A NOVEL APPROACH TO EMERGENCY MANAGEMENT OF WIRELESS TELECOMMUNICATION SYSTEM

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ABSTRACT

The survivability concerns the service continuity when the components of a system are damaged. This concept is especially useful in the emergency management of the system, as often emergencies involve accidents or incident disasters which more or less damage the system. The overall objective of this thesis study is to develop a quantitative management approach to the emergency management of a wireless cellular telecommunication system in light of its service continuity in emergency situations – namely the survivability of the system. A particular wireless cellular telecommunication system, WCDMA, is taken as an example to ground this research.

The thesis proposes an ontology-based paradigm for service management such that the management system contains three models: (1) the work domain model, (2) the dynamic model, and (3) the reconfiguration model. A powerful work domain modeling tool called Function-Behavior-Structure (FBS) is employed for developing the work domain model of the WCDMA system. Petri-Net theory, as well as its formalization, is applied to develop the dynamic model of the WCDMA system. A concept in engineering design called the general and specific function concept is applied to develop a new approach to system reconfiguration for the high survivability of the system. These models are implemented along with a user-interface which can be used by emergency management personnel. A demonstration of the effectiveness of this study approach is included.

There are a couple of contributions with this thesis study. First, the proposed approach can be added to contemporary telecommunication management systems. Second, the Petri Net model of the WCDMA system is more comprehensive than any dynamic model of the telecommunication systems in literature. Furthermore, this model can be extended to any other telecommunication system. Third, the proposed system reconfiguration approach, based on the general and specific function concept, offers a unique way for the survivability of any service provider system.

In conclusion, the ontology-based paradigm for a service system management provides a total solution to service continuity as well as its emergency management. This paradigm makes the

complex mathematical modeling of the system transparent to the manager or managerial personnel and provides a feasible scenario of the human-in-the-loop management.

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Dedicated to

My parents and my family

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LIST OF MAJOR ACRONYMS

AAA	Authentication, Authorization and Accounting
AMPS	Advanced Mobile Phone Service
AMR	Adaptive Multi-rate Voice codec
AuC	Authentication Centre
BS	Base Station
BSC	BS Controller
BMC	Broadcast/multicast Control
CAC	Call Admission Control
CDMA	Code Division Multiple Access
CM	Communication Management
CN	Core Network
CPN	Coloured Petri Net
CS	Circuit Switch
D-AMPS	Digital AMPS
DFO	Disaster Field Office
DMSS	Decision Making Support System
EIR	Equipment Identity Register
ETSI	European Telecommunications Standards Institute
FCBPSS	Function Context Behavior Principle Structure State
FEBPSS	Function Effect Behavior Principle Structure State
FBS	Function Behavior Structure
FDD	Frequency Division Duplex
GGSN	Gateway GPRS Support Node

GMSC	Gateway MSC
GPRS	General Packet Radio Service
G-S	General- Specific function
GSM	Global Systems Mobile
GUI	Graphical User Interface
HITLP	Human In The Loop
HLR	Home Location Registers
IMT-2000	International Mobile Telecommunications-2000
IP	Internet Protocol
ITU	International Telecommunications Union
ITU-T	ITU Telecommunication Standardization Sector
MAC	Medium Access Control
MSC	Mobile Switch Center
MGw	Media Gateway
MM	Mobility Management
MMS	Multimedia Messaging Service
MT	Mobile Terminal
O&M	Operation and Management System
OSI	Open System Interconnection
PDCP	Packet Data Convergence Protocol
PLMN	Public Land Mobile Network
PNs	Petri Nets
PS	Packet Switch
PSTN	Public Switching Telephone Network

QoS	Quality of Service
QPAS	Qualitative Process Abduction system
RAN	Radio Access Network
RLC	Radio Link Control
RNC	Radio Access Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
SGSN	Serving GPRS Support Node
SMS	Short Messaging Service
SS7	Signaling System #7
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TMN	Telecommunication management network
UE	User Equipment
UIM	User Identity Module
UMTS	Universal Mobile Telecommunications System
UTRA	UMTS Terrestrial Radio Access
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visiting Location Register
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
1G	First Generation of Mobile System Standard
2G	Second Generation of Mobile System Standard
3G	Third Generation of Mobile System Standard

Chapter 1

Introduction

1.1 Background

Telecommunication is a critical infrastructure which consists of telephone, data lines, cellular and personal communication service (PCS) wireless system, pager, satellite, cable, wireless broadband, radio and television. Among all the critical infrastructures, the telecommunication infrastructure system plays an important role in the functioning of our society. Moore et al. (2001) defined the critical infrastructures as physical and information technology facilities which have a serious impact on the health, safety, security, economic well-being of citizens, or the effective functioning of governments. Failure of telecommunication infrastructure will cause coordination capabilities disable and significantly hinder rescue and recovery operations (Samarajiva 2001). In the absence of telecommunication infrastructure, it is hard to conduct the repair and recovery of other critical infrastructures which may dysfunction due to incidences or accidents. Harrop (2002) examined the relationship of communications networks with other Canadian critical infrastructures and concluded that other critical infrastructures highly depend on the telecommunication network.

In 2006, the Canadian mobile and broadband sectors continued rapid growth. During 2006, mobile subscribers increased by approximately 10%, compared with a 17% increase during 2005. By the end of 2006, Canada's wireless carriers offered coverage more than 98% of the population (Report Information 2007). Canadian wireless offerings include a number of different services and technologies. In particular, available services include cellular and digital cellular service in the 800 MHz band, Enhanced Specialized Mobile Radiotelephony (ESMR) in the 800 MHz band and Personal Communications Services (PCS) in the 1.9 GHz frequency band. These services are made possible by the technologies such as Advanced Mobile Phone Service (AMPS), Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA) and Global

System for Mobile communications (GSM), high-speed fixed wireless, and satellite services (Harrop 2002).

Subscribers in a disaster area can easily connect to network at anytime and from anywhere via the radio waves. In general, a wireless or mobile network consists of a number of components, including Base Stations (BSs), BS Controllers (BSCs), Mobile Switch Centers (MSCs), Home Location Registers (HLRs), Visiting Location Registers (VLRs), Signaling System 7 (SS7), and high-capacity trunks. The impact of a failure can be measured in terms of the number of users affected and the duration of the outage indicated by (Chu and Lin 2006).

1.2 Motivation

To date, most of studies are on service continuity in wired networks. For wireless networks, there have been only a few studies on the reliability and survivability of a wireless network in emergency or disaster situations. However, because of the complexity of the wireless system, these studies are usually focused on a specific part of the entire system. Jaimes-Romero et al. (1997) analyzed the handoff function of Radio Base Station (RBS); Mendiratta and Witschorik (2003) examined the survivability of the Public Switching Telephone Network (PSTN) based on the network structure; and Varshney et al. (2001) presented an approach to modeling and simulating of the wireless network. Most of studies today are in essence at the level of the architecture of a telecommunication system (Jaimes-Romero et al. 1997, Mendiratta and Witschorik 2003, Varshney et al. 2001) - i.e. what architecture will make a telecommunication system more reliable, survivable and high Quality of Service (QoS).

Meanwhile, telecommunication system management is a very important function in each system. Normally the management system is called as Operation and Management system (O&M). Due to differences presented between any two different telecommunication systems, the management system may reasonably be assumed to be different. Furthermore, differences may also be brought to the manager of a particular telecommunication service provider company due to different vendors for the same product function. There is a huge amount of work for a network manager to get familiar with different O&M systems which may stay in a region. Thus, the problem appears to be the lack of a management tool which can present and examine the different systems from different product suppliers to conduct the management decisions efficiently.

The lack of the tool to support system management is especially serious when the telecommunication system is in emergency caused by natural accidents, incidents, or the both. It is reasonable to assume that when in emergency, the survivability of a telecommunication system becomes an important issue, which can be caused by the damage of the system components, the damage of the human operators who control the system to provide services, or the both.

There is a great need to study the survivability of a telecommunication system especially from a more fundamental perspective and in a more quantitative way. The study described in this thesis fulfills these needs. Without the loss of generality as well as for the nature of such a type of research, the study took a particular wireless telecommunication system as an example throughout the whole study.

1.3 Research goal and objectives

The goal of this study was to develop a new approach for the telecommunication system management in emergency situations. The approach may not only be useful to telecommunication systems but also to other critical infrastructure such as physical facilities, electric power generation, transportation, and water supplier system. The new approach should be superior to the common "checklist" based paradigm of approach for the infrastructure management system in practice. To achieve this goal, four research objectives were defined and they are described as follows:

Objective1: *Develop a general domain model of the wireless telecommunication system which captures the service demand, function requirement, operation constraint, structure, and behavior.*

Objective 2: *Develop an effective system reconfiguration model for the wireless system to achieve high survivability or service continuity in emergency situations.*

Objective 3: *Develop a dynamic model of the WCDMA (UMTS) system which can be used for the verification of management decisions.*

Objective 4: *Develop a human-in-the-loop decision making system framework for the emergency management of the service provider system.*

These objectives are interdependent and will be carried out by following a stepwise process. The first objective is to develop a general domain model. The second objective is to reconfigure the component based on the general domain model. The study on the third objective was motivated by the observation that the disaster management decision process is a human-in-the-loop (HITLP) process. The operation of the disaster system may be highly unpredictable; therefore, the simulation may be useful for managers to validate the decisions made in emergency situations. The fourth objective gathers all the knowledge to implement a conceptual-based tool which can be used by the emergency manager.

1.4 General research methodology

The new configuration approach is based on the function-behavior-structure paradigm called FCBPSS framework (Lin and Zhang 2004) and the concept of general function and specific function (Pahl and Beitz 1996). The FCBPSS comprises a set of core concepts: (1) structure, (2) context, (3) state, (4) behavior, (5) function, and (6) principle. With the FCBPSS framework, the domain model of an example wireless telecommunication system is established. This will address objective 1.

A concept called General function and Specific function (G-S, for short) proposed by Pahl and Beitz (1996) will be taken to study objective 2. General function in the G-S concept means the function that can be achieved by a structure without being constrained in a particular environment or context, while a specific function refers to the general function but constrained in a particular environment. With the G-S concept, the specific functions are represented along with the general function of a component and system. As a matter of fact, the general function, as mentioned by Pahl and Beitz (1996), correspond to the behavior concept in the FCBPSS framework.

With respect to objective 3, this thesis study applies the Petri Net theory to the model of the system, as the Petri Net theory can capture all the characteristics of the dynamics of a wireless service system.

With respect to objective 4, the whole system is implemented through a human-computer interface so that decision makers can interact with simulation model and observe the system state and behavior on the condition of various nature disasters.

1.5 Organization of the thesis

The remainder of the thesis will be organized as follows. Chapter 2 provides a literature review to give further justification of the proposed work, particularly with respect to the research objectives and methodologies described in Chapter 1 as well as key concepts and definitions of the work intended. Chapter 3 presents an example WCDMA system that is used for the purpose of illustration and preliminary verification of the research developed. Chapter 4 presents a domain model of the WCDMA system. Chapter 5 presents a knowledge-base system for system reconfiguration for high survivability of the system. Chapter 6 presents a Petri Net model of the WCDMA system. Chapter 7 describes the design of Decision Making Support System (DMSS) for the telecommunication network management in emergency situations. Chapter 8 presents general conclusions of the work. In addition, it also discusses limitations of the present work and further work which may overcome these limitations.

Chapter 2

Background and Literature Review

2.1 Introduction

This chapter is to provide a background of knowledge for the proposed work. It also serves as further justification of the needs of the proposed objectives for this thesis study. In this regard, there are comments and critiques on related work. In the remainder of this chapter, Section 2.2 gives a brief overview of the wireless telecommunication system. Section 2.3 discusses concepts closely relevant to emergency，disaster，reliability, and survivability in the context of the wireless telecommunication system. Section 2.4 discusses the service continuity of the WCDMA system. Section 2.5 discusses service continuity management along with related work. Section 2.6 discusses the FBS framework which is an important tool for work domain analysis – one of the general ideas underlying the approach of this thesis study to emergency management (see Chapter 1). Section 2.7 presents a scheme of the knowledge base which is based on the FBS framework. Section 2.8 discusses a decision making system for emergency and disaster situations. Section 2.9 is a conclusion of this chapter along with discussion.

2.2 Wireless cellular system

2.2.1 History

In the 1990s, the second generation (2G) wireless networks emerged based on digital transmission techniques. 2G systems aimed at providing a better spectral efficiency with a more satisfied Quality of Service (QoS) in wireless communication, voice, low-speed data services, and high security and authentication capabilities. Three major 2G network systems are: Global

System for Mobile communications (GSM), Digital AMPS (D-AMPS), and CDMA (TIA/EIA/IS-95A).

GSM is a wireless telephone standard in Europe and widely used in Europe and other countries today. The cellular network developed based on this standard is called GSM network. GSM system uses Time Division Multiple Access (TDMA) technology to provide the radio access for the mobile users. It allows several users to share the same frequency channel by dividing the signal into different timeslots (GSM 2008).

Digital AMPS (D-AMPS) is another kind of the 2G mobile phone systems. It is used throughout the North America, particularly in the United States and Canada. It adopts the same radio access technique, TDMA, as used by GSM (Digital AMPS 2008). D-AMPS replace AMPS (first generation analog mobile phone system). D-AMPS reuses the radio channel resources of AMPS channels, allows for smooth transition between digital and analog systems in the same area, and improves the network capacity and security.

CDMA is the abbreviation for Code Division Multiple Access communication. CDMA is a form of spread spectrum communications. In 1989 the Telecommunications Industry Association (TIA) adopted TDMA technology as the radio interface standard. Qualcomm, Inc., in 1990 proposed a digital cellular telephone system based on CDMA technology. In July 1993, TIA voted on and accepted IS-95 as the CDMA air interface standard (radio specifications). In 1998 a new revision of the standard is called TIA/EIA-95. CDMA systems based on the IS-95 standard and related specifications are referred to as CDMA (TIA/EIA/IS-95A). The standard defines the modulation scheme, power control, call processing, handoffs, and registration techniques. A CDMA network includes the same basic subsystems as other wireless systems, including a switching network, controller, Base Station (BS), and Mobile Station (MS) (Harte 1999).

With the emergence of the Internet, high speed and large data service are the trend of telecommunication system today. The third generation (3G) systems are designed for the support of the multimedia communication, such as data, image and video. The concept of the 3G wireless systems is defined by the International Mobile Telecommunications-2000 (IMT-2000) under the auspices of the International Telecommunications Union (ITU).

Figure 2.1 shows the general architecture of the wireless cellular system which provides various services (voices, date, video, etc) to the mobile users (Kaaranen 2005). In this figure, the basic architecture of any advanced cellular system consists of Mobile Station (i.e. Mobile phone), Base Stations, a switching network and fixed network functionality for traffic backbone transmission.

The Base Station, called Node B in WCDMA system, performs wideband radio signal receiving and transmitting (Rx and Tx), signal filtering and amplifying, signal modulation and demodulation, and transport the service data from mobile station to network component, Radio Access Controller (RNC) in the switching network.

The switching network comprises all the control and switching functional components except for the Mobile Station and Base Station mentioned above. Theses components are interconnected by the circuit groups such as Radio Access Controller (RNC), Mobile Switching Center (MSC), Media Gateway (MGw), and Home Location Register (HLR). The detailed information about these components will be described in Chapter 3. The user may originate a call by keying the called number, and then depress the "send" button of the Mobile Station. The Base Station receives the signal and delivers it to the switch network. The components of the switch network receive the information, then and establish the successful connection among the selected circuits group. Thus, the traffic data can be transmitted through these nodes following the routing or switching schemes to the receivers. The receiver may be within the same switch network or may exist in another network like the fixed network. The fixed networks can be the traditional public telephony network, other mobile wireless networks (i.e. GSM, CDMA, WCDMA, etc.), or Internet network.

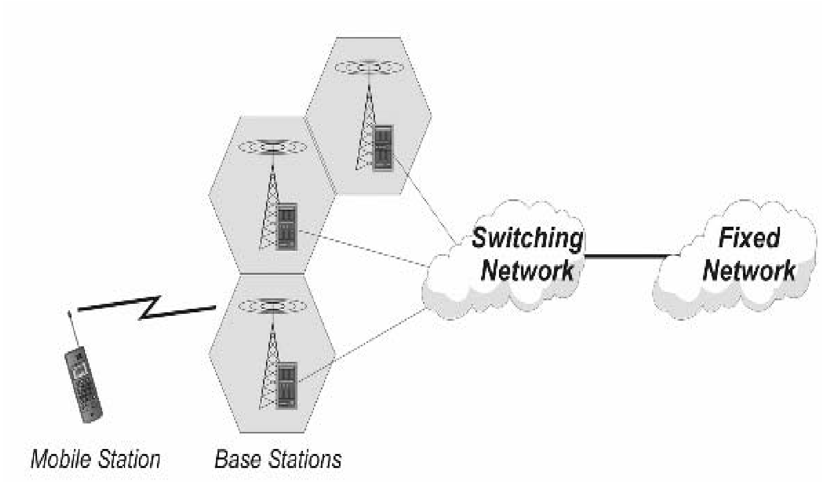


Figure 2.1 A simple architecture of wireless cellular network (Kaaranen 2005).

2.2.2 Standard of the 3G wireless system

Five radio interfaces of the terrestrial component of IMT-2000 are recommended by the ITU Radio Communication Assembly and they are as follows: (1) IMT-2000 CDMA Direct Spread, (2) IMT-2000 CDMA Multicarrier, (3) IMT-2000 CDMA TDD, (3) IMT-2000 TDMA Single-Carrier, and (4) IMT-2000 FDMA/TDMA.

The 3G WCDMA system adopts one of the five standard radio interfaces with the techniques of IMT-2000 CDMA Direct Spread which is the Universal Mobile Telecommunications System (UMTS). WCDMA is the technology used in radio interface of the UMTS Terrestrial Radio Access (UTRA) by using a direct sequence spread spectrum on a 5 MHz bandwidth and operates in both Frequency Division Duplex (FDD) mode and Time Division Duplex (TDD) mode. Thus, the UMTS system which applies the WCDMA technology in the air interface is named as WCDMA wireless cellular system. The WCDMA system utilizes the direct sequence Code Division Multiple Access signaling method (CDMA) to achieve high speeds and to support more users compared to the older Time Division Multiple Access (TDMA) signaling method of the GSM system.

2.2.3 Architecture of the WCDMA wireless cellular system

This thesis focuses on the WCDMA wireless cellular system. The WCDMA system consists of a number of logical network elements which are connected through open interfaces or access points. These elements are grouped into the Radio Access Network (RAN) and the Core Network (CN). The RAN handles all radio-related functions and Radio Resource Management and Mobility Management (RRM and MM). The CN is responsible for switching and routing calls and data connections to external networks, at the same time, to manage session and mobility information, and Communication Management and Mobility Management (CM and MM). The system is terminated by the component called User Identity Module (UIM), Mobile Terminal (MT). UIM and MT interface with the user and the radio interface. Figure 2.2 depicts the architecture of the WCDMA system. In this figure, the circles represent the functional subsystems and the squares represent the physical platforms where the respective functional subsystems reside (ITU-T Rec. Q.1711 1999, Yacoub 2002). The vertical bars between the squares in Figure 2.2 indicate the physical interfaces between the respective physical platforms. The two-sided arrows between the functional subsystems represent the functional interfaces between the respective functional subsystems. The detailed information about these interfaces can be found from Yacoub (2002).

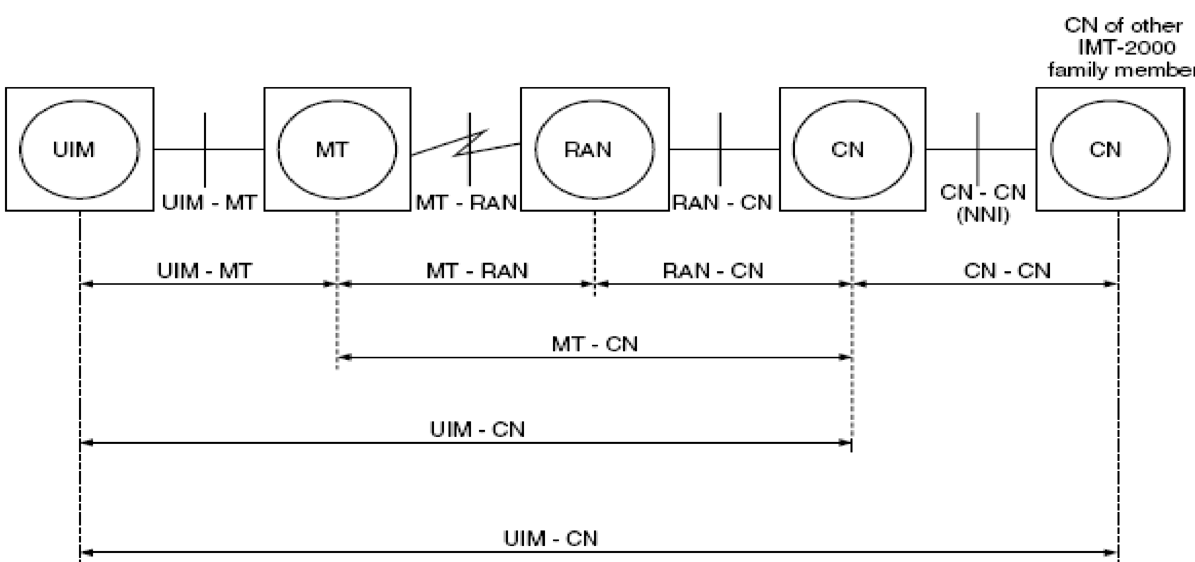


Figure 2.2 IMT-2000 architecture with interfaces (Yacoub 2002).

2.2.4 Telecommunication Management Network (TMN)

TMN is a set of international standards for managing telecommunications networks. According to ITU-T Recommendation M.3100 (1995), TMN is conceptually a separate network that interfaces a telecommunication network at various different points to send or receive information to or from it and to control its operations of the network. In other words, the principal idea of TMN is to use an independent management network to manage a telecommunications network via well-defined and standardized interfaces. Standards are required because telecommunication networks typically consist of network elements of different technologies supplied by different vendors. Figure 2.3 shows the relationship between a TMN and the telecommunication network (Wang 1999).

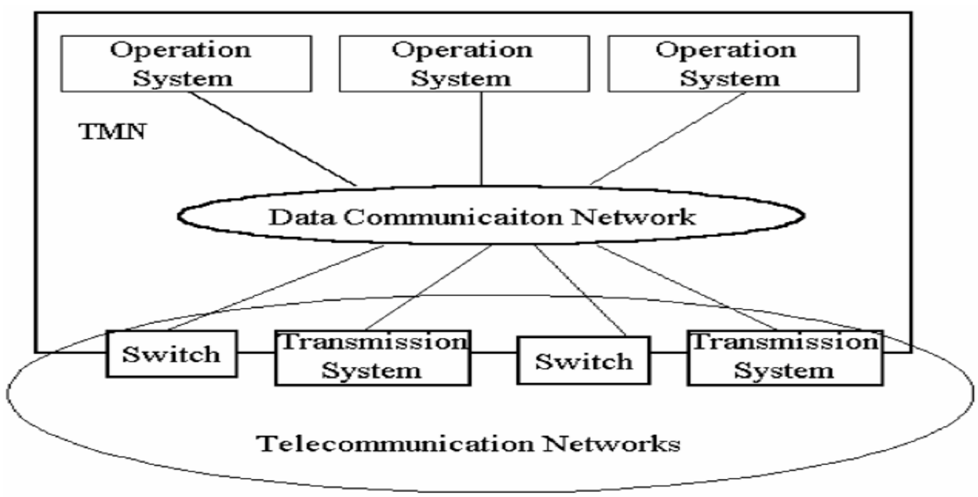


Figure 2.3 General relationship of a TMN with a telecommunications network (Wang 1999).

TMNs provide the means to transport, store and process information used to support the management of telecommunication networks and services. TMNs can be used for the management of telecommunication networks operated by administrations, customers, or other organizations and individuals. When these telecommunication networks are connected with each other, their TMNs provide the means of exchanging information required to manage end-to-end telecommunication services. All types of telecommunication networks and network elements including analogue networks, digital networks, public networks, private networks, switching systems, transmission systems, telecommunication software systems, and logical resources (such as a circuit, path, and telecommunication services supported by the resources) are managed by the TMN.

In Figure 2.4, the TMN functional architecture consists of a set of functional blocks, a set of reference points, and a set of functional components. A functional block is a logical entity that performs a prescribed management function. A reference point separates a pair of functional blocks, and two functional blocks must communicate via a reference point. One or more functional components make up a functional block (Wang 1999).

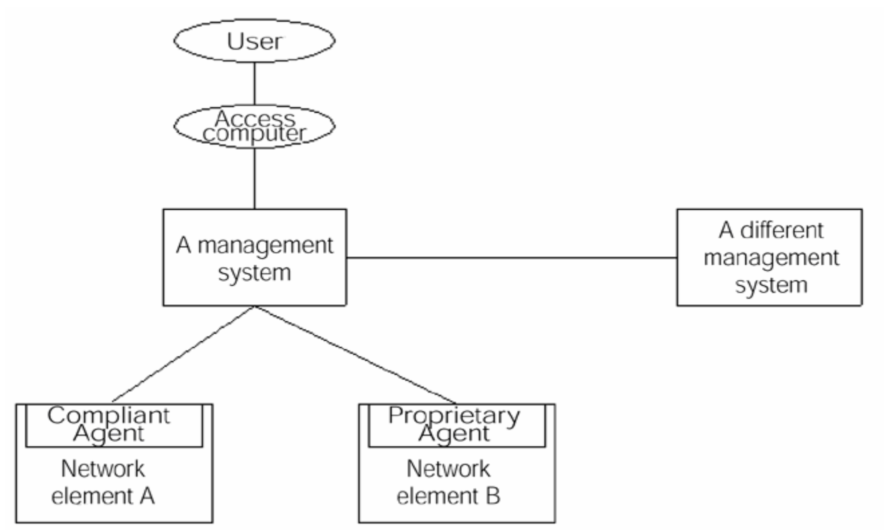


Figure 2.4 TMN functional architecture (Wang 1999).

TMN categorizes the management network into physical entities, functional entities, interfaces and reference points. It structures various management services and offers a specification methodology for interfaces according to the Open Systems Interconnection (OSI) system management paradigm (Wang 1999).

However, the deployment of TMN is slow due primarily to its complexity and the inertia of legacy systems (Glitho and Hayes 1995). Sidor (1995) said that the model of TMN in the future should support the network and service layer management functionality.

The proposed research of this thesis works on building a Petri Net model based human-in-the-loop (HITLP) management framework which is a useful supplement to the contemporary TMN. Especially, the proposed HITLP management framework can support the network managers to examine the dynamic system characteristics through a realistic simulation.

2.3 Definition

Emergency is defined as a situation which leads to an immediate risk to life, health, property or environment (Emergency 2007). The criterion to judge a damage situation as emergency or not is based on three conditions: (1) immediate threaten to life, health, property or environment, (2) loss of life, health detriment, property damage or environmental damage, and (3) probability that damage is escalated to cause an immediate danger to life, health, property or environment. A narrow and working definition of emergency was also given by Redmond Fire Department, located in City of Redmond, in Washington; emergency is defined as a condition that lasts 3-5 hours and is handled by calling 911. An example of the emergency would be a car accident or a residential fire.

Disaster is defined as the impact of a natural or man-made hazard that negatively affects society or environment (Disaster 2007). Disasters occur when hazards strike in vulnerable areas. Hazards that occur in areas with low vulnerability do not result in a disaster. Hazards are routinely divided into two types: natural and human-made. A **natural disaster** is the consequence of when a potential natural hazard becomes a physical event (e.g., volcanic eruption, earthquake, landslide, etc) that affects those vulnerable areas of human activities. A natural hazard will hence never result in a disaster in areas without vulnerability, for example strong earthquakes in uninhabited areas. Disasters having an element of human intent, negligence, or error that involves the failure of a system are called man-made disasters. Although the term disaster is subjective, it is often used in the developed world to refer to situations where local emergency management resources are inadequate to counter-act the negative effects of the event (Ezell et al. 2000, Samarajiva 2001).

Emergencies and disasters are co-existed, and emergencies may evolve to be a disaster. Contrast to the emergency, the disaster causes serious negative effects and leads to huger damages to society and environment (Disaster 2007). For example, the natural disaster is a kind of emergency which can threaten lives and cause a large amount of infrastructures damage. In this thesis, the emergency situation covers man-made incidents, emergencies and disasters. In other words, the proposed work does not differentiate between these situations. As such, theories and methodologies developed through this study can be equally applied to all these three situations.

For wireless networks, a network's service ability to cope with emergencies is measured in three ways (Snow et al. 2000, Baliga et al. 2004): reliability, availability and survivability.

Reliability (Stafford et al. 2004) is a network's ability to perform a designated set of functions under certain conditions for specified operational times. A reliable network is a network that functions normally the vast majority of the time.

Availability (Stafford et al. 2004) is a network's ability to perform its functions at any given instant under certain conditions. Average availability is a function of how often something fails and how long it takes to recover from a failure.

Survivability (Baker et al. 2004, Houck et al. 2003) is a network's ability to perform its designated set of functions given network infrastructure component failures, resulting in a service outage, which can be described by the number of services affected, the number of subscribers affected, and the duration of the outage.

Among the three ways as defined above, Baker et al. (2004) further distinguished the survivability and reliability. Survivability can be viewed as a special case of reliability, where survivability is defined in terms of specific threats or faults, while reliability is defined in terms of general threats or faults.

A survivability network (Baker et al. 2004) is one that can continue to function at reduced capability, even if disastrous things happen to isolated components with the network. Satfford et al. (2004) addressed that today's telephone networks are extremely reliable. Typically, PSTN/PLMN infrastructure is designed for 99.999% availability; this means that the network is able to complete calls, as in a normal operation, 99.999% of the time. Core network equipment designs incorporate redundancy through the means such as dual power supplies, backup storage, backup processors, working and protecting switching fabrics, working or protect port pairs on line cards, and so on. To implement a survivable network, it is important to avoid a single point of failure within a critical system (Baker et al. 2004, Ezell et al. 2000, Stafford et al. 2004).

2.4 Impact of the emergency to wireless telecommunication systems and related work

Moore et al. (2001) elaborated the potential vulnerability of the mobile telecommunications infrastructure in Canada to natural hazards and indicated a number of concerns relevant to emergency preparedness and management. Moore et al. (2001) also identified the specific components of the telecommunications infrastructure to natural hazards in order to support the emergency managers to make a reasonable assessment of vulnerability on a case-by-case basis and to help the emergency managers be aware of the various components of a telecommunications infrastructure they rely on and on their survivability in a disaster scenario.

Moor et al. (2001) listed the main components of a telecommunications infrastructure as well as their impact to the telecommunication service in their report to Canadian Office of Critical Infrastructure Protection and Emergency Preparedness. Refer to Table 2.1.

Table 2.1 Vulnerability of wireless network components.

Components of a telecommunications infrastructure	Components of wireless system included	The natural hazards affecting the components	Impact to services
Physical buildings	- Switching equipment, controllers, and other radio equipment - Dispatch facilities of first responders - Antennas on roofs of buildings	- Blowing snow, rain, or hail - Earthquakes, hurricanes, floods, and tornadoes	Service outage to mass users
Power supply	- Switching or RF, equipment, dispatch centers	- Earthquakes, hurricanes, floods, and tornadoes	Service outage to mass users
Transmission links	- Landlines (Coaxial and Copper) - Fibre optic - Microwave - UHF	- Breaks - Water damage	Service outage to partial users
Telecommunications towers	- Self supporting tower - Guyed tower	- Ice load - Wind load	Service outage to partial users
Antennas	- Antennas	- Hurricanes - Wind more than 140km/h	Service outage to partial users

There are a few studies on the survivability of the mobile network. Park et al. (2006) merely studied the reliability of the radio access component, and Base Station. Snow et al. (2000) and Chu et al. (2006) presented the impact of the different network components failures to the services as well as the ways to improve the network survivability (see Table 2.2).

Table 2.2 Effects of the failures of wireless components and mitigation strategies (Chu and Lin 2006).

Failure	**Cause**	**Number of users affected**	**Time to fix**	**Mitigation strategies**
BS/BSC	Hardware, software, nature	1,000-20,000	Hours to days	Overlay BS, redundant components
MSC	Hardware, software, operators	100,000	Hours to days	Spare components, power, smaller switches
HLR/VLR	Hardware, software	100,000	Hours to days	Replicated database, redundant components

Different degrees of wireless network service continuity and service availability are affected by the corresponding network components, in the following, this point is further noted.

(1) Base Station, called Node-B in WCDMA system, affects radio signal receiving and transmitting with the mobile users.

(2) Base Station Controller, called Radio Network Controller (RNC) in WCDMA system, affects the radio resources management and mobility management of the users; governing and control function to Node-Bs.

(3) Mobile Switching Center (MSC) affects the switching and routing function for the data transmission.

(4) Home Location Register (HLR) affects the subscriber's data management of the whole telecommunication system database, which contains service portfolio of each mobile phone subscriber that is authorized to use the telecommunication network, GSM or WCDMA system.

(5) Signaling System 7 (SS7) affects the normal control function to the circuit switch domain.

(6) High-capacity trunks affects the physical connect among the system components (Freeman 2004).

Moor et al. (2001) and Snow et al. (2000) identified the vulnerable components and their impact to the services of the wireless network in an emergency situation. They, however, have not accounted for the Mobile Station (i.e. Mobile phone) which interfaces with the user and the radio interface. The mobility of the mobile equipment is affected by the location of the users and the service continuity is related to the dynamic position of the users and their mobile phone on condition they are moving to another Node B's service area or far away from the available Node. Bs. Jorstsad (2004) analyzed the service continuity of mobile services and stated that when the user is moving and is accessing services from different places, the location of a service and its components relative to the user's location will have great influence on its availability, quality, continuity and personalization.

2.5 Service continuity management and related work

Telecommunication provides the transmission or reception of signs, images, sound or intelligence of any kind over wires, by radio waves or other technical systems. In emergency situations, infrastructure damage, loss of power, congestion and other forms of service degraded the performance in mobile telephone systems. A failure of these components or links further affects the service provision.

Barker and Maxwell (1995) listed the major shortfalls to disaster areas:

- Inadequate voice services;
- Limited sharing of information among the emergency support functions in the Disaster Field Office (DFO);
- Limited access to distributed information sources;
- Inability to send and receive e-mail messages among users and regional offices;
- Unknown or difficult procedures for addressing e-mail users;
- Congested wireline and wireless services;
- Lack of service provision for telecommunication equipment and capabilities; and
- Unknown radio frequencies and excessive radio interference.

Such shortfalls indicate the challenges in providing communication capabilities to emergency users in the disaster area. Users demand the exchange of information among other responders, technical experts, analysts, and emergency managers. These communication capabilities include network access, information processing capabilities and applications, and wireline and wireless telecommunications equipment.

The essence to the telecommunication service in emergency situations is to balance the service demands and supplied services as shown in Figure 2.5. The requirement for balance is the core issue for many studies on the telecommunication network reliability and survivability.

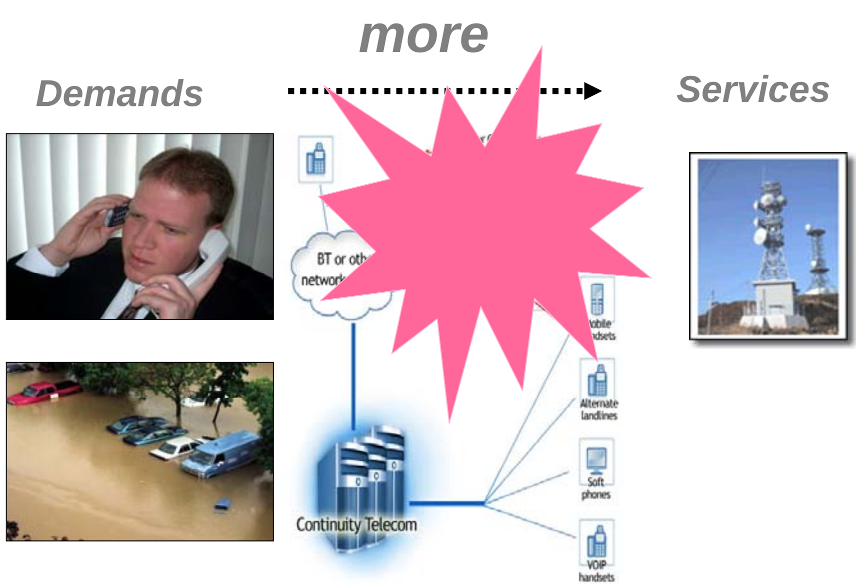


Figure 2.5 Unbalance between Service supplier and demands.

To explore the balance between service demands and supplies, Hong et al. (2005) presented a service continuity mechanism based on applying IPv6 at a mobile station for CDMA/WLAN inter-working. Jorstad and Dustdar (2004) studied a new function layer to support service continuity within heterogeneous networks and heterogeneous devices. Turina and Furuskar (2005) proposed a new mechanism to shorten the interruptions for the packet date service continuity between GSM and WCDMA changeover, and suggested developing middleware components to control a network. Snow et al. (2000) proposed the SONET Rings to interconnect

Base Station and MSC, use of multifunction and multimode phones, and use of an overlay network to improve network survivability for service continuity. The nature of these studies is to design a more flexible system, especially at the level of system architecture. However, the benefit achieved by the technology must be balanced against the acceptable reliability and survivability to the network. Actually, they are generally based on a fixed configuration of the telecommunication system and proposed to improve the network service capability by changing the structure and deploying new functions into the system.

It is noted that approach of this thesis study to maintain service continuity for the survivable telecommunication system is different from these studies. Certainly, these studies are complementary to this thesis study because this thesis studies are built upon a particular architecture of the telecommunication system such as WCDMA system.

In this study, the emphasis on reconfiguration implies a new paradigm in emergency management, that is, the first priority of emergency management is to turn attention to a system itself, instead of requesting a help from other systems. This new paradigm could provide the most rapid response. This new paradigm is based on the following assumptions: (1) A system will not run at its full capacity, and (2) The system capacity can be achieved by several different configurations.

2.6 The FBS framework

2.6.1 Concept of FBS model and the implementation

Design theory and methodology for general systems has been extensively studied in the past decades. Several well-known proposals of design theory and methodology include: Systematic Design Methodology (Pahl et al. 1996), Axiomatic Design Theory (Suh 1990). This thesis study pursued the direction of approaches which were based on the notions such as the structure, behaviour, and function. The FBS framework was initially developed for increasing intelligence of computer program systems for fault diagnosis and reasoning (Kuipers 1984, De Kleer 1984).

The knowledge representation along this direction is called Function-Behaviour-State (FBS) model as showed in Figure 2.6. Pioneer studies on this model of design refer to the work by Ulrich and Seering (1988, 1990).

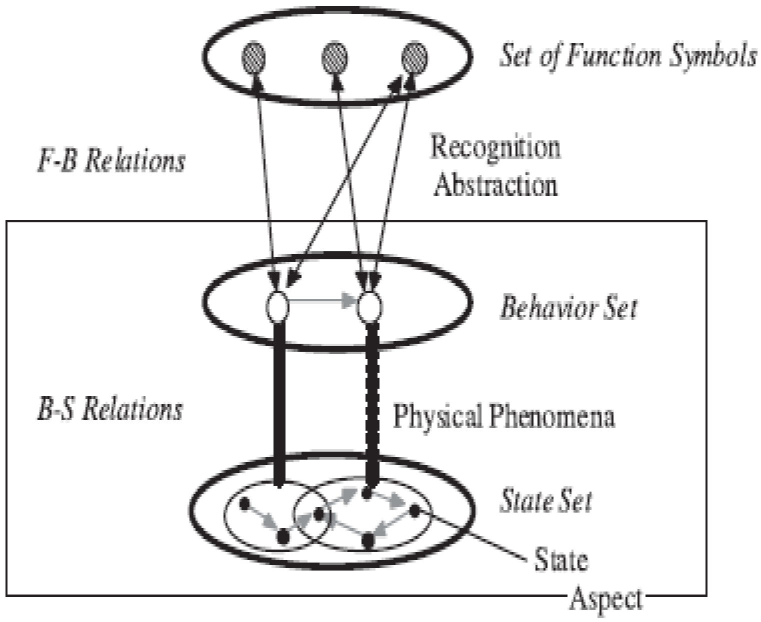


Figure 2.6 FBS model (Umeda et al. 1995).

FBS modeling defines a function as “a description of behavior abstracted by human through recognition of the behavior in order to utilize it” (Umeda et al. 1990) and represents it as an association of two concepts: human intention represented in the form of to do something and behavior that can exhibit the input and output relation function.

Umeda et al. (1990) indicated the wide usefulness of the FBS model for function, behaviour, and structure of machines and its application in the context of various applications, such as computer aided design, simulation, and diagnosis such as in building CAD systems, simulation systems, and diagnosing systems which interact with users and simulate human reasoning.

Umeda and Tomiyama (1995) and Umeda et al. (1990) addressed a modeling scheme of the FBS concept design. Umeda et al. (2005) employed the FBS modeling scheme to the product upgrade design; Kruchen (2005) proposed the FBS framework into the software engineering to direct the software design activities in large system engineering projects. Gero et al. (2003) showed the methods that FBS view can be useful to support the interaction of situated design agents. To support the FBS conceptual design, Umeda and Tomiyama (1995) presented a functional design support system called "FBS modeler" to implement the FBS framework.

2.6.2 FCBPSS framework

The FCBPSS Framework is proposed by Lin and Zhang based on these previous studies of FBS (2004, 2005). The FCBPSS framework modified and extended the Function-Behavior-State (FBS) Model to have more elaborated layers. The FCBPSS framework contains a set of core concepts, including: (1) structure, (2) state, (3) behavior, (4) principle, (5) function, (6) context, (7) relationship among concepts (1)–(6), and (8) system decomposition. Figure 2.7 shows these concepts and their relations.

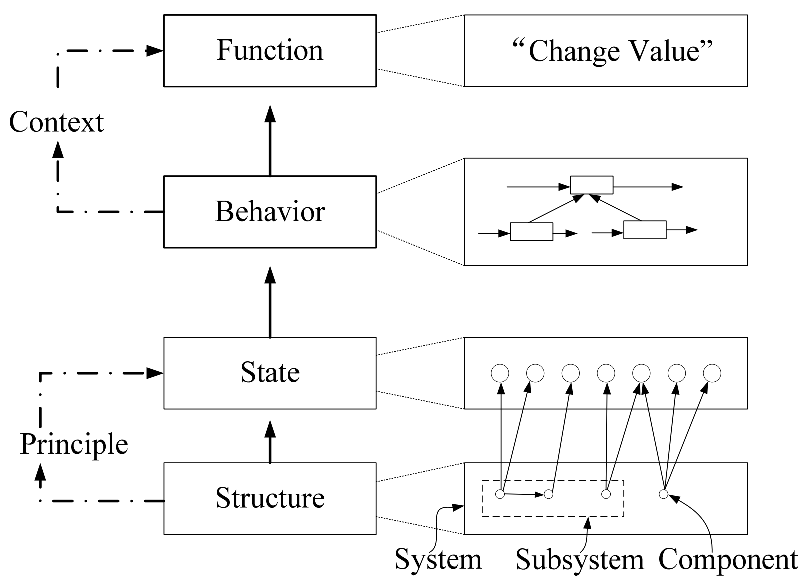
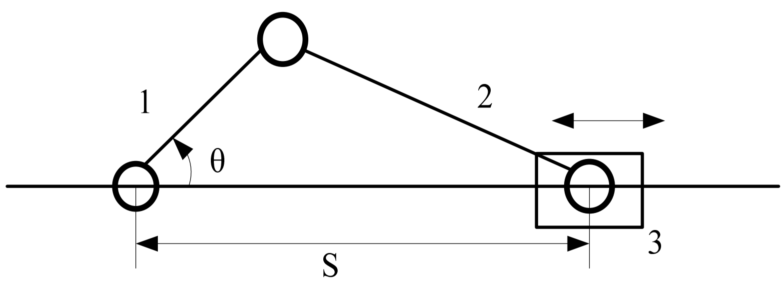


Figure 2.7 Architecture of FCBPSS framework.

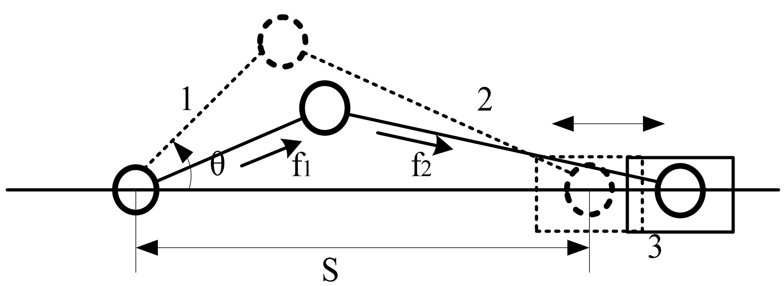
- Structure and state. A system has a structure that is a set of entities which are connected in a meaningful way. Entities are represented by a set of properties, and these properties are called the states. The states are given a name. The name of the state is the state variable.

- Behavior. The behavior is the causal relationship or structure among a set of related state variables. For a particular structure, there can be different types of state variables associated with it depending on interests on the structure. For example, for a beam in the crank-slider linkage (Zhang et al. 2005), as shown in Figure 2.8a, there are two interests on it: stress state, f1 and f2 indicating the variables of forces to the beams (Figure 2.8b) and corresponding displacement states, Δθ angle and ΔS distance (Figure 2.8c). Therefore, relationship between the structure to state variable is one to many – i.e., for one particular structure, there would be many state variables defined on it.



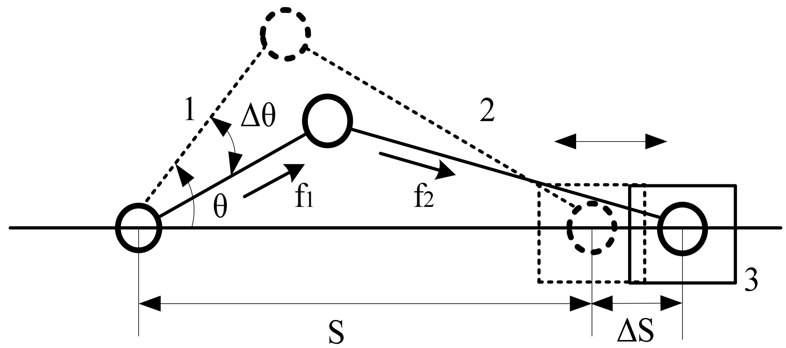
1. Beam 1 (crank); 2. Beam 2 (coupler); 3. Slider

(a) The crank-slider linkage (Zhang et al. 2005).



1. Beam 1 (crank); 2. Beam 2 (coupler); 3. Slider

(b) Stress state.



1. Beam 1 (crank); 2. Beam 2 (coupler); 3. Slider

(c) Displacement state.

Figure 2.8 The concept of behavior.

- Principle. The principle governs or accounts for the behavior in such a way that the causal relationship is derived from the principle.

- Function and Context. The function is defined as a purpose in the mind of human users and can be realized by the system (structure) owing to certain behaviors existing in the structure. The function has two aspects: (1) general and (2) specific. The general function is derived from the behavior of the system which is not tied to a particular application. The specific function is function of the system which is under a particular interest or concern and is thus governed by a particular context. The context is the particular environment where the particular system operates or works or makes sense.

- System Decomposition: A system can be decomposed into subsystems and components within the system domain. The system structure, the behavior, the principle, the states, and the function concepts follow system decomposition. This means that it makes sense to speak of the behavior and states of a system (or subsystem, component)

These concepts are related to each other – see Figure 2.8. In particular, the structure concept is located at the bottom, followed by the state, the behavior, and the function concepts. The principle concept is situated between the state concept and behavior concept in order to give rationale for constraint equations such that given a set of values of the active state variables, the passive states are found through the evaluation of the constraint equations. The context concept is situated between the behavior and the function, which gives the rationale from the behavior to the function (Lin and Zhang 2004).

However, different application domains may use the FBS concept in their domain specific ways. Kruchen (2005) examined the obstacles between the manufacture design and software design, which hinder the design methodologies developed for one domain used for another domain. For instance, software developers' use of the term "design" differs from that of engineers in other disciplines, making some of comparisons and analogies somewhat skewed or simply invalid. Qian and Gero (1996) presented formalism for cross-domain design via FBS paths and provided the mapping approach to fill in the gap to the definition of the functions, behaviors and structures in different domain.

2.7 FBS modeler and knowledge base system

To support the FBS conceptual design, Umeda and Tomiyama (1995) presented a functional design support system called 'FBS modeler' to implement the FBS framework in Figure 2.9. To support functional design in the FBS modeler, the modeler has two kinds of knowledge bases: a function knowledge base and a behavior knowledge base.

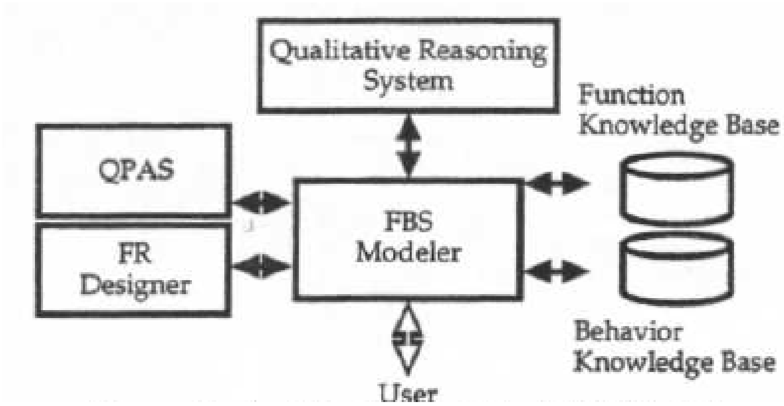


Figure 2.9 FBS modeler (Umeda et al. 1995).

- The function knowledge base stored all function prototypes. The function prototype is the functions from existing design results. The function can be decomposed into sub-functions by tasks decomposition. Tasks decomposition means that the implementations of the functions are not casually related with each other; they can occur independently (Umeda and Tomiyama 1995). The sub-functions can be divided, and so on, until the level where physical behaviors perform such sub-functions. Subsequently, the functional structure is copied to the physical structure.
- The behavior knowledge base is a building block consisting of three kinds of elements: entities, relations among entities, and physical phenomena. Each physical feature is constructed by the designer in order to be a meaningful block for representing a function.

In the architecture of the FBS modeler, there are three subsystems which cooperate with the two databases to implement the FBS concept model.

- The Qualitative Process Abduction system (QPAS) is to support the casual decomposition, derived from physical phenomena that realize the given state transition. Casual decomposition means that behavior resulting from this decomposition is casually related with each other and their interaction.
- The Function Redundancy (FR) designer is designed to implement the function redundancy. In this context, a function that can be realized by other physical features than the feature that realizes the function in its normal state.

- The Qualitative Reasoning System (QRS) gives representational scheme of behaviors and states and executes the behavioral simulation.

2.8 Decision making system in emergency situations

The network manager (decision maker) acquires the system status and makes the decision to enable or disable associated events to meet the required specifications, typically safety requirements. The human operator performs the enabled events to control the system. Lee and Hsu (2003) presented a supervisory based human-in-the-loop remote control system. The Petri Net approach is used to model, design, and verify the supervisory system. Fales et al. (2005) presented dynamic modeling, controller design, and Virtual Reality (VR)-based human-in-the-loop real-time simulation for a wheel loader control system. Based on their approach, this thesis study further develops the decision making system in Figure 2.10 to manage the WCDMA system in emergency situations. In Figure 2.10, the system works under the management from the control model in the decision making system. The information of the system states is feedback and stored in the system database as the input variants of the control model. Meanwhile, network manager can observe the system states through Human Monitor and make the corrective action so as to have the system work as desired (see Figure 2.10).

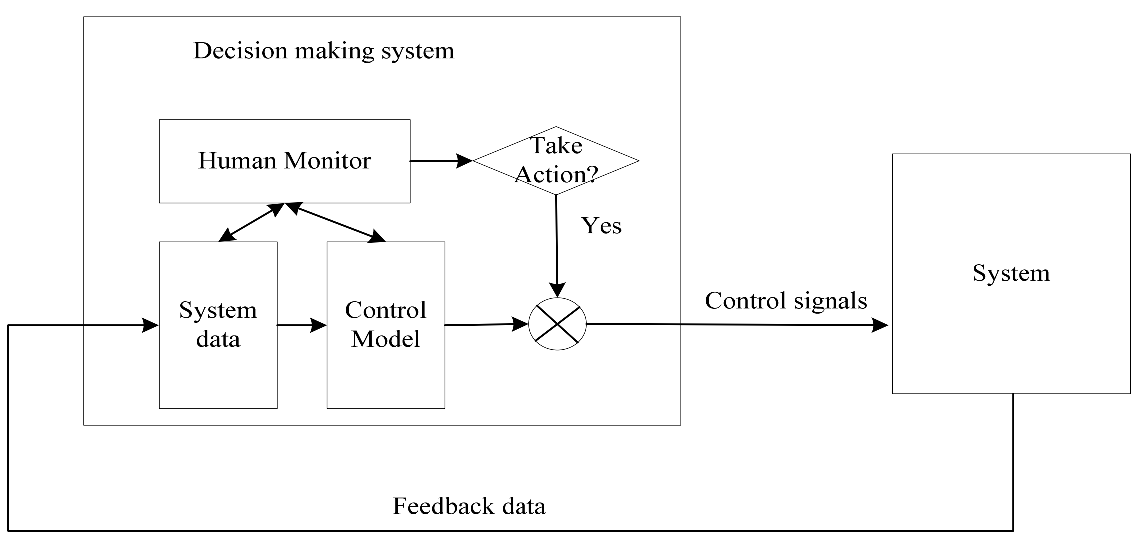


Figure 2.10 Decision making system.

It is noted that in this thesis study, Petri Net theory and Coloured Petri Net (CPN) design tool was used to model the WCDMA system and take the role of the Control Model when either a human or a computer makes decisions to reconfigure the system resources if necessary. Because the state and behavior of the “new” system are usually not easily predictable to the human decision makers, simulation of the state and behavior of the “new” system become necessary.

2.9 Conclusion

Building models to enhance the service continuity of the wireless system in emergency situations involves the domains of threaten scenarios, system infrastructure, system and decision management. This chapter systematically navigates through the literature streams of continuous service and emergency situations to understand the current state of knowledge for maintaining the service in the disaster environment. Among all the existing studies reviewed, it appears that the FBS concepts can bring research from a new aspect rather than the conventional design theory in telecommunication domain. This implies that it is novel to apply the FBS to the domain modeling of the telecommunication system, which is the first objective of this thesis study.

Lee and Hsu (2003) presented a Petri Net model in the human-in-the-loop design. In their work, the Petri Net model was mainly used to verify a supervisory system which prevents human errors. The proposed work in this thesis, especially objective 2 goes beyond the scope of their work. In objective 3, a general Petri Net model which describes the dynamics of the telecommunication system will be developed. Such a model can be used for all management related issues including design verification issue as Lee and Hsu (2003) did.

With respect to objective 2 described in Chapter 1, there appears no work in the area of the telecommunication system. In the area of general manufacture systems, reconfiguration is well studied; yet the existing reconfiguration approach is mostly based on the condition that the system is reconfigured to meet new tasks; there is no consideration that components are damaged.

With respect to objective 4, contemporary TMN has not considered the survivability and its management. As far as disaster management, the existing paradigm is based on the redundancy in design - simply put some spare components in stock prepared for emergency.

Chapter 3

An example WCDMA system

3.1 Introduction

This chapter describes an example WCDMA system for the purpose of emergency situations. Section 3.2 presents the detailed background of the WCDMA. It introduces the history of the development of the WCDMA system, the service the system can provide, the architecture of the system, and network management. Section 3.3 describes the example WCDMA system which will be used throughout discussions in subsequent chapters. Section 3.4 is the summary of this chapter.

3.2 Background

3.2.1 History of the WCDMA development

The first generation (1G) is analogical system with limited roaming capacity, and only allowed low quality voice calls. Advanced Mobile Phone System (AMPS) is the analog mobile phone system standard developed by Bell Labs and was the main standard (1982-1992) for the first generation system.

The second generation (2G) systems is digital, and it increases the network capacity and improves roaming capacities. The 2G system includes the Global System for Mobile Communications (GSM), CdmaOne and Digital version of AMPS (D-AMPS).

The third generation (3G) system is an upgrading version of the 2G system. It is based on the International Telecommunication Union (ITU) family of standards and International Mobile

Telecommunications-2000 (IMT-2000). IMT-2000 is a global standard for the 3G wireless communication as defined by the International Telecommunication Union in 1999.

The 3G system provides access to telecommunications services offered by the fixed networks and to other specific services of the mobile users. The 3G terminals, i.e. Mobile phone for 3G network, can be connected to earth or satellite networks, and they can be designed for mobile or fixed uses, for public or private networks. The 3G system provides very efficient communications with a high speed and QoS.

Universal Mobile Telecommunications System (UMTS) is the European vision of the 3G systems of the family of IMT-2000 standards. UMTS is the logical evolution of the community GSM to the third generation. In January 1998, European Telecommunications Standards Institute (ETSI) adopted the WCDMA technology (Wideband CDMA) in particular Frequency Division Duplex (FDD) or Time Division Duplex (TDD) for the radio access (Kara et al. 2006).

UMTS, in the terrestrial components, has three types of cells: Macro Cell, Micro Cell, and Pico Cell. The Macro Cell has radios from 1 km to 35 km and it is destined to offer rural coverage and highways for vehicles or other objects that move at high speed (114 Kbit/s). The Micro Cell has radios range from 50 m to 1 Km .It offers service to fixed users or who move slowly with a high density of traffic (urban) with 384 Kbit/s speeds. The Pico Cells has radios until 50 m, and offers located coverage and interior coverage, with speeds of the 2 Mbit/s.

Wideband Code Division Multiple Access (WCDMA) is a UMTS 3G mobile network technology that is used in Europe in the new IMT-2000 frequency bands. WCDMA was designed to provide efficient capacity for modern mobile multimedia applications and mobile telephone services. The WCDMA has a bandwidth around 5 MHz. This wide bandwidth supports high data transfer rates and also provides performance benefits due to the diversity of the broadcast frequency. In addition, a new technology called HSDPA will bring even higher downlink speeds over WCDMA radio access networks (Mishra 2004).

3.2.2 Services of the WCDMA system

The services are what a network, operators or service providers, offers to its customers (Kaaranen 2005). At the start of the WCDMA system era, almost all traffics were about voice. With the development of the Internet technology, WCDMA systems provide the new function through the Internet. This new function is about the TCP/UDP/IP traffic in the WCDMA network. At the same time, the transition from voice to data occurred; the telecommunication traffic system moved from circuit-switched connections to packet-switched connections in order to support high speed data services. Meanwhile, the WCDMA system takes the Quality of Service (QoS) as a general guideline. Therefore, the delay-critical applications such as speech and video telephony will be carried on both circuit-switched bearers and packet-switch bearers (Hernandez-Valencia and Chuah 2000, Zhang 2002, Zheng et al. 2003).

The best known new service feature of the WCDMA system is its higher user bit rates on the circuit-switched connections with 384 Kbps and on packet-switched connections with up to 2 Mbps. Higher bit rates naturally facilitate some new services, such as video telephony and quick downloading of data with the required QoS. There is a brief introduction of the two categories of services as follows.

(1) Services and QoS

In general, applications and services can be divided into different groups, depending on how they are considered. Like new packet-switched protocols, UMTS/WCDMA attempts to fulfill QoS requests from the application or the user. In 3G WCDMA (UMTS) system, four traffic service classes have been identified. The main distinguishing factor between these classes is how delay-sensitive the traffic is: the conversational class is meant for very delay-sensitive traffic, while the background class is the most delay-insensitive. They are listed as below.

- Conversational:

  The best-known application of this class is speech service over circuit-switched bearers. With Internet and multimedia, a number of new applications will require this type, for example voice over IP and video telephony. This is the only type of the four services where the required characteristics are strictly imposed by human perception.

- Streaming:

  Multimedia streaming is a technique for transferring data such that it can be processed as a steady and continuous stream. Streaming technologies are becoming increasingly important with the growth of the Internet, for instance, (1) Web broadcast and (2) video streaming on demand.

- Interactive:

  When the end-user, either a machine or a human, is on line requesting data from remote equipment (e.g. a server), this scheme applies. Examples of human interaction with the remote equipment are Web browsing, database retrieval, and server access.

- Background classes:

  Data traffic of applications such as e-mail delivery, SMS, downloading of databases and reception of measurement records can be delivered background since such applications do not require immediate action. The delay may be seconds, tens of seconds or even minutes. Background traffic is one of the classical data communication schemes that are broadly characterized by the fact that the destination is not expecting the data within a certain time, e.g. E-mail, Multimedia Messaging Service (MMS), and Short Messaging Service (SMS).

Corresponding to the different service demands above and the relevant QoS, WCDMA terminals set up connection with larger set of parameters indicating the radio access capabilities of the particular terminal. These capabilities determine what is the maximum user data rate supported in particular radio configuration and given independently for the uplink and downlink directions.

- 32 kbps class: this is intended to provide basic speech service, including Adaptive Multi rate(AMR) speech as well as some limited data rate capabilities up to 32 kbps,
- 64 kbps class: this is intended to provide speech and data service, with also simultaneous data and AMR speech capability,
- 128 kbps class: this class has the air interface capability to provide for example video telephony or various other data services,

- 384 kbps class is being further enhanced from 128 kbps to support advanced packet data methods provided in WCDMA,
- 768 kbps class has been defined as an intermediate step between 384 kbps and 2 Mbps class, and
- 2 Mbps class: This is the state of the art class and has been defined for downlink direction only.

(2) Location services

Location-based services and applications are one of the new functions in 3G WCDMA (UMTS) system. A location-based service is provided either by a telecommunication operator or by a third party service provider that utilizes available information on the terminal location. For instance, before traveling to an unknown city abroad, one may download information such as a map and other data through WCDMA mobile phone. By clicking the icon on the map, one gets information from the point. In emergency situations, the service may provide important location information to the victims so that they can arrange the evacuations routes.

3.2.3 Architecture of the WCDMA system

The cellular network is a complex system that includes architecture, procedures and services both on user, network and management levels. Figure 3.1 shows a general architecture of the WCDMA network, which consists of three interacting domains: the User Equipment (UE), UMTS Terrestrial Radio Access Network (UTRAN) and Core Network (CN). The WCDMA connects to the external network: Public Switching Telecommunication Network (PSTN) and Internet network. These elements are interconnected by transmission links – wired or wireless. The UE is the mobile phone that communicates with UTRAN via the air-interface. The radio link is the duplex communication channel from the Base Station to each mobile user and from user to Base Station. UTRAN provides the air-interface access method for the UE. CN provides switching, routing and transit for the user traffics. It also stores databases and provides network management functions. From the specification and standardization point of view, both UE and

UTRAN consist of completely new protocols; they are developed with the needs of the new WCDMA radio technology.

The definition of CN is adopted from GSM network and upgrade by following 3GPP R4 standard. In 3GPP R4, the CS domain structure was given an alternative implementation method, CS domain architecture defines MSC/VLR division, where call control functionality and the VLR are brought into an entity called the 'MSC server'. Respectively, user plane connectivity and related items (e.g., network inter-working) are brought into an entity called the 'Media Gateway' (MGw).

In 3GPP R4 and R5 UMTS standards (3GPP TR 25. 931 2004, 3GPP TS 23.002 2003), the Gateway MSC server replaces the GMSC in the 3GPP Release 99. The GMSC server mainly comprises the call control and mobility control parts of a GMSC. The Gateway MSC (GMSC) server may be used to interface with external circuit-switched networks. A GMSC is responsible for routing a circuit witched call to its final destination in external networks.

When the separation of the two components, MSC server and CS-MGw, is implemented, it opens up a few new interfaces within the CS domain such as the Mc, Nc, Nb, E, G, which defined the information control and transmission mechanism among MSC servicers and CS-media gateway. The detailed information is described by Kaaranen (2005) and Yacoub (2002).

In the PS domain, the General Packet Radio Service (GPRS) subsystem transmits IP packets. GPRS consists of two sub components: the SGSN for data packet delivery and the GGSN for gateway to Internet or Intranet.

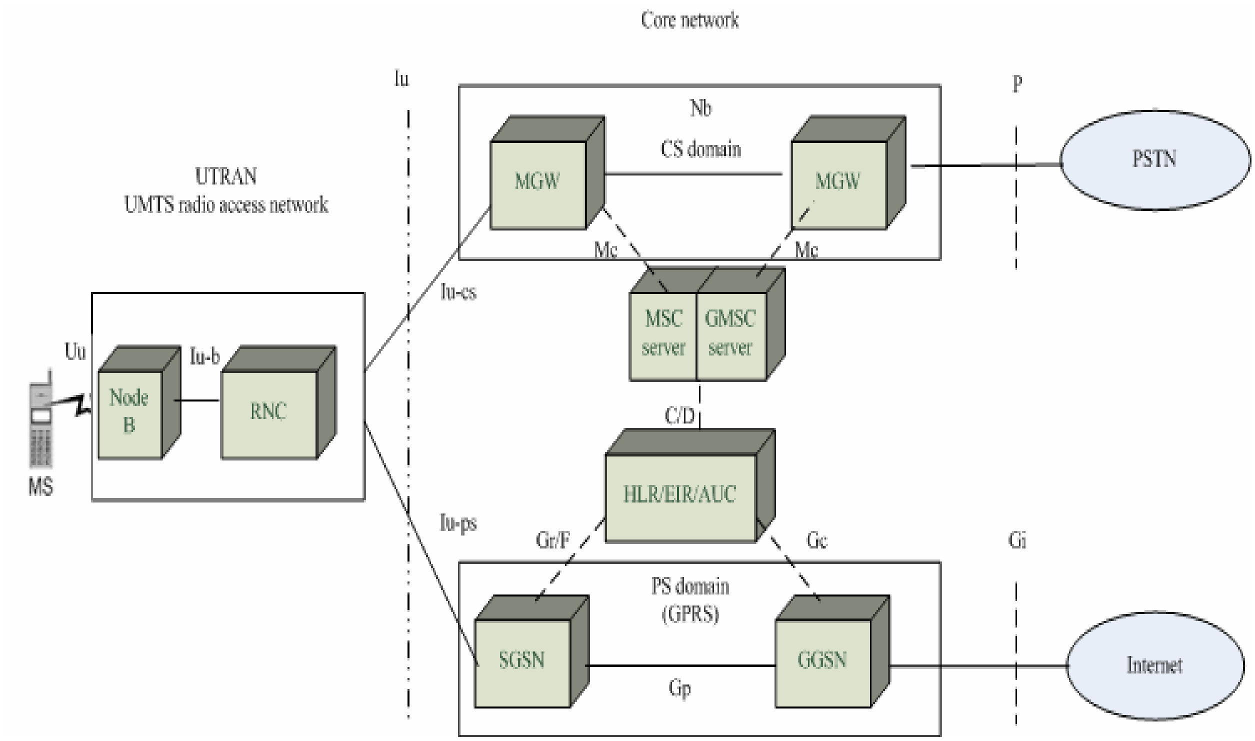


Figure3.1 WCDMA Network Architecture (3GPP TR 25. 931 2004).

The different components communicate each other through the defined interface among them. An interface defines the communication boundary between two entities, such as a piece of software, a hardware device, or a user. It generally refers to an abstraction that an entity provides of itself to the outside. This separates the methods of external communication from internal operation, and allows it to be internally modified without affecting the way outside entities interact with it. There are major interfaces in the example WCDMA system as follows:

- **Interface Uu:** It is the interface between the User terminal and UTRAN network and uses the WCDMA technology.
- **Interface Iu:** It is the interface that connects the core network with Access network UTRAN.
- **Interface Iu-CS:** This Iu-Cs interafce is used when the network is based in circuit communication. It connects the UTRAN network with the MSC.
- **Interface lu-PS:** This interface connects the access network with the SGSN of the packet

network.

- **Interface Iu-B:** This interface connects the RNC with Node Bs.
- **Interface Mc:** This interface connects the MGw with the MSC server.
- **Interface Nb:** This interface connects MGw with another MGw.
- **Interface Gp:** This interface connects the SGSN with GGSN.

3.2.4 Features of the Wideband Code Division Multiple Access (WCDMA)

WCDMA is the radio access technique used for third generation wireless cellular systems. UMTS 3G network uses WCDMA as its air interface. The main system design parameters of the WCDMA are described as follows.

- WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system, i.e. user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits, called chips, derived from CDMA spreading codes. In order to support very high bit rates (up to 2 Mbps), the use of a variable spreading factor and multi code connections are supported.

- The chip rate of 3.84 Mcps used leads to a carrier bandwidth of approximately 5 MHz. The inherently wide carrier bandwidth of WCDMA supports high user data rates and also has certain performance benefits, such as increased multi-path diversity.

- WCDMA supports highly variable user data rates. Each user is allocated frames of 10 ms duration, during which the user data rate is kept constant. However, the data capacity among the users can change from frame to frame.

- WDCMA supports two basic modes of operation: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In the FDD mode, separate 5 MHz carrier frequencies are used for the uplink and downlink respectively, whereas in the TDD mode only one 5 MHz is time-shared between uplink and downlink. Uplink is the connection from the mobile to the base station, and downlink is that from the base station to the mobile.

- WCDMA supports the operation of asynchronous base stations. There is no need for a global time reference, such as a GPS. Deployment of indoor and micro base stations is easier when no GPS signal needs to be received.

- WCDMA air interface has been designed in such a way that advanced CDMA receiver concepts, such as multi-user detection and smart adaptive antennas can be deployed by the network operator as a system option to increase capacity and coverage.

- WCDMA is designed to be deployed in conjunction with GSM. Therefore, handovers between GSM and WCDMA are supported in order to be able to leverage the GSM coverage for the introduction of WCDMA system.

3.2.5 Protocols of the WCDMA system

From the functions of the network components mentioned above, WCDMA wireless cellular system provides three major functions to manage the traffic transmission: (1) Communication Management; (2) Mobility Management; (3) and Radio Resource Management.

Communication Management (CM) covers all of the functions and procedures related to the management of user connections, such as call handling for CS connections, session management for PS connections, as well as handling of supplementary services and short-message services.

Mobility Management (MM) covers all of the functions and procedures needed for mobility and security (e.g., connection security procedures and location update procedures). Most of the MM procedures occur within the CN and its elements, but in the 3G part of the MM functions are also performed in UTRAN for PS connections.

Radio Resource Management (RRM) is a collection of algorithms UTRAN uses for management of radio resources. These algorithms handle, for instance, the power control for radio connections, different types of handovers, system load and admission control. RRM is an integral part of UTRAN.

In order to achieve such functions, the network elements need to communicate among each other under the control of the defined standards. These control duties are then refined into a set of **protocols**. A protocol (Protocol 2008) is the rules governing the syntax, semantics, and synchronization of communication. Protocols may be implemented by hardware, software, or a combination of the two. In the field of telecommunications, a communications protocol is the set of standard rules for data representation, signaling, authentication and error detection required to send information over a communications channel.

At the lowest level, a protocol defines the behavior of a hardware connection. The interface is different from different elements pair and the corresponding protocols guiding the data transmission along the interface link between components and control the execution of network functions in a coordinated manner across system interfaces (Holma and Toskala 2002, Yacoub 2002.). A simplified view of the 3G WCDMA protocol architecture is showed in Figure 3.2.

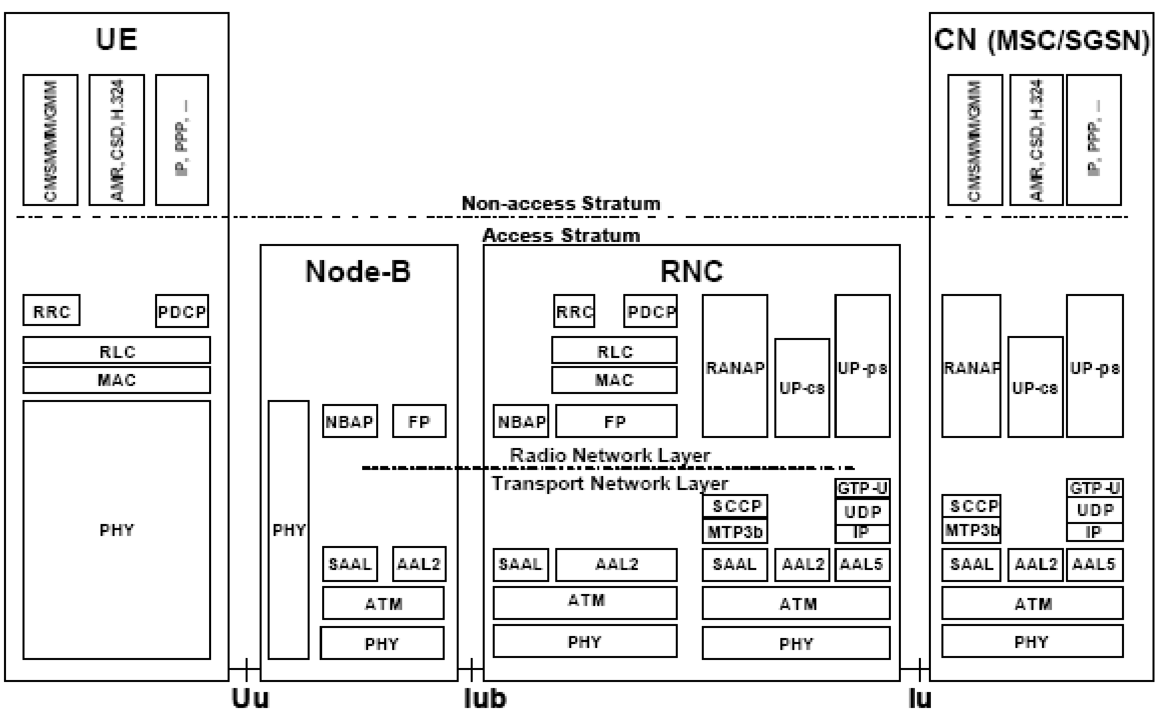


Figure 3.2 Typical protocol architecture of the 3G WCDMA (García et al. 2002).

WCDMA is the key radio access technique used in air- interface (Uu) of UMTS 3G wireless system. The Radio Interface Protocol Reference Model is taken for instance (Holma and Toskala 2002, Yacoub 2002.) which has three-layer protocol reference model illustrated in Figure 3.3. Three layers of protocols are, respectively, denoted as L1, L2, and L3, and their domain specific names are given as follows:

- L1 – radio physical layer of protocols.
- L2 – radio link layer of protocols.
- L3 – radio network layer of protocols

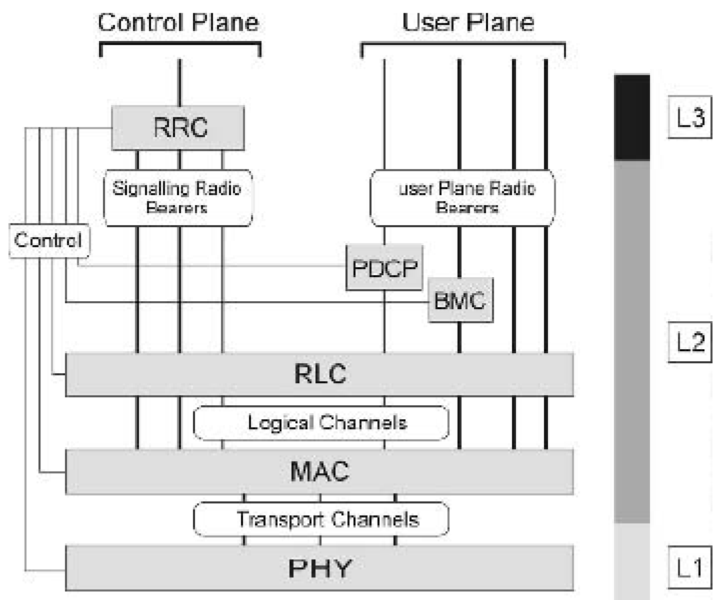


Figure 3.3 Radio interface protocol reference model (Kaaranen 2005)

L1 provides mapping functions between transport channels and WCDMA physical channels. L2 provides mechanisms for dynamic sharing of capacity in the WCDMA radio interface. This layer (L2) allows the upper layer to see only a set of radio bearers (channels), along which different kinds of traffic can be transmitted over the radio link. Further in L2, the Medium Access Control (MAC) sub-layer controls the use of the transport block capacity by ensuring that capacity allocation decisions are executed promptly at both ends of the radio interface. The Radio Link Control (RLC) sub-layer then adds regular link layer functions onto the logical channels provided by the MAC sub-layer. Due to the characteristics of radio transmission some special ingredients have been added to RLC sub-layer functionality. The Packet Data Convergence Protocol (PDCP) makes the UMTS radio interface applicable to carry Internet Protocol (IP) data packets. Another Convergence protocol (e.g. BMC) has been specified for message broadcast and multicast domains.

L3 contain protocols for interfaces over an entire network. It provides a control of all the protocols at L2 and L1 (see Figure 3.3, links from RRC to all other protocols below). L3 is logically applied to all devices of EU and UTRAN when they interact with any other device over the network.

3.3 The example WCDMA system

The WCDMA system to be used throughout subsequent chapters is also called the example WCDMA system. This system is constructed based on what is mentioned in Section 3.2.3.

3.3.1 Architecture of the example WCDMA system

In the case WCDMA system, there are the listed functional nodes: 3 Node Bs, 2 RNC, 2 MGw, 1 GPRS(including 1 SGSN and 1 GGSN), 1 HSS(including ,1 HLR, 1 EIR and 1 AuC), 1 MSC server (including VLR), 1 PSTN/PLMN network, 1 IP network and n UEs in Figure 3.4. The solid line between the nodes stands for the traffic flow (voice or data) transmitting from one component to the other. The relevant interface is indicated for each line. The dotted line stands for the control signaling among the components so that the components in the WCDMA system can operate in a managed way. In order to simplify the system, the interface type for the control signaling links is not indicated.

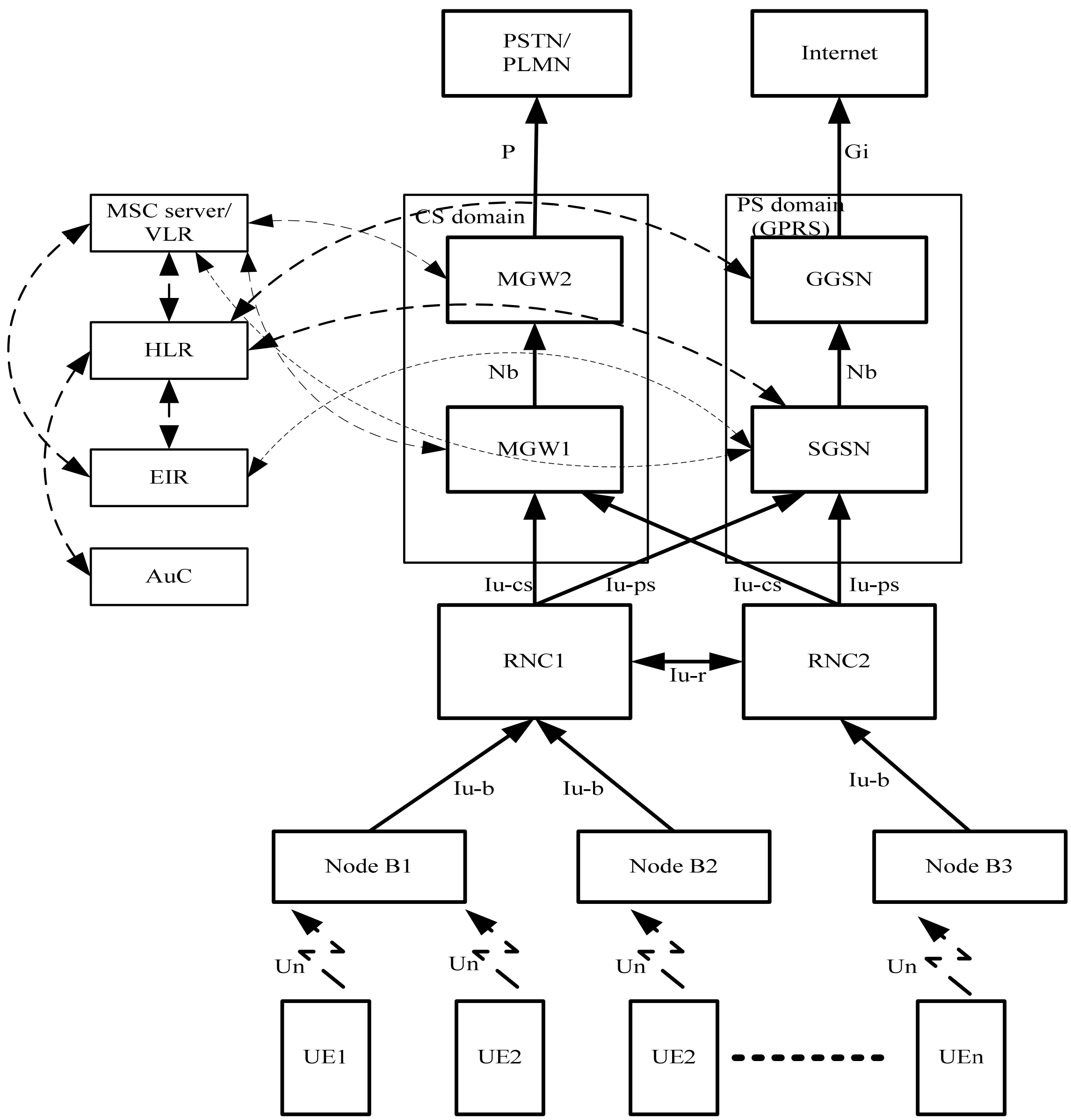


Figure 3.4 An example WCDMA system.

The function of these nodes is to provide a voice transmission through WCDM wireless network by WCDMA radio access network and traditional circuit switch network or the IP based packet switch Internet. The control mechanisms govern the behaviors of these WCDMA network components. The communication or reporting information among these components is transmitted through the interfaces and following the protocols mentioned above.

3.3.2 Configuration of the example WCDMA system

The variables and parameters for the WCDMA system are also need to be defined. Because models of telecommunication system have a large set of parameters, e.g. speed of users, size of cell, bandwidth requirements of user, etc., and there are not standard values for these parameters, it is difficult to define the parameters for the modeling and simulation of WCDMA wireless system. The system parameters are defined in a simple and easy to understand way which can simplify the system simulation and effectively provide enough insight to the research objectives. Such parameter can be general enough and suitable to any telecommunication system in the context of emergency or disasters.

- The capacity of the each network component is defined by the Maximum quantity of user in a time interval unit, i.e. per hour in a normal operation.

  (1) The maximum capacity of Node B1 is 30 users/per hour, Node B2 is 35 users/per hour, and Node B3 is 40 users/per hour.

  (2) The capacity of the other nodes is assumed to be always enough. It can smoothly switch and route the traffic from Node Bs to other network components.

- Each Node B can increase its 30% capacity within a time unit (e.g. an hour) above its normal capacity through the radio resource control mechanisms such as power control and AMR described in the Section 3.3.3. The whole network processing capacity is determined by total nodes capacity as 150 users/per hour.

- The rate of the user requests for voice service from UE to Node B follows the Poisson process. The detailed information is described in Section 6.3.5.
- The service continuity of the wireless network is expressed by the rate of serviced users divided by the total users at a discrete time, i.e., Psc= Ms/Ts (where: Psc= probability of service continuity, Ms= Number of served users, Ts= Total subscribers of the WCDMA network.)

In emergency situations, this thesis study only focused on the basic service, i.e., voice traffic. The voice traffic is transmitted through the Circuit Switching network via the Node B, RNC, MGw. The VoIP, Non-real time voice, is transferred from UE, through Node B, RNC, GRPS network, Internet network to the receivers. Other components for signaling control and database management, including MSC servers, HLR, EIR and AUC, are not under consideration in this thesis, because the network components for signaling control are highly reliable and resilient in accident (Freeman 2004, Stafford 2004).

3.3.3 Management of the example WCDMA system

In order to effectively evaluate the performance of the WCDMA system survivability, the principle model only focus on the voice service and the typical principles. The capacity of the function in core network is assumed to be infinite. The capacity restriction is determined by the radio frequency bandwidth which is controlled by the Node B and RNC. In order to simplify the analysis, some complicated scenarios like Authentication, Authorization and Accounting (AAA), location updating are not dealt with.

The WCDMA logical network elements connect through open interfaces or access points. Functionally, the RAN network handles all radio-related functionality, Radio Resource Management and Mobility Management (RRM and MM). The CN is responsible for switching and routing calls and data connections to external networks at the same time as managing session and mobility information, Communication Management and Mobility Management (CM and MM). User Identity Module (UIM) and Mobile Terminal (MT) interfaces with the user and the radio interface.

In the example WCDMA system, the typical control mechanisms are applied in the RAN network and CN network. The first control mechanism is the RAN control. It is based on the knowledge of MM and RRC. Typically based on the control mechanism of Soft Handover, Power Control, Call Admission Control (CAC). The dynamic network capacity is governed by these radio control mechanisms. The second control mechanism is for the switching function of the Core Network (CN). This thesis study simply defines the routing and switching control mechanism in the Circuit Switch (CS) domain and Packet Switch (PS) domain. The capacity of CN components is estimated to be always sufficient before and after disasters.

(1) Radio Resource Control of Radio Access Network (RAN)

There are three typical radio access control mechanisms: Soft handover, Power control, Call Admission Control (CAC) and Adaptive Multi-rate Voice codec (AMR).

- Soft handover:

  It allows mobile users to be reachable anywhere and anytime. Keeping the moving device connected to the network and managing its mobility. It is one of the three handover ways, i.e. hard handover, soft handover and softer handover (Kaaranen 2005). Hard handover occurs on condition that the old connection during the handover process is released before making the new connection. A softer handover is a handover as a result of which a new signal is either added to or deleted from the active set, or replaced by a stronger signal within the different sectors that are under the control of the same Node Bs.

  Soft handover occurs when a new connection is established before the old connection is released. Soft handover is performed between two cells belonging to different Node Bs but not necessarily to the same RNC.

  The soft handover function is adopted in network survivability analysis; because it is estimated that single point failure occurs after disaster, namely, the function node fail completely. For instance in Figure 3.5, when Node B1 fails in emergency situations, a predefined parameter is set at the point where the signal strength of the neighboring cell (Node B2) has started to exceed the signal strength of current cell (Node B1) by a certain amount and/or for a certain time. The UE set up a new radio connection to Node B2 and the traffic service are handover from Node B1 to Node B2.

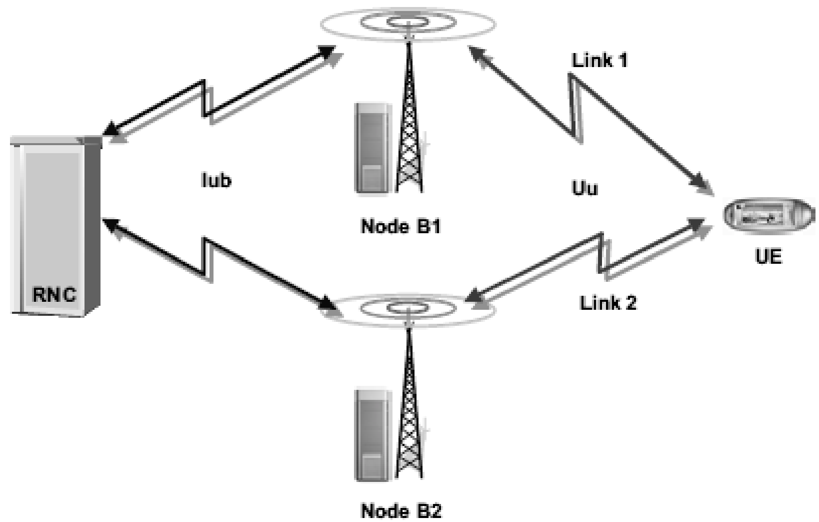


Figure 3.5 Soft handover of WCDMA (Kaaranen 2005).

- Power control:

The power control regulates the transmit power of the terminal and base station, which results in less interference and allows more users. WCDMA employs fast closed-loop Power Control. Signal to interference ratio (SIR) based power control is used where the receiver compares the estimated received SIR with a SIR target value and commands the transmitter to increase or decrease power accordingly.

The target SIR values are controlled by an outer power-control loop. This outer loop measures the link quality, typically a combination of frame and bit error rates (BER's) depending on the service and adjusts the SIR targets accordingly. Ensuring the lowest possible SIR target is used at all times results in maximum capacity (3GPP TR 25. 931 2004; Kara et al. 2006).

- Call Admission Control (CAC):

Capacity estimation in CDMA systems is an important issue which is closely related to traffic characteristics, power control, radio propagation, sectors of antenna and other factors. WCDMA system is interference limited and has a soft capacity which changes depending on the interference received by Node B at a given time. If interference increases beyond an acceptable level the system becomes unstable and may lead to call dropping. Admitting a new call always increases the interference level in the system. Hence, Call Admission Control (CAC) technique is required to accept or block potential users. The basic strategy is to protect ongoing calls by denying a new user access to the system under heavy congestion. Node B implements Admission Control algorithms and make admission decisions.

- Adaptive Multirate voice codec (AMR) :

AMR is used in both GSM and WCDMA system. AMR voice codec supports 8 different speech codec rates with bit rates ranging from 4.75 kbps to 12.2 kbps. The AMR-WB speech codec consists of nine speech coding modes with bit-rates of 12.2kbit/s, 10.2kbit/s, 7.95kbit/s, 7.40kbit/s, 6.7kbit/s, 5.9kbit/s, 5.15kbit/s, 4.75kbit/s (Holma and Toskala, 2002). The bit rate is dynamically controlled by the radio network according to the WCDMA system load. The AMR-WB codec adapts the bit-rate allocation between speech and channel coding, enhancing speech quality to prevailing radio channel conditions. While providing superior voice quality over the existing narrowband standards, AMR-WB is also very robust against transmission errors due to the multi-rate operation and adaptation.

All the four typical mechanisms are used to efficiently utilize of the air interface resources, guarantee QoS, maintain the planned coverage area, and to offer high capacity. There are more research studying increasing the capacity and coverage of RAN. Holma et al. (2002) studied the power control algorithm and states that increasing the power available will permit more users before cell loading is close to approximately 90% downlink loaded. After that, increasing the Node B power capability will not increase system capacity. Smith and Collins (2002) and Kaaranen (2005) addressed the item and parameters which are used for the handover algorithm, such as upper threshold and lower threshold for signal strength, handover margin, active list. Holma and Priyan (2005) showed that CAC and AMR technology can add network coverage and capacity. AMR dynamically adapts to changing radio conditions. It allows individual Node B cell sizes to be increased by about 30% reducing the number of Node B’s needed to cover a given area. With AMR speech codec it is possible to switch to a lower bit rate if the mobile is moving out of the cell coverage area. Different AMR bit rates leads to relative different cell ranges, meanwhile the voice capacity can be increased by using a lower bit rate AMR mode. Figure 3.6 and Figure 3.7 shows the improvement of capacity and coverage by the AMR.

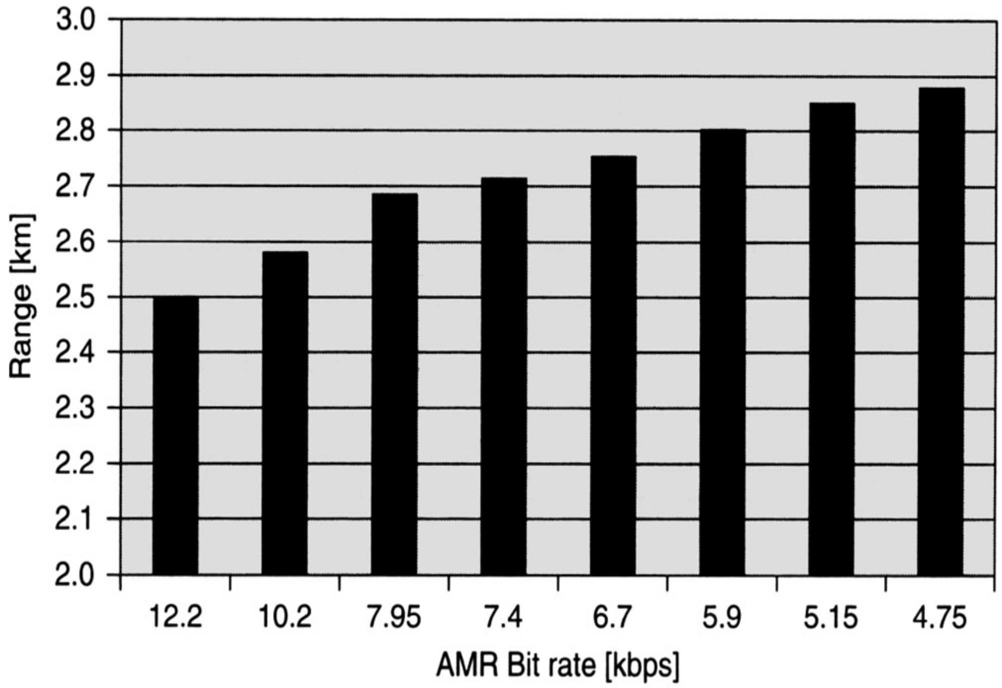


Figure 3.6 Coverage range of Different AMR Bit rates (Holma and Priyan 2005).

	AMR 12.2 kbps	**AMR 7.95 kbps**	**AMR 4.75 kbps**
Eb/No	7.0 dB	7.5 dB	8.0 dB
Capacity	66 users	90 users	134 users

Figure 3.7 Capacity of Different AMR Bit rates (Holma and Priyan 2005).

(2) Switching and routing function Core Network (CN)

The main function of the CN is for data switching and routing over the Circuit Switch (CS) and Packet Switch (PS) network.

In principle, circuit switching and packet switching both are used in high-capacity networks. In circuit-switched networks, network resources are static. A physical path is obtained for and dedicated to a single connection between two end-points (sender and receiver) in the network for the duration of the connection. The telephone company reserves a specific physical path. During that time, no one else can use the physical lines involved (Circuit switching 2008). In the circuit domain, the MSC server control and maintains connection of the Medium Gateway through the control signaling to the Media Gateway (MGw). MGw thus takes care of all physical connection set-up matters for the voice traffic. The MSC Server and CS-MGw have a one-to-many relationship, i.e., one MSC server could control numerous CS-MGws.

In packet-switched networks, the message is broken into packets, each of which can take a different route to the destination where the packets are recompiled into the original message. Packets are routed to their destination as determined by a routing algorithm. The routing algorithm can create paths based on various metrics and desirable qualities of the routing path. For example, low latency time may be of paramount concern and everything else is secondary. Once a route is determined for a packet, it is entirely possible that the route may change for the next packet, thus leading to a case where packets from the same source headed to the same destination could be routed differently (Packet switching 2008).

In the packet switch (PS) domain, the Serving GPRS Support Node (SGSN) handles all packet switched data within the network, e.g. the mobility management and authentication of the users. The SGSN handles the protocol conversion from the IP used in the backbone network to the Sub-Network-Dependent Convergence Protocol (SNDCP) and Logical Link Control (LLC) protocols used between the SGSN and the mobile users. These protocols handle compression and ciphering. The SGSN performs the same functions as the MSC for voice traffic. The SGSN is the service access point to the GPRS network for the mobile user. SGSN relays the data between the SGSN and relevant Gateway GPRS Support Node (GGSN). A GGSN is a network node that acts as a gateway between a GPRS wireless data network and other networks such as the Internet or private networks.

3.3.4 Threaten scenarios of the example system

In a network, devices or nodes are interconnected via some medium through which data can be transmitted. Transmission can occur through wires or through wireless channels. The threaten scenarios is designed based on the impact of emergency and disaster to the network components and its severity.

Bhagyavati (2001) stated that a failure is any deviation from the expected behavior of the network. A fault is an observed or externally visible failure, which is defined as an abnormal condition that adversely affects network services. For instance, the MSC does not work or can not operate in a normal condition. The fault of the MSC is observed by the symptoms (voice traffic congestion or disconnection), and these symptoms are failures.

Emergency or disaster normally causes serious damages to the system functional nodes. The fault management of network survivability in emergency situations mainly referred to the nodes failure. It is estimated that the function nodes and the links fail together. Bhagyavati (2001) indicated that a classification of the types of faults is indispensable. The faults are classified from three dimensions:

(1) Location of faults: hardware faults, software faults, resource faults
(2) Severity of faults: High, medium, low
(3) Components affected by faults: link faults, equipments faults, nodes faults.

This thesis study research anchors on the vulnerable network nodes faults. It examines the system service continuity under the condition of the failure of some nodes. These selected nodes are UE, Node B, Mgw, GPRS, SGSN and GGSN for the user traffic transmission and QoS guarantee. Other nodes for the signaling control or database function are considered to be always available because of their highly redundancy and reliability, like MSC server, HLR, EIR and SS7 system nodes. Threatens are defined at three levels of based severity.

- The low severity is the failure of Node B.
  The users within the radio area of the Cell of this Node B are disconnected from the WCDMA network. The UEs (User Equipment) have to handover to other available Node Bs in order to maintain the service continuity. UE is normally called mobile phone which provides the radio access functions for users to the WCDMA network.

- The medium severity is the failure of one RNC.
  Due to root of Tree network topology, all the Node Bs controlled by the RNC loses the connection to the WCDMA network. All the impacted UEs have to hand over to the available Nodes controlled by a working RNC.

- The high severity is the failure of one switch node MGw.
  When one MGw is damaged, all the RNC connecting to it can not transmit the traffic through it. All users served by those Node Bs controlled by such RNC can not continue their service through Circuit Domain. In order to maintain the service, RNC will switch to the other interface to IP network through SGSN/GGSN instead of the CS network through MGw.

The occurrence of the node failure is simulated by a Poisson distribution. The failure of low severity takes place most frequently. The failure of high severity takes the least. The failure of the medium severity takes place middle- frequently.

3.4 Summary

This chapter shows the construction of an example WCDMA system in emergency situations. It introduces the evolution of the wireless cellular system and the advanced feature of the WCDMA system over the previous system. The service, the architecture, control mechanism of the WCDMA system is introduced so that an example survivable WCDMA system is built up. In the context of the emergency environment, the example WCDMA is built from the service, structure and control mechanism. The goal of the example WCDMA system is to support the conceptual design in the research study. Therefore, the design of the example WCDMA system is more general other than the detailed and specified system design. By examining it, the system performance in certain environments may be examined so as to build the decision making system in subsequent chapters.

Chapter 4

WCDMA domain model

4.1 Introduction

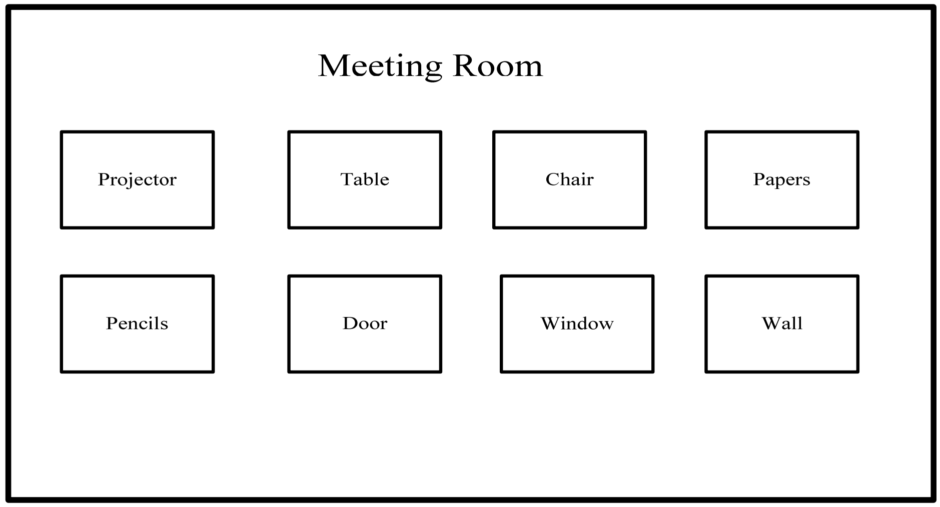
In this chapter, the domain model of the WCDMA will be described in detail. Since the domain model is relatively new in engineering systems development field, the notion of the domain model is first discussed by using a meeting room as an example (Section 4.2). Then the domain model of the example WCDMA system (Section 4.3) is presented. Finally, Section 4.4 concludes this chapter with some discussion.

4.2 The concept of the domain model

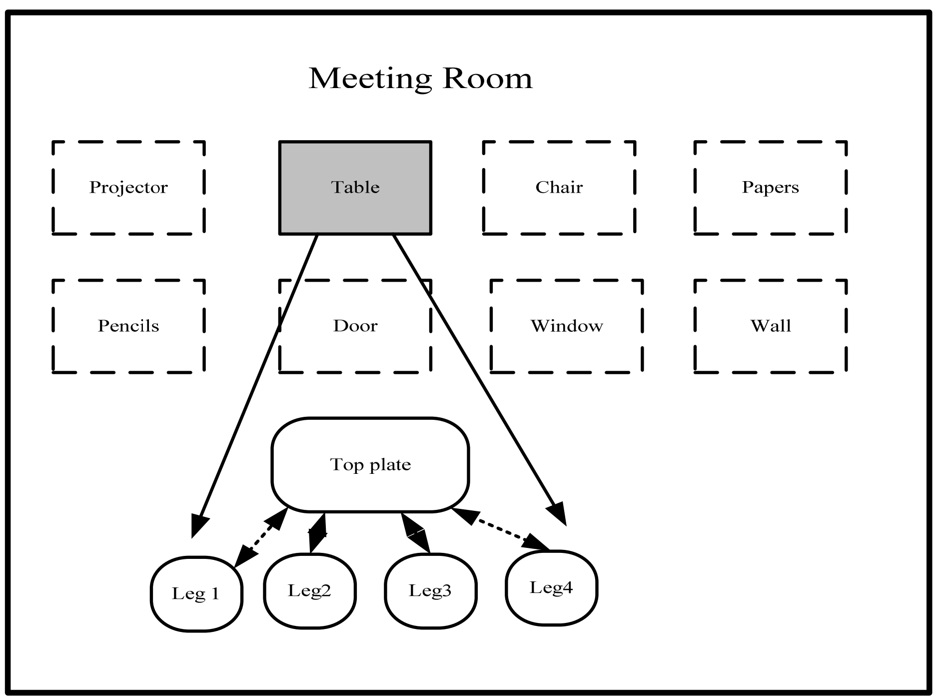
Figure 4.1 shows a meeting room, where there are a table, a few chairs, windows, a projector, and a door. For the meeting room to make sense, the components or subsystems are identified as listed. Figure 4.2a shows a representation of the semantics which is called **Aggregate relationship**. It is noted that the assembly relationship is the same as the decomposition relationship. Further looking at Figure 4.2b, the relationship among four legs and the top plate of table is identified; a kind of relationship existed among these components is different from Aggregate relationship - in this particular case, the legs are connected with the top plate but the legs are not connected to each other directly. The relationship among the legs and the top plate of Figure 4.2b is called **Assembly relationship** (see Figure 4.2b).

Figure 4.1 Meeting Room (Rentacomputer 2008).

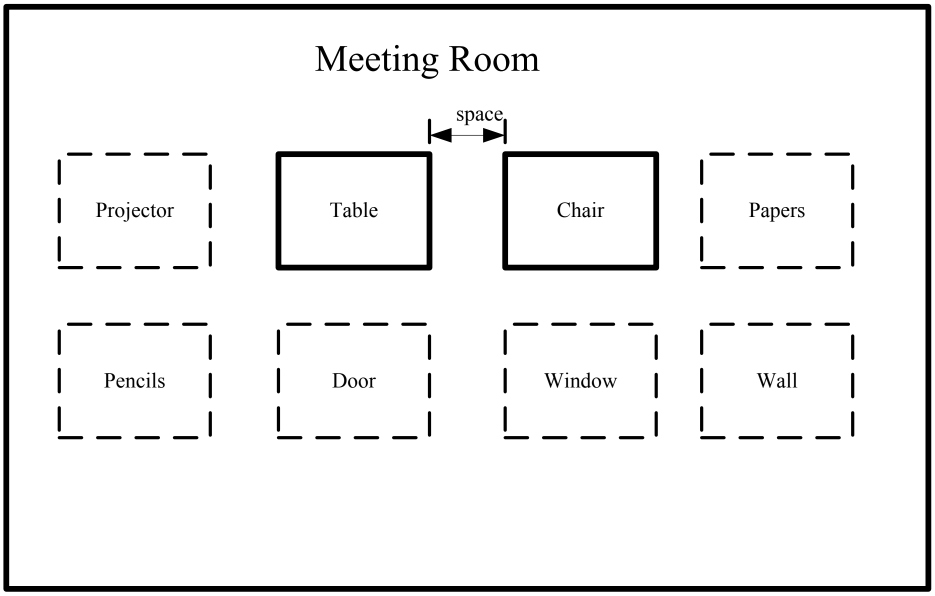
Further exploring the two categories of relationships reveals the following. The assembly or aggregate relationship results in a novel concept that is not existed in its composing components. For example, the meaning of a meeting room is more than the meaning of a room. The meeting room is more than a special semantics on the physical system; as such the meeting room aggregates the concept or objects: room, table, chair, and so on (see Figure 4.2a). The **connectivity relationship** results in a usable system; for example, there must be a sufficient space between the chair and table so that the attendants of a meeting are able to sit on the chair beside table (Figure 4.2c). People will be also considered as a kind of objects in the domain model in this case.



(a) Aggregate relationship.



(b) Assembly relationship.



(c) Connectivity relationship.

Figure 4.2 Objects relationship within domain model.

After having identified domain objects, the FCBPSS framework is applied to the domain objects. This means to further identify the structure, state, behavior, principle, function, and context of the domain objects and subsystems. In this way, the domain model of the meeting room is completed.

4.3 The domain model of the example WCDMA system

4.3.1 Domain objects of the example WCDMA system

The holistic WCDMA network system comprises of the telecommunications network and the management network. The telecommunications network has the function to transport the information between the ends. The management network has the function of invoicing, pricing, registering, managing the security, detecting and resolving failures or anomalies and of the disabled operation after disconnection or the recovery periods of some of these components. The

WCDMA network system comprises of four basic components: (1) Core Network (CN), (2) UMTS Terrestrial Radio Access Network (UTRAN), (3) User Terminal/Mobile Equipment (UE/ME), and (4) Transmission Network (i.e., physical mediums). Figure 4.3 shows the assembly relationship of an entire WCDMA system. The components and sub-systems which construct the example WCDMA system are listed in Table 4.1.

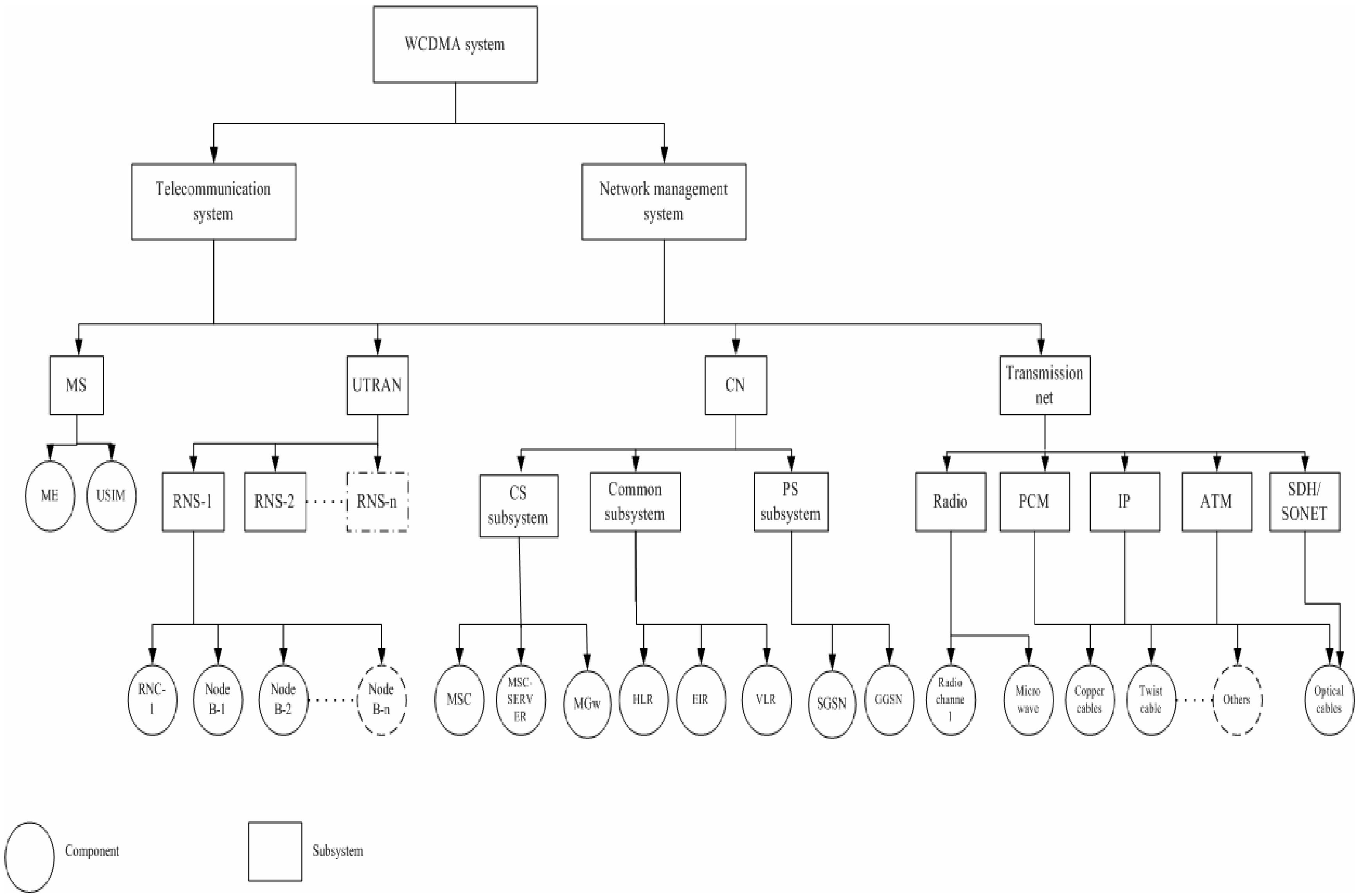


Figure 4.3 Holistic structure of the WCDMA wireless cellular system.

Table 4.1 Components of the WCDMA system.

Components	Description	Components	Description
MS	Mobile Station	MGw	Media Gateway
ME	Mobile Equipment	HLR	Home Location Registration
USIM	Universal Subscriber Identity Module	EIR	Equipment Identity Register
UTRAN	UMTS Terrestrial Radio Access Network	VLR	Visitor Location Register
RNS	Radio Network subsystem	SGSN	Serving GPRS Support Node
Node B	Base Transceiver Station in WCDMA	GGSN	Gateway GPRS support node
CN	Core Network	PCM	Pulse Code Modulation
CS subsystem	Circuit Switch subsystem	IP network	Internet protocol(IP) network
PS subsystem	Packet Switch subsystem	ATM network	Asynchronous Transfer Mode network
Common subsystem	Subsystem shared by CS and PS subsystem	SDH/SONET	Synchronous Digital Hierarchy/Synchronous Optical Network
MSC	Mobile Switching Centers	Other Physical Medium	Copper, optical, twist cables; and Radio frequencies
MSC server	Mobile Switching Center Server		

4.3.2 The example WCDMA system - Function

In the telecommunication domain, the services of the system refer to the functions in the FCBPSS domain. Because of the different words 'service' and 'function', it makes some confusion to study the function of telecommunication system from engineering domain. Kaaranen et al. (2005) indicate that 'Service' is a word that suffers from inflation in the telecommunication business area as the businesses seem to use it in almost any context. In the telecommunication domain, the term 'service' is used in its original meaning: the services that a network/operator/service provider offers to its customers. The service function can be decomposed into several more specific functions. The function is directly associated with a set of behaviors of the system structure.

In the WCDMA system, the function of a system is derived from the service request from the users. Based on the QoS request from the user or applications, there are four service classes (1) conversational, (2) streaming, (3) interactive, (4) and background classes. The detailed introduction of the four services was discussed in Chapter 3 – especially Section 3.2.2.

Each service class comprises a set of sub-functions. For example, the conversational service function comprises the speech traffic transmission, video telephony transmission, Voice transmission over IP and video games. The interactive service function comprises the Web browsing function and net games function. Among the sub-functions, some functions are primary, others are secondary. Primary functions determine the name and the concept of the design product to achieve the service in normal situations, while secondary functions are supportive, realized or user interpreted to play the similar role as primary function. For example, the traditional real-time voice/speech function is primary function while the VoIP is the secondary functions instead.

This thesis study focused on the function of voice service in the WCDMA system. Voice function is divided into the sub-functions such as (1) Speech function- provided by the circuit switching system, (2) VoIP which is provided by the packet switching system, and (3) Videophone- provided by both circuit and packet switching system.

In order to support the target function, the WCDMA system has sub-functions which are associated with the behavior of the components in the WCDMA structure, and they are in particular:

- Transmission / reception radio signal - Node B,
- Control radio resources -RNC,
- Mobility management - RNC, MSC-server, VLR,
- User's data handling routing in Circuit Switch domain –MGw,
- Mobile subscribers information and portfolio management -HLR,
- Call control -MSC server,

- Data packet switch and delivery –SGSN,
- Gateway to Internet/enterprise network –GGSN, and
- Authority management to users/equipment -AUC/EIR.

For instance, in order to provide the speech function, the speech analogy signals have to be received by the Mobile phone. Mobile phone coded the analogy signal into digital signals, and sends the digital signals to the Node B after convolution, correlation and modulation function; the Node B receives the signals from Mobile equipment via radio frequency. After speech procession, transcoding (Transcode, 2008) and Rate Adaptation, signals are transmitted to the RNC, RNC collects a group of the Node B and transmits the data traffic from Node B to the MGw. MGw then selects the routing to forward the signals to the destination within the WCDMA network or external network such as the PSTN network or other PLMN network. The relations among the functions and the context are described in Figure 4.4. Furthermore, the effects are derived from the context where the system exists, especially to the service system.

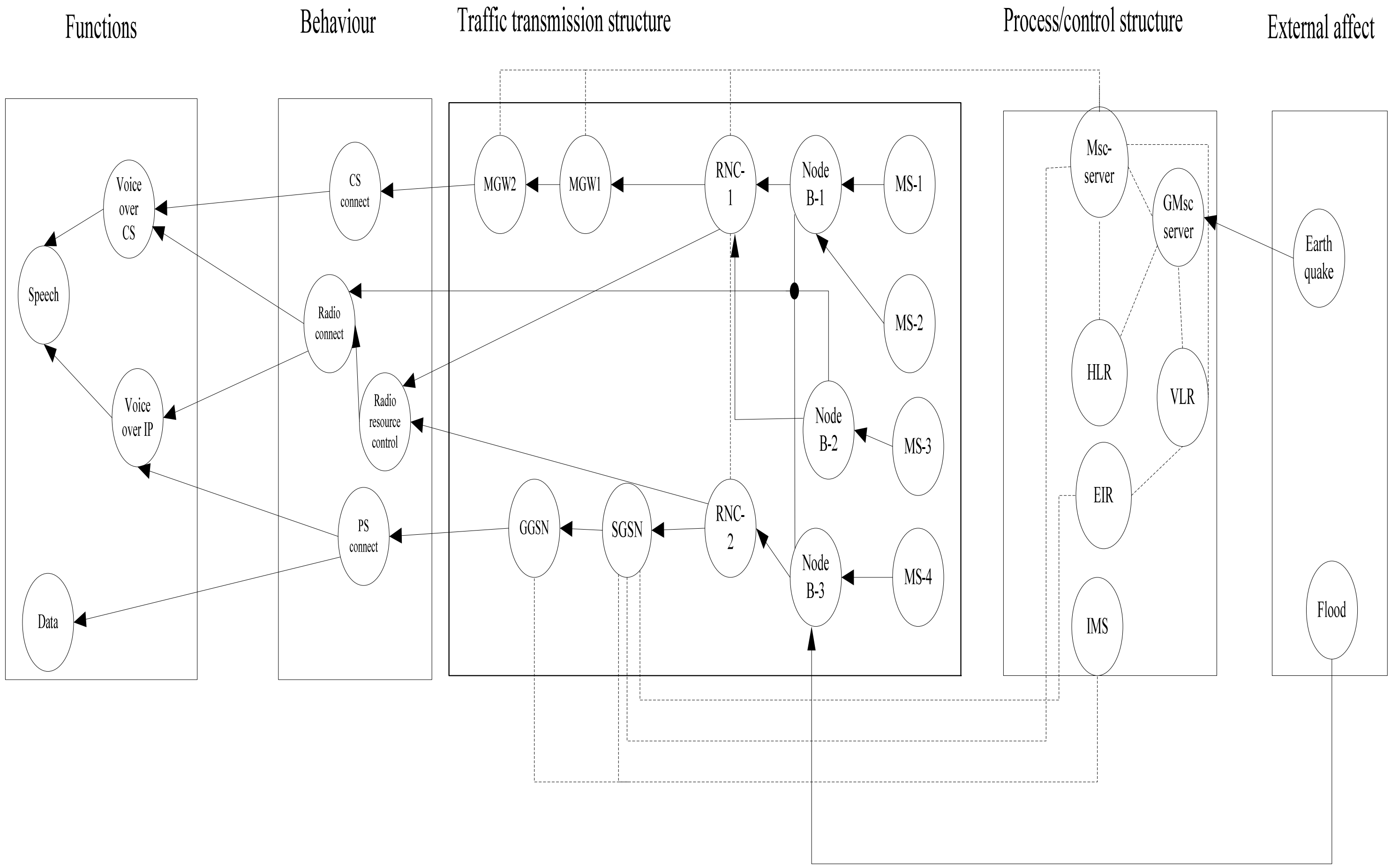


Figure 4.4 Function and context based WCDMA system.

4.3.3 The example WCDMA system - Structure

In the WCDMA system, the various subsystem or components are grouped according to the state variables and their interdependency. The structure is divided into two parts: the traffic transmission structure and the system process/control structure. The traffic transmission structure represents that the components receive and transport the traffic data to destination under the control of the components in operation/process structure. The system process/control structure represents that the components inside follow the rules or operation standards to control the behaviors of the components in the traffic transmission structure to provide the communication resources and to allocate traffic channels to the end-user.

The transmission links (physical medium) connect the different network components and integrate the entire network. To simplify the system structure, all the transmission links which spread within the system network are considered to be as a single link with sufficient capacity between any two connected components, i.e., the physical transmission link (radio wave, copper cable and optical fibers, etc) connecting each two network components in the traffic transmission structure and the operation/process structure is represented by a single cable.

The components in Figure 4.5 are related if they are joined by an arc. Each arc between two components is the transmission link to delivering the signals and data. The components in the operation/process are related to the controlled components in the traffic transmission structure with dotted lines.

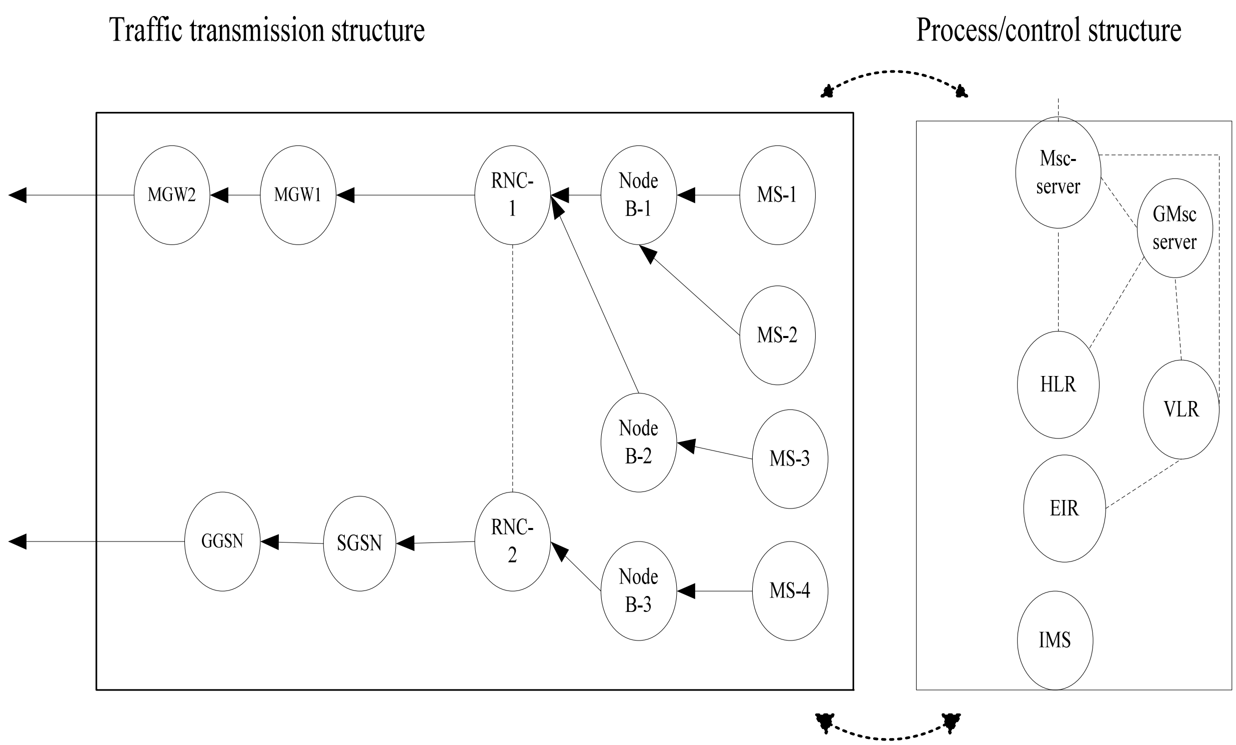


Figure 4.5 Structure of the example WCDMA system.

When the WCDMA system is in operation and transmitting the signals between the sender and receiver, the states of the components in the process/control structure are perceived when the components are monitoring the system performance by collecting the state information of the components in the traffic transmission structure. Before and after the call or session, the components will also detect the information from outside environment and active/deactivate the components in the traffic transmission structure to take the correct actions corresponding to the outside demand. The components in the traffic transmission structure will take action under the command of the components in the process/operation structures so as to achieve the correct behavior. For instance, the component, UTRAN, is responsible for functions that relate to access, radio mobility and resource utilisation. It consists of two components, RNC and Node B. Node B's radio coverage range can be increase or decrease; data throughput can be changed depending on the number of users, the height of the antenna and the transmitting power can be adjusted by the control parameter of Node B itself. Meanwhile, the RNC has three states. The RNC controlling the Node B is known as Controlling RNC (CRNC), which manages the radio resources provided by its controlled Node Bs. After the communication channel is connected between UE and CN, the RNC controlling the UE is known as Serving RNC (SRNC). While during soft handover, a UE could be communication with a Node B which is under control of the RNC which is not the SRNC. Such a RNC is called Drift RNC (DRNC). DRNC does not perform any user data processing. The user data is handled by SRNC while passed transparently through DRNC. Thus, the SRNC is responsible for the logical connection between the UE and the CN. The DRNC provides additional radio resources for a UE that is in a dedicated connection and a soft-handover state. Node B that is attached to the DRNC will provide the physical resource to the UE, and the information on the uplink and the downlink is routed towards the SRNC.

There are static structure and dynamic structure. In a static structure, the states and their relationships are fixed, and no active component or process is included. Dynamic structure means that components, states, and their relationship to one another can be changed in capacity, location, and hardware / software adjustment. For example, the capacity of the RNC or MGw can increase or decrease when system is upgraded or in fault. Some substructures or components are detached from the main body of the designed system.

4.3.4 The example WCDMA system - Principle

In the example WCDMA system, the components in the network communicate and interact with each other through the signaling. They are defined through standard interfaces and protocols for signaling between any two components. The standard of the interface and protocol for signaling and other telecommunication technology are defined and specified by telecommunications associations such as 3rd Generation Partnership Project (3GPP).

Signaling traffic is transported between the interfaces of two network components and conforms to the specific protocols between the two communication components. In the field of telecommunications, a communication protocol is the set of standard rules for data representation, signaling, authentication and error detection required to send information over a communications channel.

In short, a protocol is the rules governing the syntax, semantics, and synchronization of communication. Protocols are implemented by hardware, software, or a combination of the two. At the lowest level, a protocol defines the behavior of a hardware connection. The interface is different from different component pairs and the corresponding protocols guiding the data transmission along the interface link. Holma and Toskala (2002) elaborated the various interface within the network components in the WCDMA network in Figure 4.6. The Uu interface is used between the User terminal and UTRAN network. The IuCs interface is used when the network is based on circuit commutation; it connects the UTRAN network with the MSC. The Iur interface is used for the connection between two RNCs to provide the soft handover function. The interface IuPS connects the access network with the SGSN of the core network in packet communication, etc. In Figure 4.7, this study simplifies the interfaces and protocols of the complicate WCDMA system and map them into the FCBPSS based WCDMA system structure. The dotted line is used to indicate the principles which govern the network components. It is further noted that the principles of the WCDMA system are about the protocols and controls of the WCDMA system, and they were discussed in Chapter 3 – especially Section 3.2.5 and Section 3.3.3, respectively.

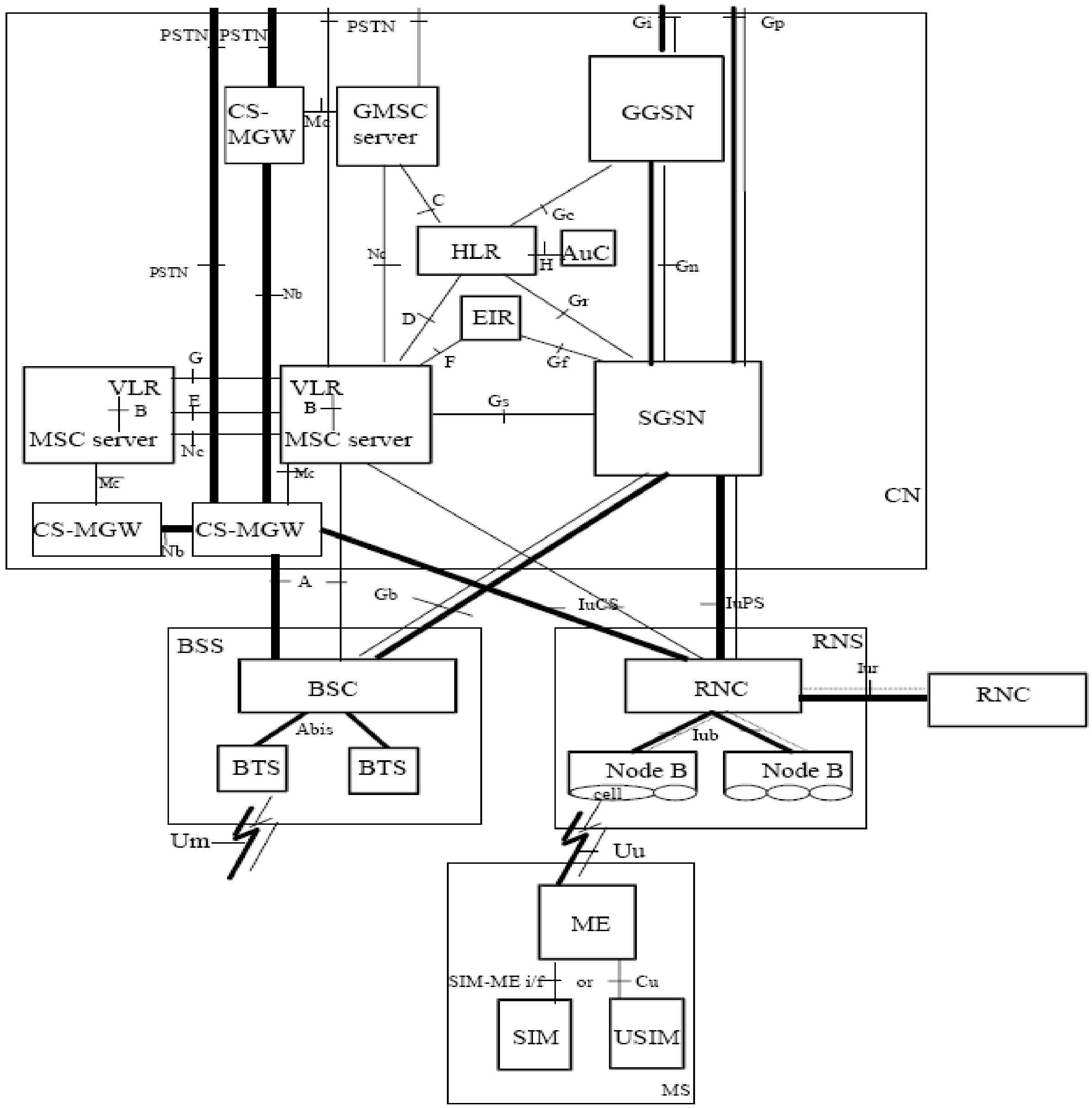


Figure 4.6 UMTS R4 logical architecture (3GPP TS 23.002 2003).

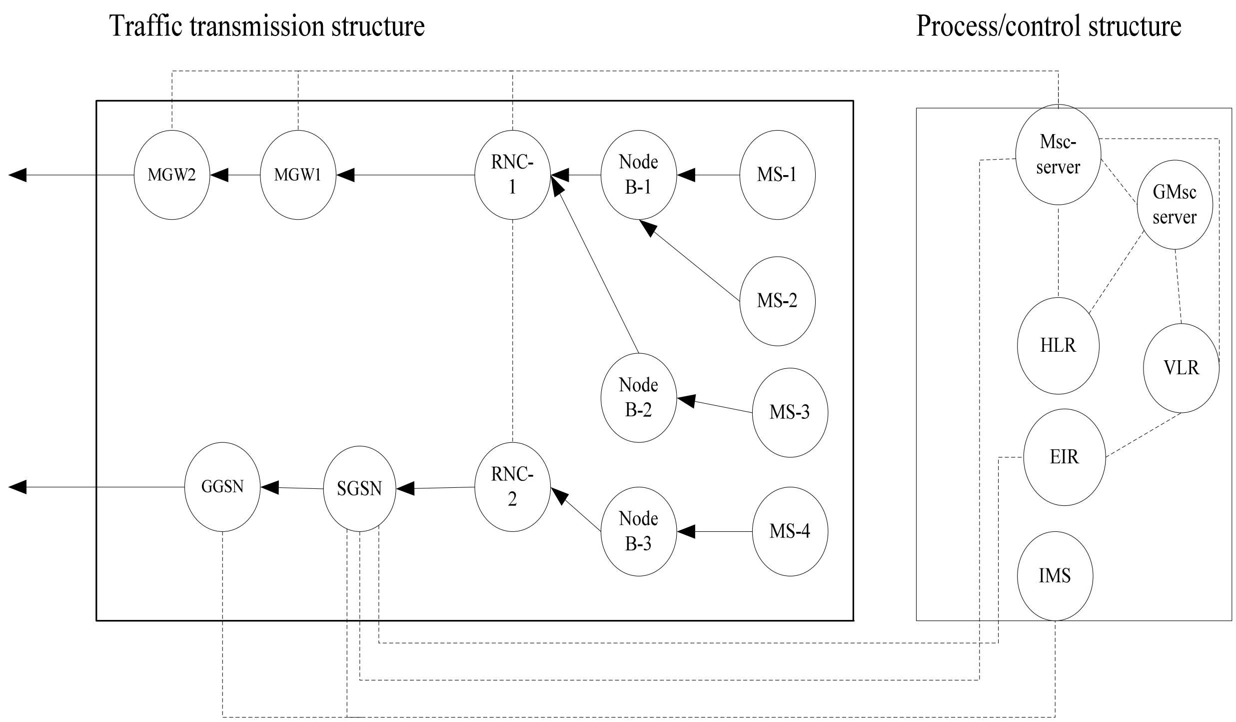


Figure 4.7 Principles of WCDMA system.

4.3.5 The example WCDMA system – Behavior and State

The behavior can be generalized into two classes. (1) Spatial behavior describes the behavior of ordered objects in 2D or 3D space. For example, in WCDMA system, Node B increases its transmission power through its antenna to cover large area under the control of the closed loop power control operation. (2) Temporal behavior obeys time constraints. Events can happen sequentially, overlap one another, be simulations, or be of specific duration. The effects of these events are states in different times or intervals (Qian and Gero 1996).

The behavior has two types of state variables. (1) The structural behavior variable is system or components actual behavior derived from the structure and software codes without any external effect. For example, the state of RNC may be receiving the report from Node B about the radio resource information or responding to the Node B with the commands. (2) The indirect behavior variable is shown when an external object is applied to a structure. For example, in the WCDMA system, the system throughput and data rate are indirect behavior states which will change depend on the external effect such as noise interferences to the signals, the different service requirements to the radio bandwidth, etc.

The components behavior in the WCDMA system can be inferred by the ways that the system operates. For example, in WCDMA system, power control is an essential feature of any CDMA-based cellular system. Without utilizing an accurate power control mechanism, these systems cannot operate. The main reasons for implementing power control are the near–far problem, the interference-dependent capacity of WCDMA and the limited power source of the User Equipment (UE). Whatever the radio environment, power received should be at an acceptable level, e.g., at the BS for the uplink to support the requested QoS. The target of power control is to adjust the power to the desired level without any unnecessary increase in UE transmits power. This ensures that transmit power is just within the required level, neither higher nor less (Kaaranen 2005).

The detailed illustration about the relationship between structure and behaviors is shown by the example of power control of the example WCDMA system as shown in Figure 4.8. Figure 4.8 shows the example of the WCDMA system downlink power control procedure. Power control is employed in both uplink and downlink directions. Downlink power control is basically for minimizing interference with other cells and compensating for the interference from other cells, as well as achieving an acceptable Signal to Interference Ratio (SIR). Uplink power control is to mitigate the near–far problem by making the transmission power level received from all terminals as equal as possible at the home cell for the same QoS (3GPP TR 25. 931 2004).

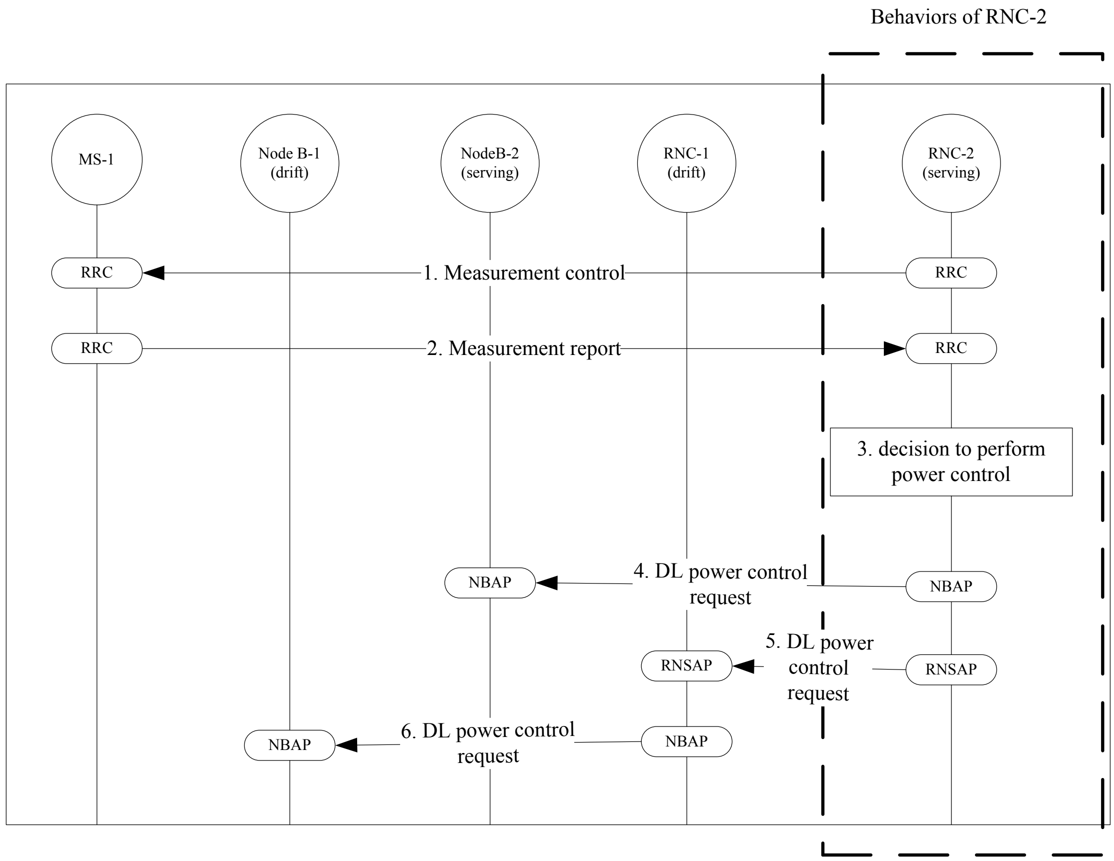


Figure 4.8 Downlink Power Control of WCDMA systems.

(1) RNC-2 sends to MS-1 a Radio Resource Control (RRC) Measurement Control message to setup a quality measure.

Parameters: Measurement ID number, Measurement type, Measurement command; this message is optional in the described flow.

(2) MS-1 after having performed the measure, send towards RNC-2 the report in Measurement Report.

(3) RNC-2 decides to request NodeB-1, 2 lower levels (L1) to change power in Down Link (DL).

(4) RNC-2 sends the NBAP message **DL Power Control Request** to the controlled Node B-2 Parameters: RL ID, RL Reference power, Max Adjustment Step, Adjustment Period, Adjustment Ratio.

(5) RNC-2 sends the RNSAP message DL Power Control Request to the RNC-1

Parameters: RL ID, RL Reference power, Max Adjustment Step, Adjustment Period, Adjustment Ratio.

(6) RNC-1 sends the NBAP message DL Power Control Request to the controlled Node B-1
Parameters: RL ID, RL Reference power, Max Adjustment Step, Adjustment Period, Adjustment Ratio.

Figure 4.9 shows the behaviors of the WCDMA system components in downlink power control procedure. Each component has its own set of behavior. For example, the RNC-2 has its temporal behavior in the dotted line rectangle frame. The behavior of the all components involved in the power control event is described in the different time intervals as shown in Figure 4.8.

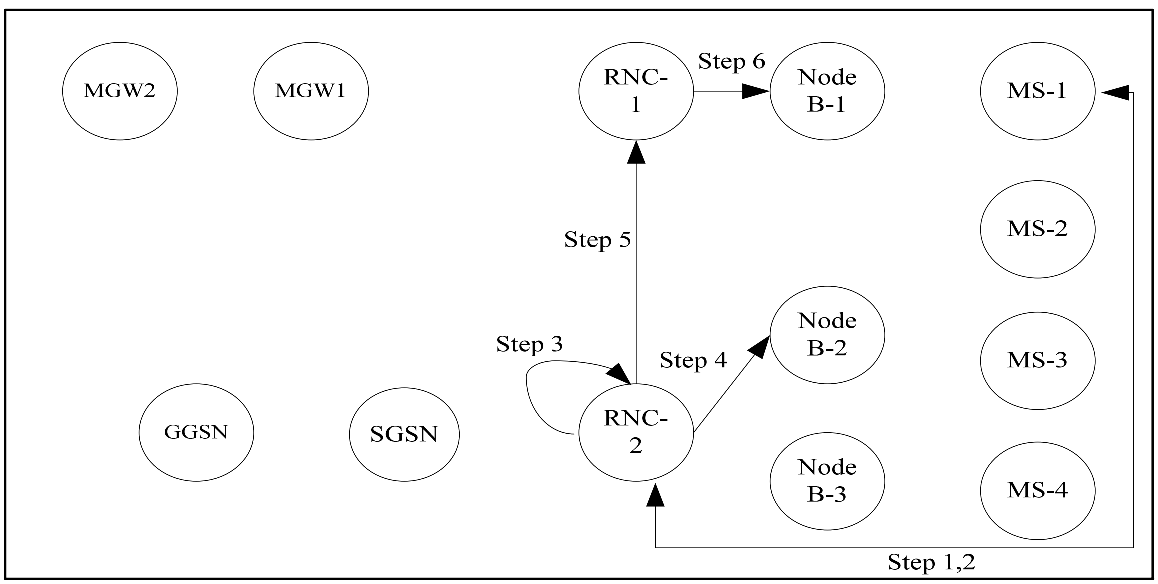


Figure 4.9 Behaviors of the example WCDMA system.

4.3.6 The example WCDMA system - Context

The context impacts behaviors of the system through two factors: internal and external effects. In the thesis study, the context mainly refers to the external effects due to the emergency situation. The external effect can be a human action or any environmental effect applied to the design such as man-made failure or natural disaster. Many engineering designs, such as mechanical design and electronic equipment design, require external operations to change the structure status to reach a goal.

Although the external effect does not belong to the design, it affects the design structure, lead to the changed behavior as well as function outage. An exogenous variable applied to a structure variable may cause a change in the structure if the structure variable is dynamic. For instance, in the WCDMA system, the emergencies or the natural disaster such as earthquake or flood may affect the system structure. The structure components like Node B, RNC, SGSN maybe damaged and outage of the functions.

4.4 Conclusion with discussion

This chapter presented the domain model of the WCDMA system which has captured the most important semantics of the system. The use of the tool called FCBPSS framework described in Chapter 2 is extremely helpful; the FCBPSS framework is a semantic or natural tool to model the domain of a system. In comparison with the method of Umeda and Tomiyama (1995), the FCBPSS framework provides the most complete definition of all the fundamental concepts. In contrast, in the method of Umeda and Tomiyama (1995), the structure and state appear to be interchangeable in use, which is not true from the viewpoint of the FCBPSS framework. Further, they have never explicitly included the principle and context in their FBS model. It will be shown in later chapters that are absent of an explicit representation of the principle concept will be unable to do the operational management of the system.

Chapter 5

Reconfigurable WCDMA system

5.1 Introduction

In Chapter 4, a domain model of the example WCDMA system was presented. This model is expected to address what the WCDMA system is; in particular, the model has provided a backbone of the WCDMA system. This chapter will present a reconfigurable WCDMA system which is based on the backbone (i.e. the domain model of the WCDMA). The remainder of this chapter will present a new approach to achieve this goal. In particular, Section 5.2 discusses the basis of this new approach. Section 5.3 illustrates this new approach to the WCDMA system to make the approach more visible and presents a concrete reconfiguration WCDMA system along with a procedure to perform reconfiguration in emergency situations. Section 5.4 presents a knowledge base which supports this new reconfiguration approach. Section 5.5 provides a conclusion.

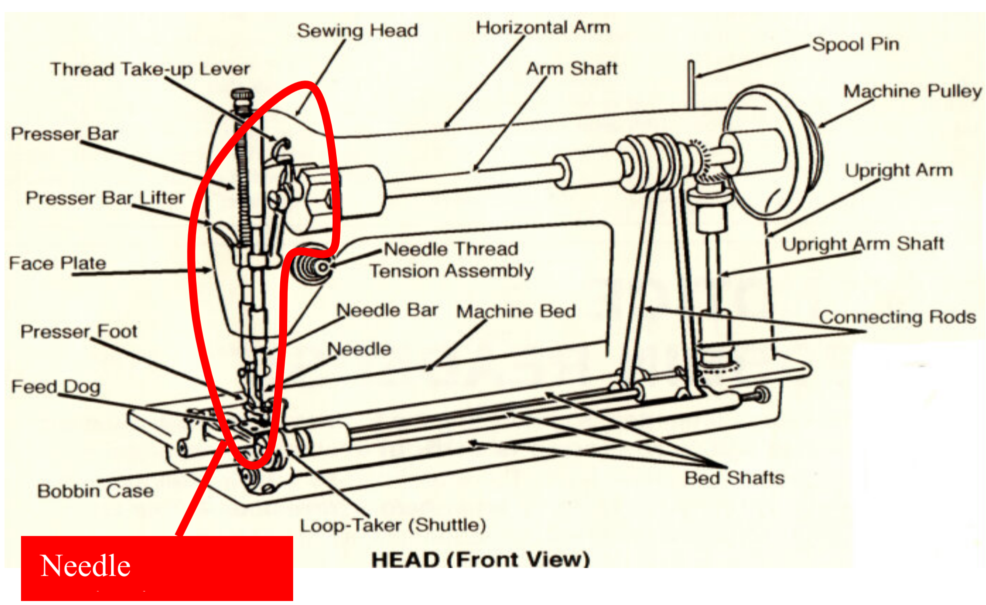
5.2 A new system reconfiguration approach

Reconfiguration of a system means to change the connectivity of the system as well as its components for the purpose of changing the behaviors of the system. In this thesis, a new approach to reconfigure the system is proposed which is based on the concept of general and specific function in engineering design proposed by Pahl and Beitz (1996).

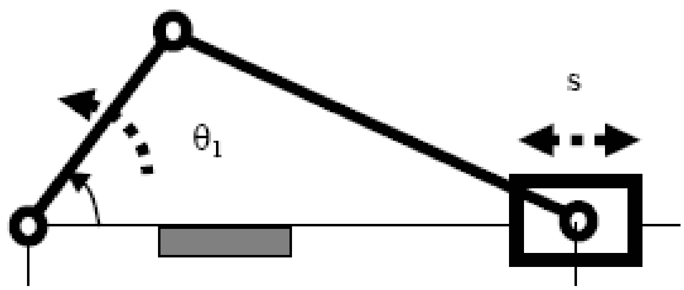
5.2.1 The general and specific function concept

Pahl and Beitz (1996) introduced a concept in engineering design called "general function and specific function". A *general function* is defined as an abstract function of the system which plays its role independent of any particular environment. A *specific function* is defined as a concrete function with task-specific or service-specific environment where the system entities are to play their role. From these definitions, the general function can be concluded as the function without any context; while the specific function is the function with context. The following is presented an example to illustrate this concept further.

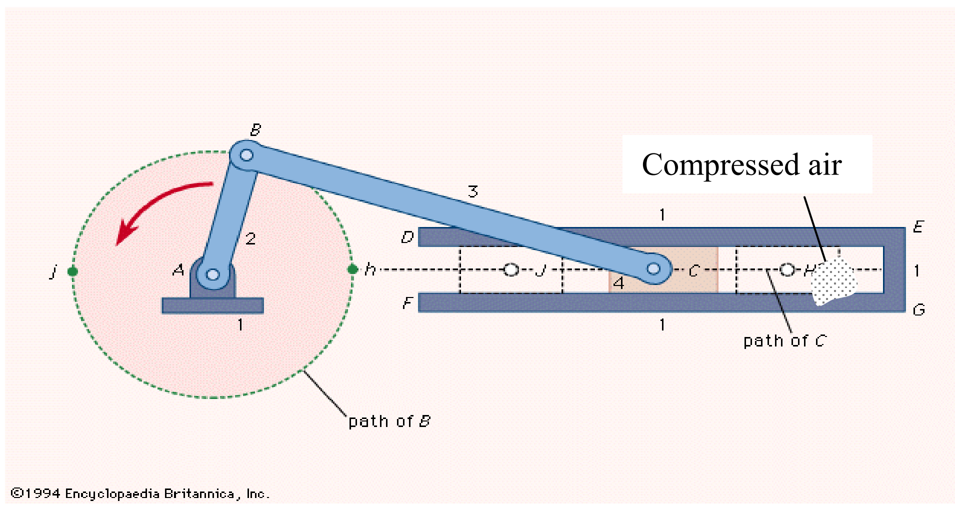
In Figure 5.1a, the needle mechanism is within the context of the sewing machine to play the role of carrying the upper thread into and through the cloth. Figure 5.1b is a schematic diagram of the needle mechanism which removes the context of the sewing machine. The system shown with this schematic diagram may be called crank-slider mechanism, and it demonstrates a kind of general function. Further in Figure 5.1c, the crank-slider mechanism is put in the context of the compressor machine, where the gas in the chamber is pressured by the piston which is in fact the slider of the system shown in Figure 5.1b. Thus the structure shown in Figure 5.1b has two specific functions: one is the needle mechanism in the context of the sewing machine (see Figure 5.1a) and the other is the pressing mechanism in the context of the compressor machine (see Figure 5.1c).



(a) Sewing machine (Needle machine n.d.).



(b) General function of sewing machine (Zhang et al. 2005).



(c) Compressor machine (Slider-crank mechanism 1994).

Figure 5.1 General and specific function concept

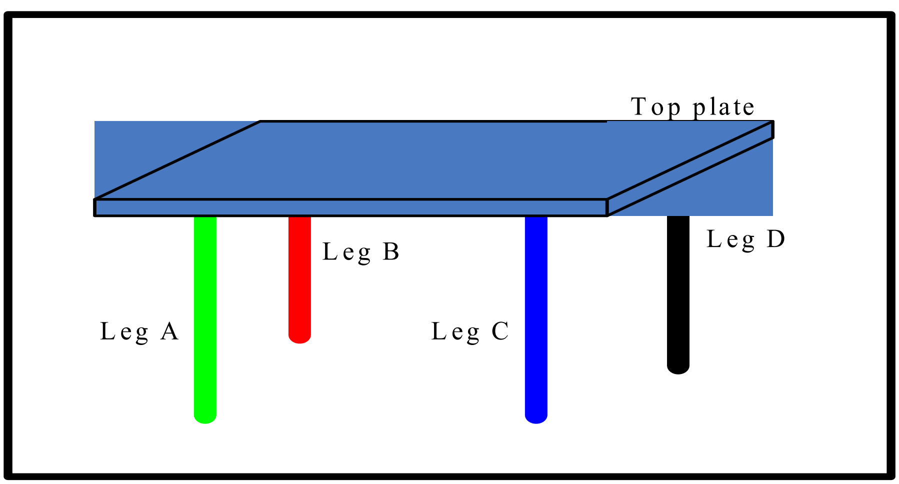
Hereafter, the general and specific function concept are called G-S concept for short. Further, the general function concept may correspond to the behavior concept in the FBS framework; while the specific function concept to the function concept in the FBS framework. This understanding of the general function and specific function concept seems to extend the understanding described by Pahl and Beitz (1996).

5.2.2 System reconfiguration based on the G-S concept

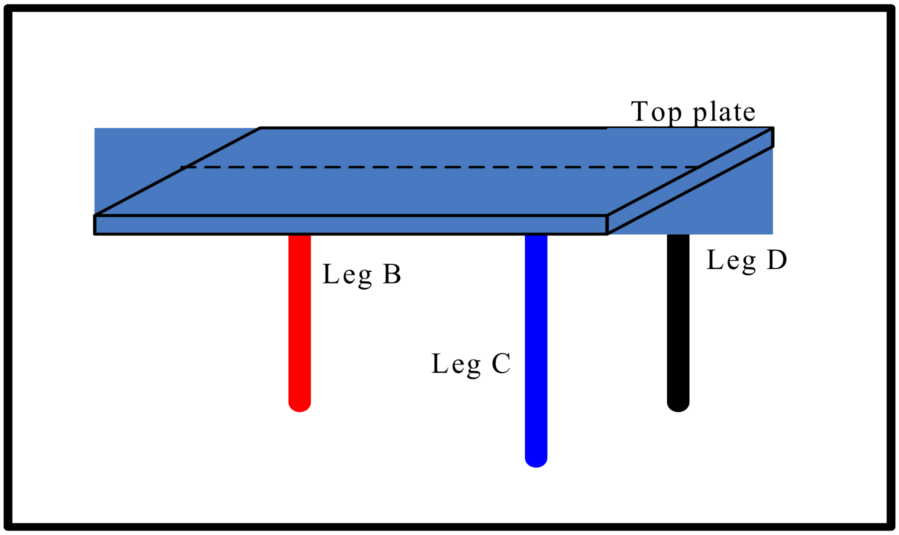
System reconfiguration in this thesis is for enhancing the survivability of a service system. As such, there is always an assumption that a couple of components of a system are damaged and their functions are lost. The goal of system reconfiguration is then to find out ways upon the existing system (including those damaged components) to remedy the lost functions and maintain a satisfactory level of QoS for all the services or functions of the survivable service provider system.

There are three ways to achieve this goal and they are: (1) Reconfiguring the remaining system (excluding the damaged one), (2) Exploring the damaged components, and (3) Exploring the capacity of the existing system under the assumption that the existing system usually does not run to its full capacity.

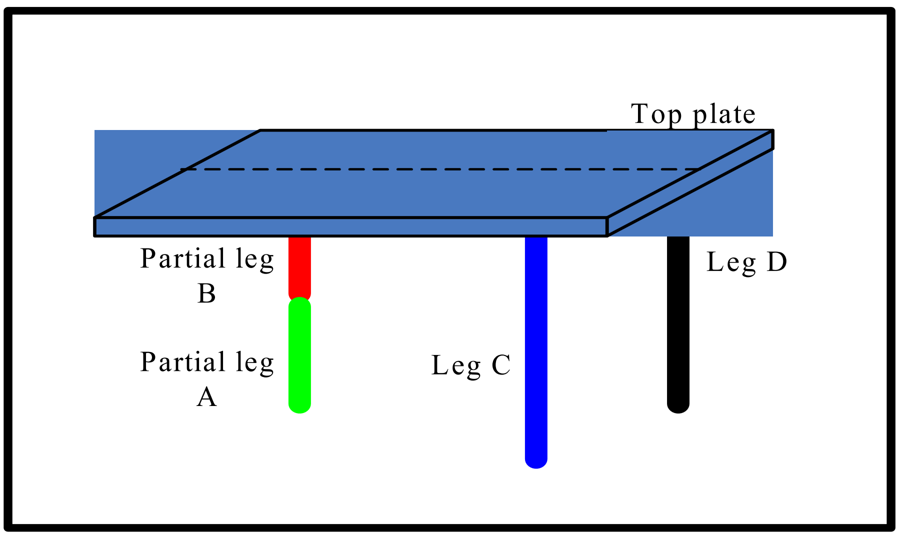
The first way can be demonstrated using the example of the table (see Figure 5.2). In Figure 5.2a, there is a table which has four legs and a top plate. In Figure 5.2b, one leg (e.g. Leg A) of the table is broken; yet by adjusting one existing leg to the somewhat middle part of the top plate, the table can still function which is also affected by the load on the top plate and its location(see Figure 5.2b).



(a) Original table



(b) A reconfigured table (method 1)

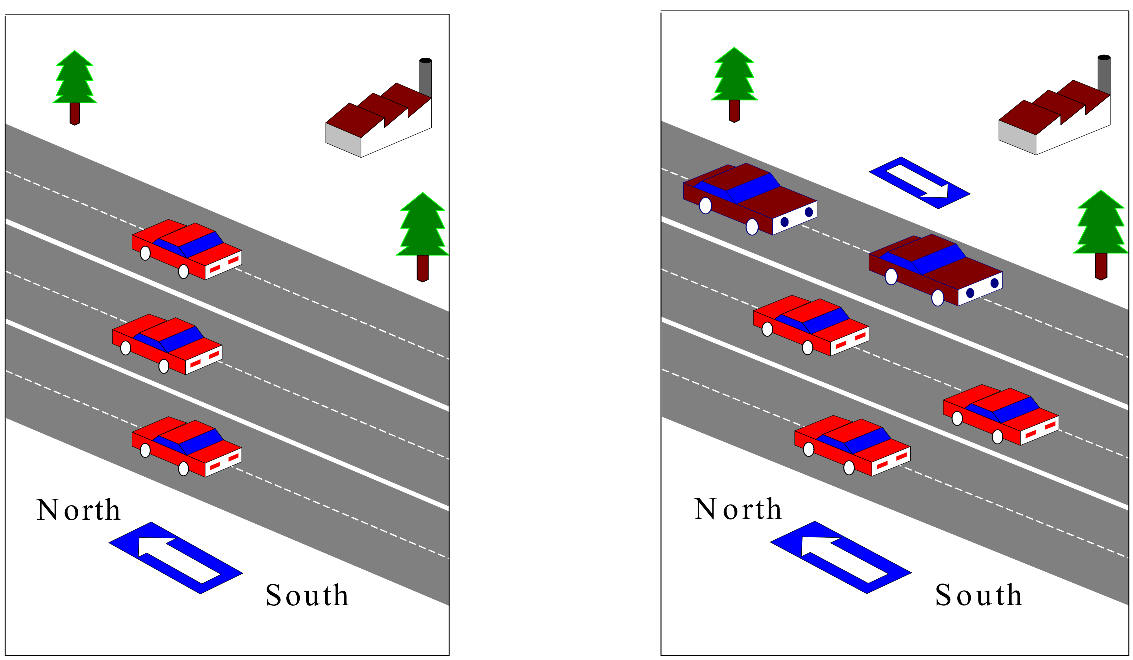


(c) A reconfigured table (method 2)

Figure 5.2 New methods for system reconfiguration

The second way can also be demonstrated by the table example. Suppose two legs (e.g. Leg A and B) are broken. In this case, the table can barely function. However, in Figure 5.2c, the two broken legs are assembled together to become a functional leg and which is further assembled somewhere in the middle of the top plane (see Figure 5.2c), so the table can still function.

The third way can be demonstrated by a particular transportation system. In some rush hour, the routes are adjusted to accommodate an increase of traffic in a particular direction. Figure 5.3a shows a normal operation situation where the transportation capacity in the direction from the south to north has not been fully utilized. Figure 5.3b shows that the route direction is changed to give some capacity of transportation from the north to south.



(a) Normal traffic (b) Emergency traffic

Figure 5.3 A new system reconfiguration method

The above three ways of system reconfiguration can be explained with the G-S concept. In the case of the first method, the two configurations of the table: the four leg table (see Figure 5.2a) and the three leg table (see Figure 5.2b) are considered two specific functions of the table. In the case of the second method, for one damaged leg, its reuse is based on its general function, i.e., the leg services as a column, subject to a certain workload, and the assembly of two damaged legs into one is based on the fact that a new specific function of the leg (i.e.; the new leg assembled with two damaged legs) is established. In the case of the third method, the general function of a physical route system is to transport substances from one direction to another. The specific function of the route is established when a set of traffic rules is imposed on it – leading to the "south to north" route or the "north to south" route.

For the simplicity of discussion but without loss of generality, in this thesis hereafter, only two specific functions of a component (subsystem, or system) along with its general function are considered; in particular, one specific function is called 'primary function', while the other is called 'secondary function'. This thesis study does not explicitly present the general function in the context for the WCDMA system.

5.3 WCDMA reconfigurable (G-S) model

In this section, a reconfigurable WCDMA system is described by applying the G-S model as described before.

5.3.1 The WCDMA domain model: revisited

The example WCDMA system in the Section 3.3.1 is revisited and shown in Figure 5.4. The overall architecture of UMTS includes three basic blocks: User Equipment (UE), UMTS Terrestrial Radio Access Network (UTRAN), and Core Network (CN). These elements are connected among themselves and to external networks. In the following, these blocks are explained in details.

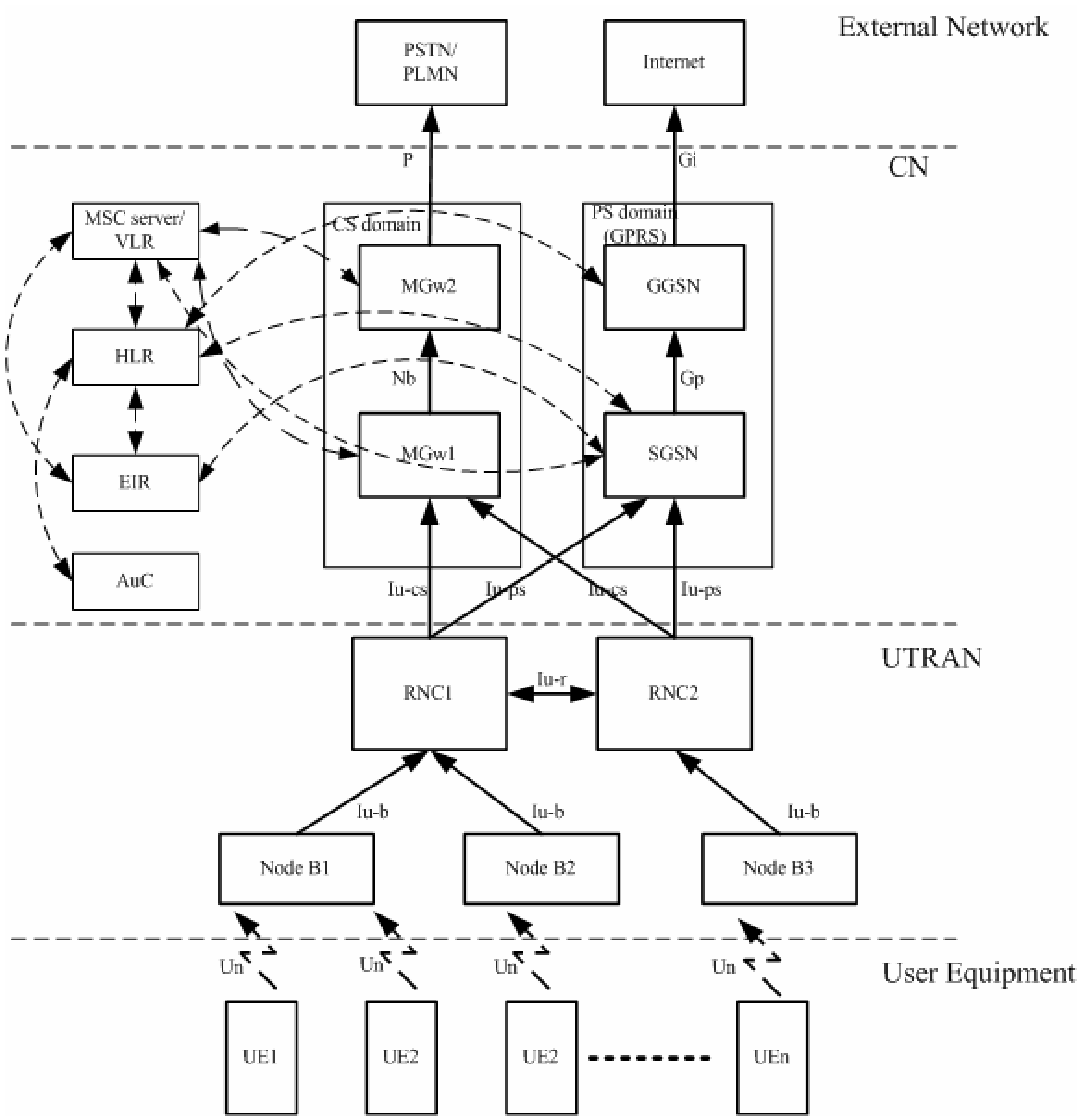


Figure 5.4 Structure of the example WCDMA system.

(1) *User Equipment* (**UE 1…n**). The **UE** provides means for the user to access the WCDMA system. It consists of the Mobile Equipment (ME) and UMTS Subscriber Identity Module (USIM). ME supports the radio access to the system; USIM supports the user security and user service.

(2) *UMTS Terrestrial Radio Access Network* (**UTRAN)**. The **UTRAN** performs functions to support communication with the Mobile Terminal (MT) and with the Core Network (CN). It provides means for exchanging information between MT and CN, acting as a bridge, router, or gateway. It consists of a set of Radio Network Subsystems (RNS), each of which contains a Radio Network Controller (RNC) and one or more entities known as Node B. **Node B** is an entity supporting radio frequency transmission, reception, system access, and information broadcast. The **RNC** supports radio access control, connection control, geographic positioning, and access link relay management.

(3) Core Network (**CN**). The **CN** performs functions to support communication with the UTRAN and with other CNs. It provides means to support user mobility and user service. It comprises the elements for circuit-switched services and the elements for packet-switched services. The basic elements of a CN are the Mobile Switching Center/Visitor Location Register (MSC/VLR), Home Location Register (HLR), Gateway MSC (GMSC), Serving GPRS Support Node (SGSN), and Gateway GPRS Support Node (GGSN). In the following, these elements are explained further.

- The **MSC** performs the switching functions and coordinates the calls and routing procedures within the network. The **VLR** is a database containing a copy of the service profile of the visiting subscriber as well as information on the location of the subscriber within the system. In 3GPP R4, the CS domain structure was given an alternative implementation method; in particular the CS domain architecture defines MSC division, where the call control functionality and the VLR are brought into an entity called the ‘‘**MSC server**’’. Respectively, the maintenance of the CS connection and establishment of all physical connection sets up are brought into an entity called the ‘‘**Media Gateway**’’ (MGw). The operation of MSC server and MGw opens up a few new interfaces within the CS domain such as Mc, Nc, Nb, E, G, which define the information control and transmission mechanism among the MSC server and CS-Media Gateway. The detailed information about them is referred to (Kaaranen 2005, Yacoub 2002)

- The **HLR** is a database residing within the home system and contains a list of home subscribers with their respective service profiles.

- The **Gateway MSC Server (GMSC server)** replaces the Gateway MSC (GMSC) in the 3GPP Release 99. A GMSC is responsible for routing a call from circuit witch network to its final destination in external networks. The **GMSC server** mainly comprises the call control and mobility control parts of a GMSC, and it may be used to interface with external circuit-switched networks. In many cases, an **MSC server** can support the function of a **GMSC server** (Smith and Collins 2002**).** Thus, in this thesis study, the function of GMSC server is embedded in the MSC server.

- The **SGSN** acts as a logical interface to the UTRAN responsible for the delivery of packets to the correct Node B.

- The **GGSN** acts as a logical interface to the external Packet Data Network (PDN), which includes the IP PDN or X.25/X.75 packet-switched PDN. For an external IP network, GGSN is seen as an ordinary IP router.

The typical and simplest infrastructure of the example WCDMA system (see Figure 5.4) includes one MSC server, two MGws, associated HLR, VLR, Auc, EIR, two RNCs, and three Node Bs homed to RNC. A Node B serves hundreds of mobile users in a given area (Cell) by allocating radio resources for making new calls or for users to continue their calls. A RNC provides switching support for several neighboring base stations (Node B) and thus can serves thousands of users. The link between Node B and RNC and also between RNC and Media Gateway (MGw) are typically wireline, although the use of radio or microwave links to connect these components has been increasing. The MGw is a larger switch and can serve tens of thousand of users. HLR, VLR, MSC-server keep track of users who permanently register or temporarily visit the service area.

In a wireless system, a Node B that communicates directly with MEs is a critical facility. If more Node Bs are deployed, the coverage as well as the system's capacity can be enhanced, but there is a greater possibility of failure of Node B. Thus, partial users may be out of service and the overall QoS would degrade. A failure of MGw, HLR/VLR, MSC server or GMSC-server and a link between them or external network (e.g. PSTN, PLMN) can affect a large number of customers.

There are varying degrees of protections and redundancy to these types of system components. The MSC, MSC Server and GMSC-server in charge of the signaling control have highly fault tolerant and redundancy. A failure of one MSC, MSC server, or GMSC-server, another one in a different geological location can take over its function (Ohrtman 2003, Yacoub 2002). The database HLR/VLR is implemented as a centralized, distributed, or even redundant database (Varshney et al. 2001). Therefore, all the components for signaling and data storage have higher survivability. However, the network components such as UE, Node B, RNC, MGw, SGSN, and GGSN which provide traffic transportation are much more vulnerable, as mentioned before. The qualitative assessment of failure of the WCDMA wireless components, their impact, hazard, and recovery strategies are listed in Table 5.1 (Varshney et al. 2001).

Table 5.1 Impacts, failures and recovery strategies of the WCDMA components.

Component failing	Potential Impact	Failure frequency	Typical Hazard	Typical recovery strategy
MSC-server, GMSC-server, HLR/VLR, EIR	Very High	Low	Operation error, Software update, Random hardware failure	Function redundancy, reboot, hardware replacement
MGw, SGSN,GGSN	High	Moderate	Software update, Random hardware failure	Reboot, hardware replacement, revert to old software
RNC	Moderate	Moderate	Software update, Random hardware failure	Reboot, hardware replacement, revert to old software
Node B	Low	High	Random hardware failure, Outdoor antenna damage	Hardware replacement, repair

5.3.2 Reconfiguration of the WCDMA system based on the (G-S) model

In the WCDMA system, the functions of the system can be categorized into four service classes: conversational, streaming, interactive, and background. Each service class comprises a set of sub-functions. For example, the conversational service function comprises the speech traffic transmission, video telephony transmission, and voice transmission over IP, and video games. The interactive service function comprises the web browsing and net games. The four services are generalized and categorized into two overall functions: (1) function for voice transmission, and (2) function for data transmission. The overall function can be decomposed into more specific functions including the primary function and secondary function.

A component or subsystem may have a primary function as well as a secondary function. For example, the TCP/IP Internet network system has the primary function for non-real time data routing, download for web browsing, network games, and E-mail. Its secondary function is to transmit the voice and speech data. The primary function as voice and speech transmission is normally provided by the conventional telecommunication network (e.g., the circuit switch network). In the case of emergency situations, the conventional telecommunication networks are damaged, the Internet can take over the voice and speech transmission service through its secondary function. This thesis study focused on the voice service, so in the following, it is discussed on how to keep the voice service for a high continuity based on the G-S model.

The voice function is further divided into the sub-functions: (1) Speech function which is provided by the circuit switching system, (2) Voice over IP (VoIP) which is provided by the packet switching system, and (3) Videophone which is provided by both the circuit and packet switching systems. Further, since the videophone is at a higher service level, and it only works in the normal condition of the network and need more radio resources and bandwidths, it is thus out of the scope of this study. This study focuses on the speech function provided by circuit switch and the VoIP function by packet switch.

The WCDMA system function, behavior, structural components are shown in Figure 5.5, and they are explained as follows.

- UTRAN for connectivity between the UE (user equipment) and the core network. It includes the RNC component for the radio resource control and component Node B for the transmission and reception radio signals.
- MSC-server for the call control, mobility management
- MGw for the User's data handling
- GPRS subsystem for transmitting IP packets. It consists of SGSN for data packet delivery and GGSN for gateway to Internet/enterprise.
- UE for the user to access the WCDMA wireless system.

In the following, it is assumed that all users are legal and have the authority. In other words, these components are not included, such as: (1) AUC/EIR for Authority to users/equipment, and (2) HLR for Mobile subscribers' management.

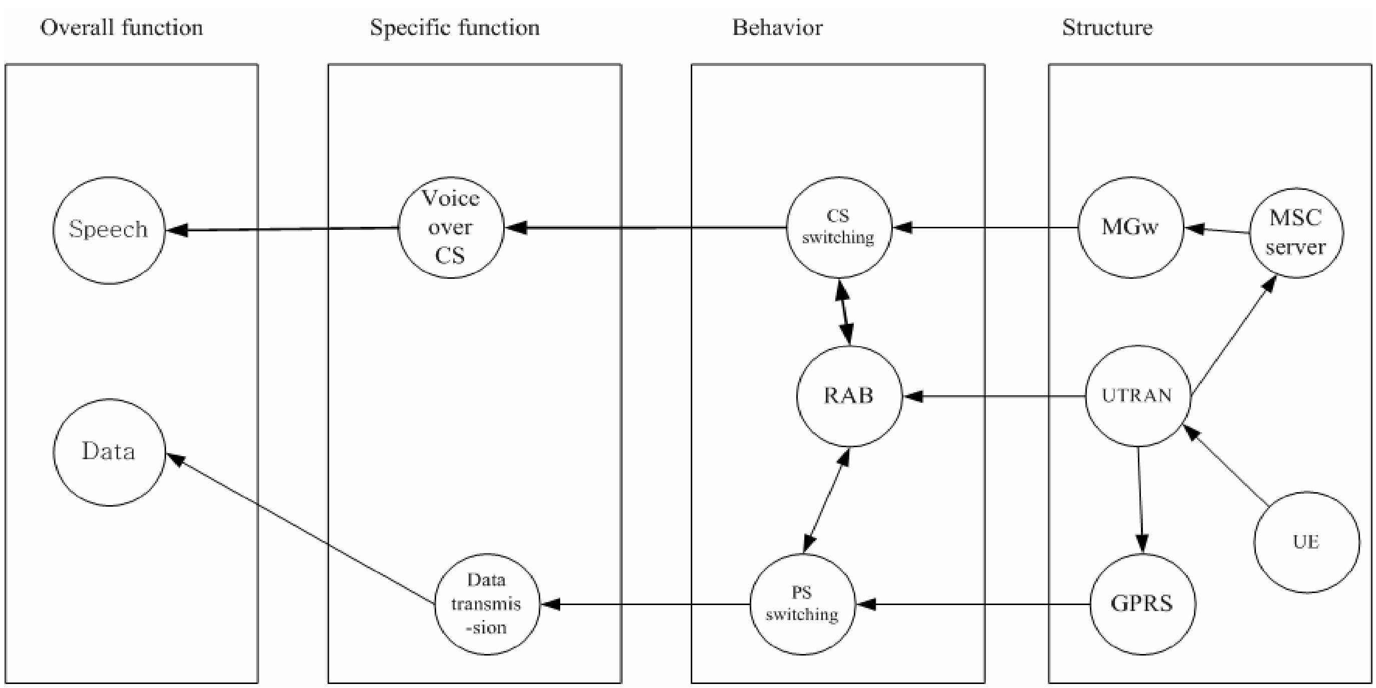


Figure 5.5 A typical overall function of WCDMA system.

Figure 5.5 lists two overall functions in the WCDMA system: one is the speech function for the voice service and the other is the data function for the data packet transportation. For the speech service function, the speech analog signal is received by the mobile phone, i.e. UE. UE codes the analog signal into digital signals which are sent to UTRAN after the convolution, correlation, and modulation function via radio frequency. After speech procession, transcoding (Transcode 2008) and Rate Adaptation, signals are transmitted to the MGw. MGw handles the circuit switch connection in CN by selecting the traffic route to forward the signals to the destination within the WCDMA network or external network such as the PSTN network or PLMN network. MGw is under the control of the MSC server which controls MGw to accomplish the transforming of the traffic bearer in circuit-switching network. The MSC Server and MGw have a one-to-many relationship (i.e., one MSC server could control multiple MGws).

For the data service function, the UE sends the subscriber's session information to the UTRAN by the Packet Data Protocol (PDP) context when the subscriber has an active session. A Radio Access Bear (RAB) is allocated by SGSN and GGSN for packet data transfer. When the packet session is open, the UE can transmit uplink or downlink data packets. The downlink data packet first arrives at the UTRAN over the radio links forming a radio bearer for this session. Packet traffic is then tunneled between the UTRAN and the SGSN by means of the GTP-U protocol. The tunnel ends at the GGSN, from where user data packets are further routed to an external packet data network, according to the method described in the connection-type parameter of the PDP context.

When the system is in failure, there are three levels of failure scenarios which are defined in this thesis study in accord with the telecommunication system: (1) Radio frequency access layer: failure of Nodes B, (2) Radio access control subsystem layer: failure of RNC, and (3) Transport layer: failure of MGw in CS domain, and failure of SGSN/GGSN in PS domain. A complete failure scenario is described in Chapter 3 where the example WCDMA system was presented. In the following, Media Gateway (MGw) in the circuit switching domain is supposed to be failed in order to demonstrate the application of the G-S model for system reconfiguration to enhance the survivability of the system. The following steps are applied:

The first step is to analyze the lost function by decomposition it into a tree until to the component level. The function tree will include the particular function whose components (MGw) is damaged. The second step is to find a secondary function of any component including the one (MGw) which is damaged. For the example, the third method of system reconfiguration is considered; in particular, the PS route is considered for providing unused capacity, in the form of its secondary function to make this reconfiguration idea work. The third step is to explore the principle which is implicitly represented by the new-reconfigured structure.

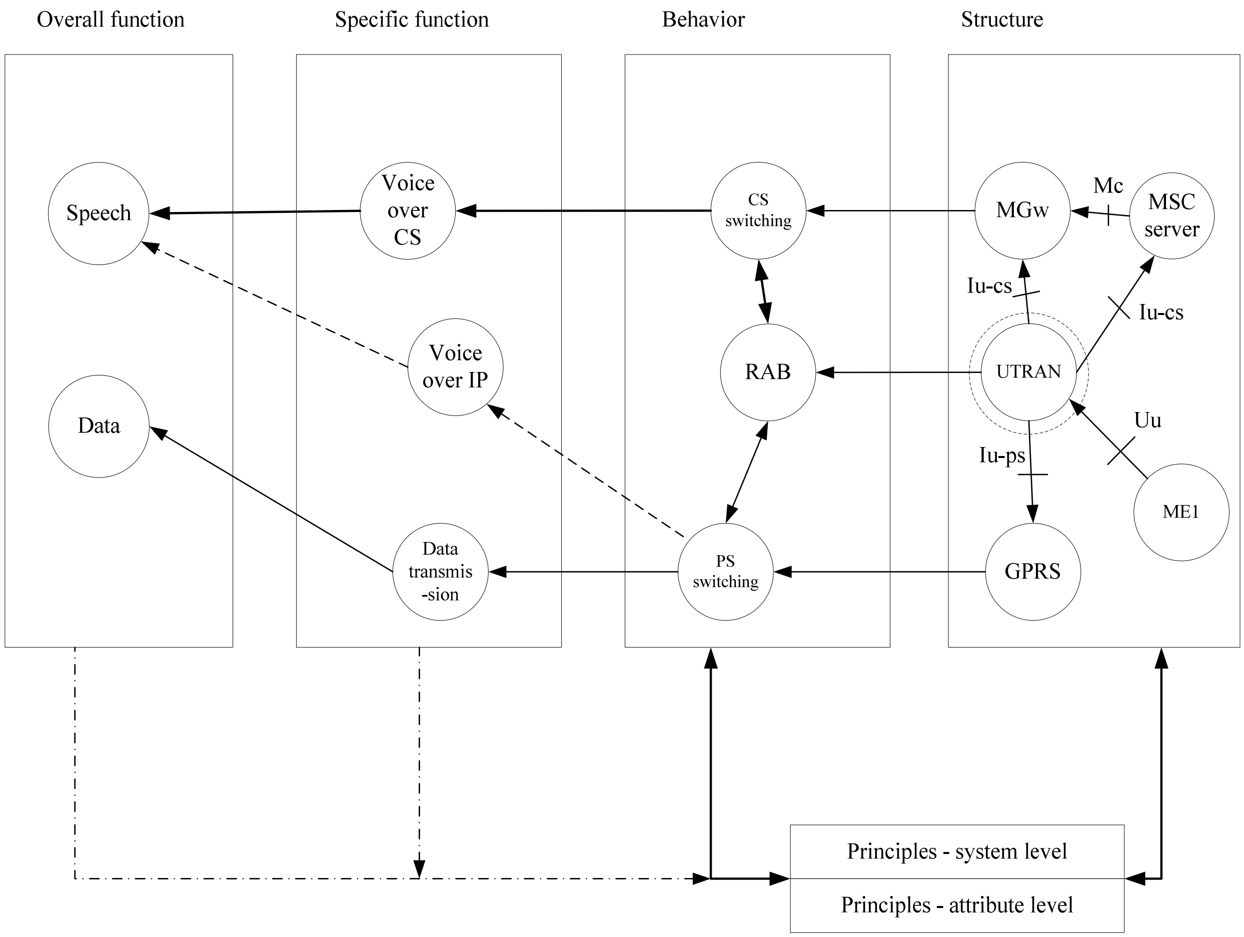


Figure 5.6 Generalized reconfigurable WCDMA

Figure 5.6 shows this reconfiguration solution. The overall function, ‘speech’, can be realized by primary function ‘Voice over CS’. The ‘speech’ function is mainly realized by the behaviors of

‘CS switching’ and ‘Radio Access Bear (RAB)’. Both behaviors are generated by the structural functional entities: MGw, MSC server, UTRAN and ME1. Now, the lost primary function ‘Voice over CS’ has be replaced by the secondary function through the component or subsystem such as: GPRS, UTRAN and ME1. Thus, the original overall function ‘Speech’ can be recovered.

5.4 A Knowledge Based System to support system reconfiguration

For the discussion above, it is clear that it is necessary to develop a knowledge base for supporting the G-S concept of reconfiguration. The knowledge base should contain function, structure, and principle of a particular system (WCDMA in this case). Therefore, this knowledge base consists of three parts: (1) function knowledge base, (2) structure knowledge base, and (3) principle knowledge base. They are described in separate sections in the following.

5.4.1 System Function knowledge base

The system function knowledge base collects and describes the functions of the existing system. The function may be called function prototype. The scheme of the function prototype is shown in Table 5.2 (Umeda et al. 1996).

Table 5.2 Definition of function prototype.

Item	**Contents**
Name	Verb+objects+modifies
Decomposition	Function tree

The item ‘Name’ is used to represent a designer’s intention in the form of ‘to verb objectives modifiers’. Objects represent entities and things related to the function such as ‘Voice’ and ‘Data’. Modifiers qualify a function and include such terms as ‘stability’ and ‘reliability’. When the general function and specific function are described, normally the Verb ‘transmit’ is omitted in the name ‘transmit data’, ‘transmit speech’ or ‘transmit voice’ as the fundamental function of telecommunication is to transmit something, and word ‘transmit’ is then connect to all the signals.

The item ‘Decomposition’ is used to describe the feasible candidate for the function in the form of networks of sub-functions. The function hierarchy is composed of all primary and secondary functions. The general function may also be included; yet in this research, it has not included the general function for simplicity. It is worth noticing that according to Palh and Beitz (1996), every specific function corresponds to a general function; in other words, given a specific function, it can always find its general function. This point implies that the absence of the general function in this thesis study hereafter is without loss of generality.

From the function scheme, the structure of the WCDMA system function knowledge base (Holma and Toskala 2002, Smith and Collins 2002, Yacoub 2002) is illustrated. Figure 5.7 shows the holistic architecture of the functions including the function decomposition and overall-specific function relations, G-S relationship (3GPP TR 25.931. 2004, 3GPP TS 23.002. 2003, ITU-T Rec. Q. 1711. 1999).

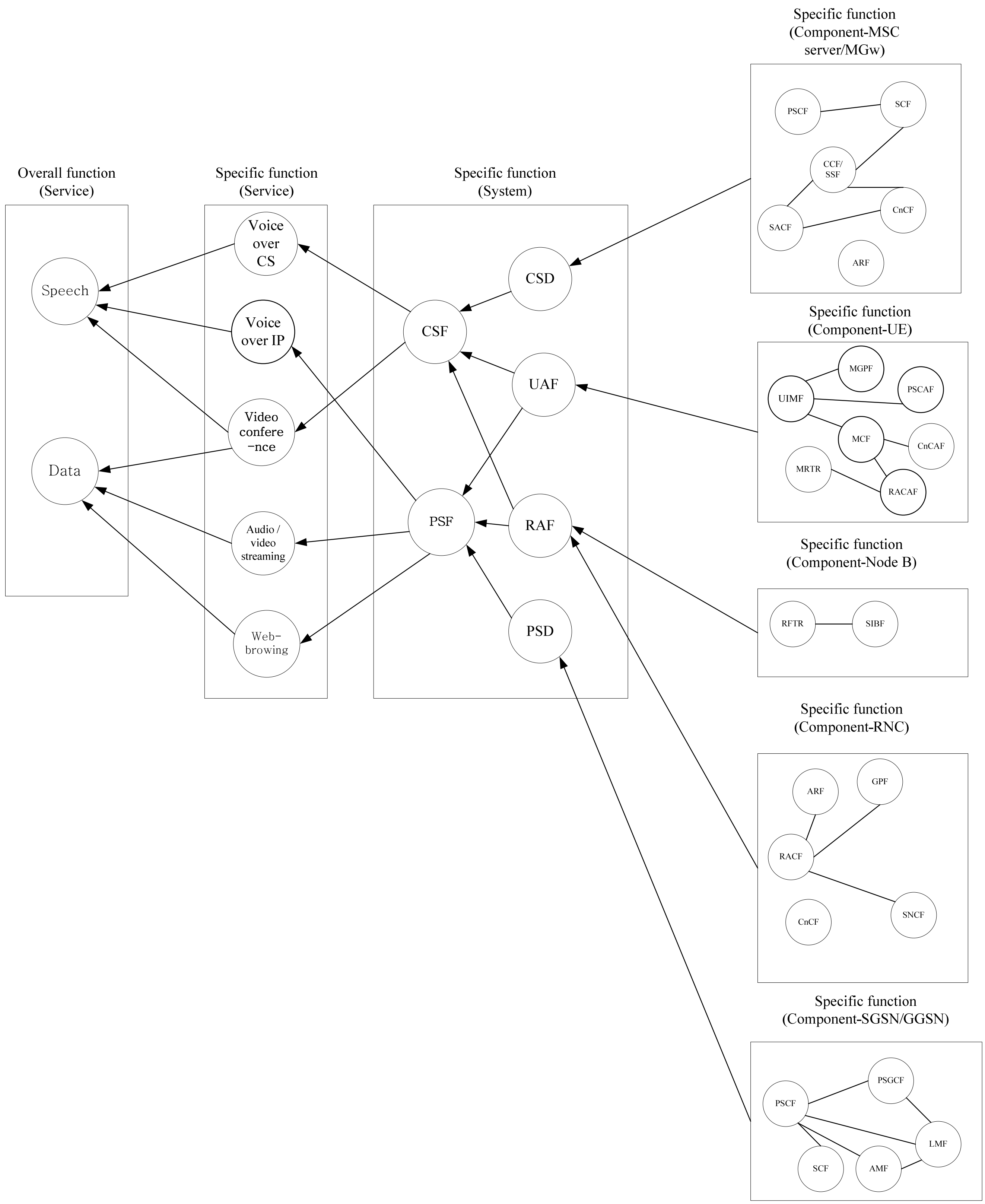


Figure 5.7 Holistic architecture of the function.

In Figure 5.7, there are two overall functions of the WCDMA system, the speech and data transmission. The ‘speech’ function can be realized mainly by three specific function services: the Voice over Circuit Switch, Vice over IP by Internet or Video conference service. The ‘data’ function is realized mainly by other three specific functions: Video conference for imagine, Audio/Video streaming, Web-browsing, etc. Such specific functions are also grouped into the four types of service class based on the QoS standards, (1) conversational, (2) streaming, (3) interactive, (4) and background (Holma and Toskala 2002, Kaaranen 2005).

In the following, a detailed description of the function decomposition for the example WCDMA system is given. Three steps to decompose the functions are devised.

Step 1: the specific functions (service) are decomposed into a set of sub-functions (system). In the WCDMA system, there are two functions: Circuit data Support Function (CSF) and Packet data Support Function (PSF). The CSF further consists of a set of functions to transfer the signal via dedicated circuit (or channel) between nodes and terminals with real time service. The PSF consists of a set of functions transferring data packet over a shared network.

Step 2: the CSF and PSF specific functions are further decomposed into the functions. The CSF function is realized by the three specific functions. The three functions are ‘User Access Function (UAF)’, ‘Radio Access Function (RAF)’ and ‘Circuit Switch Domain function (CSD)’ in Figure 5.7.

- The UAF provides means for the user to access the WCDMA wireless system through radio frequency.
- The RAF provides means for exchanging information between Mobile Terminal (MT) and Core Network (CN), acting as a bridge, router, and gateway, as required.
- The CSD means that the set of all the CN entities offering "CS type of connection" for user traffic as well as all entities supporting the related signaling. A "CS type of connection" is a connection for which dedicated network resources are allocated at the connection establishment and released at the connection release. The entities specific to the CS domain are: MSC, GMSC, VLR, etc.

- The PSD means the set of all the CN entities offering "PS type of connection" for user traffic as well as all the entities supporting the related signaling. A "PS type of connection" transports the user information using autonomous concatenation of bits called packets: each packet can be routed independently from the previous one. The entities specific to the PS domain are the GPRS specific entities, i.e. SGSN and GGSN.

Step 3: the above subsystem specification function can be decomposed into sub sub-system or component specific function entities. In Figure 5.7, the CSD function is decomposed into the specific function group which constitutes the system functional component-MSC -server/MGw (ITU-T Rec Q. 1711. 1999, Yacoub 2002).

- Service Control Function (SCF): it contains the overall Intelligence Network (IN) service control functionality in the IMT-2000. Service logic can be triggered by call processing, mobility management, or non-call associated events.
- Packet Service Control Function (PSCF): it provides the packet service control functionality in the IMT-2000 Core Network for updating, network control, updating and routing contexts.
- Connection Control Function (CnCF): it provides connection processing control.
- Enhanced Call Control Function (CCF): it is based on the Call Control Function defined in Recommendation Q.1224 (IN CS-2). It has been enhanced for mobile communications. It provides call/connection processing control.
- Service Switching Function (SSF): it is associated with the CCF. It provides the set of functions required for the interaction between the CCF and SCF.
- Service Access Control Function (SACF): it provides both call-related and call-unrelated processing and control (e.g. in relation to mobility management).
- Access link Relay Function (ARF): it handles the overall control for the transit of a branch of the BS approach link between two instances of the Radio Access Control Function (RACF). RACF exists in the RNC subsystem.

The UAF function is decomposed into the specific function group which constitutes the system functional component-User Equipment (UE) (ITU-T Rec Q. 1711. 1999, Yacoub 2002).

- Mobile Geographic Position Function (MGPF): it provides the overall control for the geographic position finding function on the mobile terminal side.
- User Identification Management Function (UIMF): it provides the means to identify both the IMT-2000 user and the mobile terminal to the network and/or to the service provider, and contains processing capability for authentication and service handling in the UIM.
- Packet Service Control Agent Function (PSCAF): it provides the packet service control agent functionality in the IMT-2000 mobile terminal.
- Connection Control Agent Function (CnCAF): it provides connection control functions for users.
- Mobile Control Function (MCF): it provides the overall service access control logic and processing at the mobile side of the radio interface. Specifically, it interacts with the network for mobility management.
- Radio Access Control Agent Function (RACAF): it handles the mobile side of the association and access link control between the mobile terminal and the network.
- Mobile Radio Transmission and Reception (MRTR): it controls the interconnection and adaptation of the access radio link to the rest of the mobile terminal.

The RAF function is decomposed into two specific function groups. One group constitutes the system functional component - Node B; the other group constitutes the system functional components- RNC (ITU-T Rec Q.1711.1999, Yacoub 2002).

(1) The first group further consists of the following functions:
  - System access Information Broadcast Function (SIBF): it handles the overall control of system access information broadcasting. The information to be broadcast may be made available to the function via an operation and maintenance function.
  - Radio Frequency Transmission and Reception (RFTR): it controls the interconnection and adaptation of the access radio link corresponding to the BS approach link. This includes radio channel error protection coding and decoding.

(2) The second group further consists of the following functions:

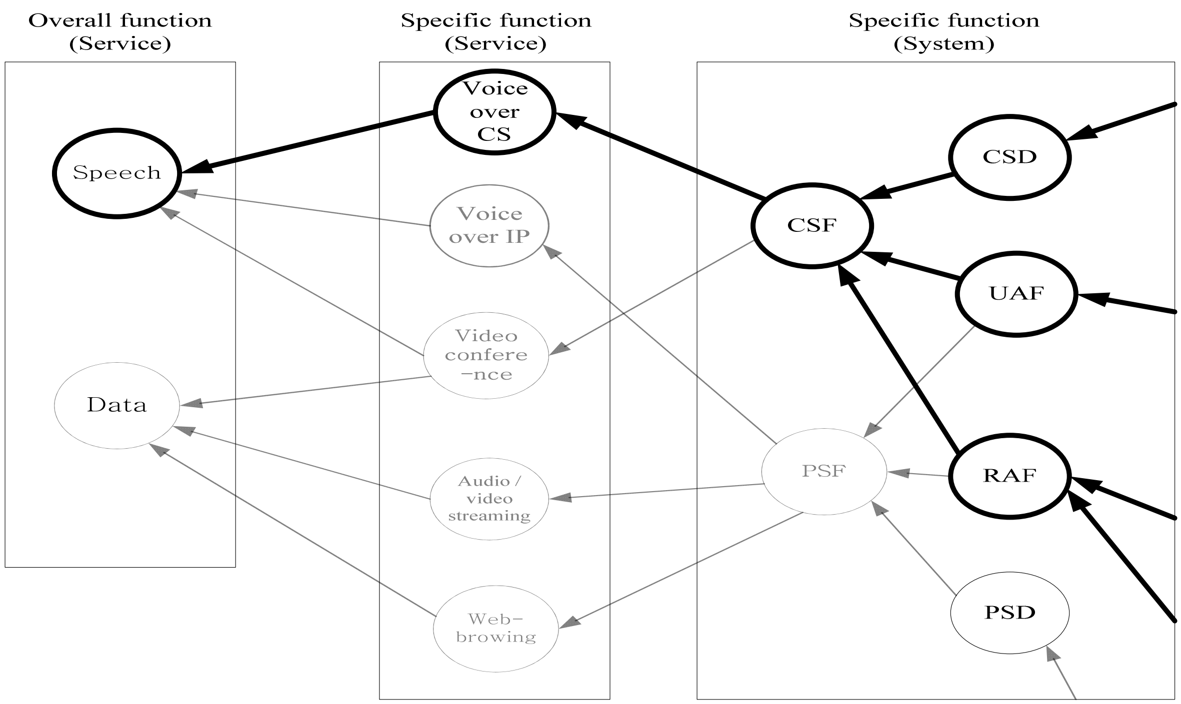
- Geographic Position Function (GPF): it handles the tasks associated with geographic positioning in the radio access side.
- Access link Relay Function (ARF): it handles the overall control for the transit of a branch of the BS approach link between two instances of the RACF.
- Radio Access Control Function (RACF): it handles the overall control of the association and access link(s) between a mobile terminal and the network.
- Satellite Network Control Function (SNCF): it dynamically controls the configuration of radio network resources, in response to demands for connections to and from mobile terminals. In particular, in satellite networks, optimal use of scarce communication resources requires these dynamic behaviors.
- Connection Control Function (CnCF): it provides connection processing control.

Step 4: the PSD function is decomposed into the specific function group which is embodied with a combined SGSN/GGSN network component, mainly for packet traffic service (ITU-T Rec. Q.1711.1999, Yacoub 2002). The group consists of the following functions.

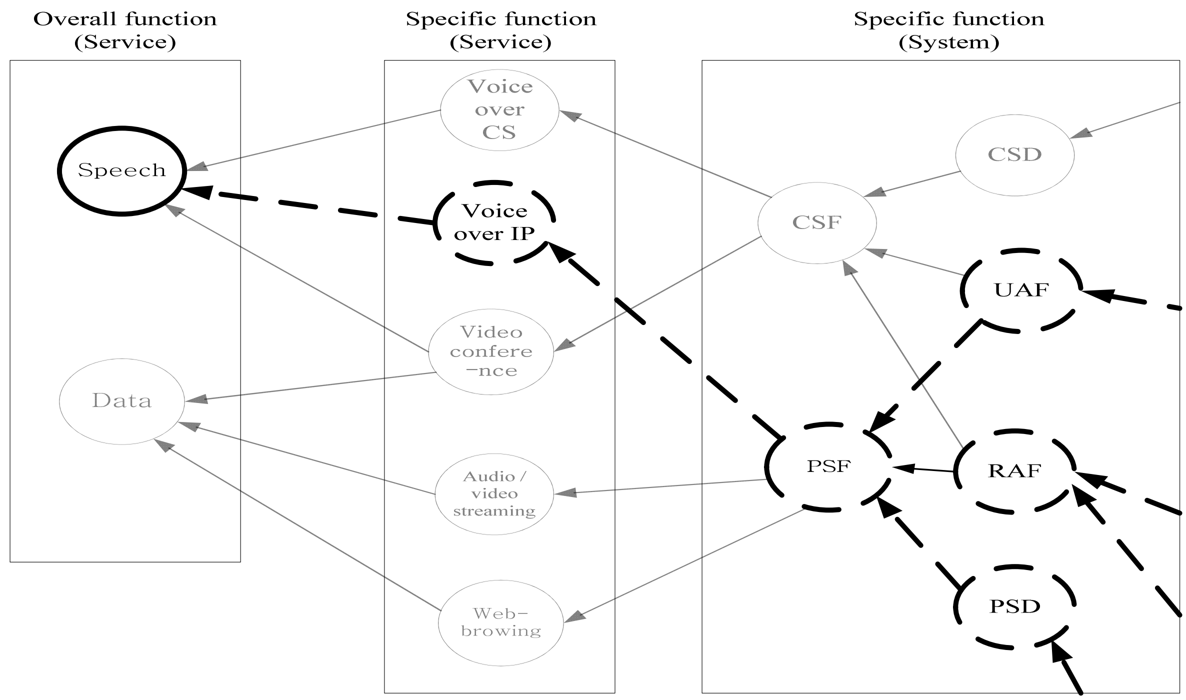
- Packet Service Gateway Control Function (PSGCF): it provides the packet service gateway control functionality in the IMT-2000 Core Network.
- Packet Service Control Function (PSCF): it provides the packet service control functionality in the IMT-2000 Core Network.
- Location Management Function (LMF): it contains the basic terminal mobility logic. It supports location management, mobility management, activation status management, and identity management. The LMF interacts with other functions to access additional logic or share information. It also handles storage and access to subscriber mobility data.
- Authentication Management Function (AMF): it handles storage and access to authentication data. It also provides the authentication function and confidentiality control.
- Service Control Function (SCF): it contains the overall IN service control functionality in the IMT-2000. Service logic can be triggered by call processing, mobility management, or non-call associated events. The SCF interacts with other functions to access additional

logic or to obtain information (service, user or network data) required processing a service logic instance.

The function knowledge base mentioned above supports the emergency manager to realize the function reconfiguration in different contexts. Figure 5.8a and Figure 5.8b show the snapshot of the function decomposition and function reconfiguration by the G-S concept in disaster situations. Figure 5.8a shows that the speech service is provided by the primary specific function (i.e. circuit switch network) to transport the voice signals. The secondary specific function for speech function (i.e. VoIP) is depicted with dotted line in Figure 5.8b. It describes the function reconfiguration.



(a) Decomposition of speech function.



(b) Network Reconfiguration of Speech function.

Figure 5.8 Function decomposition and reconfiguration by the G-S concept.

It is noted that the specific reconfiguration idea described above is justified by many other studies in the field of telecommunication system. Sief and Dakroury (2004) evaluated the performance of UMTS (3G) network and its effect on the QoS of VoIP. Their research showed that a mobile can communicate IP over a packet radio access network by running the IP over radio protocol. The delay of the data and multimedia service is within an acceptable performance and tolerable total delay. Cuny and Lakaniemi (2003) presented the results a study on Quality of Service (QoS) for VoIP service over 3G WCDMA networks. An end-to-end simulation platform was used for this purpose. The simulations run on Adaptive Multi-Rate (AMR) speech codec at 12.2kbit/s with the combination of RTP, UDP and IPv6 protocols. The results included buffering statistics, end-to-end delay estimates, and packet loss statistics. Their end-to-end QoS analysis showed that 3GPP networks will be able to offer an adequate level of quality for Voice over IP (VolP) services. Kara et al. (2006) examined the performance of a multimedia traffic transfer over real 3G WCDMA mobile network. They identified the 3G WCDMA mobile network performance to carry widespread multimedia services of video or audio streaming, FTP, HTTP, and VoIP based on the TCP and UDP protocols. The testing result of VoIP showed that the VoIP tests all passed successfully on the 3G network even though there was one-way delay and the delay variation (jitter) were measured on the uplink and the downlink directions for voice transfer. An acceptable voice quality was obtained using the QoS profile.

5.4.2 System structure knowledge base

The structure of the WCDMA system is divided into two parts: the traffic transmission structure and the system control structure. The traffic transmission structure includes the entities that receive and transport the traffic data to destination, while the system control structure includes the entities that follow the rules or operation standards to manipulate the entities in the traffic transmission structure.

Theses components are further categorized into five groups: (1) User interface, (2) Radio signal Access, (3) Signaling control (4) Data transportation, and (5) System database. Table 5.3 shows the typical constitution of the structure of 3G WCDMA network and the states or properties of the components (Mishra 2004, Smith and Collins 2002).

Table 5.3 WCDMA system structure knowledge base (3GPP TS 23.002 2003).

Structure	Groups	Component	Capacity	Interface	Location/ Topology	Coverage	Survivability
System control structure	System database	HLR	- Depend on number of subscriber records in the whole system	C, D, Gc, Gr	- Mesh network - Logical function centralization - Centralized site location	WCDMA System service area	Top
		VLR	- Depend on mobile subscriber base, their calling behaviour and the number of the mobile users - Continuous value - Static capacity, improved by the HW or SW extension	B	- Mesh network - Logical function centralization - Centralized site location	MSC or MSC- server service area	Top
		AUC	- Depend on the specific dimensioning rules and capacity limitations by the particular vendor	H	- Mesh network - Logical function centralization - Centralized site location	WCDMA system service area	Top
		EIR	- Depend on the specific dimensioning rules and capacity limitations by the particular vendor	F, Gf	- Mesh network - Logical function centralization - Centralized	WCDMA system service area	Top

					site location		
	Signaling control	GMSC-server	- Depend on subscriber base, their calling behavior and the number of RNCs, MGw - Continuous value - Static variable, improved by HW and SW extension	C, Mc, Nc	- Mesh network - Logical function centralization - Centralized site location	External PSTN or PLMN network to the MSC service area	Top
		MSC-server	- Depend on subscriber base, their calling behaviour and the number of RNCs, MGw - Continuous value - Static capacity, improved by the HW or SW extension	Iu-CS, D,F, G, E, Mc, Nc	- Mesh network - Logical function centralization - Centralized site location	MSC service area	Top
Traffic transmission structure	Data transportation	MGw	- Depend on subscriber base, their calling behaviour and the number of RNCs - Continuous value - Static capacity, improved by the HW or SW extension	Iu-CS, Nb, Mc	- Tree network to RNC - Mesh network to others - Logical function centralization - Distributed site location	MGw service area	High
		SGSN	- Depend on the number of attached subscribers or the total throughput.	Iu-PS, Gn, Gf, Gp,Gr, Gs	- Tree network to RNC - Mesh network to others	SGSN service area	High

					- Logical function centralization - Distributed site location		
		GGSN	- Depend on the total throughput and the number of simultaneous PDP contexts	Gn, Gc, Gi	- Mesh network to others - Logical function centralization - Distributed site location	External IP network to the MSC service area	High
	Radio signal Access	RNC	- Depend on RF network elements (such as sites, sectors, and TRXs) and Iub interface capacity - Continuous value - Static capacity, improved by the HW extension	Iu-CS, Iu-PS, Iu-r,Iu-b	- Tree network to MGw or SGSN - Distributed site location	RNC location service area	Moderate
		Node B	- Depend on the uplink and downlink capacity	Iu-b, Uu	- Tree network to RNC - Distributed site location	Radio access area (Cell)	Low
	User interface	UE	- Discrete value - Dynamic capacity by different services portfolio	Uu	- Tree network to RNC - Dynamic and distributed site location	Radio access area (Cell)	Very Low

The emergency manager searches the knowledge base by following the procedure (see Figure 5.9). It starts from the structures (either control structural part or traffic transmission structural), then the groups of each structure, then the components, and finally the attributes of the selected components.

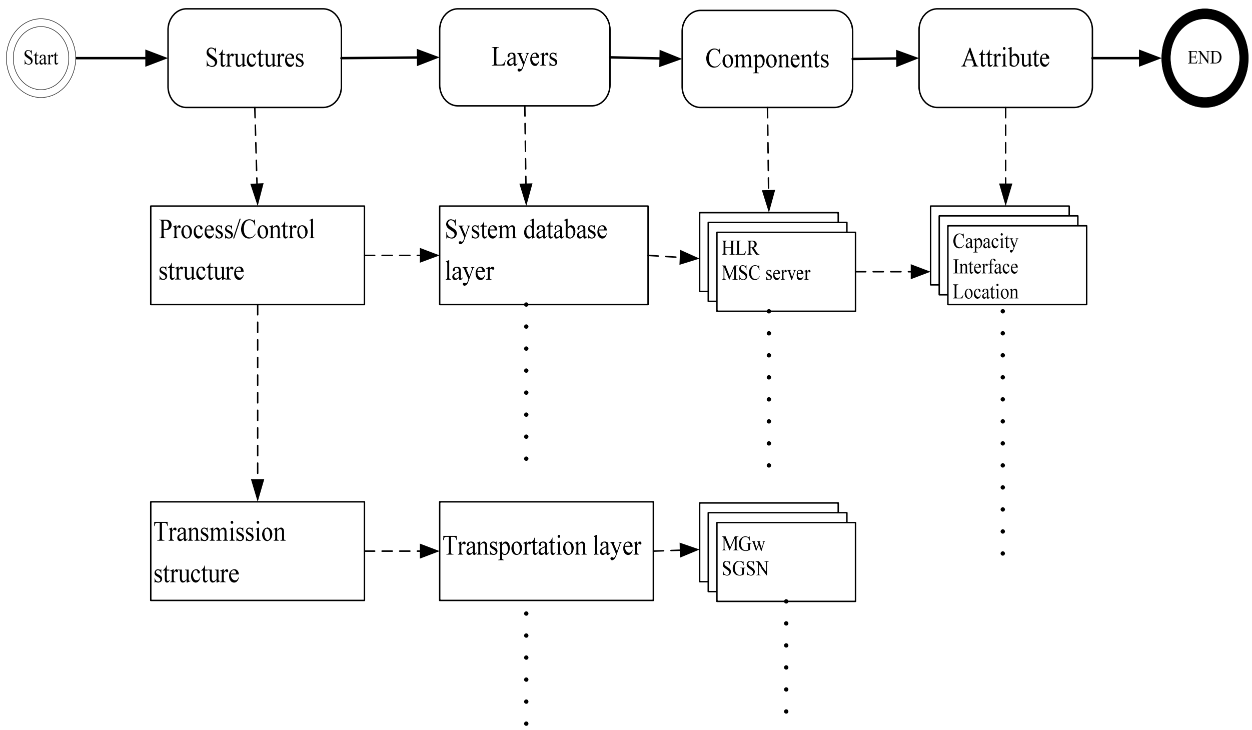


Figure 5.9 Design procedures for the structure knowledge base.

Figure 5.10 shows a simple example of applying the above procedure for the voice function in the circuit switch domain. The manager starts with the transmission structure in the User Equipment (UE) layer. The UE supports the UMTS service with the Uu interface and within the radio coverage area of Node B, the Cell of Node B. The components in other groups such as Radio signal access, data transportation, are identified to provide the circuit switch function. All the selected components have their own state variables. The relation between the components is determined by the state variables (e.g. capacity and interfaces). When the state variables of the two different components can match each other, they can interact. For instance, the UE-1 is only related with the Node B because the Node B has the same Un interface. Their interfaces match each other. Meanwhile the capacity of the Node B also impacts the relation with the UE.

Meanwhile, if the Node B-1 does not have enough capacity to process the service request from the UE, the UE has to request other node (e.g. Node B-2), which has enough capacity. The Node B-2 will transmit the traffic to the RNC-2 through the Iu-b interface between them. If the RNC-2 does not have enough capacity, UE-1 has to hand over to another Node B which can find an available traffic channel from RNC and CN. The RNC-2 is assumed to have enough capacity and MGw can allocate enough channels to the call services. Then the voice traffic can be transported from the RNC-2 to the MGw through the Iu-CS interface and forwarded to users in local network or other PLMN/PSTN network. Figure 5.10 shows the selected components and their provision of the WCDMA CS domain voice function. Similar to the Voice function realization, the VoIP function can be provided by the network components UE-1, Node B-2, RNC-2 and GPRS, etc. These components transport the packet Voice data to the IP network and relay to the users in other PSTN/PLMN networks.

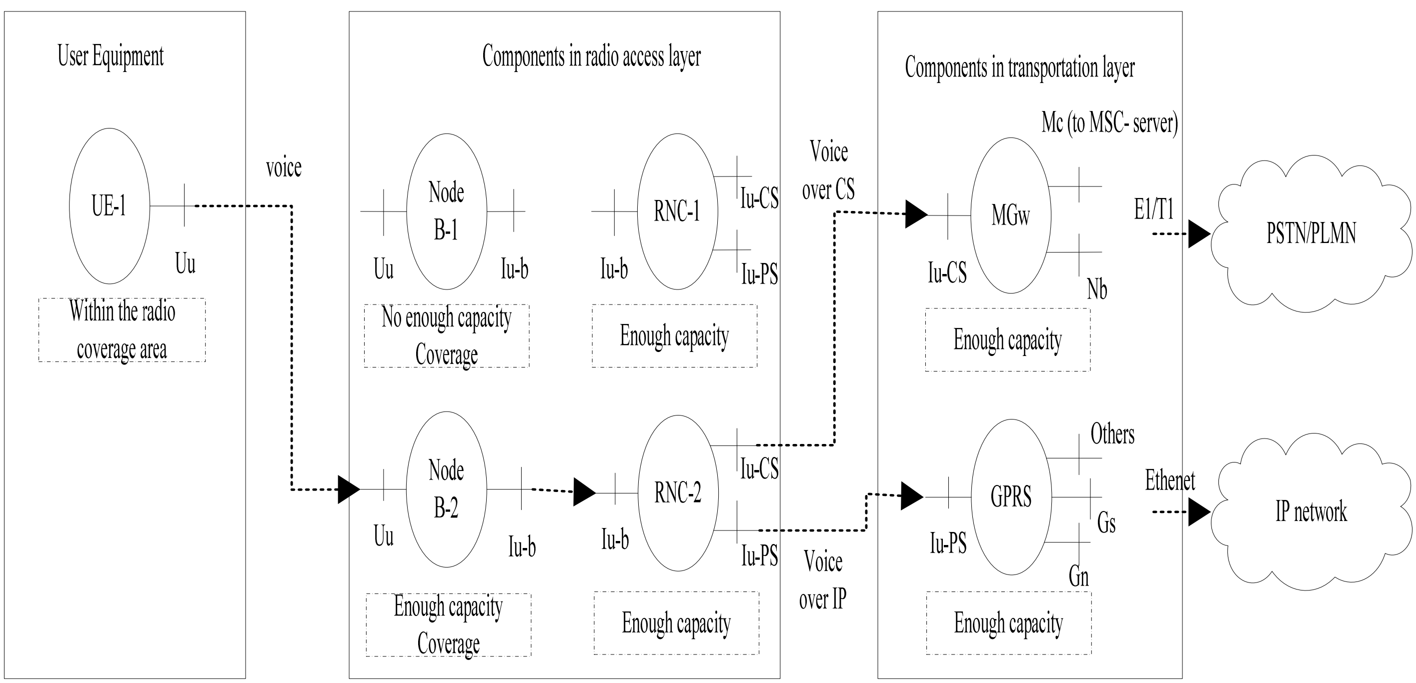


Figure 5.10 Configuration of network components.

5.4.3 System principle knowledge base

The principle of telecommunication system (e.g. 3G WCDMA system) refers to standard interfaces or protocols. Protocols may be implemented by hardware, software, or a combination of the two. At the lowest level, a protocol defines the behavior of a hardware connection. The UMTS protocols are used to control the execution of network functions in a coordinated manner across system interfaces (Kaaranen 2005). At a higher level, protocols are grouped in stacks, which are standard interfaces. There are three reference protocols and they are: (1) The Radio Interface Protocol Reference Model; (2) UTRAN Protocol Reference Model; and (3) The CN Protocol Reference Model. The architecture of each model consists of the protocol stacks (Kaaranen 2005). A view of the 3G WCDMA protocol architecture is shown in Figure 5.11 (García et al. 2002). In this figure, the protocols are grouped under the three reference models; the detailed knowledge about all these protocols is beyond the scope of this thesis. Further, these protocols are classified into access stratum and non-access stratum. The non-access stratum concerns the user service request, while the access stratum concerns the processing of radio signals.

Table 5.4 is a schema of the principle knowledge base. In this table, the first column shows two operation levels, namely non-access stratum and access stratum. The second column shows the functions of the components which are governed by the protocols. The third column shows the components involved. The fourth column shows the protocols that are applied to the components (in the third column) to play the functions as shown in the second column. In the following, three examples are presented to further explain how the protocol works.

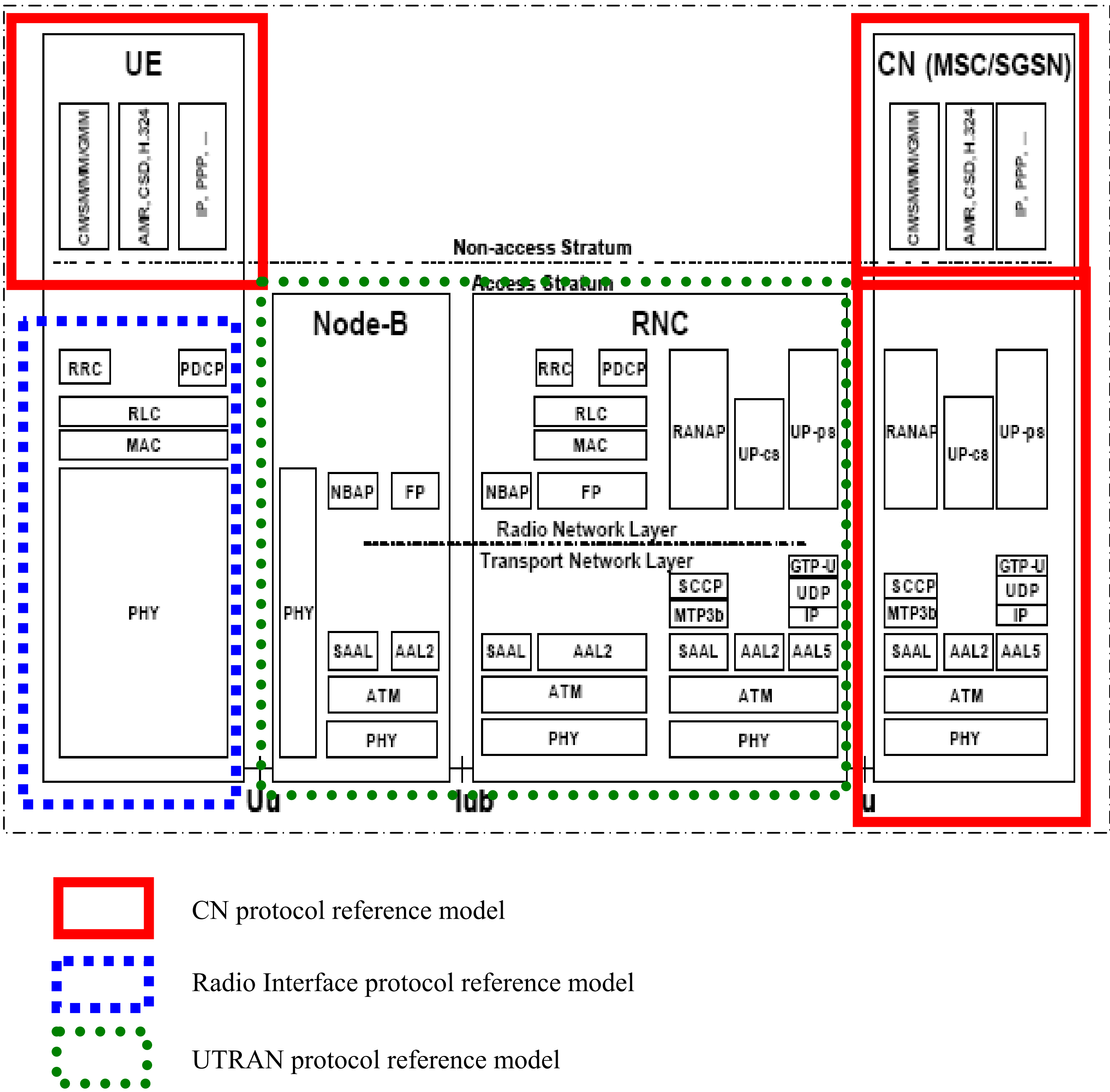


Figure 5.11 Typical protocol architecture of the 3G WCDMA (García et al. 2002).

Table 5.4 WCDMA system principle knowledge base.

Operation level	Function	Components	Protocols
Non-access stratum	VoCS	UE, Node B, RNC, MSC server, MGw, HLR, EIR	Call Control (CC) protocol in non-access stratum (refer to the horizontal axis in Figure 5.11); All the protocols in Access stratum (refer to the vertical axis in Figure 5.11)
	VoIP	UE, Node B, RNC, SGSN,GGSN, HLR, EIR	Session Management (SM) protocol in non- access stratum (refer to the horizontal axis in Figure 5.11); All the protocols in Access stratum (refer to the vertical axis in Figure 5.11)
	MM	UE, Node B, RNC, MSC server, MGw, SGSN,GGSN, HLR, EIR	Mobility Management (MM) and GPRS Mobility Management (GMM) protocols in non- access stratum(Refer to the horizontal axis in Figure 5.11); All the protocols in Access stratum (refer to the vertical axis in Figure 5.11)
Access stratum	PC	UE, Node B, RNC	RRC and PDCP protocols and other lower support protocols (Figure 5.11)
	CAC	UE, Node B, RNC	RRC and PDCP protocols and other lower support protocols (Figure 5.110

Example 1: Principle of Voice over Circuit Switch domain

In Figure 5.12, the Voice over Circuit Switch domain (VoCS) principle and the interaction between the protocols and components are described. It shows how the principle governs the behavior and procedure of each component under control. This example shows an example of a voice originated call establishment on 3G WCDMA circuit switch domain. The principle identified the required components (i.e. UE, UTRAN, MSC server, MGw) for the target function shown in the horizontal axis. The working procedure in time sequence is showed following the vertical axis.

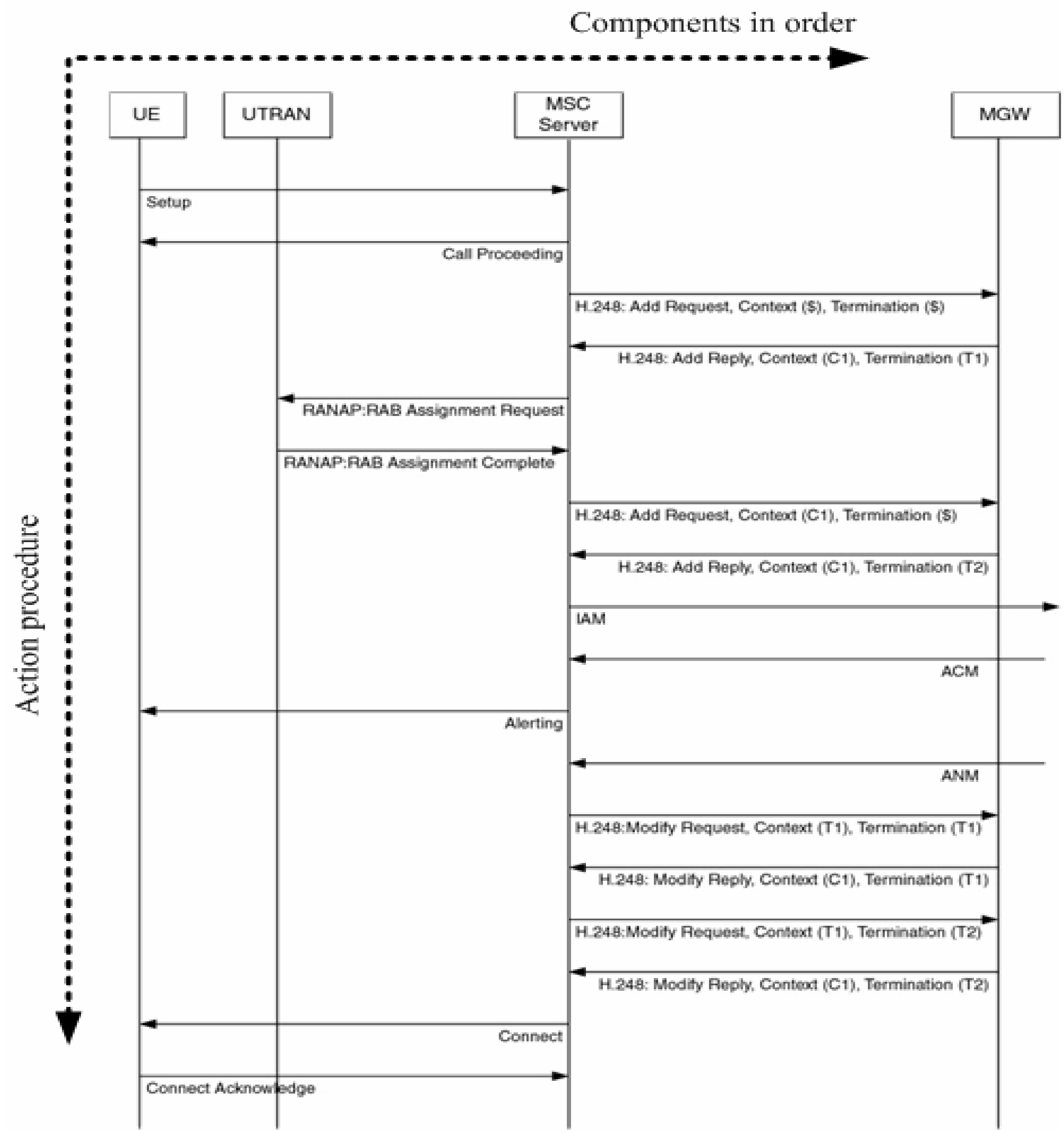


Figure 5.12 Principle VoCS for managing the mobile call (Smith and Collins 2002).

When the Setup message arrives from the UE, the MSC server performs a call-routing determination. It then responds with a 'Call Proceeding message' to the UE. Based on the call-routing determination, the MSC server chooses a MGw to handle the call. It instructs (Add Request) the MGw to establish a new context and places a termination in that context. The termination in question (T1) will be on the network side of the MGw. Once the new context is established by the MGw, the MSC server requests the RAN to establish a RAB to handle the call. Once the RAB has been assigned, the MSC server is in a position to establish a media connection between the RNC and the MGw. Therefore, it requests the MGw to add a new termination to the context that has just been established. This new termination (T2) will face towards the RNC. Because the new termination is in the same context as termination T1, a path is created from one side of the MGw to the other.

The MSC server then sends the ISUP Initial Address Message (IAM) to the called network (such as the PSTN). Upon the receipt of an Address Complete Message (ACM) from the far end, the MSC server sends an Alerting message to the UE. Typically, the called user will answer, which causes an ISUP Answer Message (ANM) to be received at the MSC server. At this point, the MSC server may optionally modify the context established on the MGw. Specifically, when the terminations were established in the new context, they may have been configured to not provide a complete through-connection. For example, one or both of the terminations could have been configured to allow only a one-way media path (from the far end to UE for the purposes of receiving a ring-back tone). In such a case, the MSC server requests the MGw to modify the configuration so that a full two-way media path is established. Finally, the MSC server sends a Connect message to the UE and the UE responds with a Connect acknowledge (Smith and Collins, 2002).

Example 2: Principle of VoIP

VoIP is the routing of voice traffic over the Internet or any other IP-based network. Using the Internet's packet-switching capabilities, VoIP technology has been implemented to provide telephone services. In the IP world, there are two main methods of providing call-control functionality: ITU-T Recommendation H.323, and the IETF Session Initiation Protocol (SIP).

The basic components of the voice service are two user terminals with IP-based voice applications and a network that provides end-to-end transport between the terminals. The two IP-based terminals exchange voice samples that have been encapsulated in RTP over the IP network. The terminals exchange control signaling between them and maintain communication sessions through the network according to either the H.323 or SIP paradigm (Eriksson et al. 2000).

There are two protocol families which is conjunction with H.323 and SIP protocols by supporting the data transportation and control. The Real-Time Transport Protocol (RTP), along with its associated Real-Time Control Protocol (RTCP). They constitute the technical foundation of the Voice over IP industry. The detailed information about the protocols is addressed in (He 2007). Figure 5.13 shows the protocol stacks of RTP and RTCP.

RTP, RTCP
Transport Layer (UDP/TCP)
Network layer (IP)
Datalink Layer
Physical layer

Figure 5.13 A simple VoIP protocol stack.

The mobile terminal supports cellular access (UMTS/WCDMA or EDGE) and a complete VoIP application that is based on either SIP or H.323. The principle which governs the operation of the system to achieve the VoIP function is embodied by the interactive protocols to control the bevaiour of the structural components.

Figure 5.14 gives the typical example of the SIP-based telephone protocol stacks, which shows how the principle works. In this figure, SIP stands for Session Initiation Protocol. It is an application-layer control (signaling) protocol for initiating, manipulating, and tearing down sessions. These sessions include Internet telephone calls, multimedia distribution, and multimedia conferences. SIP's main purpose is to help session originators deliver invitations to potential session participants. It is an alternative to H.323.

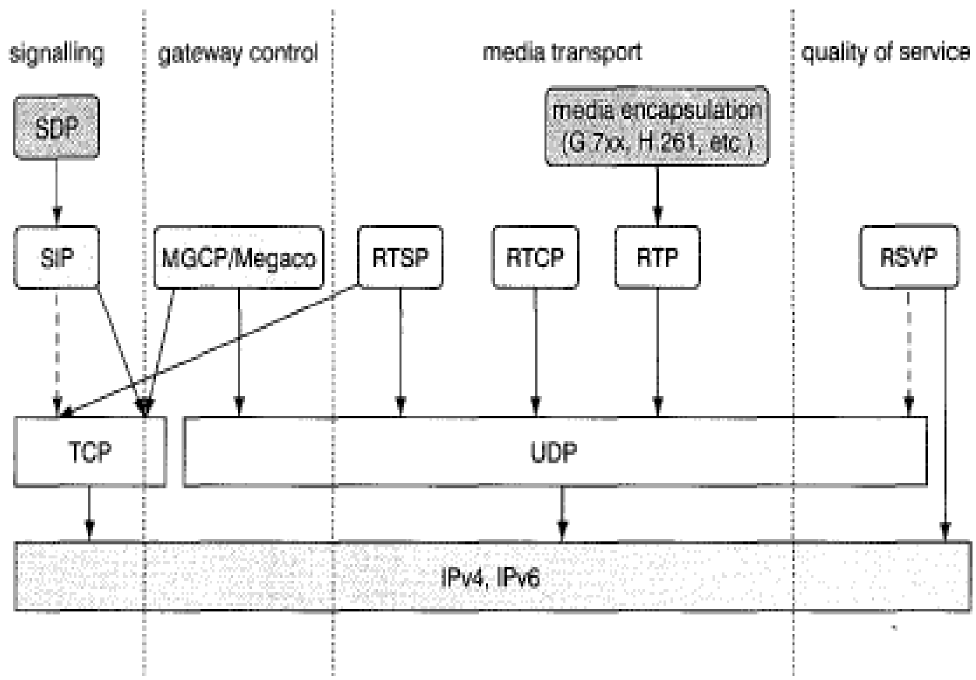


Figure 5.14 Principle of SIP-based protocols (Zhang 2002).

The SIP lies in the application layer and must be used in conjunction with other protocols in order to provide real-time services. When a SIP signaling session is successfully set up, an Real-Time Transport Protocol (RTP) media session is opened and the virtual session begins. The digitally encoded voice stream is carried over an IP network by using the Real-Time Transport Protocol. The RTP Control Protocol (RTCP) is a companion protocol of RTP and is used for providing quality-related feedback. The Resource Reservation Protocol (RSVP) is an optional protocol that will manage the resources being reserved at each node along the data path to meet the quality-of-service requirements of particular application data streams. The Real-Time Streaming Protocol (RTSP) functions as a network remote control for on-demand delivery of real-time data. The Media Gateway Control Protocol (MGCP) or Megaco is used for media gateway control when interoperating with traditional circuit-switched networks.

Example 3: Principle of Power Control process

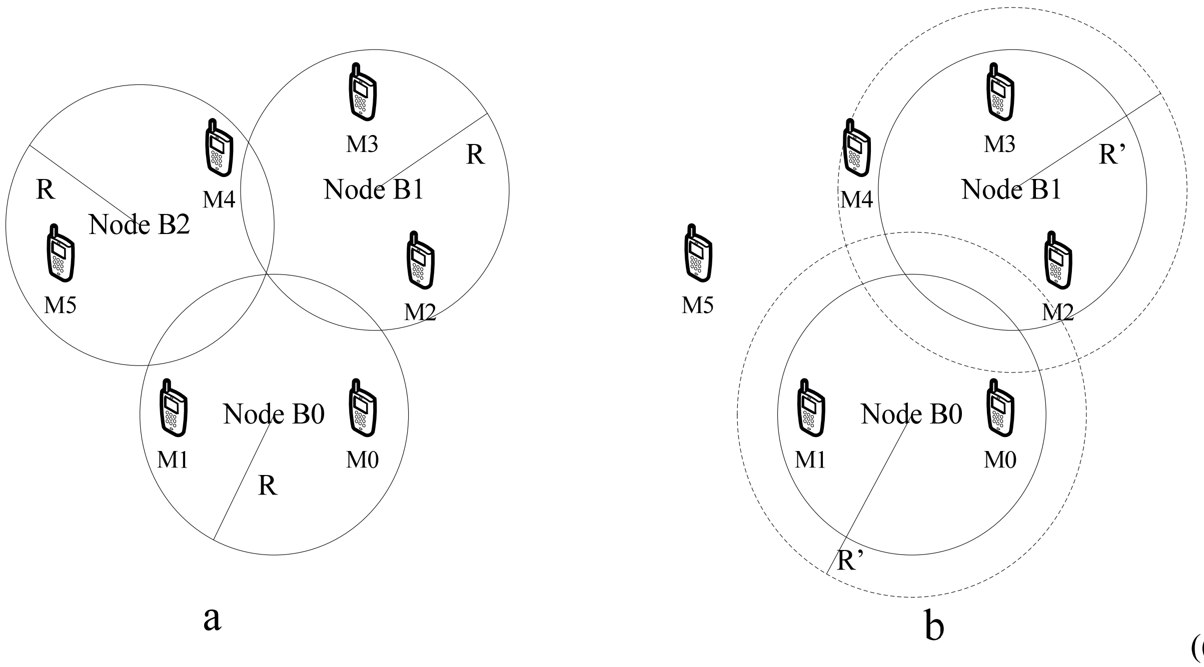
A typical infrastructure of a cellular network consists of a number of components. A failure of one component may affect nearly all customers covered. In a wireless system, a Node B that communicates directly with UEs is a critical facility. If more Node Bs are deployed, the coverage as well as the system's capacity can be enhanced, but there is a higher possibility of Node B failure. Thus, partial users may be out-of-service and the overall QoS would be degraded. In terms of operating, if some of the failed Node Bs could be recovered, it would enhance Node Bs and provide survivable service. Accordingly, Node Bs recovery is one of the most important approaches for minimizing the total system Call Blocking Rate (CBR). It is important to find the way to provides network survivability by allocating redundant resources. Power control process of WCDMA system plays a vital role in adjusting the transmission power of all available/workable Node Bs, reduces the impact of Node B failures. It has a direct impact on the coverage and capacity of the network. Air-interface capacity in the downlink is more critical and is dependent on the transmitted interference. If the required transmitted power can be reduced to a bare minimum, the capacity can be increased. However, in the uplink, both the transmitted and received power will increase interference to, respectively, adjacent cells and users of the same cell. The better the isolation between the cells, the higher the capacity, and decreasing power levels to the minimum required can increase this isolation. Therefore, efficient and fast power control is the key to system capacity and service maintenances of WCDMA technology. Power control is based on the SIR. Both uplink and downlink power control is necessary, with downlink control being the more critical. Power control of the common channels is necessary, the most important ones being the CPICH, AICH, PICH and CCPCH (Mishra 2004).

A rather simple mathematic model of PC is shown in Equations (5.1) (Nuaymi et al. n.d.).

$$\gamma_{m,b} = \frac{g_{bm}\, p_m}{\sum_{j=1;\, j \neq m}^{M} g_{bj}\, p_j + n_b} \tag{5.1}$$

At a given instant, M mobiles are transmitting information sharing a Common Radio Channel (CDMA). Each mobile should communicate with one of the Node Bs, "b". The index of the Node B to which mobile m is assigned as b_m . A mobile is connected to the best received power level of Node B, which is not always the closest one due to fadings. Mobile m transmitted power is p_m and the link gain from mobile m to base b is noted as g_{bm} , so matrix G = (g_{bm}) is of size (B x M). Mobile m received SIR on Node B, noted *mb,* where n_b is the receiver noise, also called thermal noise, at Node B. The received SIR of mobile *m* on its assigned Node B is noted as γ_{m_b} . A mobile is outage of the service when the SIR is below the defined threshold.

Figure 5.15 shows an example of three Node-BS (Node B0, B1, B2) and six Mobile equipments, MEs, (M 0–5), where two MEs are covered by each Node Bs. In Figure 5.15a, all Node Bs work normally (no failures) within power radius R. M0 and M1 are served by Node B0; M2 and M3 are served by Node B1. M4 and M5 are served by Node B2, respectively. In Figure 5.15b, Node B2 is failed. Thus, both the Node B0 and Node B1 adjust transmission power within R' to serve the impacted M4 and M5, respectively by deploying the power control process and algorithms for power management. Figure 5.15b shows alternative ways of recovering Node B2. M4 is recovered within the coverage area R' of Node B1, while M5 is outage of the service due to the far distance beyond the Maximum coverage area of Node B0 and B1.



(a) Normal situation. (b) Node B2 Failure.

Figure 5.15 An example of Power Control.

5.5 Conclusion with discussion

This chapter presented a new approach to system reconfiguration. The approach is based on the General-Specific (G-S) concept and thus the approach is also called G-S model. The essential point with the G-S model is that every component, subsystem, and system has two aspects: general function and specific function. To facilitate the modeling of the general and specific function, the general function can be thought of being context insensitive, while the specific function can be though of being context sensitive or context specific. In theory, there will be many specific functions. It is reasonable to assume that a system usually does not run in its full capacity in its normal operation situation; in particular, if it is composed of a set of components (A, B, C, etc.), it is likely that A, B, and/or C may not operate in their full capacities. This further means that a part of A, B, and/or C may possibly be used for another specific function when a specific context is given.

To simplify the demonstration of the application of this general and specific function concept to system reconfiguration, it is considered that each system (or component or subsystem) has two specific functions which are called primary function and secondary function, respectively. A particular component or subsystem plays its primary function in one specific situation which may be called the named situation. When some components or subsystems are damaged, implying that they can no longer perform their primary functions, they will be replaced by other components or subsystem in the same system or in its relevant systems through their secondary functions which are not made available in their corresponding named situations.

There are some related works in a broader area of system engineering and management, notably the work of Umeda and Tomiyama (1995) and the work of Ulrich and Seering (1988). Umeda and Tomiyama (1995) illustrated a design methodology called function redundancy for highly reliable machines. They proposed that function redundancy is achieved by using the potential functions of the existing parts in a slightly different way from the original design. They illustrate this idea using a simple example. In case of emergency when the engine stops, a car with a manual transmission can run for a while. This function redundancy is achieved depending on the car system in redirecting power flow - in particular changing from function 'to start the engine' to the function 'to generate driving force'. This idea is essentially similar to the idea which was presented in Figure 5.3 (transportation system reconfiguration) in the sense that in their case the motor is idle after its function to start the engine is completed, and later the motor is reused. However, their approach is not of coverage of the method which is shown in Figure 5.2b and Figure 5.2c, respectively, which are in essence to employ the damaged components or subsystems.

Ulrich and Seering (1988) proposed a concept called function sharing as a kind of design method for general product design. The function sharing is defined as a correspondence between several functional elements and one structural element or physical property of the design. In essence, whenever a single structural element can map to more than one functional element, then the device shows the function sharing. In a more general sense, one can imagine that their design methodology tries to build a many-to-many relation between the design features and functions.

The function sharing concept is close to the function redundancy concept and seems to be restricted to a single component only in their original description. The function sharing concept has not been applied to the survivability of a system.

In comparison with these two methods in engineering design, the approach based on the G-S model is the most general one. The other two approaches are at most useful to the reliability of the system but not to the survivability of the system. This point is noted with a special reference to the first two methods of Figure 5.2b and Figure 5.2c (respectively), which are a part of the approach described in the thesis.

Chapter 6

Petri Net Dynamic Modeling and Simulation of WCDMA

6.1 Introduction

This chapter presents a dynamic model of the WCDMA system using Petri Net theory, in particular Colored Petri Net (CPN). There are a couple of purposes of having such a dynamic model. First, with the dynamic model, the emergency manager can validate his or her particular decision through the simulation of the system behavior. Second, the emergency manager can study the system vulnerability through a fault or damage engine which generates system damage scenarios to be applied to the system. Further, this Petri Net model is integrated with the domain model of the WCDMA system, which leads to a new way to apply the Petri Net theory to a complex service system. As such, the proposed dynamic model has a close relation with the FBS framework which was used to develop the domain model of the WCDMA system (see Chapter 4). In the remainder of this chapter, Section 6.2 discusses the basic concepts of Petri Net theory. Section 6.3 presents an integrated FBS and Petri Net modeling approach to the WCDMA system. The code of the Petri Net model is shown in Appendix A. Section 6.4 presents an interface which is used to examine the dynamics of a service provider system - the example WCDMA system in this thesis study case. Section 6.5 concludes this chapter with some discussion.

6.2 Petri Net theory

6.2.1 Petri Net

Ordinary Petri Net, or simply Petri Net (PN), was initially developed by Carl A. Petri in 1962. It is a powerful tool for modeling discrete event systems. The definitions about Petri Nets are summarized in Table 6.1 (Murata 1989).

Table 6.1 Basic definitions of Petri Nets.

A Petri Net is a 5-tuple, PN = (P, T, F, W, M_0) where:
P = $\{p_{1,} p_{2,\cdots,} p_m\}$ is a finite set of places,
T = $\{t_{1,} t_{2,\cdots,} t_n\}$ is a finite set of transitions,
F $\subseteq$ (P x T) $\cup$ (T x P) is a set of arcs (flow relation),
W: F→ (1, 2, 3, . . .} is a weight function,
M_0: P →(0, 1, 2, 3, . . .} is the initial marking,
P $\cap$ T = Ø and P $\cup$ T $\neq$ Ø.
A Petri Net structure N = (P, T, F, W) without any specific initial marking is denoted by N.
A Petri Net with the given initial marking is denoted by (N, M_0).

The dynamic behavior of systems can be described with system states and their changes. In Petri Net, the state corresponds to the marking. A state or marking in a Petri Net is changed according to the following transition (firing) rule:

(1) A transition ‘t’ is said to be enabled if each input place ‘p’ is marked with at least w(p, t) tokens, where w(p, t) is the weight of the arc from ‘p’ to ‘t’.

(2) An enabled transition may or may not fire, depending on whether or not the event actually takes place.

(3) The firing of an enabled transition t removes w(p, t) tokens from each input place ‘p’ of ‘t’, and adds w(p, t) tokens to each output place ‘p’ of ‘t’, where w(p, t) is the weight of the arc from ‘p’.

The above transition rule is illustrated in Figure 6.1a and Figure 6.1b using a simple example which describes a call process from set up to finish through using one cell of Node B in WCDMA system. The model of the call procedure with Petri Net is defined as follows:

Token: The black dot means the traffic channels in the single radio cell or each call of users.

Place 'Capacity': There are 3 tokens inside the place, which means 3 available channels in this radio cell now (initial marking).

Place 'Usage': There is an empty token, which means Zero channel is being used (initial marking).

Place 'Idle (User A)': There is one token, which means User A is in idle status (initial marking).

Place 'Idle (User B)': There is one token, which means User B is in idle status (initial marking).

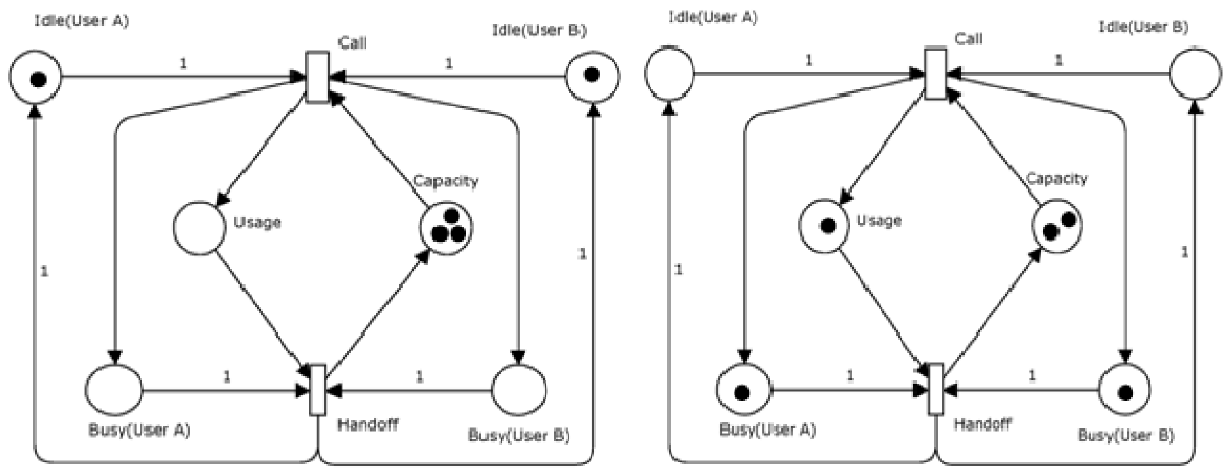
Place 'Busy (User A)': There is one token, which means User A is on-line for a call.

Place 'Busy (User B)': There is one token, which means User B is on-line for a call.

Transition 'call': It means the user makes a call.

Transition 'handoff': It means the user terminates a call.

Figure 6.1a shows that user A and B are in idle status, and there are three available channels in radio cell. Figure 6.1b shows 'User A' makes a call to 'User B' so that the transition 'Call' is fired. 'User A' and 'User B' are in busy status with one token in each place 'busy' for 'User A' and 'User B', respectively. Meanwhile, the cell capacity is reduced to 2 available traffic channels while one change is in a used status. After the user completes the call, transition will 'handoff' fire. The status of user and radio cell will change back to the status in Figure 6.1a.



(a) A marked PN before firing. (b) A marked PN after firing transition ‘call’.

Figure 6.1 An example of the Petri Net model.

6.2.2 Colored Petri Net

A major weakness of basic Petri Nets discussed above is the complexity in writing up a PN model. Petri-net-based models become too large for analysis even for a modest-size system (Murata 1989, Zhang et al. 2000). Because of this, different modifications of PN high-level and higher-order PN modelling have been attempted although with irregular results. Janneck and Esser (2002) indicated that one key extension to the basic Petri Net is the High-level Petri Nets such as colored Petri Net (Jensen 1992), which make the basic Petri Net more useful for practice.

Jensen (1992) extended PN into a colored, hierarchical, and temporized PN (CHTPN) network. According to Jensen (1992), Colored Petri Net (CPN) is defined as a tuple $CPN = (\Sigma, P, T, A, N, C, G, E, I)$, where Σ is a finite set of non-empty types called **color sets**; P is a finite set of **places**; T is a finite set of **transitions**; A is a finite set of **arcs** such that: $P \cap T = P \cap A = T \cap A = \Phi$; N is a **node** function defined from A into $P \times T \cup T \times P$; C is a **color** function which is defined from P into Σ; G is a **guard** function which is defined from T into expressions so that: $\forall t \in T$: [Type($G(t)$)={false, true}$\wedge$ Type (Var($G(t)$))$\subseteq \Sigma$]; E is an **arc expression** function which is defined from A into expressions so that: $\forall a \in A$: [Type($E(a)$) =

$C(p(a))$MS $\wedge$Type (Var($E(a)$)) $\subseteq \Sigma$], where $p(a)$ is the place of $N(a)$, MS denotes multi-set, and Var denotes a set of variables; I is an **initialization** function defined from P into closed expressions so that: $\forall p \in P$: [Type($I(p)$)=$C(p)$ MS]. For CHTPN, each page is a non-hierarchical CPN, where S is used to denote the finite set of pages, so for each page $s \in$ S and $CPN_s = (\Sigma_s, P_s, T_s, A_s, N_s, C_s, G_s, E_s, I_s)$, where $\Sigma = \bigcup_{s \in S} \Sigma_s$, $P = \bigcup_{s \in S} P_s$, $T = \bigcup_{s \in S} T_s$, $A = \bigcup_{s \in S} A_s$. It should be noted that the color sets always have the common elements, i.e., $\forall s \in S, \forall p \in P_s : C(p) = C_s(p)$, while the sets of net elements are disjointed, i.e., $\forall s1, s2 \in S : [s1 \neq s2 \Rightarrow (P_{s1} \cup T_{s1} \cup A_{s1}) \cap \quad (P_{s2} \cup T_{s2} \cup A_{s2}) = \phi]$. A hierarchical CPN is defined as a tuple $HCPN = (S, SN, SA, PN, PT, PA, FS, FT, PP)$. Jensen (1992) proved that given a HCPN, the equivalent non-hierarchical CPN could be derived.

The CPN Tool is a software program, developed by the University of Aarhus, Denmark, for modeling, simulating and analyzing Colored Petri Nets. The CPN Tool can define the color sets of Unit, Integers, Real, Boolean, String Enumerated Value etc. The CPN Tool also provides three kinds of type constructors which can construct new and complex data type, namely product, record, and list.

A CPN model can be created as a graphical drawing and Figure 6.2 contains a simple example of the CPN model. This model is used to simulate a simple transport process. The left part models the sender, the middle part models the network, and the right part models the receiver (Kristensen et al. 1998). The CPN model shown in Figure 6.2 is composed of seven places (drawn as ellipses or circles), five transitions (drawn as rectangular boxes), a number of directed arcs connecting places and transitions, and some inscriptions next to the places, transitions, and arcs.

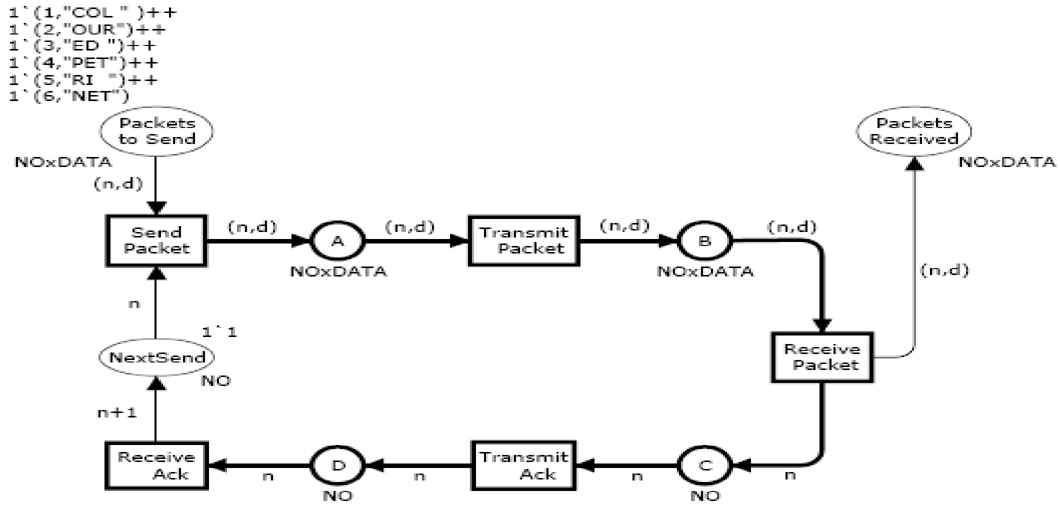


Figure 6.2 A simple transport protocol (Kristensen et al. 1998).

The places are used to represent the state variables of the system. Each place contains a set of markers called tokens. In contrast to Classic Petri Nets, each of these tokens carries a data value, which belongs to a given type. These types are called the colour set of the place and written below the place, e.g. the places 'NextSend', 'C' and 'D' have the colour set NO; the places 'A', 'B' and 'Packets to send' have the colour set NO × DATA. The inscription at the upper right side of place 'NextSend' specifies that the initial marking of this place consists of one token with the value 1. It indicates that data packet number 1 is the first data packet going to be sent.

The inscription at the upper left side of place 'Packets To Send':

1'(1,"COL") ++

1'(2,"OUR") ++

1'(3,"ED ") ++

1'(4,"PET") ++

1'(5,"RI ") ++

1'(6,"NET")

specifies that the initial marking of this place consists of six tokens with the data values: (1,"COL"), (2,"OUR"), (3,"ED "), (4,"PET"), (5,"RI "), (6,"NET").

The transitions represent the events that can take place in the system. When a transition occurs, it removes tokens from its input place and adds tokens to its output places. The same as the ordinary Petri Net, one transition can only occur when all of its input places have at least one token. The arcs describe how the state of the CPN changes when the transitions occur. These arc expressions are written in the CPN ML programming language and are built from variables, constants, operators, and functions.

6.3 CPN modeling of the example WCDMA system

From the inspiration of the work done by Zimmermann and Hommel (1999) and the FBS domain model, a three layers CPN model of the WCDMA system is proposed, namely function, structure and principle. Because the WCDMA wireless system is a complex system, there are many standards and rules. In the following, the thesis study focuses on the voice service of the WCDMA system and they are described as follows.

There are two additional components associated with the three layers as mentioned: (1) demand generator which model the traffic load, call attempt behavior, the voice calls or VoIP calls by using the Poisson process, and (2) threaten scenario which will simulate the disturbances to the system such as failing some of the functional components and links at a given time and the recovery of the failed components.

Figure 6.3 shows the architecture of the simulation engine with all major system components. In this figure, the left column indicates the two inputs: demands and threaten. The middle column is the CPN model of the telecommunication system. The right column is the outputs of the simulation which include various service performances. On the right column, the decision making is put in the context; in particular, decisions need to be taken in response to the provided service, and the decisions are affecting the structure of the telecommunication system. In the following, the detailed information of the three layers are discussed as shown in Figure 6.3.

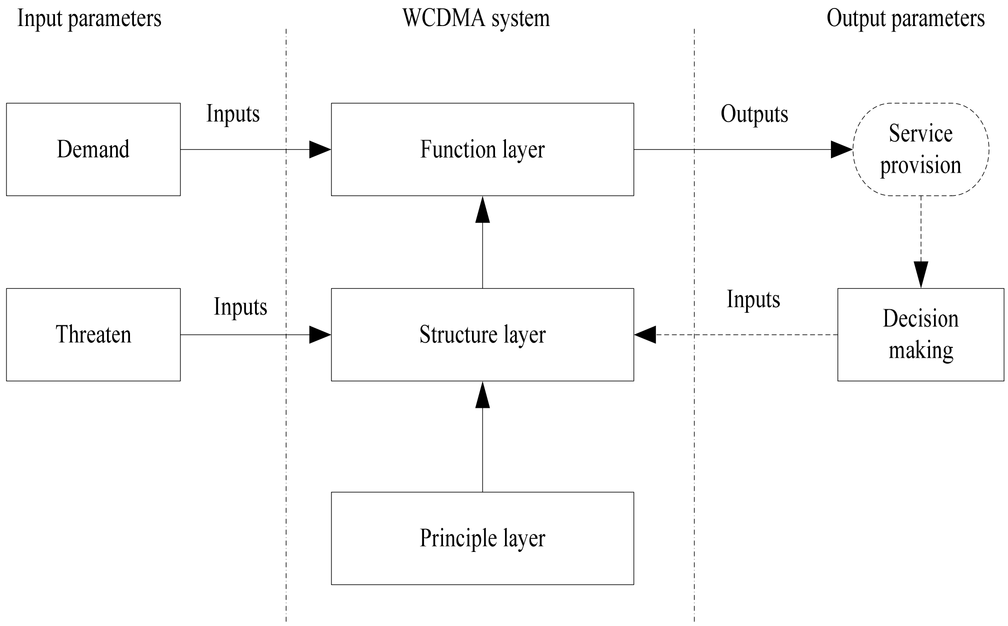


Figure 6.3 Architecture of the simulation engine.

6.3.1 Modeling the function of the example WCDMA system

The function of the CPN model is depicted in Figure 6.4. It can express the whole working process of the systematic functions layer based on the function knowledge base described in Section 5.4. The structure of the function layer is composed of 8 sorts of places and 5 sorts of transitions. The corresponding notations in the model are described in Table 6.2.

Table 6.2 Notations of the function model.

Place	Description	Transition	Description
Demand(Voice)	Voice data to be transmitted	RA	Radio signals access to system
RR	Radio Resource	CS	Circuit Switch
VoCS	Voice data in the Circuit Switch domain	PS	Packet Switch
VoIP	Voice data in the Packet Switch domain, i.e. Internet	TCS	Data Transmit through CS domain
Service	Services provided from system	TIP	Data Transmit through PS domain
System Capacity	Data of system capacity		
Connected call	Data of connected calls		
Blocked call	Data of blocked calls		

The place 'Demands (Voice)' contains the information about the demand as one single token of a color set. A list of color sets is defined as a different volume of traffic demands from different groups of users. It is assumed that the voice service is the priority for the user in a disaster area contrast to the data service.

The place 'RR' contains complete information about the resource of the radio frequency bandwidth. The 'RR' means the maximum radio resource capacity i.e. the service to meet the maximum amount of the users at some time intervals (e.g. one hour). The limited radio bandwidth is a bottleneck problem which restricts the capacity of the radio access system.

The place 'VoCS' contains color set tokens which show the dedicated users using the circuit channels for the voice traffic.

The place 'VoIP' contains color set tokens which show the dedicated users occupying corresponding data bandwidth of the Internet.

The place 'Services' contains color set tokens which shows the amount of the users who can get the services from either CS network or IP network.

The three places of 'System Capacity', 'Connected call' and 'Blocked call' register the system information by the corresponding token so that the performance of the system during the simulation process can be analyzed.

The whole process starts from the transition 'RA' standing for radio access from mobile users to the WCDMA mobile network. It is followed by the transition 'VoCS' through Circuit Switching or 'VoIP' through Packet Switching on a sufficient network capacity. Thus the transition 'TCS' or 'TIP' is fired which means the voice traffics are transmitted through the CS network or IP network to the destination user. They produce the tokens which are delivered to the place 'service' so as to stand for the services provided by the system.

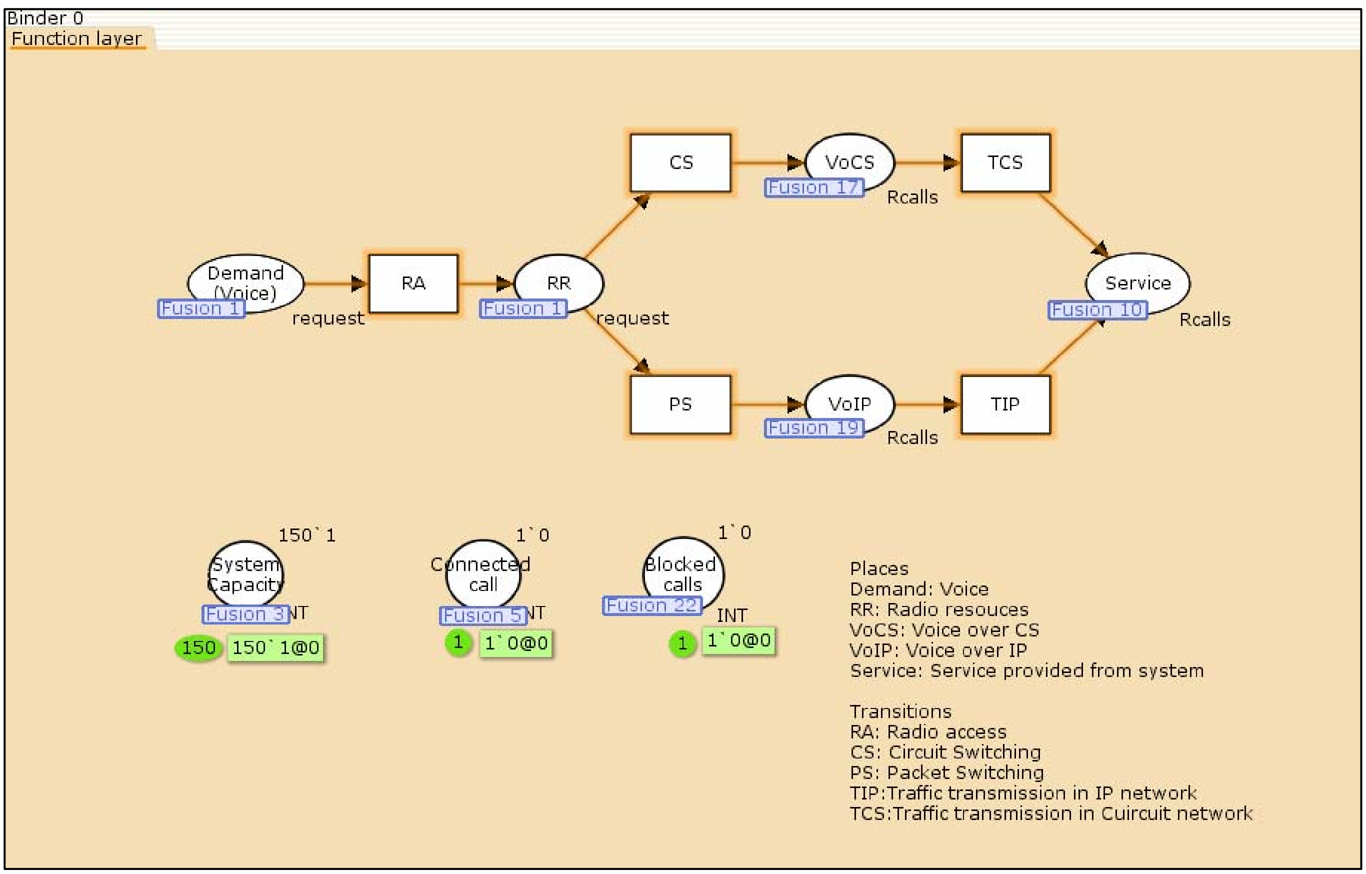


Figure 6.4 Function layer.

6.3.2 Modeling the structure of the example WCDMA system

The structure layer of the CPN model is depicted in Figure 6.5. The CPN structure model of the example WCDMA system is constructed based on the structure knowledge base described in Section 5.4. Because the model follows the layout of the practical WCDMA network system, it is not only understandable but can also be derived easily from a layout sketch of the wireless mobile network. The functional components (e.g. Node B, RNC) of the WCDMA mobile network structure are modeled with transition and the capacity of each component is described as place. The tokens of each place stand for the traffic channels used by each user. The maximum system capacity for the mobile user is considered in this thesis study, so that each user is supposed to be allocated with one traffic channel for the voice service.

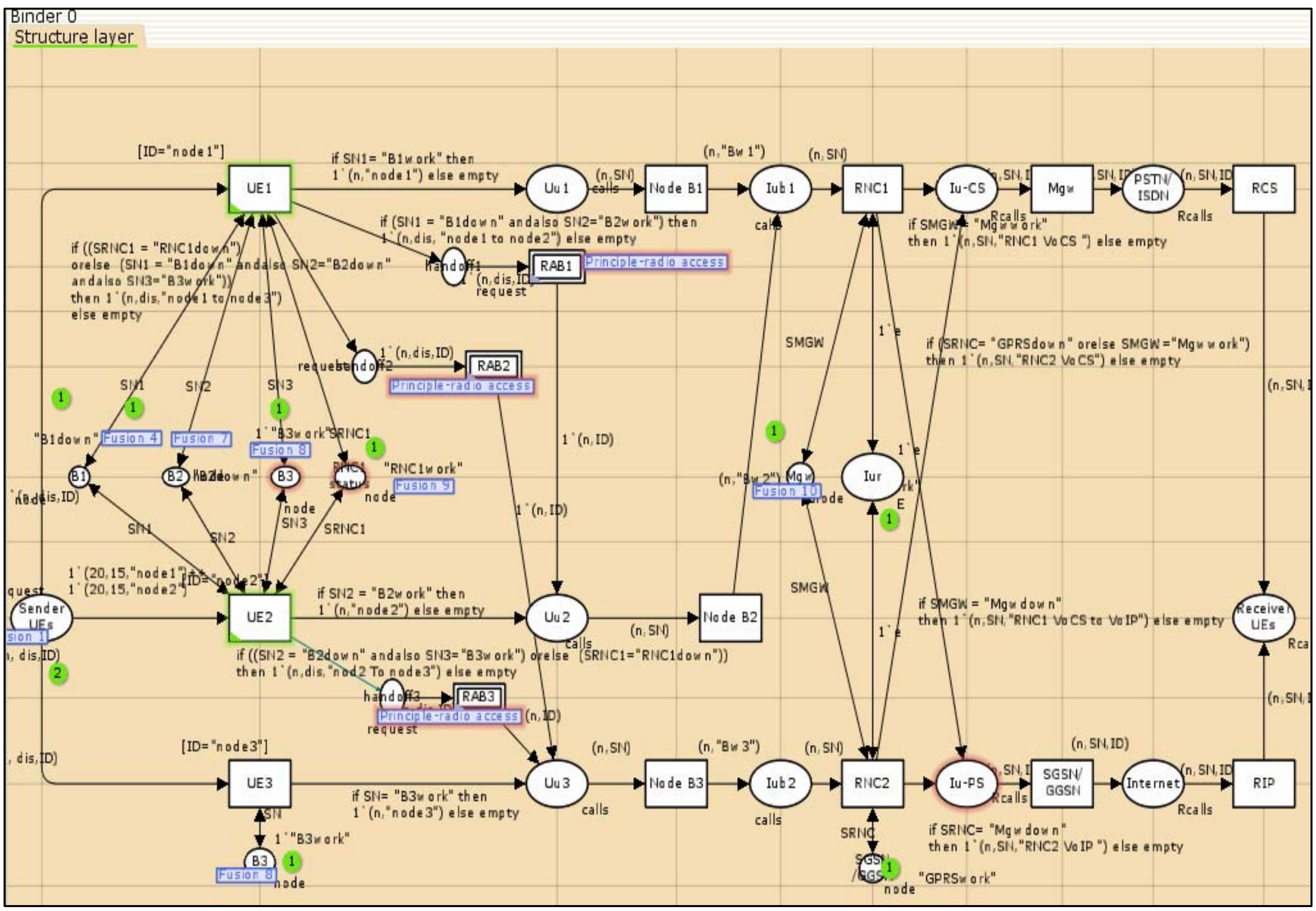


Figure 6.5 Structure layer.

The structure layer of the WCDMA system consists of 10 kinds of places and 11 kinds of transitions. The corresponding notations are described in Table 6.3. The structure layer of the CPN model describes the system structure and the state variables. Each of the transitions shows the behavior of the system and each place shows the system state after the corresponding event is fired.

Table 6.3 Notations of structure model.

Place	Description	Transition	Description
Senders (UEs)	Mobile users for demanding services	UE	Transmit voice signal between users and network
Uu	Radio signals governed by air Interfaces protocol	RAB	Establish Radio Access Bearer
B (1..3), RNC1, MGw	Working status of Node B, RNC1,MGw	Node B (1...3)	Transmit/receive radio signal from/to mobile users
Iu-b (1…2)	Formatted data governed by the Iu-b protocols	RNC (1...2)	Control radio access and allocate radio resource
Iu-r	Formatted data governed by the Iu-r protocols	Mgw	Establish traffic bearer and allocate the resource in CS domain
Iu-CS	Formatted data governed by the Iu-CS protocols	GPRS (SGSN/GGSN)	Establish traffic bearer and allocate the resource in PS domain
Iu-PS	Formatted data governed by the Iu-PS protocols	RCS	Transmit and rout the data through CS network
PSTN/PLMN	External telecommunication network	RIP	Transmit and rout the data through IP (internet) network
Internet	External computer data network		
Receivers	The mobiles users being called		

The structure comprises the components for traffic bear services in a tree root for the network topology. The traditional real time voice traffic is transmitted through the circuit switching network via the Node B, RNC, MGw under the control of the signaling nodes. The VoIP, Non-real time voice, is transferred from UE through Node B, RNC, GRPS network, IP network to the receivers.

Other components such as MSC server, HLR, EIR, and SS #7 for signaling control and database management are not shown in the structure layer. Those components are highly reliable and resilient under accidents. Therefore, these components are supposed to function even in the emergency situations. Their functions are applied in the principle layer to control the network components for data transmission (i.e. the components in the structure layer).

6.3.3 Modeling the principle of the example WCDMA system

After modeling the structure layer of the example WCDMA system, the principle to govern the behavior of the system structure is modeled for the functional subsystems. The principle layer of the CPN model is constructed based on the control mechanism of the example WCDMA system described in Section 3.3.3 and the principle knowledge base described in Section 5.4, respectively. Thus, the CPN principle layer is designed from two aspects: the Radio Resource Control (RRC) and Switching and Routing Control.

(1) Modeling the principle of the CPN model based on RRC control rules

Based on the handover rule, when one of the Node Bi (i=1…3) is failed, the impacted call services will be taken over by other available Node Bi. The handover principle to the example WCDMA system is simply defined as follows.

- If Node B1 fails, Node B2 takes over the service from Node B1.
- If Node B2 fails, Node B3 takes over the service from Node B2.
- If Node B1 and B2 fail, Node B3 takes over their services.
- If Node B3 fails, Node B2 takes over the services from Node B3.
- If RNC 1 fails, RNC 2 take over the service from RNC1.

Based on the PC, CAC and AMR rules, the maximum capacity and coverage of the Node Bs are considered to support the continuous services in the event of system failure. As the coverage range is also related with the capacity of the Cell of each Node B, coverage is simply considered as part of the capacity of each Node B. It is estimated that each node can reach its potential capacity to 30% after the disaster occurs. The control mechanism was designed in the principle layer for radio access (see Figure 6.6). The capacity of a WCDMA network is defined as the maximum number of simultaneous users for all services.

(2) Modeling the principle of the CPN model based on Switching and Routing function

Since the main function of the Core Network (CN) is for data switching and routing over the Circuit Switch (CS) and Packet Switch (PS) network. It is assumed that the traffic capacity of CN components is always sufficient before and after disasters. The switch function of CN network as the routing table is simply defined as follows.

In normal operation of the example WCDMA system, the rules are generalized as follows:

- RNC 1 route the real time voice traffic through MGw to Receivers
- RNC 1 route the Non-real time traffic through GPRS to receivers
- RNC 2 route the real time voice traffic through MGw to Receivers
- RNC 2 route the Non-real time traffic through GPRS to receivers

In partial failures of the system, the rules are generalized as follows:

- If MGw failure, RNC 1 route the real time voice traffic through GPRS to Receivers
- If MGw failure, RNC 2 route the real time voice traffic through GPRS to Receivers

The failure of GPRS network is not considered, as the GPRS network is considered as a node of Internet. Internet is a mesh network with highly redundant routing node such as routers, switch, and bridges. Meanwhile, the IP backbone based PS network is the trend for the communication network which is under the way to replace and cover an entire heterogeneous network including the CS network. The state of the place 'MGw' in Figure 6.5 controls the handover function above. The state of the places is the output from the threaten scenarios to the WCDMA system.

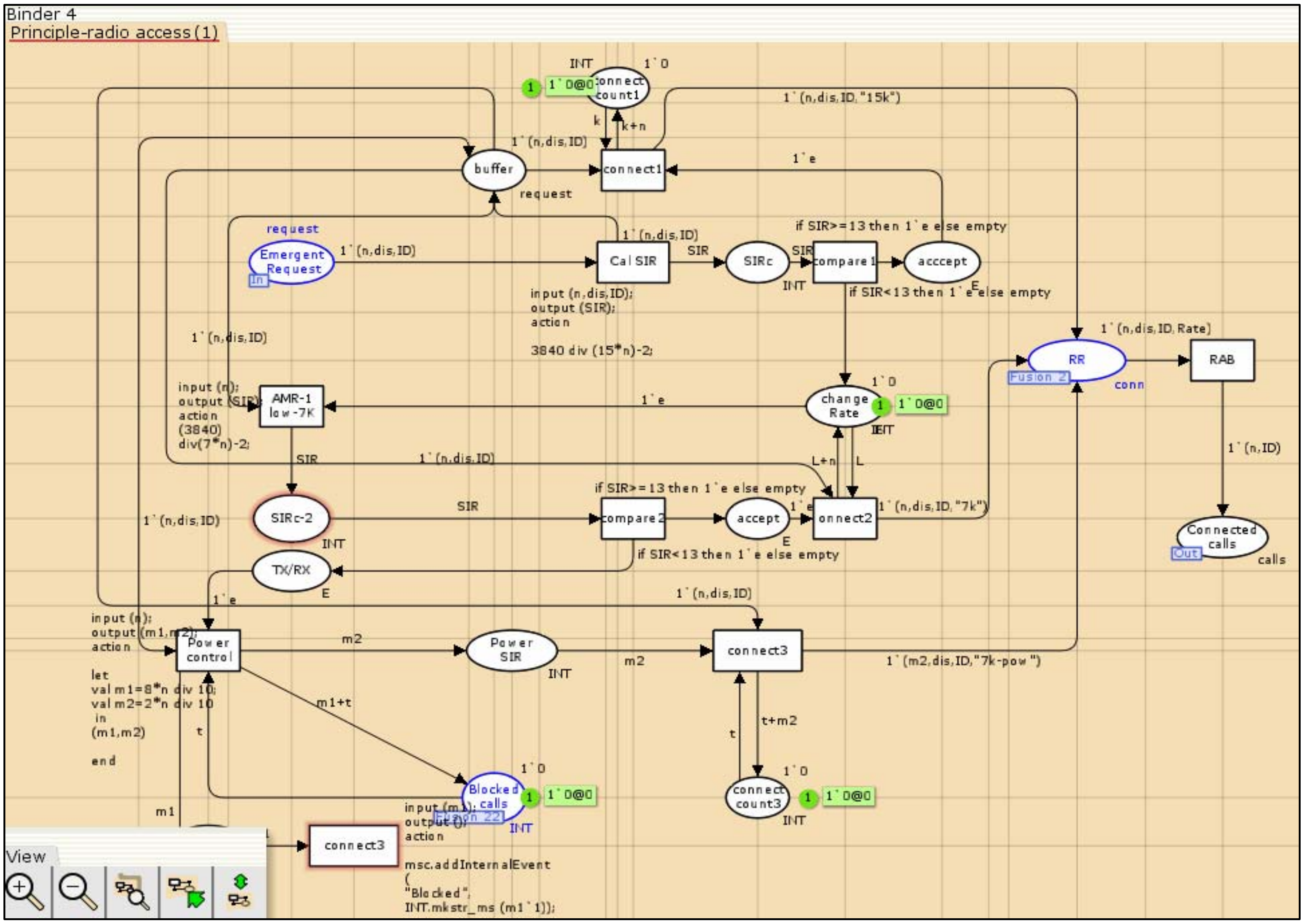


Figure 6.6 RRC principle layer.

6.3.4 Modeling the threaten of the example WCDMA system

The model of the threaten scenario was designed based on the impact of emergency to the network components and the severity of impact to the service continuity when the relevant components are damaged due to emergency or disasters.

The example threaten scenario is represented by the color set of token and corresponding places in Figure 6.7. The occurrence of the node failure is simulated by a random time of Poisson distribution. The failure of system components with low severity to services takes place most frequently. The failure of the components with high severity to service takes the least time. The failure of the medium severity takes place in frequency between the preceding two situations.

After the components are damaged, the network manager will take decisions to recover the failed components. There can be more solutions to recover the failed components. For instance, new equipment can be delivery to replace the failed ones; the recovery team can be sent to fix and restore the failed equipments, emergency telecommunication vehicles can run to the site and take over the function temporarily, or satellite communication can be deployed to solve the service outage, etc. In this model, all the recovery actives are represented by the repair time.

Therefore, the failure frequency and recovery time are defined to different system components based on their roles in the system as follows.

- The system components, Node Bs, have low severity to services, highest failure frequency, and shortest repair time. The failure frequency is defined to follow Poisson random process with the expected number of occurrences with time unit 3.0 to 5.0. The time unit can be day, hour, or seconds by the designers. The Mean Time to Repair (MTR) is relatively short and the repaired mean time is defined with time unit 10.

- The system components, RNCs, have middle severity to services, middle failure frequency, and middle repair time. Thus the failure frequency is defined to follow Poisson random process with the expected number of occurrences with time unit 4.0 to 6.0. The Mean Time to Repair (MTR) is relatively longer than Node Bs, and the repaired mean time is defined with time unit 20.

- The system components, MGw and GPRS, have highest severity to services, least failure frequency, and longest repair time. Thus the failure frequency is defined to follow Poisson random process with the expected number of occurrences with time unit 6.0 to 8.0. The Mean Time to Repair (MTR) is relatively longer than Node Bs and the repaired mean time is defined with time unit 30.

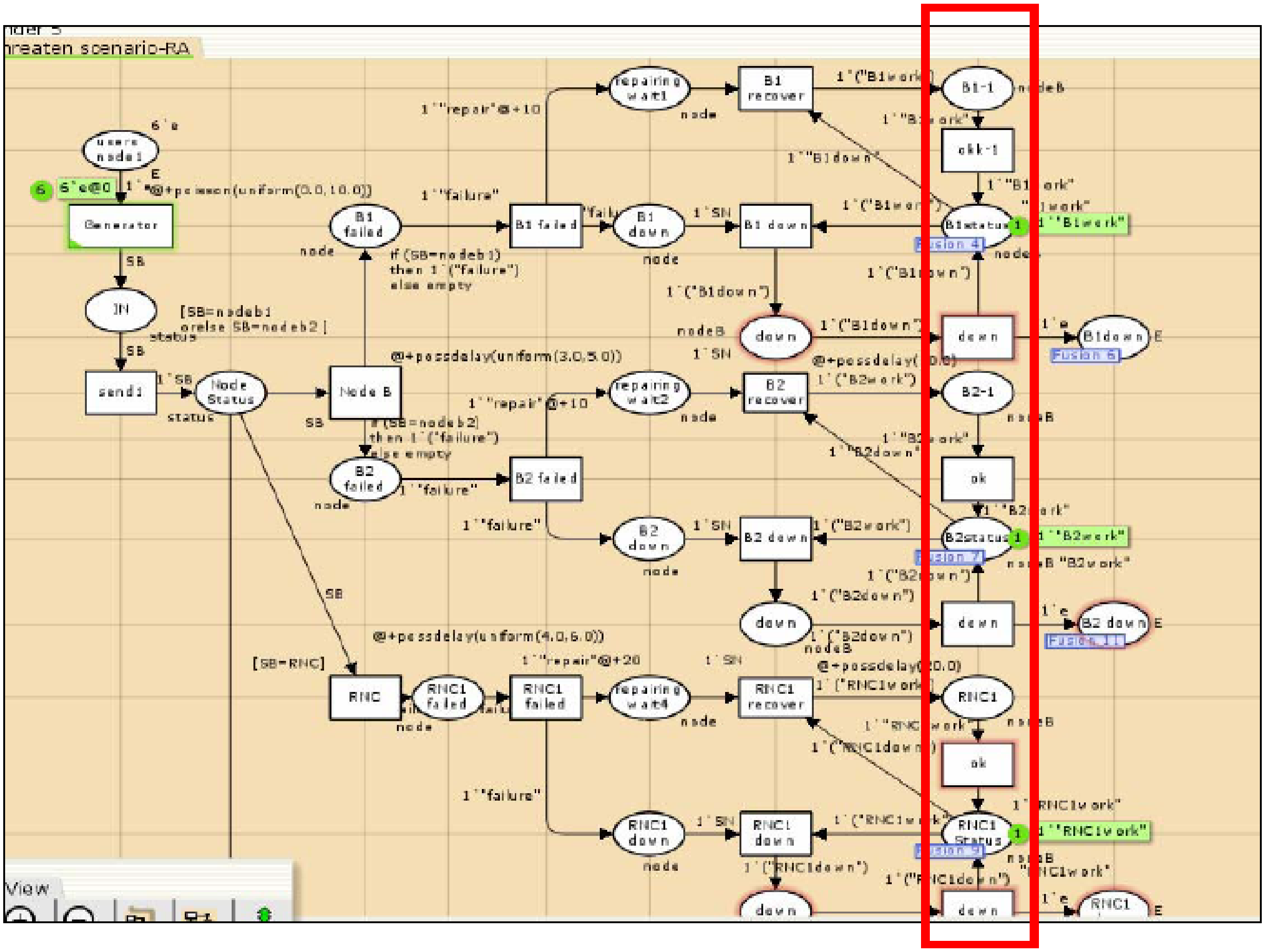


Figure 6.7 Threaten scenario of the WCDMA system.

6.3.5 Modeling the demand of the example WCDMA system

The model of the demand was designed based on the service request from the mobile users. The demands of call service follow the Poisson process. In Figure 6.8, the average service demands of each radio cell and the maximum capacity of the each Node B are simply defined as follows:

- The average service demands to the Node B1 are within 10 to 20 in the time unit; the maximum capacity of the Node B1 is 30.

- The average service demands to the Node B2 are within 10 to 20 in the time unit; the maximum capacity of the Node B2 is 35.

- The average service demands to the Node B3 are within 20 to 30 in the time unit; the maximum capacity of the Node B3 is 40.

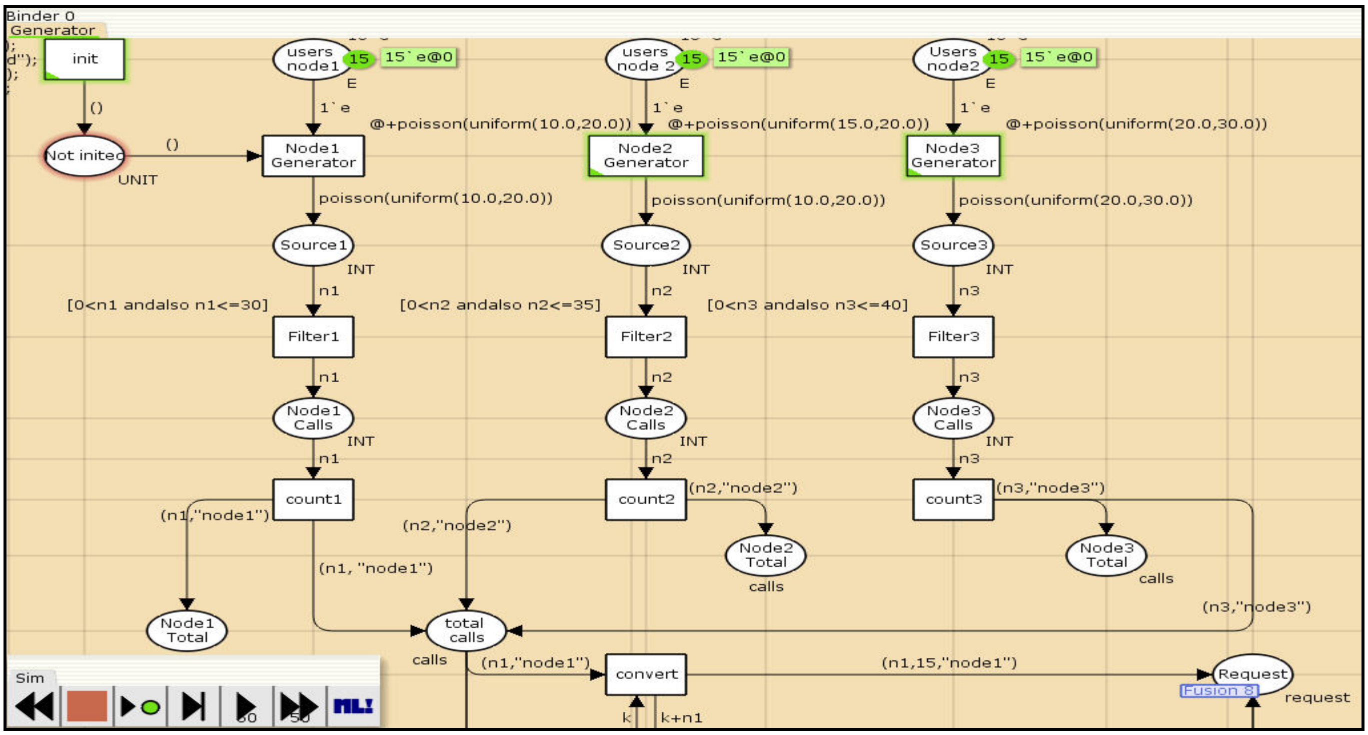


Figure 6.8 Demand generator.

6.4 The performance of the WCDMA PN model

The PN model of the WCDMA system can be coded into a simulation system for the dynamics of the WCDMA system to analyze the system performance. There are several applications along with the dynamic model simulation system. *First*, with the dynamic model, the emergency manager can validate his or her particular decision through the simulation of the system behavior when he or she has made a decision on the system. *Second*, the emergency manager can study the system vulnerability through the demand generator and threaten generator engines to test the functionality of the system – i.e., enable to meet the demand with an acceptable QoS under the disaster situations. *Last*, the dynamic model will also be useful as a tool for enhancing the service continuity in a normal operation situation.

For all of these potential applications of the PN model, the model should be enabled to predict the state and behavior of the WCDMA system so that network manager can be aware of the system performance. The simulation of the WCDMA system shows the states and behaviours of the WCDMA system. The information flows among the components. The system behaves under the governing principles and responds to the impacts from the external disturbance. In this case, the WCDMA system behaves with different states facing the external demands from users and the disruption to the system structure due to the emergency or disasters. In the following, performance of the system is shown through the simulation of selected states and behaviors of the WCDMA system and is discussed with two parts: (1) MSC and histogram chart for interaction among system components, and (2) systematic block rate and capacity.

6.4.1 MSC and histogram chart of the WCDMA system

Figure 6.9 shows the behavior of the WCDMA system by the MSC (Message Sequence chart). The MSC (Message Sequence Charts) is a graphical and textual language for the description and specification of interactions between system components (Westergaard and Lassen 2006). The MSC is used to give an overview of the communication behaviors of the WCDMA system – especially the switching system.

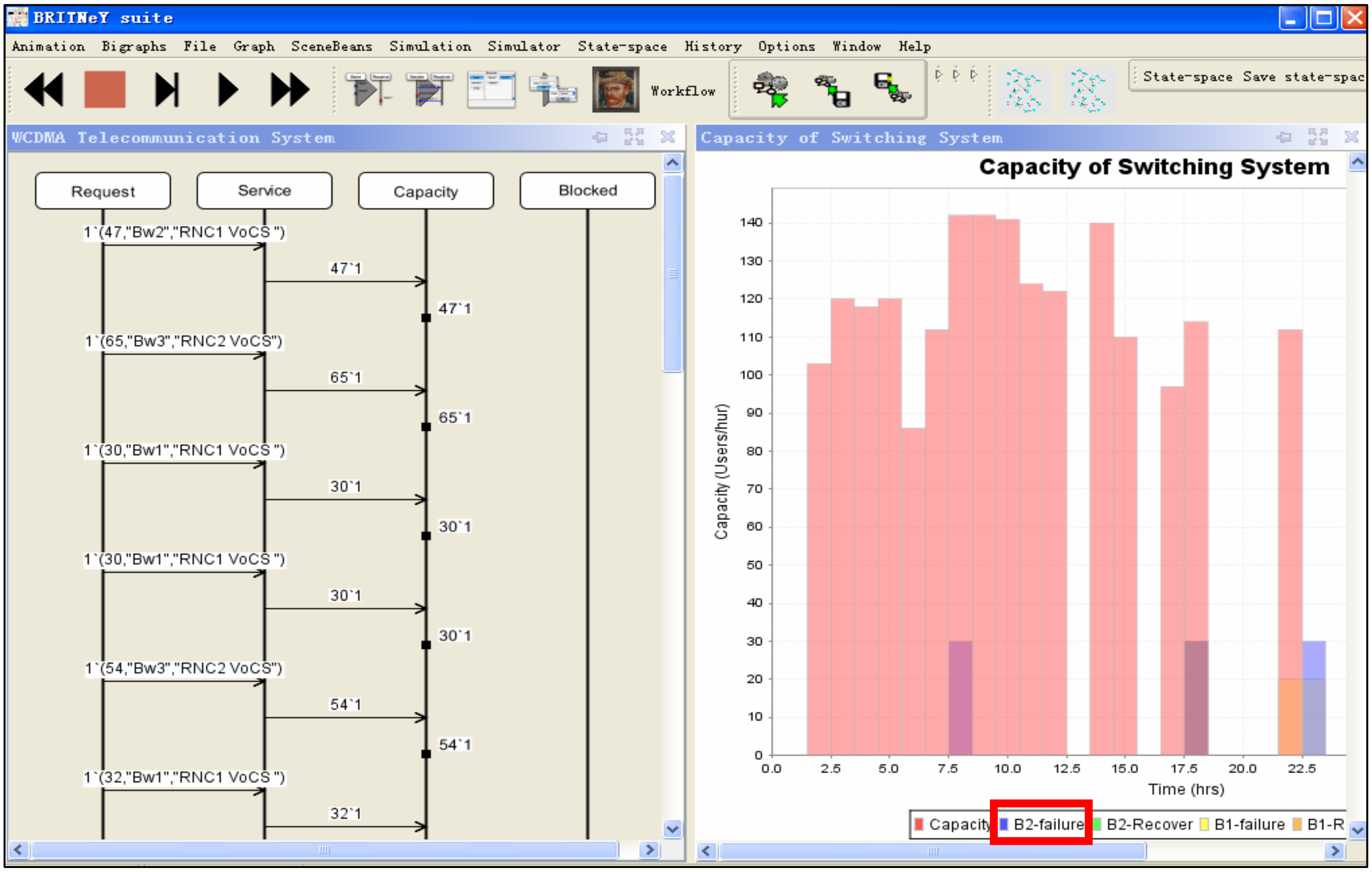


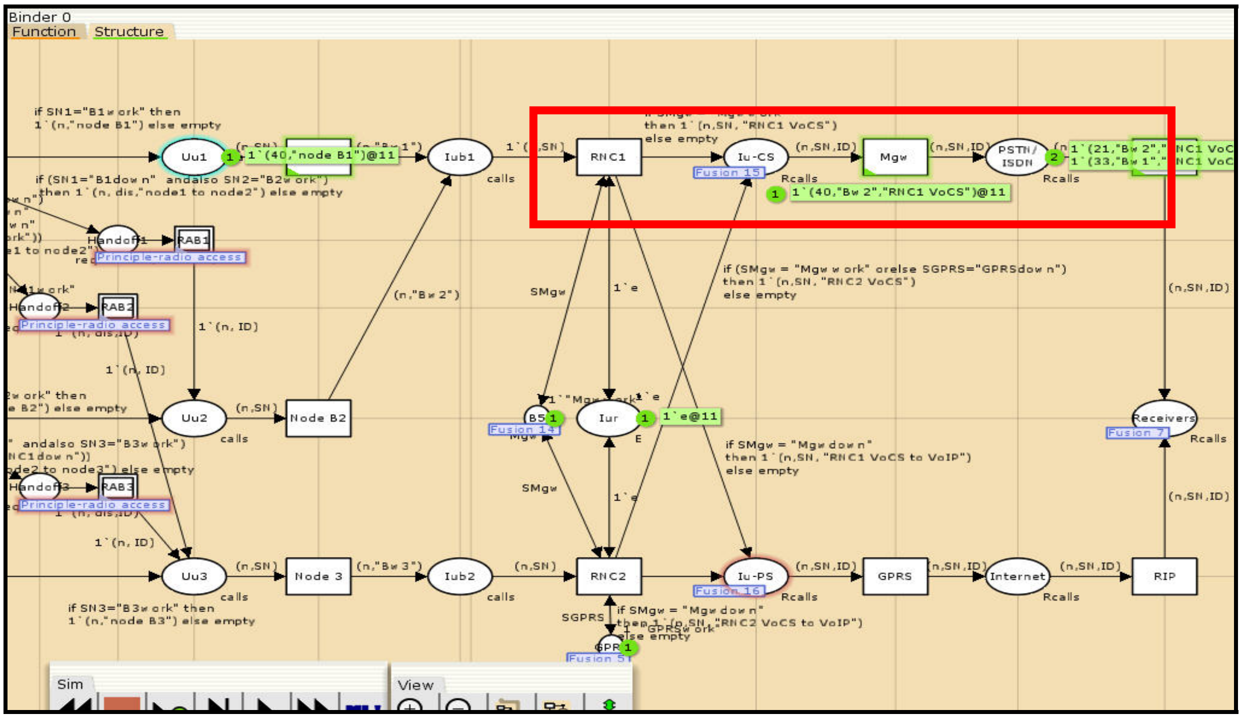
Figure 6.9 MSC and histogram chart.

The MSC chart in Figure 6.9 captures a scenario in which there are requests from users who need the services of the WCDMA system. The WCDMA system supplies the service to meet the demands. The information 1'(47,"Bw2", " RNC1 VoCS") between the two functions "Request" and" Service" shows that 47 users connect to the WCDMA system through Node B 2 radio channel, Node B2 is under the control of RNC 1, and the traffic data are transported through the circuit switch network backbone from the sender to the receivers. The function "Capacity" (47'1) means that 47 traffic channels are assigned to the users. The system still has enough capacity available so no any traffic is blocked. The vertical lines represent the life-lines of the processes taking the four function parts in the scenario. As usual, time is assumed to flow downwards along each life-line. The directed arrows going across the life-lines represent the causal link from a send event (the source of the arrow) to the corresponding receive event (the target of the arrow) with the label on the arrow denoting the message being transmitted.

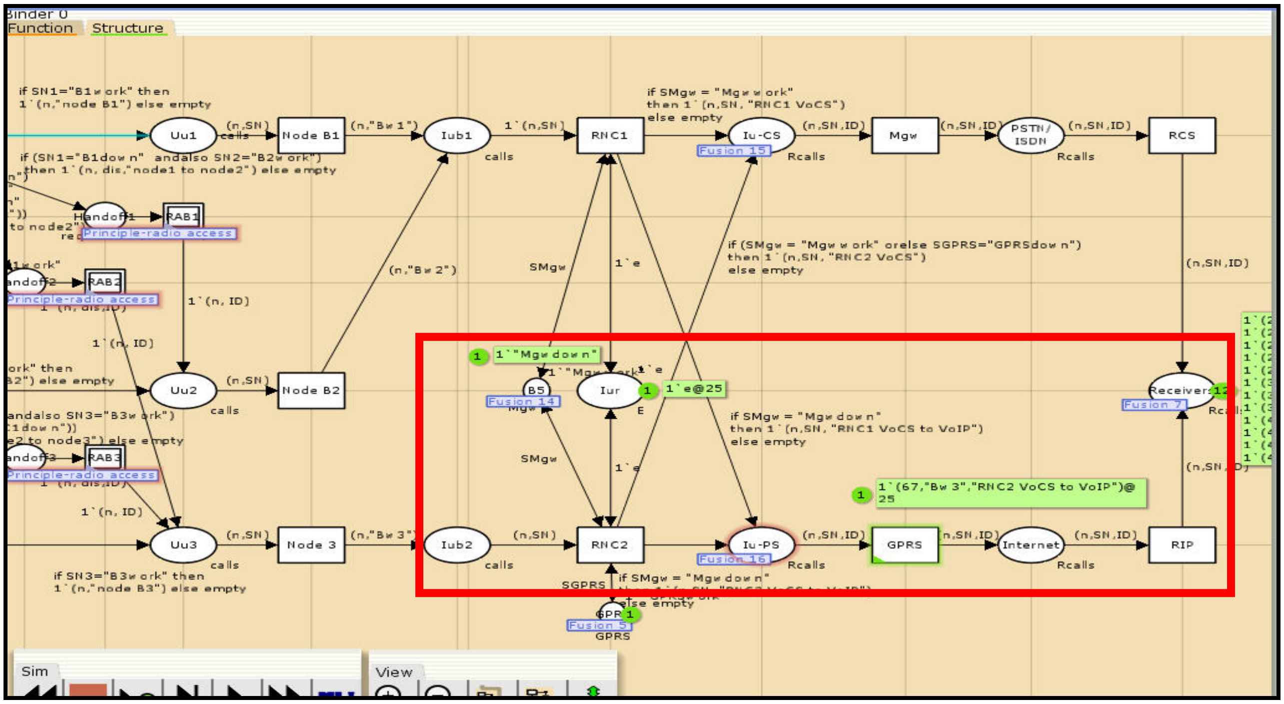
The histogram chart (Westergaard and Lassen 2006) on the right side of Figure 6.9 shows the system capacity states in a different time and under a different system structure failure. For instance, at the time of 2.5 hours, the capacity of the system is 105. At the time of 7.5 hour, the capacity of the system in the normal operation is 140, but the actually available capacity is 110, because Node B2 failed (which causes the outage of 30 of the capacity). The damaged state of Node B2 is shown on the bottom of the histogram chart as "B2- failure" (see Figure 6.9). The corresponding states of the components can also be shown in the places in the threaten layer and structure layer. In the structure layer, we can view the token in the Petri Net places 'B (1..3)', place 'RNC1', and place 'MGw'. The tokens fired into these places are from the places in the layer of the threaten scenario such as place 'B1 status', 'B2 status', 'RNC1 status' (see the red rectangle box shown in Figure 6.9).

The corresponding status of the reconfiguration is shown in the structure layer by the token flow. For example, the tokens which indicate the voice traffic are transmitted through the Circuit Switch network (see Figure 6.10a). The meanings of a part of tokens are shown as well (see tokens highlighted with a red rectangle in Figure 6.10a). For example, the color token 1'(40, "B w2", "RNC1 VoCS" @11) means that at the time 11 hours from the beginning of system operation, there are 40 users who have got the services from the system component Node B1. "B w2" stands for Node B2 working, "RNC1 VoCS" means that "RNC1" and "MGw" are available for the CS function. To provide these functions, the corresponding components are Node B2, Node B1, RNC1 and MGw.

Suppose that at the time 25 hour, the component Media Gateway (MGw) failed. The tokens which indicate the voice traffic are thus transmitted through the Packet Switch network (see Figure 6.10b). The meanings of the relevant tokens are shown as well (see tokens highlighted with a red rectangle in Figure 6.10b). For example, the color token 1'"Mgw down" means that the component "Media Gateway" was outage. The color token 1'(67, "B w3", "RNC2 VoCS to VoIP" @25) means that at the time of 25 hours from the beginning of system operation, there are 67 users who get the services from the system component Node B3. "B w3" stands for Node B3 working, "RNC2 VoCS to VoIP" means that RNC2 is working and voice traffics are transferred through the Packet Switch (PS) network and Internet. The component "GPRS" which provides a packet switching function takes over the backbone role in replace of the damaged component "MGw". To provide the PS function, the involved components are Node B3, RNC2, and GPRS.



(a) Voice over CS (VoCS).



(b) Voice over IP (VoIP).

Figure 6.10 Status of the reconfigurable WCDMA system

6.4.2 Systematic block rate and capacity

There are two typical parameters, ‘Block rate’ of the calls and ‘Capacity’ of system, measured in order to evaluate the performance of the WCDMA system. Block rate of the calls is described in the discrete time sequence. It indicates the fraction of user’s demands at certain time that can not be accepted by the system due to the lack of the service capacity of the system, especially under threatens of outside disasters or emergencies. In other words, ‘Block rate’ shows the percentage of rejected calls to the total call requests from mobile phone users at a discrete time. i.e. Br = Rc/Ts (where: Br = Block Rate of calls, Rc= Rejected calls, Ts= Total calls from subscribers).

The parameter of 'Rc' is shown by the token in place 'Blocked call'; the parameter of 'Ts' is the sum of rejected calls (Rc) and connected calls. The parameter of the connected calls is shown by the token in place 'Connected call' (see Figure 6.11).

Figure 6.11 shows part of information in the output file of the CPN model. It shows the system state information after simulation of 237 steps. For example, 'after step: 237' means after the simulation of 237 steps, the place 'Blocked calls' shows the token '1`139@9', which means that 139 calls are rejected after 9 hours; i.e, Rc=139. The place 'Connected calls' shows the token '1`258@8', which means 258 calls are connected after 8 hours. The Ts is calculated, i.e., Ts=139+258=397. Then, the approximate 'Block rate', i.e., Rc =139/397=0.35.

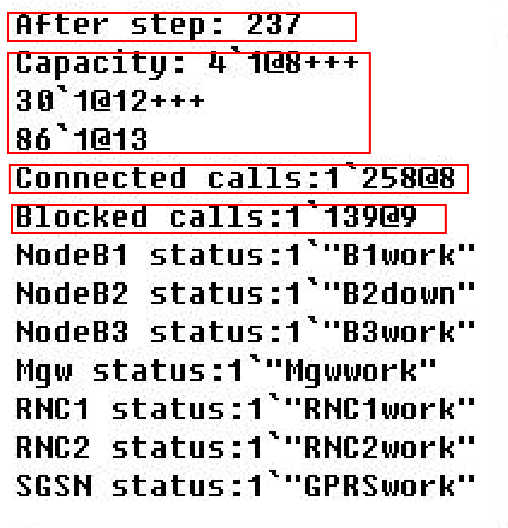
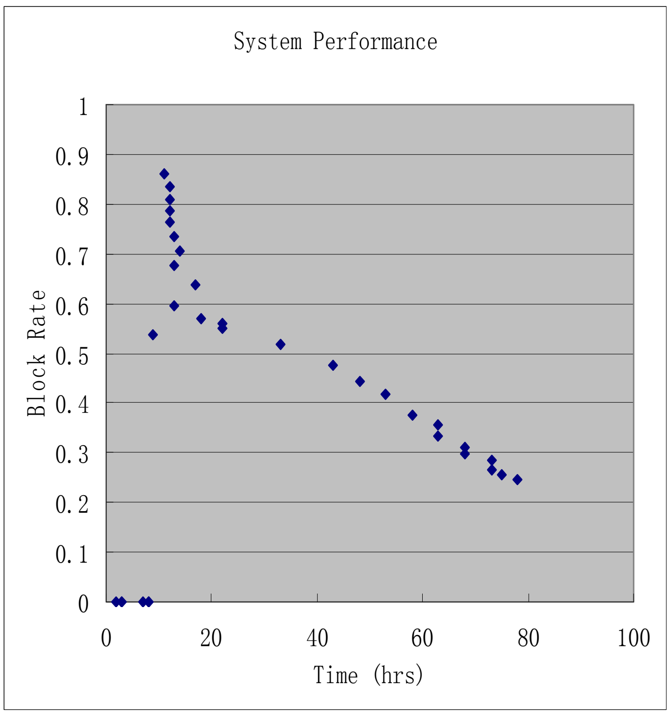


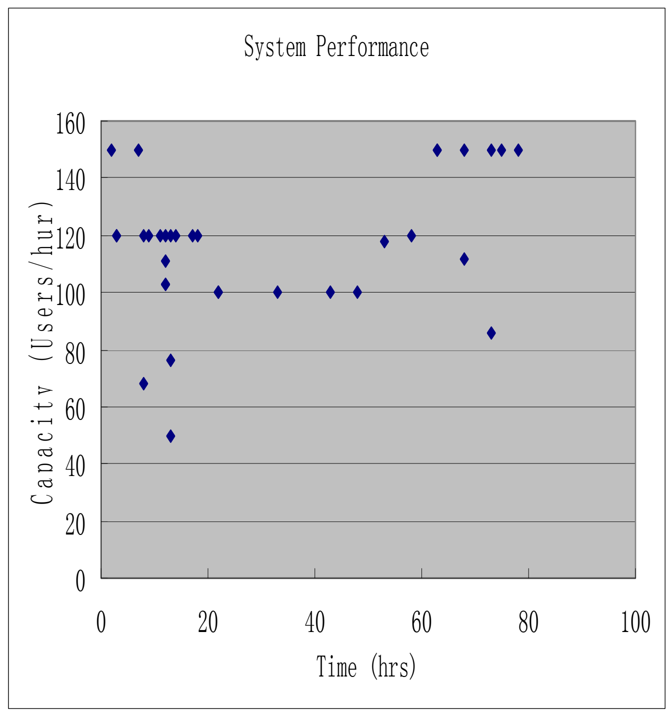
Figure 6.11 Output file of CPN model

Capacity of the system is shown by the token in place 'Capacity' (see Figure 6.4); the parameter of 'Capacity' is the sum of the tokens in the place. For example, in Figure 6.11, after the simulation of the 237 step, the place 'Capacity' shows three tokens: token '4`1@8++' means there are 4 idled available channels after 8 hours; '30`1@12++' means there are 30 idled available channels after 12 hours; '86`1@13'means there are 86 idled available channels after 13 hours. Thus, the total 'Capacity' is 120 after 13 hours.

Figure 6.12a shows a snapshot of the 'Blocked rate' and 'Capacity' from the beginning of the operation up to100 hours based on the output file from CPN dynamic model. The block rate to the user's demands is Zero at the beginning of the system operation. It means the WCDMA system is in a normal operation state, which can provide necessary services to all users. At the time (17 hrs), there is the peak block rate that shows the system can not provide enough services to the user and the system performance severely degraded. Figure 6.12b also shows the system capacity change following the state change in a different time when the structure of the system is changed due to the impacts from external factors.



(a) Block rate of WCDMA system.



(b) Capacity of WCDMA system.

Figure 6.12 Statistic of Systematic block rate and capacity.

6.5 Related work

There are other works in which the Petri Net are used in the telecommunication system. In general, these works only examine system dynamics partially or in one angle of view. For instance, Kurt et al. (2007) only applied Colored Petri Net to model a data transmission protocol of the telecommunication system to verify the reliability of the system. Klaric et al. (2001) only applied Petri Net in the ISDN to model call set up and the charging process. Boubour et al. (1997) limited to examine the faults detection and alarm observation. Bruno et al. (1994) proposed to apply Hierarchy Petri Net in develop the telecommunication software to supervise a railway network; the essence of the approach is still limited to examining the reliability of the protocol and rule to control the railway system. There are few works to study an entire telecommunication system; there are few works to examine the survivability of the telecommunication system.

There are works in which the Hierarchy Petri Net are used to study the dynamics of the manufacturing system. For instance, Bruno et al. (1994) proposed to apply Hierarchy Petri Net in develop the telecommunication software to supervise a railway network. Each individual hierarchy layer models the different functions (i.e., ground processor function, and radio processor). The two functions are modeled in different layers, and they interact with each other. The Hierarchy Petri Net Model presents a relationship among different functions, but it does not represent an entire system in terms of the function, structure, and principle. Zimmermann and Hommel (1999) applied Hierarchy Petri Net to model a complex manufacturing system. The manufacture system is modeled by the hierarchical structure, process, behavior, and work plan (states) separately. The work of Zimmermann and Hommel (1999) seems better to represent a system; but we argue that their model still lacks an explicit system design concept and lacks a concrete methodology to make the system design method more practical. Their approach may be limited only to their specific work domain (i.e., manufacture system).

Our proposed FCBPSS framework based PN approach provides a complete view of system dynamics as it brings the constituent elements (structure, behavior, principle) together under one framework. The approach may not only be useful to telecommunication systems but also to other critical infrastructure system such as physical facilities, electric power generation, transportation, and water supplier system.

6.6 Conclusion with discussion

This chapter presents a dynamic model of the example WCDMA system. Since the example WCDMA system is a typical system that has the major features of the WCDMA system, the modeling approach presented in this paper can be applied to other telecommunication systems and other complex dynamic systems as well. The proposed modeling approach has the following unique features: (1) Hierarchy CPN modeling structure (2) Integration of CPN tool with the FBS framework. With these two features, the bottle-neck problem with a PN model, for whatever types of Petri Nets, can be further tackled; in other words, the complexity of a PN model can be reduced with the FBS-PN approach. This benefit is extremely significant to modeling complex dynamic systems with PN and making the PN model more practical for large systems.

In conclusion, integration of the FBS and PN in structuring the PN model into three layers, namely the function layer, structure layer, and principle layer, is naturally representing the dynamics of a complex system. Such a division allows for the implementation of a paradigm called total system modeling. The proposed modeling approach demonstrates a highly promising way to model the complex dynamics of a service system aiming to be further used in the control and management system for the complex service systems.

Chapter 7

Decision making support system

7.1 Introduction

In this chapter, it will be discussed how the models and systems that were described in the preceding chapters can be integrated into a high level system that can be useful for the managerial team or manager in emergency situations. Such a system is called Decision Making Support System (DMSS). The architecture of such a system will be developed. With this in the mind, the remainder of this chapter is organized as follows. In Section 7.2, the concept of DMSS and its system architecture is presented. Section 7.3 shows detailed information of the system components. Section 7.4 shows the operation of DMSS through an example. Section 7.5 is a conclusion with discussion.

7.2 Architecture of Decision Making Support System (DMSS)

DMSS assumes that the emergency manager should not be required to know the Petri Net model; instead they should focus on the semantics of the system and making decisions which are expressed in a meaningful way to the manager. In particular, the DMSS should be able to provide the manager with the following pieces of information: (1) a summary of system behaviors and performances, (2) a throughput of the traffic passing through the switch node, and (3) reconfigured alterative routes to cope with faults which cause damages of the system. Further, the DMSS should provide an interface for the manager to cast his or her decision into the system.

To meet the above requirement, the architecture of the DMSS is proposed as shown in Figure 7.1. In this figure, there are four modules: WCDMA domain model (Chapter 4) with which a particular WCDMA system is rooted, WCDMA PN model (Chapter 6) which represents the dynamics of a particular WCDMA system, and WCDMA reconfiguration knowledge base which supports system reconfiguration (Chapter 5). There are two kinds of humans involved in DMSS: emergency manager and system designer. The system has three interfaces covering human-human interface, human-computer interface, and computer-computer interface. The reconfiguration knowledge base system is also called Human Assistance System (HAS) which can be viewed as a machine decision maker; yet it is only an "assistant" to the manager. More generally, the HAS and human manager work together to manage emergency situations. This thesis study focused on Interface 1, Interface 2, and Interface 3 (partial) only.

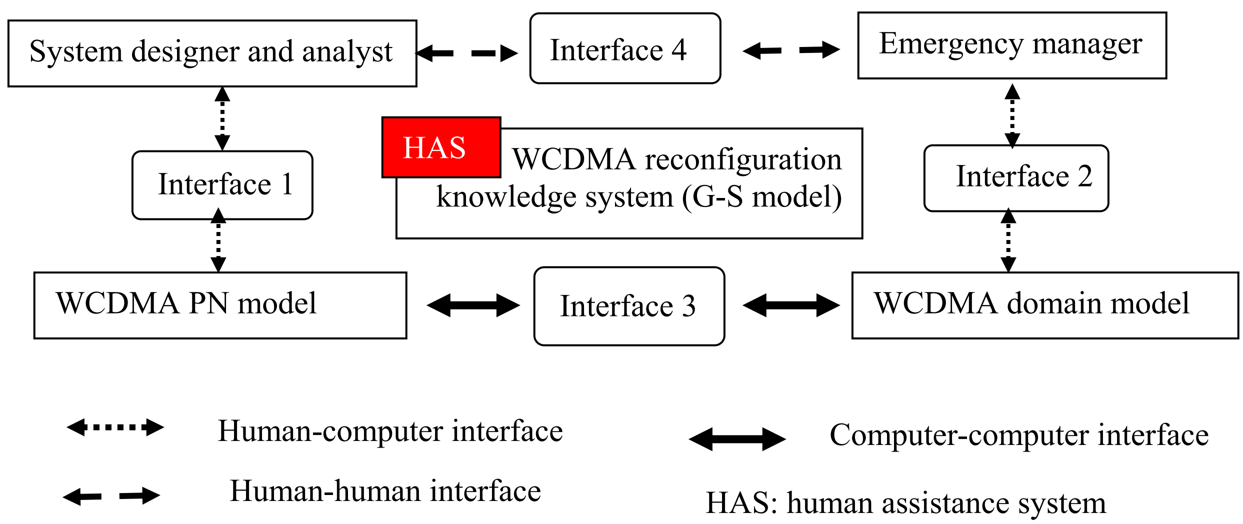


Figure 7.1 A framework of the DMSS system

7.3 Interface Module Development

7.3.1 Interface 1

Interface 1 is a graphic user interface (GUI) for constructing a CPN model of a dynamic system, and it was developed using CPN Tools version 2.2.0 (Copyright © 1999-2004 CPN Group, University of Aarhus). Figure 7.2 shows a screenshot of CPN Tools (Kurt et al. 2005). The rectangular area on the left is the index window. It includes the Tool box for a CPN model. Additionally, it contains tools for manipulating the graphical layout and the appearance of the CPN model. The index window also contains tool for model which shows a variety of information such as the name of the model, the declaration for the model, the modules of the model, and the hierarchical structure of the model (CPNTOOLS 2007).

The remaining part of the screen is the workspace contains a suite of tools (CPNTOOLS 2007， Kurt et al. 2005) which are briefly described in the following:

- A tool named 'binder 0' allows define CPN model (see Figure 7.2).
- Tools called 'SIM' and 'SS' are to operate the model to examine the state and behavior of the model.
- Another rectangular window is called 'tool palette' which contains a set of tools to edit the CPN model.
- A tool with a circular shape allows specifying markings.

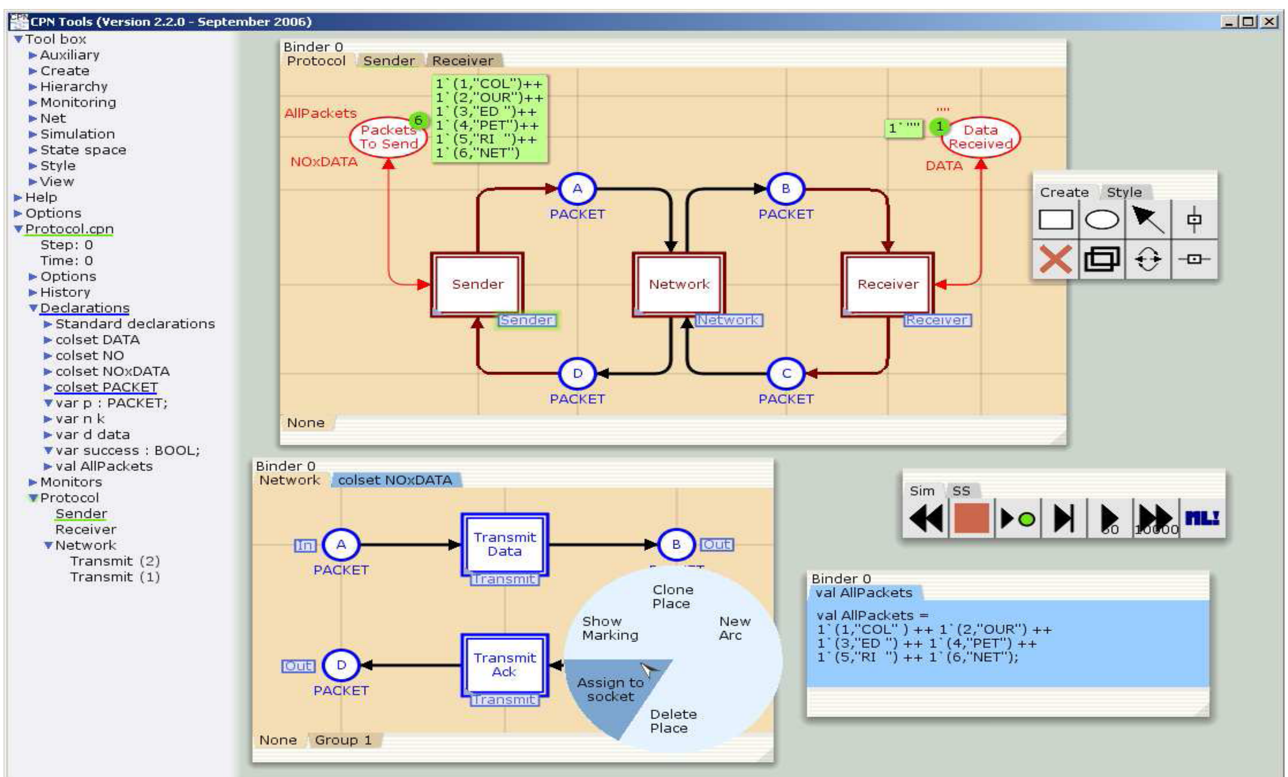


Figure 7.2 Interface 1 – for system designer (Kurt et al. 2005).

The state and behavior of a CPN model are further examined by a program called 'BRITNeY Suite'. BRITNeY Suite provides access to the data structures and a simulator for Colored Petri Nets via a powerful scripting language and plug-in-mechanism, thus making it easy to perform customized simulations and visualizations of CPN model (Westergaard n.d.).

Figure 7.3 shows the relationship between the BRITNeY suite with CPN Tools (Westergaard and Lassen 2006). CPN Tool is split into two components, an editor and a simulator. The BRITNeY suite animation tool, in the right part of the figure, communicates with CPN Tools using a standard remote procedure call protocol, called XML-RPC, in order to allow vendors of other tools to directly integrate their tools with BRITNeY suite. BRITNeY suite uses plug-ins to make the actual visualizations and animations. BRITNeY animation tool works together with CPN Tools to make different views on the CPN model. Examples of such views are Message Sequence Charts (MSC), gantt charts, or SceneBeans animations; all of them show the state of the system.

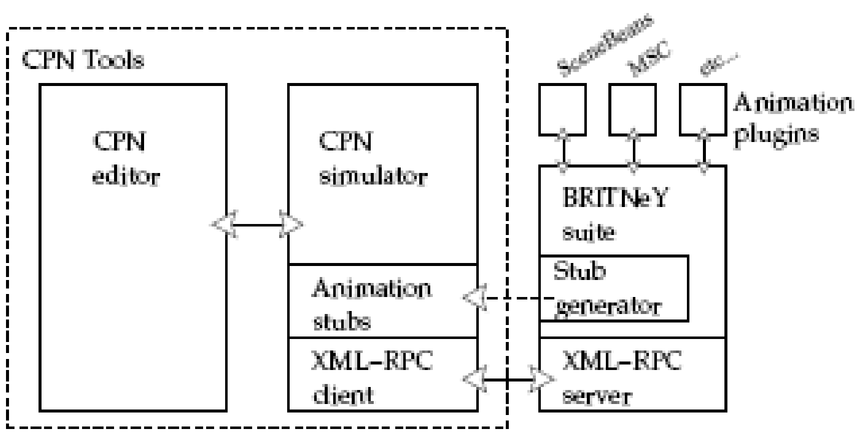
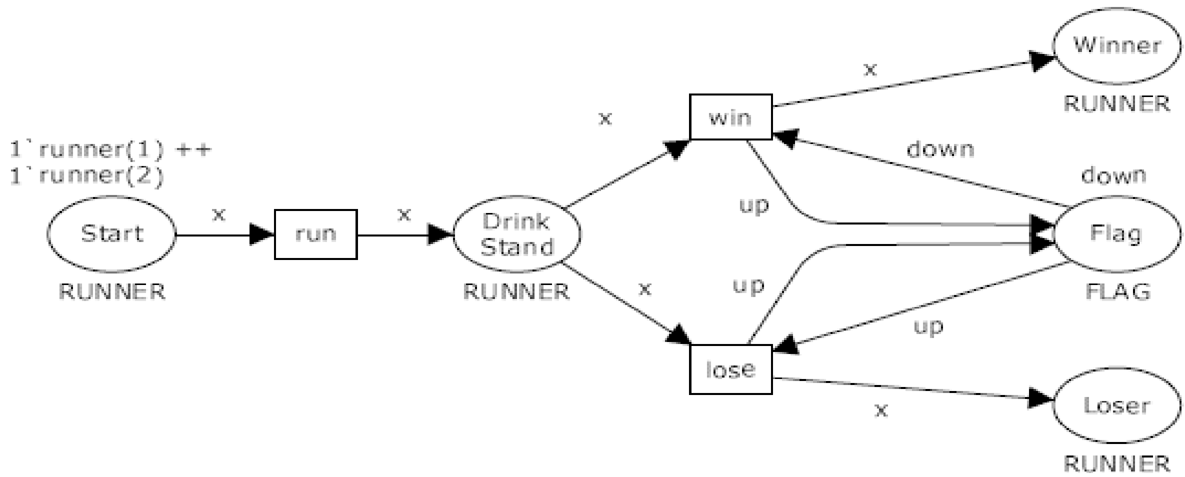
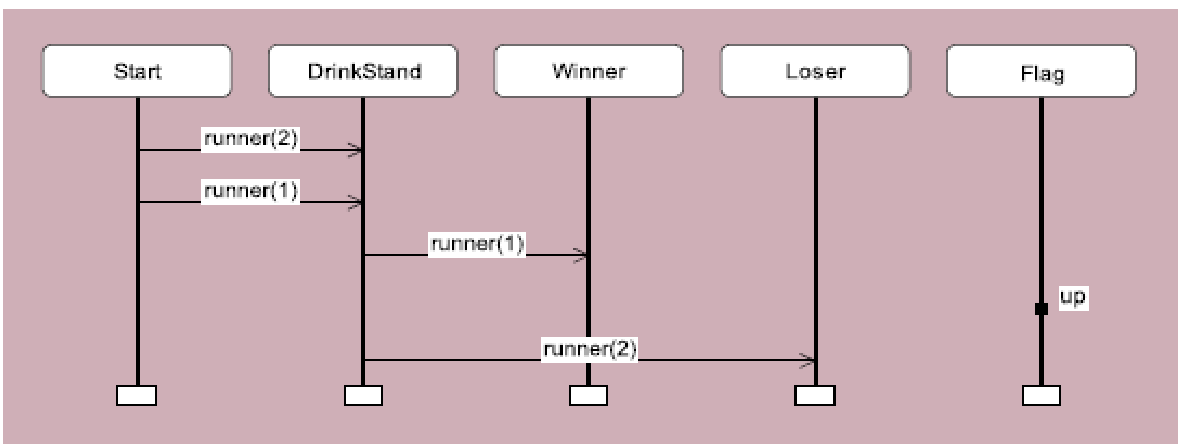


Figure 7.3 Integration of the animation tool with CPN Tools (Westergaard and Lassen 2006).

In the following, a simple example is used to show how the animation tools work with the CPN model (Westergaard and Lassen 2006, Westergaard 2006) in Figure 7.4a and Figure 7.4b, respectively.



(a) A CPN example model of runners (Westergaard and Lassen 2006).



(b) MSC model (Westergaard and Lassen 2006)

Figure 7.4 An example of CPN model.

The CPN model of Figure 7.4a describes that two runners are competing to win a race. It captures the behavior of the two runners modeled by tokens runner (1) and runner (2). Initially the runners are at the start of the race, and they can then continue to the end of the race. During the race, the runners pass a drink stand. When the first runner passes the finish-line, he is declared the winner of the race, and a flag is lowered to celebrate. When the other runner crosses the finish-line, he is declared the loser of the race. Figure 7.4b present the execution of the CPN model and shows the behavior of the two simulated runners using Message Sequence Charts (MSC).

7.3.2 Interface 2

Interface 2 (i.e., the interface between the manager and the domain model as well as the knowledge based system) was implemented with visual basic languages. The design of interface 2 followed the FBS interface design framework (Lin and Zhang 2004, Lin et al. 2006). According to the FBS methodology, the **first step** is to develop a domain model, the WCDMA domain model in this thesis study case; the WCDMA domain model (see Chapter 4) serves for the purpose. The **second step** is to develop a task model which describes what the operator is supposed to do; the emergency manager is the operator in this case. In the emergency management practice, the task of the manager is of cognitive kind- i.e., making decisions according to the actual performance of the system (e.g., WCDMA) in emergency with faults or damages. The task in the physical sense is that the emergency manager communicates with various bodies of emergency management personnel to implement the (cognitive) decision made by the manager, which will then take effect on the real system. The interface, particularly display interface in this case, should have the attributes to allow facilitating the communication of the manager with various personnel. Quite obviously, the state of the system in emergency situations needs to be provided on the interface.

Figure 7.5 is an example interface for the WCDMA system. This interface has three parts: left, middle and right. The left part provides the information about (1) what part of the WCDMA system is currently being investigated, (2) what system function is being examined (e.g. capacity, connected calls, etc.), and (3) the point of the time that the current state of the system in emergency is being examined. The middle part shows the system state and performance which are primary sources for the manager to evaluate the situation, which can further lead to his or her decision. On the right part of the interface, there are control commands for the manager to use to cast his or her decision. One of them is the recovery solution command which will allow the manager to put his or her decision on to the system. It is noted that the manager's decision may not be directly and automatically taking effect on the physical system. The decision may need to be reviewed by another person or so on; however, this is not a part of scope of this thesis study. A further detailed explanation of this display will be provided in Section 7.3.4. The Visual Baisc (VB) code of implementing this interface can be found in Appendix B.

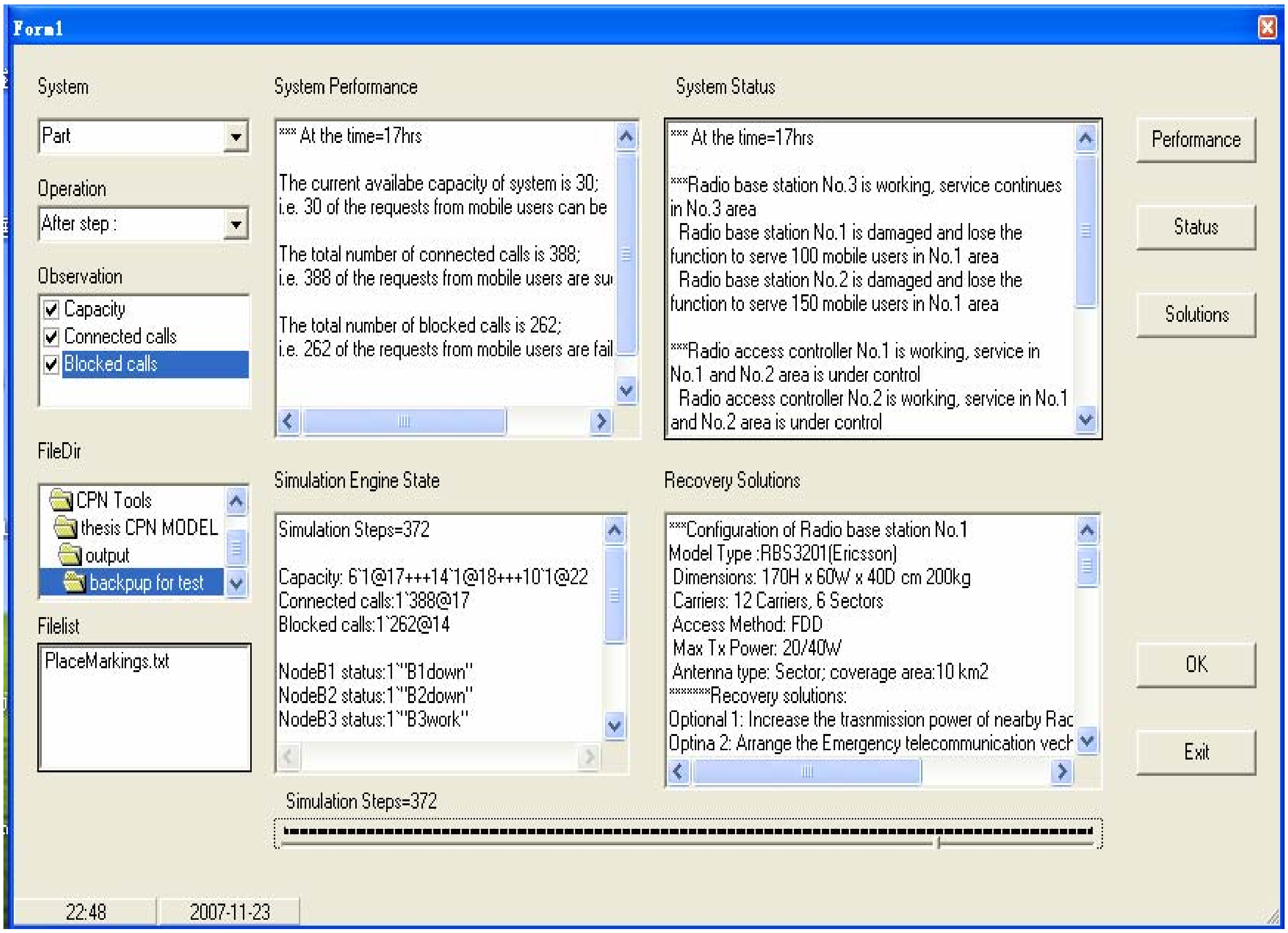


Figure 7.5 Interface 2 – for emergency manager

7.3.3 Interface 3

Interface 3 lies in between the WCDMA model and its CPN model, and it has two models: ‘PN to FBS’ (the semantics transfer from a PN model to a FBS model) and ‘FBS to PN’ (the semantics transfer from a FBS model to a PN model). This thesis study has done a preliminary implementation of the ‘PN to FBS’ model. The general idea in the implementation of the ‘PN to

FBS' module is to develop a computer program to interpret the output of a CPN model which includes the states and their changes into the semantics expression of the WCDMA system which can be meaningful to the network managers (see Figure 7.6).

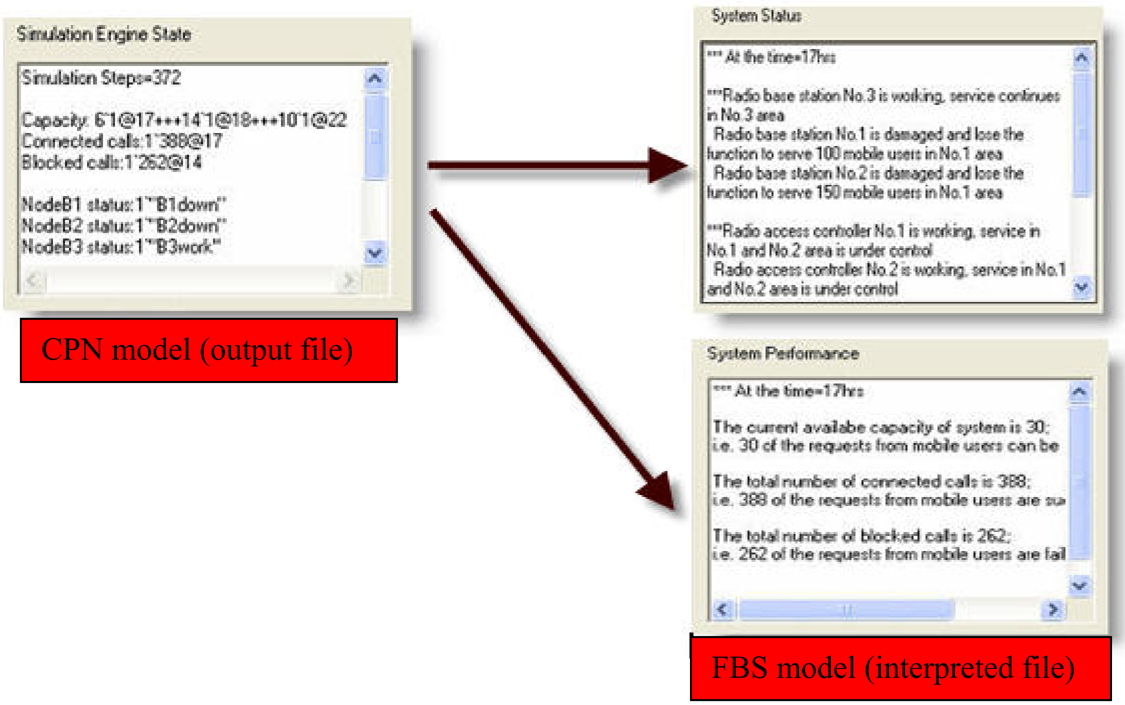


Figure 7.6 Interface 3- CPN to FBS model

7.4 Operation of DMSS

Firstly, revisit the Figure 7.5. In this figure, the window of 'System Performance' indicates the capacity and block rate of the WCDMA system in certain times. The window of 'system status' indicates the status of the each component in certain times. It shows the states of the components, their normal or failed status, and the impact to the system capacity. The window of 'Simulation engine state' shows the performances of the underlying system. The window of 'Recovery Solutions' shows the specific information of the damaged components as well as the proposed solutions to recover their function.

For instance, in Figure 7.5, the information in the window '**System performance'** shows that the performance state of the WCDMA system after working 17 hours. At that time, the system has the capacity to service 30 more Mobile users. The extra user will not get the service due to the current system capacity. In addition, the windows also shows that system has provided services to total 388 demands from users within the past 17 hours, while the 262 demands for service from the users are rejected when the demand is more than the service provision from the WCDMA system.

Further, the information in the window **'System Status'** shows that the state of each system components after 17 hours. The window shows that a disaster occurring after 17 hours. It leads to the damage of Radio Base Station No.1 and Radio Base Station No.2. Thus, they lost the service to about 250 users within its radio coverage area. Only Radio Base No.3 is still working and keeps providing services in its service area. The other components such as Radio Network controller No.1 and No.2, Media Gateway GPRS are still available to provide the Circuit Switch and Packet S witch functions. The information in the window **'Recovery solution'** shows the proposed solutions to recovery the system function or to re-arranges the victims in the disaster area. In this window, it provides the information of the damaged component and their location, design parameters. Then it provides a recovery solution such as increasing the transmission power of Node B No.3, or delivering emergency telecommunication vehicles to the damaged site, or asking the evacuated crowd to move to the service area of Node B No.3.

7.5 Conclusion with discussion

This chapter described a decision making system for emergency management. The system integrates the domain model, reconfiguration and dynamic model of the WCDMA system. The implementation of the system was preliminary at this point of time. Based on the concept formulation and the preliminary implementation it can be concluded that (1) emergency managers only needs to focus on the semantics of the WCDMA system; they do not model the dynamics of the WCDMA system, (2) the transfer of information from the PN model to the FBS model of the WCDMA system is possible, and (3) a simulation-based emergency management can help the manager know about the information in a rapid time.

Chapter 8

Conclusion

8.1 Overview of the Thesis

This thesis study concerns the survivability or resilience of a complex service provider system. A preliminary literature analysis began with this study. This analysis has led to the goal of the thesis – i.e.; to develop a general methodology for managing the telecommunication system to achieve a high survivability. The wireless telecommunication system, 3G WCDMA (UMTS) system, was taken as an example system to ground this research for the purpose of illustration and validation of the proposed methodology. To achieve this goal, the following specific objectives were proposed:

Objective 1: *Develop a general domain model for the wireless telecommunication system which captures the service demand, function requirement, operation constraint, structure, and behavior.*

Objective 2: *Develop an effective system reconfiguration model for the wireless system to achieve high survivability or service continuity in emergency situations.*

Objective 3: *Develop a dynamic model of the WCDMA (UMTS) system which can be used for verification of the management decisions.*

Objective 4: *Develop a human-in-the loop decision making framework for emergency management in emergency situations.*

These objectives have been achieved. In particular, it begins with the discussion of some basic concepts in Chapter 2 that underlie the entire work, such as the definition of survivability, and emergency management. The domain modeling tool called FBS framework is introduced to support one of the basic ideas in conducting this thesis work - i.e., ontology based management system. Here, the purpose of domain modeling is to capture the ontology of a system in interest. An example system called WCDMA system is presented to ground the research. The intention of this thesis study was to make use of the example WCDMA system to illustrate and validate the ideas. To follow the ontology-based system, a domain model of the WCDMA system is developed by using the FBS framework in Chapter 4.

Subsequently, in Chapter 5, a new configuration approach is developed, which is based on the General function and Specific function (G-S) concept. The G-S concept was proposed by Pahl and Beitz in 1996 in engineering design, which is a methodology to represent the function of a complex dynamic system. In the development of this approach, especially to the survivability of a system, the idea of ontology-based system is further demonstrated in the sense that the relationship between the domain model and the system reconfiguration method are exhibited.

In Chapter 6, it began with the development of a dynamic model of the WCDMA system. Petri Net theory was employed for this purpose. A Petri Net dynamic model was successfully built for the WCDMA system, and the simulation of the dynamic behaviors of the WCDMA system was demonstrated. The use of this simulation system in the areas of vulnerability analysis and decision making for emergency management were explored.

In Chapter 7, decision making support system was further detailed based on the Petri Net model and simulation engine by preliminarily implementing a computer-based emergency management system. This system was based on the integration of several models and systems that were described in the preceding Chapters, in particular the domain model, dynamic model, reconfiguration system and human decision maker. The implementation of several interfaces among these models and systems (including human decision makers) was demonstrated, such as the interface between the emergency management and simulation system, the interface between the Petri Net model and domain model of the WCDMA system (from the former to latter).

The following major conclusions can be drawn from this thesis study:

- The telecommunication system is a complex service provider system. The work domain model approach to cope with this complexity is necessary. In the presence of the domain model in an emergency management system, the decisions can be made on the system structure and resource level and can be further made effect to the system behavior and performance level.

- The survivability of a service provider system always depends on the contexts. The current emergency management method in telecommunication industry normally treats the damaged system as a static and fixed network configuration. As such, the traditional recovery solutions are normally limited to the use of backup resources, spare parts of the vulnerable components, or the repair of the failure parts, or asking for help from others. The new approach proposed in this thesis opens an avenue to increase the degree of the survivability of a complex dynamic system such as the WCDMA system by exploring the structure of the complex service provider system, including both its damaged components and left undamaged components, for a solution to recover the lost function through the reconfiguration of all components including damaged ones.

- Telecommunication system management is a very important function in each system. Normally, the management system is called as Operation and Management system (O&M). At present, the O&M operation systems are proprietary, a situation that may hinder an effective management of emergency for high survivability, because in reality it is highly demand on an integrated approach to such management. The approach developed in this thesis study appears to provide an integrated solution to management, as the entire system is highly modularized with focuses on the construction of interface among them including human-computer interface.

8.2 Major contributions

The main contributions of the thesis are described as follows:

- This study develops a new approach for emergency management, which is adaptable to all service systems. The study has realized the similar function as the work of the Bell Lab (Houck et al. 2003) to analyze the survivability of the telecommunication in disaster or emergency situations; however, the approach developed from this thesis study is much more general than that of Bell Lab.

- This study provides a new methodology for system reconfiguration which is more sophisticated than the existing approaches based on the concept of function redundancy and sharing. In the case of the WCDMA wireless cellular system, the methodology provides a cost effective and quick response solution to enhance a service system on the condition when the system is partly damaged due to the natural disasters or incidents. Furthermore, this new methodology implies a new paradigm for emergency management, that is, the first priority of emergency management is to turn attention to the system itself. This new paradigm will provide the most rapid response to emergency.

- This study provides a new Petri Net approach to model complex dynamic system based on the idea of integrating Petri Net theory and FBS framework. This approach provides a complete view of system dynamics as it brings the constituent element (structure, behavior, principle) together under one framework. In comparison, the contemporary approach only examines system dynamics partially or in one angle of view. For instance, Kurt et al. (2007) only applied Coloured Petri Net to model a data transmission protocol of the telecommunication system. Klaric et al. (2001) only applied Petri Net in the ISDN to model call set up and the charging process. Boubour et al. (1997) limited to examine the faults detection and alarm observation.

8.3 Limitations and future Work

8.3.1 Limitation

The major limitation with this research is that it addresses only one type of service system, namely the 3G WCDMA wireless cellular system only. WCDMA is a wideband spread-spectrum mobile air interface that utilizes the direct sequence CDMA techniques to achieve higher speeds and support more users. The extension of this research beyond WCDMA to other wireless cellular system such as CDMA2000, GSM or PCS can not be directly established, because of different network air interface technologies used in these systems. Another limitation to this research is that it focuses on the general network architecture. However, the nature of this research would refine the network elements on some detailed levels.

8.3.2 Future work

The first future work concerns a practical implementation by users (e.g., Sasktel) to evaluate the feasibility of the developed model. Meanwhile, the company can also obtain a better support to this study and improve their service in terms of system survivability in emergency situation as well as service continuity optimization in normal situations.

The second future work is to develop a model transfer from the FBS to PN of the underlying system. This study supposed that the information communication between the network manager and system designer is transparent and always established. The communication methods can be in manual ways such as oral, fax, or automation by software agents. Software agents can be designed in the future to automate communication between network manager interface and designer interface.

The third future work concerns the study of vulnerability of the service system in facing attackers. An extended study is to exploit the way to enhance the resilience of various service system in any threaten from outside environments. The interdependency of various service infrastructures with the telecommunication system in disaster or emergency situations can be further analyzed.

The fourth future work concerns the security of the telecommunication system. In the disaster and emergency situations, the damaged system is vulnerable facing the attackers. Unauthorized users may gain access to agency systems and information, corrupt the agency's data, consume network bandwidth, and degrade network performance. Sensitive data may be lost due to the damaged components as well.

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Appendix A

Code of the WCDMA CPN model

* The completed coded is stored in CD-ROM

The code comprises the 5 typical models within different layers, which are listed as follows:

(1) Dynamic model of the demands,
(2) Dynamic model of the functions,
(3) Dynamic model of the structure,
(4) Dynamic model of the principles, and
(5) Dynamic model of the threaten scenarios

The descriptions of each model and the relations among them are mentioned in Chapter 6. The complete list of codes is stored in the attached CD-ROM with a file called 'CPN model of WCDMA system'.

Appendix B

Code of the interface 2 for decision making support

* The completed code is stored in CD-ROM

The program is to realize the function of interface 2 to translate information from the WCDMA PN model to the WCDMA domain model.

The code comprises two parts, which are listed as follows:

(1) Main program to realize the control windows for interfaces 2, and
(2) Module sub-program to archive the database and realize the translation function.

Detailed descriptions of Interface 2 are mentioned in Chapter 7. The complete list of codes is stored in the attached CD-ROM with a file called 'Interface 2 for decision making support system'.