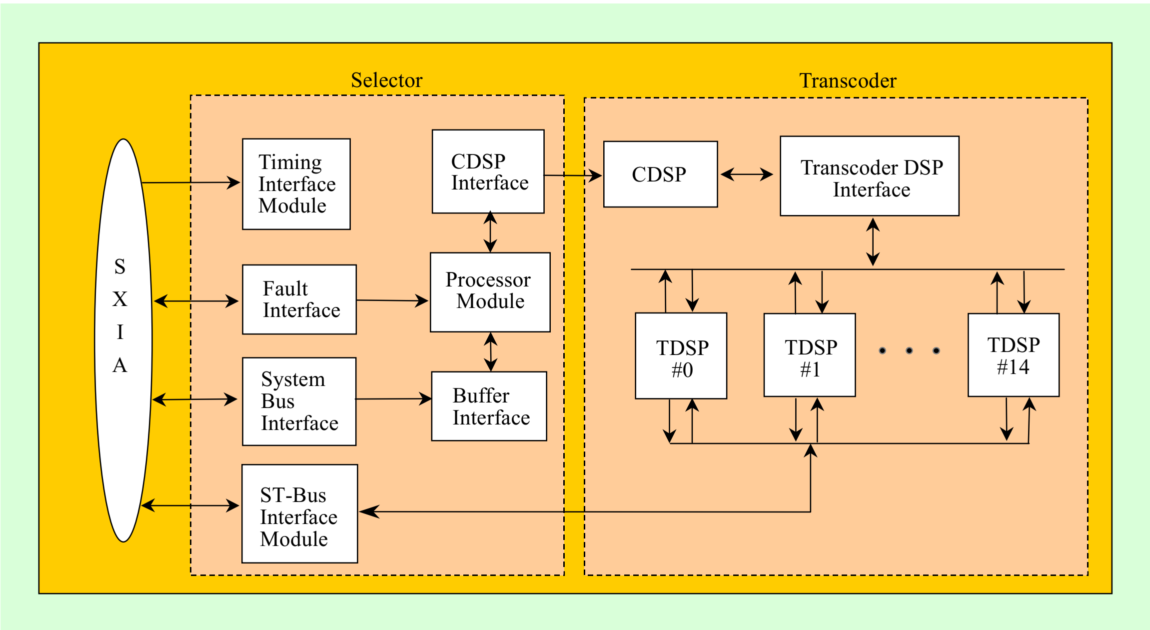

Fig. 9. Block diagram of selector and transcoder.

received at this module. The received messages are analyzed and used for transcoding, power control, and handover, etc. In the forward direction, the processor module collects traffic data from the transcoders, formats and passes them to the system bus interface module.

The control DSP (CDSP) interface block between selector and transcoder consists of four dual port static-RAMs (4∗2k bytes). The transcoder block contains a CDSP, 15 transcoding DSPs (TDSPs) and a DPRAM (2k bytes) between the CDSP and the TDSPs. The CDSP works with the TDSPs through the dual port static-RAM (SRAM) and directs the operation of the TDSPs with command messages. It may request the status from the TDSP. The CDSP operates with the TDSPs and arbitrates data path among processor module and TDSPs. The CDSP allows downloading the transcoding program in the boot ROM to the SRAM of the TDSPs. All the communications are initiated by the command from the selector. The TDSP contains encoding and decoding functions. On the forward link, the PCM data from ST-bus are demultiplexed and sent to the assigned TDSP. The TDSP encodes the 64 kbps PCM data into variable rate vocoded data (QCELP: 8k/4k/2k/1k) and passes the data to the CDSP. On the reverse link, the TDSP decodes the variable rate vocoded data to 64 kbps PCM data. The PCM data from TDSP are multiplexed and sent to the ST-bus.

3. Call Control Processor

The CCP performs call control and hand-off in cooperation with TSBs, BTS control processors (BCPs) of the BTSs, and access processor of the MSC. The CCP supports following functions: registration of mobiles' location, paging, call control, handover, and maintenance of the BTSs and BSC. The CCP operates with duplication in an active/standby mode for the system stability.

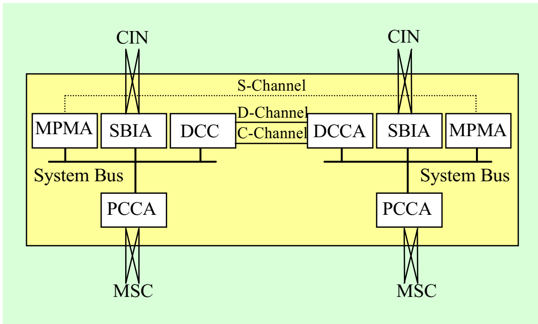

Fig. 10. CCP structure.

The structure of the CCP is shown in Fig. 10. The CCP is designed based on four functional modules: main processor and memory board assembly (MPMA), processor communication control board assembly (PCCA), duplex communication control board assembly (DCCA), and signaling bus interface board assembly (SBIA).

The MPMA consists of a main processor, memory and peripheral interface circuits. The main functions of MPMA are execution of operating system (OS) and application program including interrupt handling, timer control for scheduling, and the maintenance of standby module of the CCP.

The PCCA connects the inter-processor communication unit (IPCU) of MSC that provides the functions of routing the control messages for call processing. The PCCA module contains the HDLC controller that converts the serial HDLC messages to parallel and reports the messages to the MPMA.

The DCCA provides a duplication control for the CCP. The DCCA exchanges the duplication information between the active processor and the standby processor through communication channel (C-channel) and serial channel (S-channel). The data channel (D-channel) is used for the expansion of main processor system bus (MPS-bus). The data updated by the active CPU are written concurrently to the active and standby processors through the D-channel.

The SBIA provides the interfacing function for the message packet communication with the CIN.

IV. BASE STATION CONTROLLER APPLICATION

The configuration data of the BSC, which are dependent on the cell sites, are separated from the program and accessed by library primitives. So the data are hidden to application programmers. The program is decomposed into several execution modules. Each execution module is individually loaded and operated in the processors. When the execution module starts, a module process is created. The module process creates service processes associated with call attempts and maintenance & administration functions. The processes control mobile calls in cooperation with the BCPs of the BTSs and the selectors of the TSBs. They also cooperate with the MSC. These design concepts can improve program productivity and reliability because each process cooperates only with loosely coupled messages and library primitives [1].

1. Registration

For a mobile termination call, the mobile network must check the mobile's location and page the mobile. Registration is the process that the mobile notifies the BS of its location, and its location is stored in the HLR via MSC. There is a tradeoff between registration and paging. The less frequently registration is done, the more frequently paging is required, and vice versa [7].

Figure 11 shows the registration procedure. When location, status, identification, slot cycle, or other characteristics of a mobile are changed, the mobile sends a *registration* message to the BCP in BTS via the access channel. Then the BCP sends a *registration* message to the CCP in BSC, and the CCP sends it to a visitor location register (VLR) via the MSC. The VLR checks and updates the registration information to itself and the HLR, and informs the CCP of the *registration* [*accept/reject*]. Then the CCP sends it to the BCP, and the BCP sends it to the mobile via the paging channel. This registration procedure program is performed independently from the other functions such as call processing.

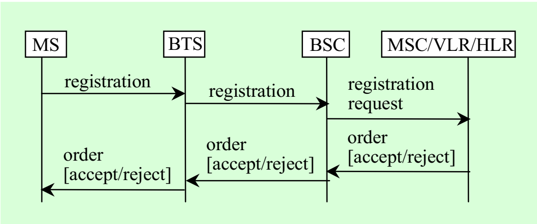

Fig. 11. Registration procedure.

2. Call Control

The call control in the CCP is performed by a pair of service processes: origination service process for the origination procedure and termination service process for the termination procedure. The service process controls only half of the call. So the call control software has a simple structure and the merit for easily handling the call between the distributed processors. The selector of the TSB receives control data from the MS and transmits them to the MS. The BCP of the BTS manages radio channels.

A. Mobile Origination Call Procedure

Figure 12 shows the mobile origination call processing procedure.

(1) Acceptance of mobile call attempt
Upon receiving mobile *origination* message through the access channel, the BTS sends the *acknowledgment order* to the mobile to stop repeating access trials through the paging channel. The BCP allocates a TCE for the call, and the TCE starts transmitting *null-traffic* to the mobile. This null-traffic is not demodulated by the mobile until the mobile receives a *channel assignment* message through the paging channel. After that, the BCP sends the *origination* message to the CCP.

(2) Connection of traffic channel
The CCP selects the available selector/transcoder in the TSB and sends *selector assignment request* to the TSB with the information such as BS configuration and power control data. The TSB initiates the transcoder and makes *time synchronization* which connects the path between the selector and the TCE in the BTS, and selector sends *traffic channel connection* to the CCP. After connecting the radio link of traffic channel, the selector sets up the connection with the mobile (*mobile-acq-ctl/BS-ack-order/mobile-ack-order*). The TSB reports the *mobile connection* to the CCP.

(3) Connection to the MSC
The CCP requests the call *setup* message to the MSC after receiving the mobile connection. After analyzing the required message, the MSC acknowledges to the CCP that the call is in *call-progress*, and accomplishes the call connection to termination user by interworking with the VLR or HLR. When ringing to termination user, the MSC transmits *allerting* message to the CCP. The CCP transmits it to the TSB. The TSB sends *allerting (tone-on)* message to the mobile through the traffic channel already connected.

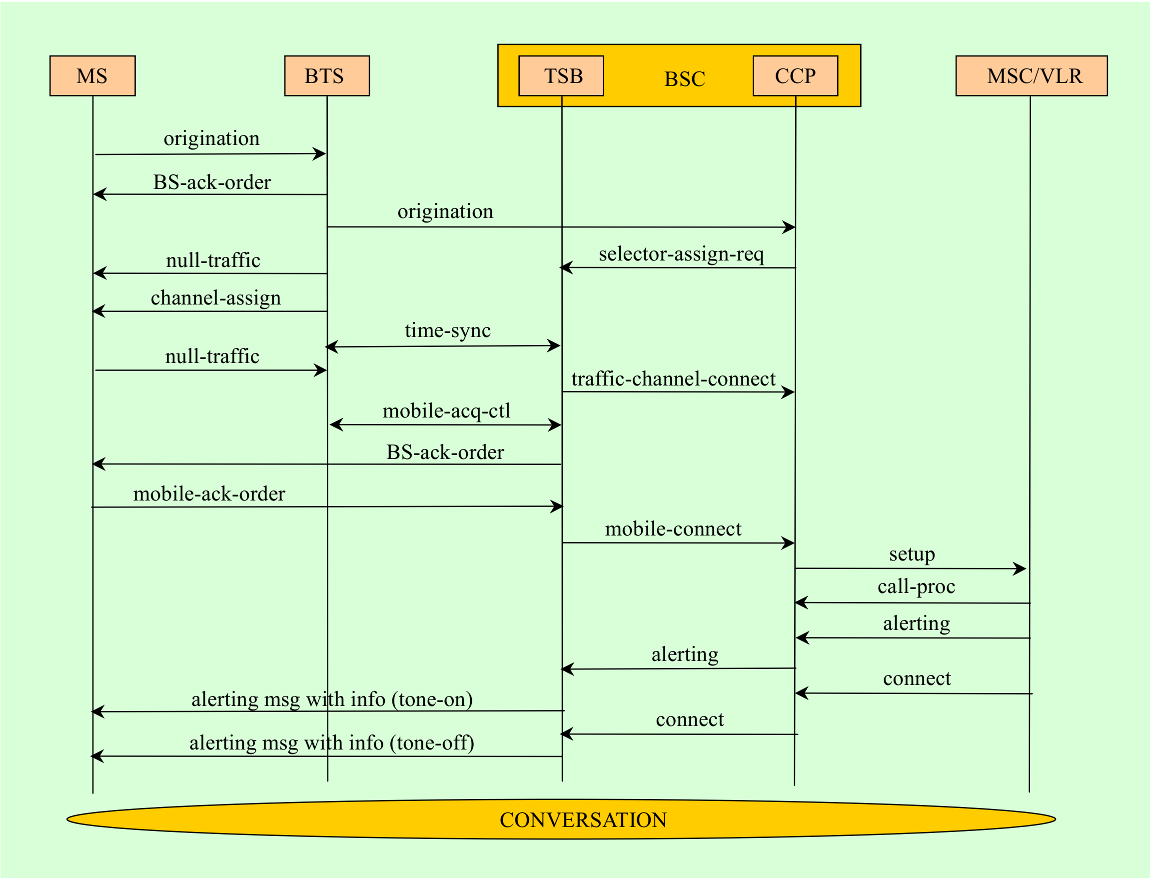

Fig. 12. Origination call procedure.

(4) Conversation

When receiving the *connection* message from the MSC after the termination user answers, the TSB transmits the *allerting (tone-off)* message to the mobile, and the conversation is started. For the optimum voice quality, the BSC controls the transmission power according to the mobility characteristics of the mobile and radio environment variation, and supports the softer/soft/hard handover to keep the continuity of conversation when the mobile passes through the cell boundary. The TSB observes the radio channel status, receives the required information from the mobile, and reports it to the CCP if necessary. When receiving the handover message from the TSB, the CCP controls the handover procedure.

B. Mobile Termination Call Procedure

Figure 13 shows the message flow of the mobile termination call procedure.

(1) Paging mobile

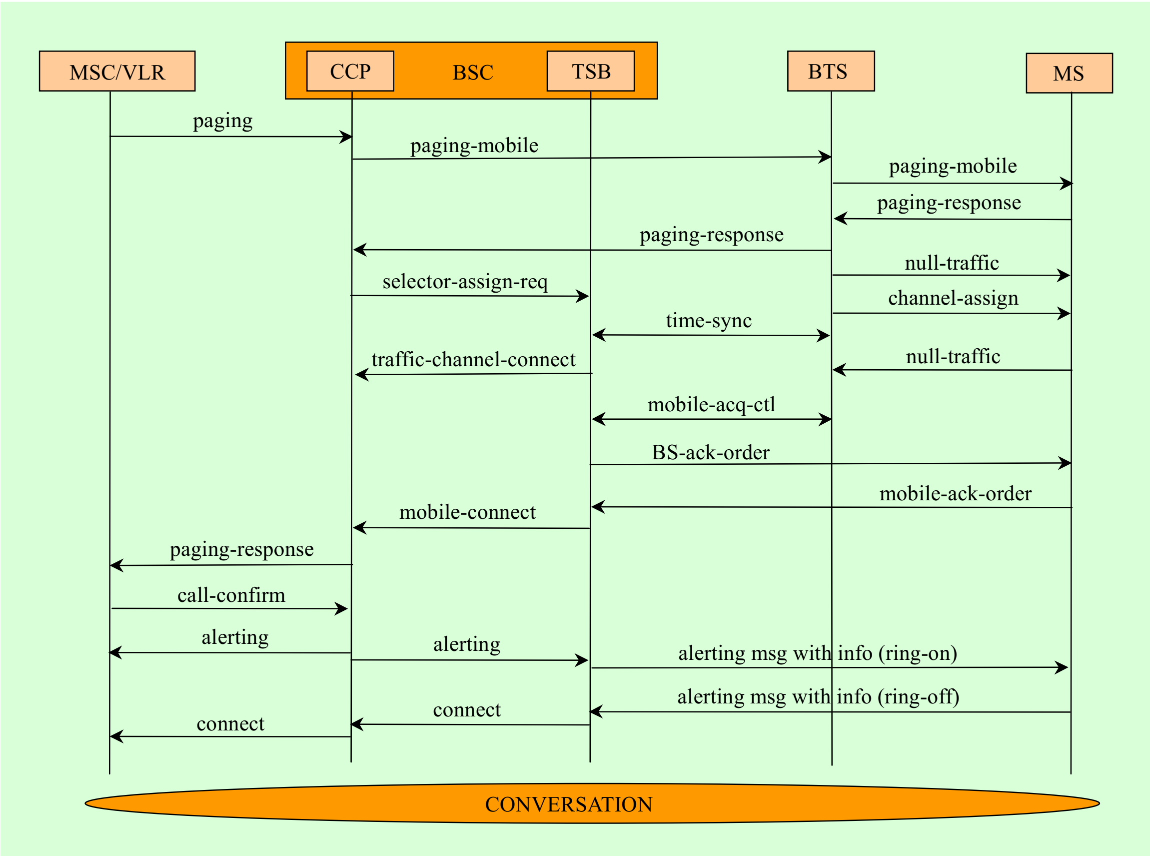

Fig. 13. Termination call procedure.

The paging request message from the MSC initiates the mobile termination call. Receiving the *paging request*, the CCP finds out the BTSs located at the paging area from the configuration data table and sends *paging-mobile* message to them. The BTSs receiving paging-mobile message transmit *paging-mobile* signal through paging channel over the air. After receiving the *paging response* from the mobile, the BTS transmits it to the CCP.

(2) Reception of paging response

After receiving the *paging response* message from the mobile, call control procedures on the BSC such as resource allocation and traffic channel connection are the same as the case of mobile origination call.

(3) Connection to the MSC

After receiving *mobile connection*, the BSC sends the *paging response* message to the MSC. Receiving *call confirmation* from the MSC, the CCP sends *alerting* to the TSB. The TSB sends the *alert-*

ing (ring-on) to the mobile through the traffic channel.

(4) Conversation

If the mobile responds during the ringing, the TSB receives an *allerting (ring-off)* message from the mobile and sends *connection* to the CCP. The CCP sends it to the MSC, and after that the conversation starts. The power control and the handover procedures are performed in the same way as the origination call.

3. Handover

Handover is a procedure which maintains the conversation between the BS and the mobile when a mobile travels from one cell area to the neighbor. Hard handover is a handover in which the mobile moves into disjoint sets of the BSC or the MSC, different frequency assignments. The radio link is not maintained for hard handover. So the conversation gets a short interrupt. Soft handover is a handover in which the mobile moves into a different cell within the BSC. Softer handover is a handover in which the mobile moves into a different sector in a cell. The CDMA uses the same frequency among the cells, so it is possible to keep a conversation without interruption by using multiple traffic channels at the same time [7]. The soft and softer handovers make no interrupt to the conversation. The soft handover procedure is as follows as in Fig. 14.

(1) When the strength of a new pilot from neighbor BTS comes to exceed T_ADD, mobile sends *pilot strength measurement* message to the BSC.

(2) The BSC determines the destination BTS by looking up the neighbor list table and requests for a new traffic channel to the BTS. If the allocation and the acquisition of a new traffic channel are successful, the selector of TSB sends a *handover direction* message to the mobile through both the BTSs.

(3) The mobile transfers the pilot to the active set and sends *handover completion* message to the BSC through both BTSs. The TSB communicates with the mobile through both BTSs. In reverse link, the selector selects a traffic message of better quality between them and sends it to the transcoder. In forward link, the TSB sends the traffic message to the mobile through both the BTSs.

(4) After a while when the strength of a pilot in active set comes to drop below T_DROP, the mobile starts the handover drop timer T_TDROP. After it expires, the mobile again sends *pilot strength measurement* message to the BSC.

(5) The BSC sends *handover direction* message to the mobile station to drop the origination BTS.

(6) The mobile moves the pilot from the active set to the neighbor set and sends *handover completion* message to the BSC.

(7) The BSC releases the origination BTS, and it completes the soft handover procedure.

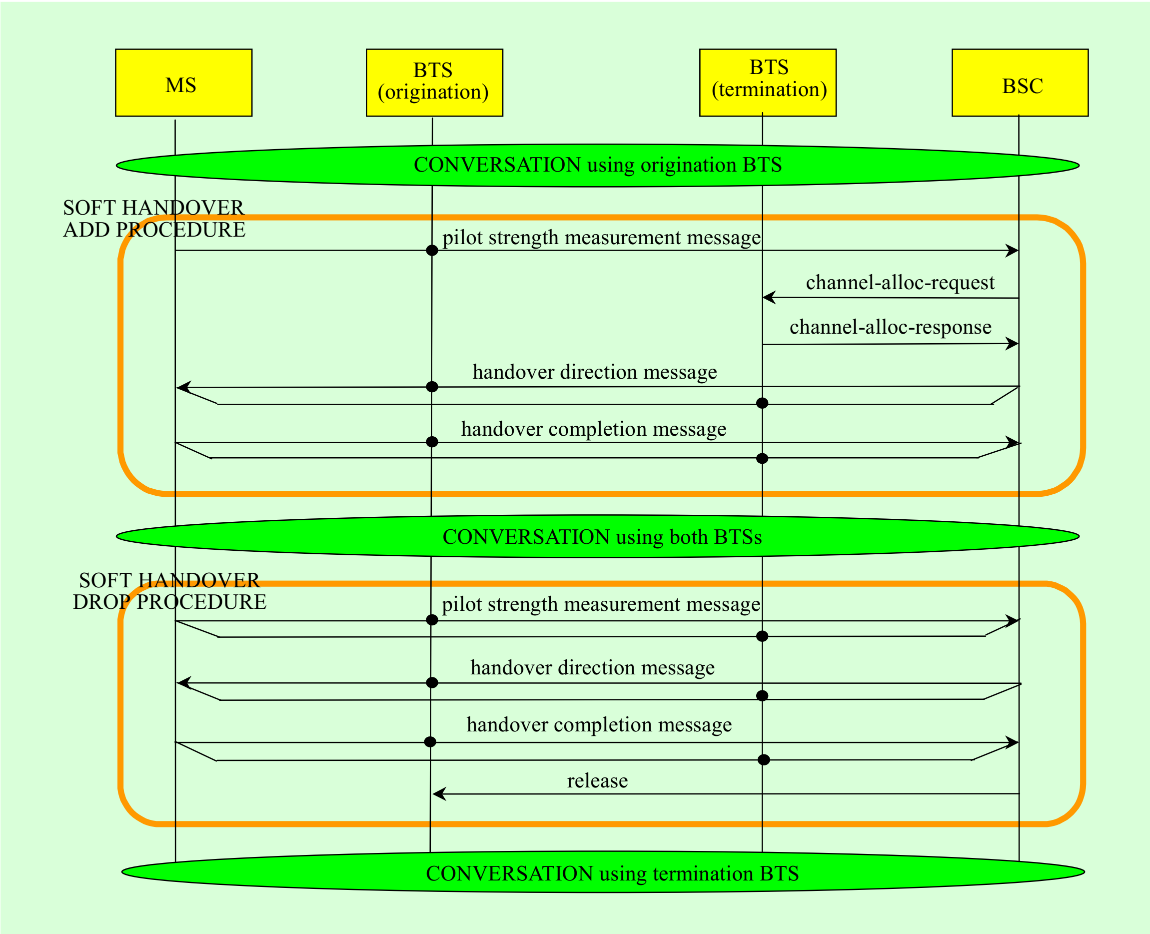

Fig. 14. Soft handover procedure.

4. Power Control

A. Outer Loop Power Control on Reverse Link

Under the same E_b/N_o, the reverse link frame error rate (FER) from a fast moving mobile is higher than that of a static mobile because of fading. The mobile suffering from deep fading needs higher transmission power level. It means that higher preset E_b/N_o should be applied to the closed loop power control in deep fading environment. The outer loop power control is to change dynamically the preset E_b/N_o for closed loop power control on reverse link [7].

A selector receiving a traffic message from the BTS every 20 ms performs outer loop control scheme. First, the selector identifies the kind of frame by the values of frame rate, frame quality metric, and CRC from the received traffic message. There are three kinds of frame types: GF-A, full- or half-rate good frames; GF-B, fourth- or eighth-rate good frames; and BF, full-rate frames with CRC error or frames with 0 value of quality metric. The procedure to change the preset E_b/N_o is as follows.

- When receiving a GF-A frame after the number of consecutive GF-A frames exceeds the selector decreases the preset E_b/N_o by *dec_high* dB because the current power level may be excessive.
- When receiving a GF-B frame, the selector decreases the preset E_b/N_o by *dec_low* dB because the radio environment is not bad and lower rate communication does not need high power.
- When receiving a BF frame before the number of consecutive GF-A frames exceeds the selector increases preset E_b/N_o by *inc_middle* dB.
- When receiving a BF frame before the number of consecutive BF frames exceeds *bad_cnt*, the selector increases preset E_b/N_o by *inc_low* dB. And if the selector receives a BF frame after the number of consecutive BF frames exceeds *bad_cnt*, the selector increases preset E_b/N_o by *inc_high* dB because the radio environment must be worse for communication.

The newly determined preset E_b/N_o must be checked whether it is within the pre-determined range. Increment or decrement steps mentioned above are defined in *configuration data* which are received from the CCP during the call connection process, and these step sizes are determined according to the density of users and cell capacity.

B. Closed Loop Power Control on Forward Link

Forward link power control scheme is applied to meet the required FER and to reduce the interference to neighboring cells. The mobile sends a *power measurement report message*, which has forward traffic channel status information, periodically or after the number of error frames exceeds the threshold. Receiving the *power measurement report message*, the selector invokes the closed loop power control scheme on the forward link [7].

Initially, when a call is connected, the BTS transmits the signal as the nominal power level which is defined in *configuration data*. To find the optimum transmission power level of the BTS, the selector starts the timer whose period is also defined in *configuration data*. When this timer expires, the BTS transmission power level is decreased by a pre-determined step until it reaches the pre-determined minimum level. If the *power measurement report message* is received while the power level is being decreased, the forward power control scheme works to get the increment of power level.

To determine the increment step size of power level, the selector compares the number of error frames in the *power measurement report message* from the mobile with FER threshold in *configuration data*.

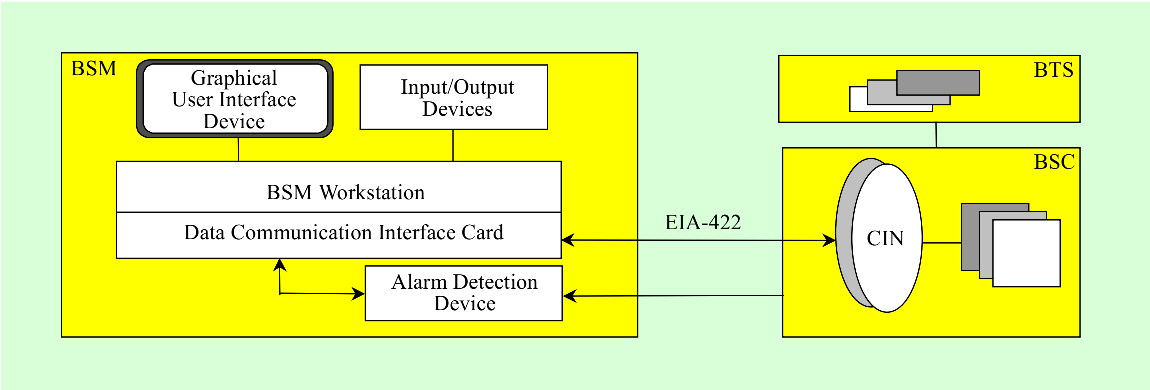

Fig. 15. BSM structure and interface.

If the number of error frames is more than the threshold, the power level is increased by *inc_high* dB, and if not, increased by *inc_middle* dB. The newly determined power level must be checked whether it is within the pre-determined power level range and sent to the channel element as the new transmission power level.

V. BASE STATION MANAGER

The BSM provides the operation, administration and maintenance (OAM) functions for the BS. This OAM functions is classified into five features: program downloading, configuration data management, fault management, status management, and measurement and statistics for the BS. The BSM also offers the graphical user interface to provide an user-friendly working environment for operators.

1. BSM Structure

The BSM uses a commercial workstation with the UNIX™ operating system as a hardware platform [1]. The BSM is connected to the CIN in the BSC using a communication interface card. The communication interface card is equipped on the BSM workstation and controlled by UNIX™ device driver software, and it supports E1/T1 rate speeds and HDLC protocol with EIA-422. The BSM also has some input and output peripherals such as speaker, tape driver, and printer. They are used for audible alarm sound and to back up the system's data and programs, and to prepare a hard copied output.

Figure 15 shows the BSM system hardware structure and interface. To provide a reliable communication, the communication channels are duplicated in a hot standby way. When one channel between the BSM and the CIN has problems, the other is activated to continue the communication.

The BSM functions are implemented with several software modules which perform each OAM function and own function

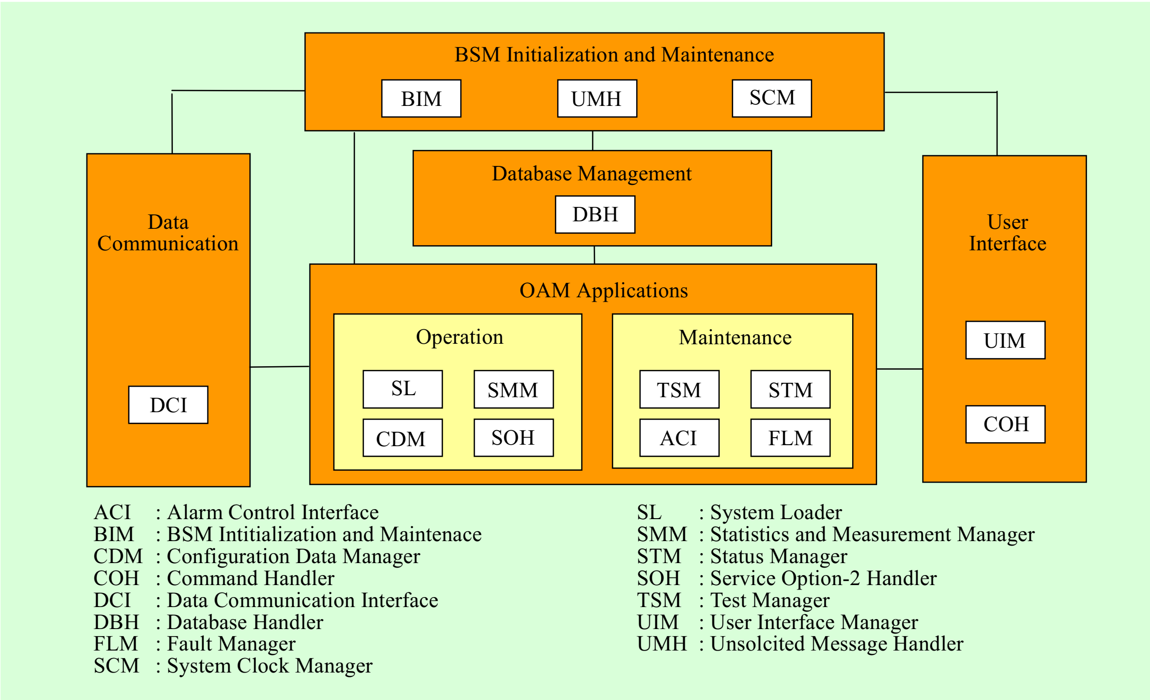

Fig. 16. BSM block structure.

of the BSM such as BSM initialization and maintenance, database management, and so on. The communication between each function is accomplished by the message queue which is supported by UNIX^{TM} operating system. Figure 16 shows the software module and their structure of the BSM.

2. Operation And Maintenance

A. Program Downloading

The program downloading function loads the executable codes and the operational parameter data for the control processors in the BS at the initialization phase. The BS has maximum 12 BSCGs, and each BSCG has 1 CCP, maximum 32 selector interface processors (SIPs) and maximum 48 BTSs. Each SIP has maximum 4 selector and vocoder processors (SVPs). Each BTS has a BTS control processor (BCP) and many channel card controllers (CCCs) [8]. A lot of time is required for loading all the control processors in the BS simultaneously. In order to reduce the time required in the loading, we design the loading function as a hierarchically layered structure.

Figure 17 shows the loading hierarchy and their inter-relationships. The procedures for the loading are as follows: first, when the CCP is power-on or reset, the CCP sends a *Downloading-request-message* to the BSM. Then the BSM loads all the executable codes and data for the control processors such as CCP itself, SIPs, SVPs, and BCPs to the CCP. Second, when the CCP receives the loading request from the BCP or SIP, the CCP loads the requested executable code and data to the BCP or SIP. Thirdly, if the SIP is loaded successfully, the SIP also performs the downloading to the SVP with the similar procedure, and the same scheme is applied between BCP and channel card controller. Thus, this supports a parallel loading to minimize the loading time. Moreover, when a replacement of single block code or software version is required, the partial loading function is used with the same methods.

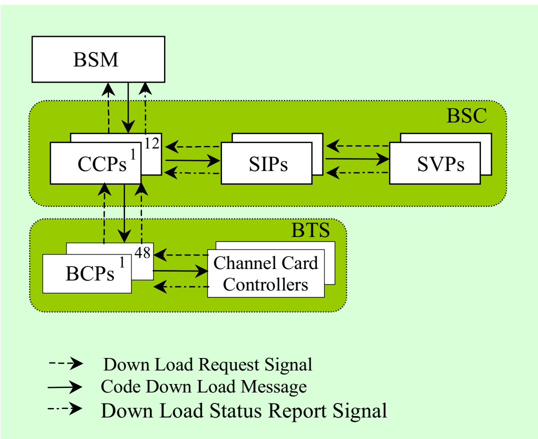

Fig. 17. System downloading hierarchy.

B. BS Configuration Data Management

The configuration data management (CDM) function maintains the operational CDMA parameters and the BS system configuration data. These data are contained in the processor load data (PLD) file in the BSM. The PLD is stored in the main memory of the control processors at the initial loading phase so that it can be manipulated by the operator's commands during the operation. For data consistency, the changing of data must occur on both the entry of the PLD file and the memory in the control processors. A handshaking protocol is used for their consistency confirmation.

In general, the basic operations of data processing are retrieval, updating, insertion and deletion for the related data. The CDM function is also accomplished by the above four operations for the CDMA parameters and the BS configuration data.

In case of updating of parameter data, the handshaking procedure is as follows. If the operator intends to change a system's configuration parameter, the CDM retrieves the data entry from the related PLD file and compares it with the input data from the operator. When a difference happens, CDM sends a *Change-Request-Message* with the input data to the related control processors such as the CCP and BCP, and waits for a *Response-Message*. When the receiving *Response-Message* is positive, the CDM updates the related entry of the PLD file with the input data. With the similar procedure, it manipulates the system's hardware equipment status and configuration such as blocking/unblocking, activation/deactivation, and addition/deletion. But the retrieval operation is simple and does not use any handshaking protocol because it only show the related entry of the PLD file in the BSM.

C. Fault Management

Faults take the system into an unreliable state, so consequently the quality of service is reduced or the service continuity is broken. Therefore, faults must be managed and controlled in order to improve the reliability and serviceability.

The fault management function is designed with a hierarchical structure according to its control hierarchy, and both the software and hardware faults are managed. The software faults are detected by continuous checking or periodic supervision, and hardware faults are detected by an alarm detection equipment. Detected faults are managed by fault manager in the BSM with assistance of fault management module in the control processors such as the CCP and BCP. The fault manager analyzes the occurred faults and manages them using databases. According to the occurrence rate of faults and their severity, it also provides some management functions that consist of the fault and alarm notification, device isolation, service control and so forth, in order to reduce the influence for normal operation.

There are three fault degrees according to their importance or severity: critical, major and minor faults. Critical fault is one that has a serious effect on the system operation and service, so it must be immediately recovered regardless of its occurrence time. A major fault affects the system services or causes a malfunction of circuits, so it must be reported to the operator for testing or recovering. Finally, a minor fault indicates a faulty degree that does not affect system services, but it must be reported to the operator for the purpose of maintenance. If these three degrees of faults occur simultaneously, it is indicated to the operator according to the degree by the predefined priority.

When a faulty system state happens, the BSM offers an audible, visible and textual notification to inform the faulty source and degree to the operator rapidly. Audible fault notifications use the three kinds of sounds, which are different and distinct volumes in order that the operator can recognize and distinguish the faulty occurrence. A visible fault notification displays the occurring position and degree of fault on screen using three colors: red, orange, and yellow for critical, major, and minor faults, respectively. Finally, a textual fault message with fault degree and code, time of day, source, and states of fault are also displayed on the output window of the BSM monitor screen.

A number of on-demand and automatic tests are implemented for fault diagnostics and fault localization more precisely. BSM diagnostic test function performs the test on T1/E1 trunks between BSC and MX, signaling and traffic links between BSC and BTS, and important devices such as the selector and transcoder devices in the BSC and channel elements in the BTS. These tests and its test configurations are controlled by the BSM. To test on the devices, the test manager function is cooperated with the test module in each equipment devices. The test functions are executed as a periodic timer job, and it can also be executed by operator's command. The results of testing are reported to the test manager module in the BSM. Then, the test manager module analyzes and processes the received result message, and displays it on the monitor screen and stores it in the database in cooperation with the fault and status management functions.

D. Status Management

The status management function observes how the control processors and equipment devices of BS are operated. The status changes of all of the processors and devices are supervised continuously and controlled by the upper level control processor in the control hierarchy. It is important that the status management keeps the exact status of processors and devices. Therefore it must cooperates with fault management function and diagnostics test function to keep the system status exactly.

The processor status supervision is performed in such a way that the upper level control processors exchange a *Keep-Alive-Message* with the lower level processors periodically, and this *Keep-Alive-Message* is exchanged in either an uni-directional or a bi-directional answer back way. But, since supervision method like this cannot distinguish a hardware faults, the hardware alarm detection equipment must be used in parallel.

The devices' status is classified into the maintenance status such as normal, block and abnormal, and the service status such as idle and busy. The status management function keeps only maintenance status and provides available/unavailable status of devices to service functions such as call processing. The current status of devices is kept with consistency on the memory of control processors and the database in the BSM, so that whenever the status for each device is changed, the BSM displays the current devices' status on the BSM monitor screen graphically.

E. Measurement and Statistics

The BSM provides the measurement and statistics function to evaluate and report the behaviors and operational information of the BS. The statistics evaluated by the BSM include traffic statistics, fault statistics and overload statistics. The traffic statistics, which are evaluated periodically or on-demand, are the call information related to originating call, terminating call, handover, paging, and registration. The fault statistics are the number of alarms and faults occurred, and the overload statistics are the information about the occupied processing load of the control processors in the BS.

To find out the traffic statistics such as the number of calls and handover attempts, the ratio of blocking to call attempts and so on, the BSM collects the raw data related to traffic statistics with assistance of a data collection module in the control processors, and then processes the collected raw data for statistical representation which is displayed on the BSM monitor screen. The BSM shows the number of failed calls according to failure reason for more detail analysis. The paging and registration attempts are also shown as traffic statistics.

The traffic statistics function is executed by two methods: one is executed by the timer every hour, and the other is executed by operator's request for the purpose of measurement. The former calculates the predefined statistic items related to call traffics every hour in the BSM. The later is only executed by operator's request according to the given time schedule and cell site information. In this case, since operator handles the measurement time, the more detail traffic data are obtained for less then one hour. These traffic statistics play an important role in effective cell design and operation to improve the performance of CMS.

The fault statistic is collection of the summarized information of occurred fault and alarm. When the fault and the alarm are detected, its data are stored on the database of the BSM. The process that is to make statistical information is periodically executed every hour. The result of the process is displayed in output window of the BSM as the fault statistics. The main item of fault statistics is the number of the faults for each fault degree, the number of the alarms occurred per one hour, and history of those.

The overload statistics are much like fault statistics in character, which provide summarized information to operator and are executed periodically. The number of pollings of control processors, the number of responses from them, and CPU idle time of main control processors are reported as overload statistics.

The BSM also controls the test call based on the service option-2 schemes for estimating the system capacity and performance. That is, test calls according to the service option-2 are defined by test engineer using the commands in the BSM. Then the BSM generates the test calls and gathers some information related to call setup and release. This information gives useful information for capacity and performance analysis to the test engineer with the data from another logging facilities such as CDMA performance analysis tool (CPAT) and CDMA data analysis tool (CDAT).

3. User Interface

The user interface function in the BSM provides man–machine interface (MMI) to the BS. It offers a direct command entry, menu-item selections using mouse, batch file executions, history management, the system message display, security controls, and some user help functions for the various user interface.

The BSM user interface is implemented with the GUI especially to show explicitly operation status, faults status, and some statistics information for the BS. It uses Motif™ and a graphic software package, SL-Graphic Modeling System (SL-GMS) that introduces an object-oriented architecture, for the structured design of graphic windows and the fast output of real-time status data on that windows. The windows are hierarchically designed in a simple and logical form because of the enormous amount of graphic information.

The BSM main screen consists of five windows: menu bar, alarm window, graph window, output message window, and command window. The partitioning of the command window and the message window among these screens enables input and output data to be processed simultaneously, and operator can also grasp all the system status at a glance. Figure 18 depicts the layout of the GUI screen of the BSM.

The BSM GUI provides various dialogue styles–direct data entry, menu-item selection and form-filling. The form-filling style must have one-to-one correspondence of screen format and command, and contains a number of factors in changes according to operations environment. It is known that the method of form filling helps unfamiliar user to feel easy to use the system, and when both the essential data items and the optional ones are needed, it is very useful. In real systems, many commands that we use have variable factors which tend to

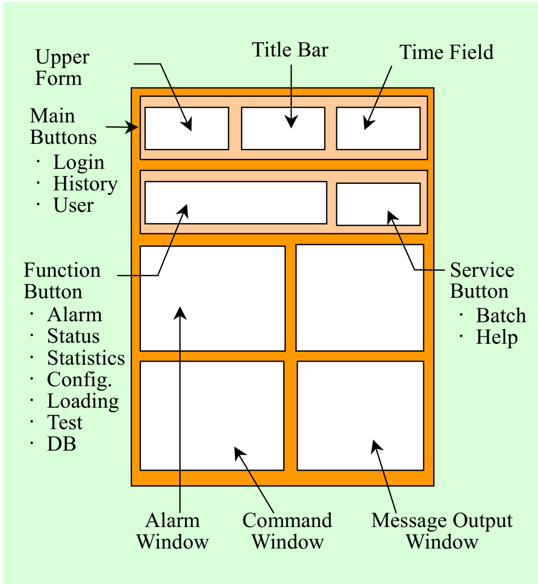

Fig. 18. Screen layout of the BSM GUI.

change according to the system's operation environments.

The GUI function internally consists of independent modules–message output and graphic display module, and command check module–which are divided by function performed. Aiming at reduction of conflicts among system components in the BSM GUI, we use a database and message queue as a communication path between application and the GUI functions. Because all flows of information from application function to the GUI function are attained through database and message queue access, it becomes possible to share function loads through independent design of functions.

The GUI uses new technology for the command description and its processing.

The command description definition (CDD) plays an interface role between the GUI function and other application functions for OAM in the BSM. The CDD is a database for command description. It is needed to check syntax and semantics of the input commands and must be made for each command by the application function. A CDD is composed of a command part, a parameter part, and a help part. The help part is for the user's quick reference about the command format and parameter description for entry. The CDD has some writing rules and must be described by these rules. Also, the user command's syntax for direct data entry dialogue is based on ITU-T man-machine language (MML) [9]. The command is entered by the various dialogue schemes such as menu selection, direct entry using a command on command window, and so on. In all the dialogue cases, the command syntax and semantics are checked by the command handling module, and the CDD data are used during this syntax and semantic checking. If an input command is unfit for the syntax rule, an error message is displayed on command window. The error information must include the exact location and reason of error.

The command window provides a prompt for the user's entry and command history management facility like UNIX™ system. Because direct entry of a command is faster than menu selection or form-filling, it is useful for a skilled user.

All messages from the BSM that need to be displayed to users are passed to the display module. Then the display module shows the messages from whole system in order on the message output window. The BSM can display various graphs–histogram, pie, or chronograph–to present statistics data of users on the graphic window.

VI. CONCLUSIONS

The CMS system has been designed to provide mobile subscribers with robust call services. Design objectives, system structure, and functions of the BSC and BSM are described. The BSC is located between BTSs of mobile network and an MSC of wired network. It connects mobile stations and controls mobile calls in cooperation with BTSs and an MSC. And the BSM manages the BS including BTSs and BSC. Major hardware units are duplicated to maintain a reliable system.

The BSC is composed of CIN, TSB and CCP. The BSC software has characteristics of a functional modular structure, so it is easy to add new features and to upgrade the existing functions. The packet switch and the distributed control architecture offer a flexible configuration of the BSC which supports wide range of cell sites up to 512. The BSC has 23,000 selectors which can connect 23,000 traffic channels from the 512 BTSs.

The CIN is designed to provide a large high-speed packet switching capacity for large soft handover area. The two-phase round-robin scheme presented here minimizes the transmission delay and offers good quality of service. So it is possible to handle high traffic and to cover a large soft handover area. The TSB is designed to provide high density selector/transcoder, and fifteen TDSPs have been implemented in a single selector and transcoder card. A mobile subscriber travels along a path that passes through neighboring cells. To guarantee enough signal strength during a mobile call, the TSB controls the outer loop power on the reverse link and closed loop power on the forward link. The CCP controls mobile calls in cooperation with the TSBs, BTSs and MSC. To maintain a connection path while a mobile subscriber travels from one cell to another, the CCP and TSB provide handover functions.

The BSM, which is implemented for operation and maintenance of the BS in the CMS, provides a powerful and user-friendly GUI functions to the operator.

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