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TD-SCDMA Relay Networks

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TD-SCDMA Relay Networks

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Submitted for the Degree of Doctor of Philosophy

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Abstract

When this research was started, TD-SCDMA (Time Division Synchronous Code Division Multiple Access) was still in the research/development phase, but now, at the time of writing this thesis, it is in commercial use in 10 large cities in China including Beijing and Shang Hai. In all of these cities HSDPA is enabled. The roll-out of the commercial deployment is progressing fast with installations in another 28 cities being underway now.

However, during the pre-commercial TD-SCDM trail in China, which started from year 2006, some interference problems have been noticed especially in the network planning and initialization phases. Interference is always an issue in any network and the goal of the work reported in this thesis is to improve network coverage and capacity in the presence of interference.

Based on an analysis of TD-SCDMA issues and how network interference arises, this thesis proposes two enhancements to the network in addition to the standard N-frequency technique. These are (i) the introduction of the concentric circle cell concept and (ii) the addition of a relay network that makes use of other users at the cell boundary. This overall approach not only optimizes the resilience to interference but increases the network coverage without adding more Node Bs.

Based on the cell planning parameters from the research, TD-SCDMA HSDPA services in dense urban area and non-HSDPA services in rural areas were simulated to investigate the network performance impact after introducing the relay network into a TD-SCDMA network.

The results for HSDPA applications show significant improvement in the TD-SCDMA relay network both for network capacity and network interference aspects compared to standard TD-SCDMA networks. The results for non-HSDPA service show that although the network capacity has not changed after adding in the relay network (due to the code limitation in TD-SCDMA), the TD-SCDMA relay network has better interference performance and greater coverage.

Acknowledgement

First I would like to express my biggest and sincerest "thanks" to my supervisor, Prof Laurie Cuthbert for his understanding, support, encouragement and personal guidance during these years, especially as he flew from London to Beijing many times to supervise my research on the spot as well as spending a lot of time on remote supervision. Without his continuous help I would not have completed my PhD study and this thesis would not exist.

I would like to thank my ex-colleagues in Siemens Ltd. China as well. Although this research work has been done entirely by myself, their valuable sharing of knowledge and rich working experiences did help me cope with the part-time PhD distance research. Without their understanding and support, I would not have finally finished the research work without affecting the quality of my daily job.

Also I would like to express my gratitude to the Wireless Signal Processing and Network Lab at Beijing University of Posts and Telecommunications (BUPT) who provided me the basic simulation materials and shared their advice generously.

Furthermore I would like to thank all those in the Department of Electronic Engineering, at Queen Mary, who have given me valuable advice and support, either locally during my periodic short visits or remotely when I was in China.

Finally, my love and gratitude from my heart go to my dearest parents; their generous support and love are beyond words.

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Abbreviations

2G	Second Generation (mobile)
3G	Third Generation (mobile)
3GPP	3G Partnership Project
ARIB	Association of Radio Industries and Businesses
BCH	Broadcast Channel
BER	Bit Error Rate
BLER	Block Error Rate
BS	Base Station
CATT	China Academy of Telecommunications Technology
CBC	Common Broadcast Centre
CC	Call Control
CCSA	The China Communications Standards Association
CCPCH	Common Control Physical Channel
CCTrCH	Coded Composite Transport Channel
CDMA	Code Division Multiple Access
CIR	Carrier-to-Interference Ratio
CN	Core Network
CS	Circuit Switched
DARPA	Defence Advanced Research Projects Agency
DCA	Dynamic Channel Allocation
DECT	Digital Enhance Cordless Telephone
DL	Down Link
DPCH	Dedicated Physical Channel
DSP	Digital Signal Processing
DwPTS	Downlink Pilot Time Slot
DwPCH	Downlink Pilot Channel
EDGE	Enhanced Data Rates for Global/GSM Evolution
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standard Institute
FACH	Forward Access Channel
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FPACH	Fast Physical Access Channel

GP	Guard Period
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
IMT-2000	International Mobile Telephony 2000
ITU	International Telecommunication Union
JD	Joint Detection
LTE	Long Term Evolution
MAC	Medium Access Control
MAI	Multiple Access Interference
MCL	Minimum Coupling Loss
ME	Mobile Equipment
MM	Mobility Management
MS	Mobile Station
MSC	Mobile service Switching Centre
MT	Mobile Terminal
NBAP	NodeB Application Protocol
OVSF	Orthogonal Variable Spreading Factor
PC	Power Control
P-CCPCH	Primary CCPCH
PDA	Personal Digital Assistants
PG	Processing Gain
PHS	Personal Handy phone System
PRACH	Physical Random Access Channel
PS	Packet Switched
QoS	Quality of service
RAB	Radio Access Bearer
RF	Radio Frequency
RLC	Radio Link Control
RNC	Radio Network Controller
RNP	Radio Network Planning
RNS	Radio Network Subsystem

RRC	Radio Resource Control
SDMA	Space Division Multiple Access
SGSN	Service GPRS Support Node
SIR	Signal-to-Interference Ratio
SMS	Short Message Services
TA	Timing Advance
TCH	Traffic Channel
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division Synchronous CDMA
TE	Terminal Equipment
TIA	Telecommunications Industry Association
TPC	Transmit Power Control
TS	Time Slot
TTA	Telecommunications Technology Association
UE	User Equipment
UL	Up Link
UMTS	Universal Mobile Telecommunication System
UpPTS	Uplink Pilot Time Slot
UpPCH	Uplink Pilot Channel
UT	User Terminal
UTRAN	UMTS Radio Access Network
UWC	Universal Wireless Consortium
WARC	World Administrative Radio Conference
W-CDMA	Wideband Code Division Multiple Access

Chapter 1 Introduction

1.1 Research Motivation

One aspect that is always important in mobile networks is the radio planning to ensure that there is coverage over the desired geographical area, without any "holes"; planning of coverage is also important in terms of network capacity and minimising congestion, but it is the geographical aspects that are of direct interest to this research.

It is common knowledge that even in urban areas, there are locations where the mobile network coverage is poor or even non-existent. In rural areas, the situation is much worse as it is not economic to install base stations in areas where there is little population, so while a village might see good signal strength, the coverage is rapidly lost as the user moves away from the populated area.

In a country like China where there is a mix of very densely populated cities and vast rural areas, the coverage patterns vary greatly. Although the percentage penetration of mobile terminals is similar with other countries (around 43%) the number of users is large: 608 Million (statistics by the Ministry of Industry and Information Technology of China in September 2008.) out of a population of 1.4 Billion. This figure is growing very rapidly. With around two thirds of the population living in rural areas there is a challenge of how to provide network coverage for them, but to do so is seen as been essential as the economy develops and more services are provided over mobile networks.

This thesis considers one aspect of the problem: how to extend coverage beyond that of the base station by using relay network techniques to allow the network to reach users by transiting the connection through a user on the boundary of coverage. It does this for TD-SCDMA, the 3G network technology proposed for China. An additional benefit is that the approach can "fill in" gaps in coverage within urban areas as well as extending coverage in rural ones.

A similar problem has also been studied in WCDMA. In [HW01], a proposal is given about how to optimize the placement of relay nodes to improve HSDPA

data reception when the terminal is in a poor coverage area by relaying data through a node in a good coverage area; the results show that the added relay did improve the coverage and capacity of the HSDPA cell in a WCDMA network. [HN01] introduces a relay network into non-HSDPA cells in WCDMA networks. The work considers how to select the relay stations in the network while the results indicate that no matter which proposed relay station selection strategy is adopted, the system capacity is improved dramatically. A detailed comparison will be introduced later in the background chapter of this thesis.

1.2 Research Scope

This work is the first to investigate a mixture of relay and infrastructure techniques for TD-SCDMA networks.

TD-SCDMA is different from the other 3G techniques (W-CDMA [HH01] and CDMA2000) in many ways, and these differences are explained in Chapter 2 (section 2.2). Work with a similar rationale for W-CDMA [HW01], is, therefore, not directly applicable.

In this research, the basic approach is that where there is no infrastructure coverage from the TD-SDCMA network, a relay can be used to transit connections through a mobile terminal in coverage. Given this purpose, a new TD-SCDMA relay network structure is proposed adopting the N-frequency technique and concentric circle cell concept.

To investigate the network performance under the suggested TD-SCDMA relay network structure, a detailed simulation model has been produced that allows two very different scenarios to be investigated

- HSDPA[1] service in dense urban areas;
- Non-HSDPA data service in rural areas.

It should be noted here that the research restricts itself to data services and does not include voice; the reasons for this choice are:

[1] High Speed Downlink Packet Access

- Voice is a real-time service, and the jitter introduced by including a relay segment will have an impact on quality; network operators in China believe that deterioration in quality is to be avoided.

- Users of data services tend to move less than voice users: a user might continue walking when talking on the phone, but is likely to stop when using a data service (although this does not apply to users who are passengers in vehicles). Lower mobility means that once a relay segment has been established, it is less likely to disappear quickly.

- Data connections, especially new high-speed services, are seen as being a particularly important source of revenue for operators.

1.3 Contributions

The main contributions in this work are:

- The introduction of the concentric circle approach to TD-SCDMA.

- The combination of the N-frequency and concentric circle techniques in TD-SCDMA.

- The addition of relay in TD-SCDMA to give a heterogeneous environment that allows TD-SCDMA network coverage to be extended or "holes" to be filled in, through transiting data connections over a relay link.

- A detailed network simulation of this heterogeneous approach for two different scenarios that shows that with the new structure, the HSDPA capacity of the TD-SCDMA relay network increases significantly compared to the TD-SCDMA network without N-frequency and compared to the TD-SCDMA N-frequency network without relay.

1.4 Author's Publications

[YS01] Y. Sun "Siemens TD-SCDMA White Paper" version 2005

[YS02] Y. Sun and L. Cuthbert, "TD-SCDMA and Ad Hoc Hybrid Network", Wireless Communications, Networking and Mobile Computing, 2007.

WiCom 2007. International Conference on, 21-25 Sept. 2007 Page(s):775 - 778, Digital Object Identifier 10.1109/WICOM.2007.200

[YS03] Y. Sun and L. Cuthbert, "HSDPA in TD-SCDMA Relay Network", submitted to the 8th ANNUAL WIRELESS TELECOMMUNICATIONS SYMPOSIUM (WTS 2009).

1.5 Author's Notes

The author was employed by Siemens Ltd. China (now Nokia Siemens Network, Ltd. China) as TD-SCDMA Product Manager between 2003 and 2007. The "Siemens TD-SCDMA White paper" version 2005 was written by the author and now it is public documentation.

This research work has been completed entirely by the author, not by the company, including the concentric circle cell and add-in relay network.

1.6 Organisation of the Thesis

Chapter 2 gives background information about the networks used in this research, on TD-SCDMA and on relay networks. In Chapter 3, the interference introduced, the approach used and research scenarios are explained.

Chapter 4 shows results of the link budget calculation based on the current practical network situation which is the input of the next stage, the simulation. Based on the proposal in Chapter 4, the new network structure is implemented into the TD-SCDMA HSDPA simulation platform which is introduced in Chapter 5. The simulation results of the TD-SCDMA relay network are analyzed and compared with genuine TD-SCDMA networks.

HSDPA is not implemented everywhere, and Chapter 6 addresses non-HSDPA applications of TD-SCDMA relay networks.

Conclusions and further work are given in Chapter 7.

Chapter 2 Background

2.1 3G Mobile Networks

It is now well known that GSM technology was too limited in terms of capability for offering the modern services that users and network operators want. In particular, GSM was not able to provide high bit-rate data services – which led to the standardisation and introduction of 3G; this evolution is shown below in Figure 2-1.

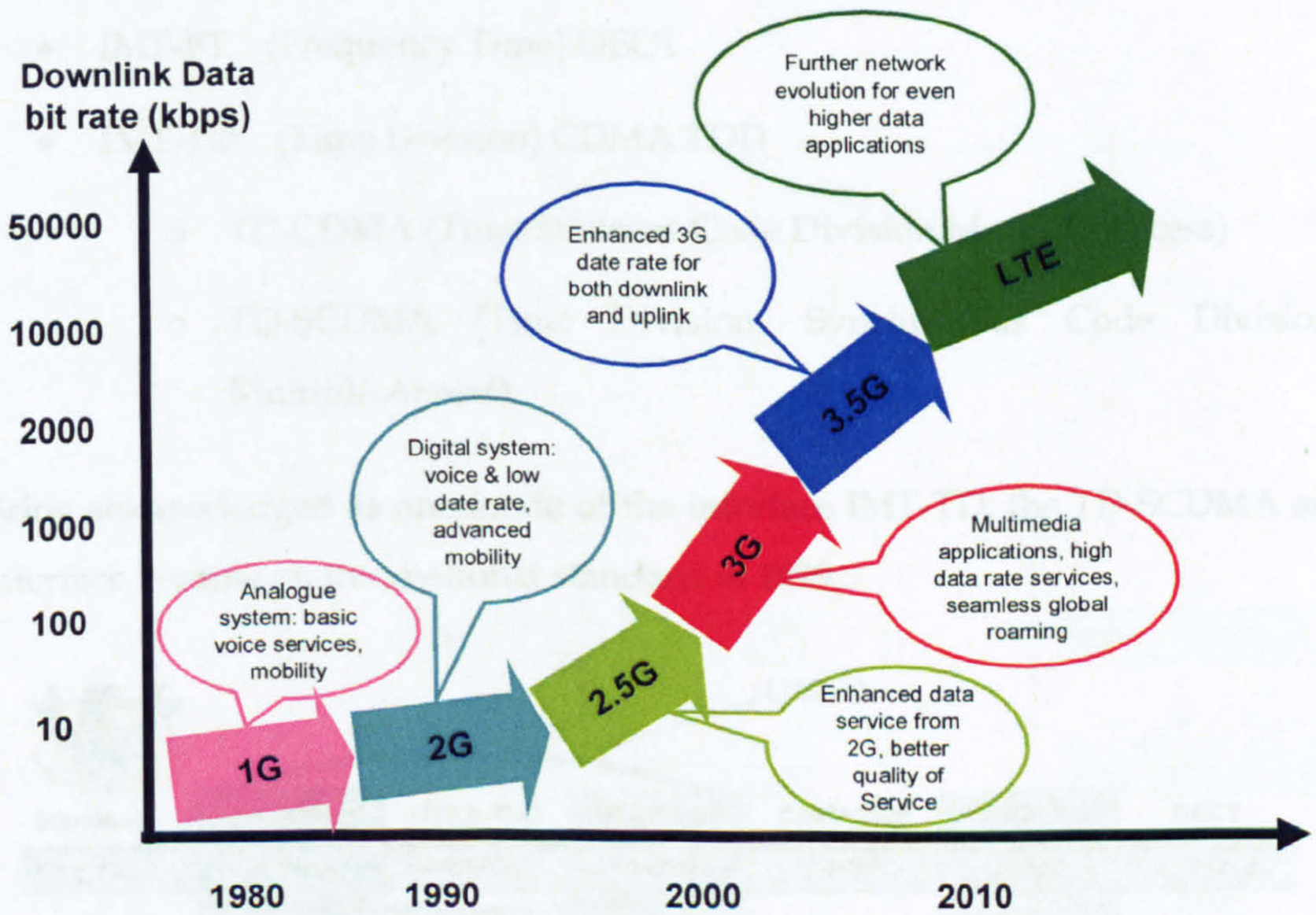


Figure 2-1 Cellular evolution

This thesis only considers 3G/3.5G so an explanation of GSM (or indeed of the 2.5G technologies like GPRS and EDGE) will not be included in this background chapter.

UMTS networks offers better service performance by using an advanced access technology designed for multimedia communication and integrated services. The three variants are W-CDMA (ARIB/ETSI), cdma2000 (TIA) and TD-SCDMA. Since this thesis focuses on TD-SCDMA, this is the main technology that is considered in this chapter.

The international 3G standards (including, CDMA2000, W-CDMA and TD-SCDMA) were accepted by the ITU [ITU01] under the generic name *International Mobile Telecommunication – 2000* (IMT-2000) with a comprehensive set of terrestrial radio interface specifications being approved in November 1999. These included (Figure 2-2) [ITU02]:

- IMT-DS (Direct Spread) W-CDMA
- IMT-MC (Multi Carrier): CDMA2000
- IMT-SC (Single Carrier): UWC
- IMT-FT (Frequency Time) DECT
- IMT-TD (Time Division) CDMA TDD
    - TD-CDMA (Time Division-Code Division Multiple Access)
    - TD-SCDMA (Time Division- Synchronous Code Division Multiple Access)

Being acknowledged as one mode of the interface IMT-TD, the TD-SCDMA air interface became an international standard in 1999.

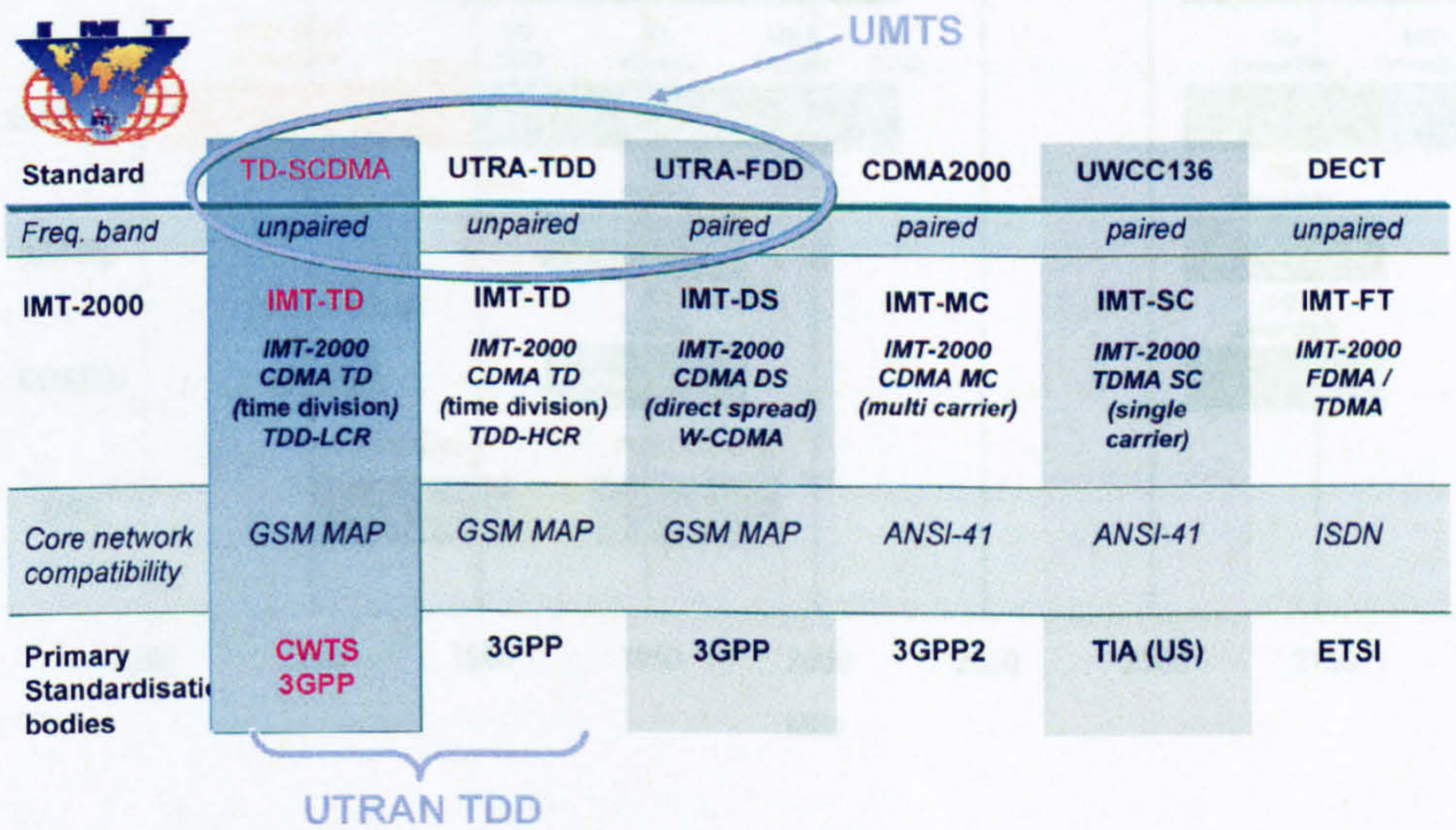


Figure 2-2 IMT-2000 Radio Interface Standard [ITU01]

In Europe, the 3G standard was initially developed by ETSI [ETSI01] under the designation of UMTS [UMTS01]. The radio access interface of the UMTS (UTRA) comprises two standards for operation in the FDD and TDD modes. Both

interfaces have been accepted by ITU and are designated IMT-DS and IMT-TD respectively.

The UMTS standard is being currently defined by the Third Generation Partnership Project (3GPP): a joint venture of industry organisations and of several Standards Developing Organisations (SDOs) from Europe (ETSI), US (T1), Japan (ARIB), Korea (TTA), and China (CCSA). 3GPP is introducing UMTS in phases and annual releases.

Currently UMTS is in service in many countries round the world and the number of handsets in use is growing fast.

UMTS uses frequencies in the band around 2 GHz. The actual frequency bands are 1885-2025 MHz and 2110-2200 MHz and were allocated in March 1992 at the World Administrative Radio Conference (WARC) of the ITU. Figure 2-3 illustrates the spectrum allocation in different countries. [HH01]

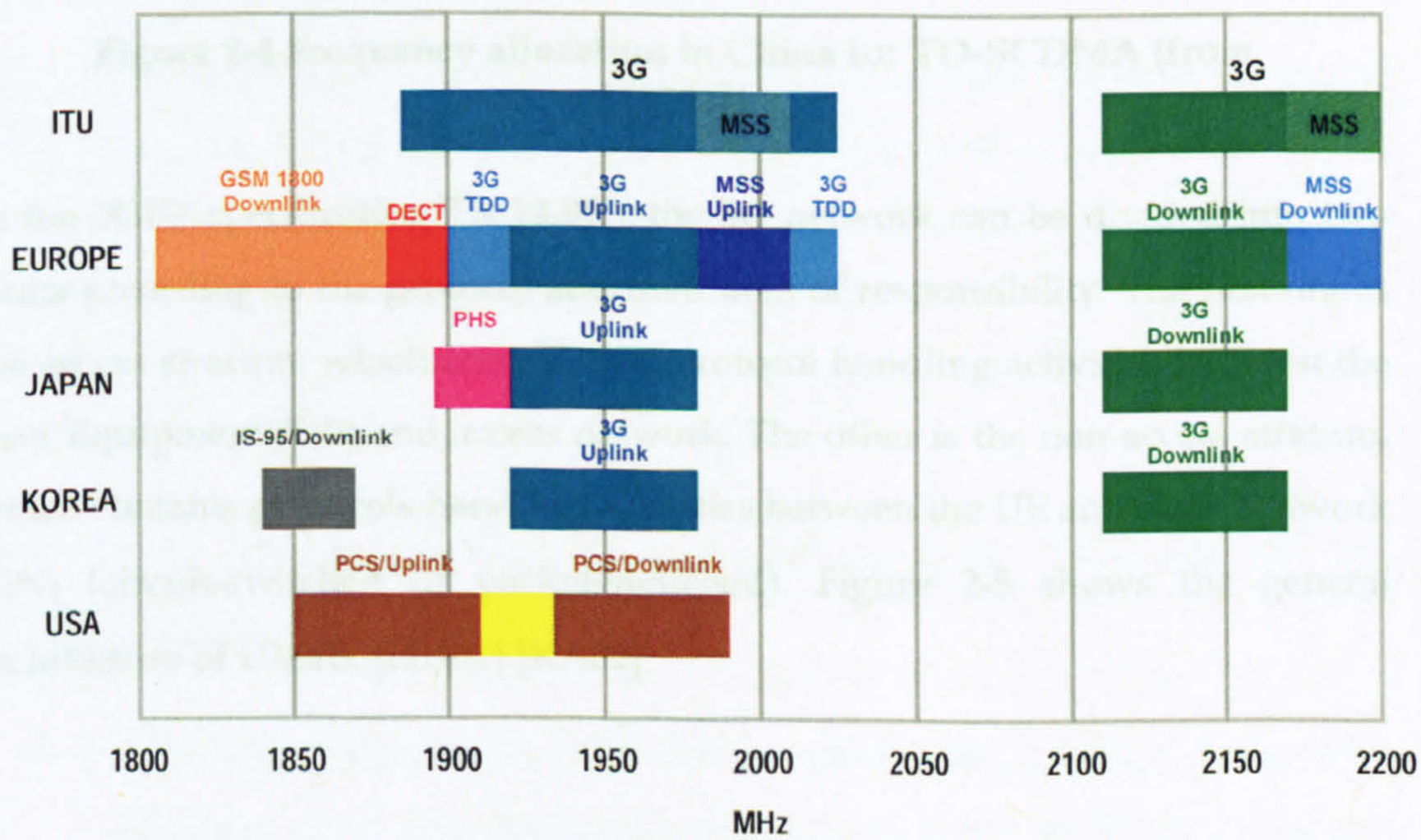


Figure 2-3 Spectrum allocation in different countries (from [HH01])

TD-SCDMA is the technology developed jointly by Siemens and the China Academy of Telecommunications Technology (CATT), TD-SCDMA (Time

Division Synchronous Code Division Multiple Access) is one of the IMT-2000 standards accepted by the ITU.

In March 2001 the standard was also adopted by the Third Generation Partnering Project (3GPP), as part of UMTS Release 4. In this way it became a truly global standard, which covers all radio deployment scenarios: from rural to dense urban areas, from pedestrian to high mobility.

The frequency allocation of TD-SCDMA in China is shown below [TD01]:

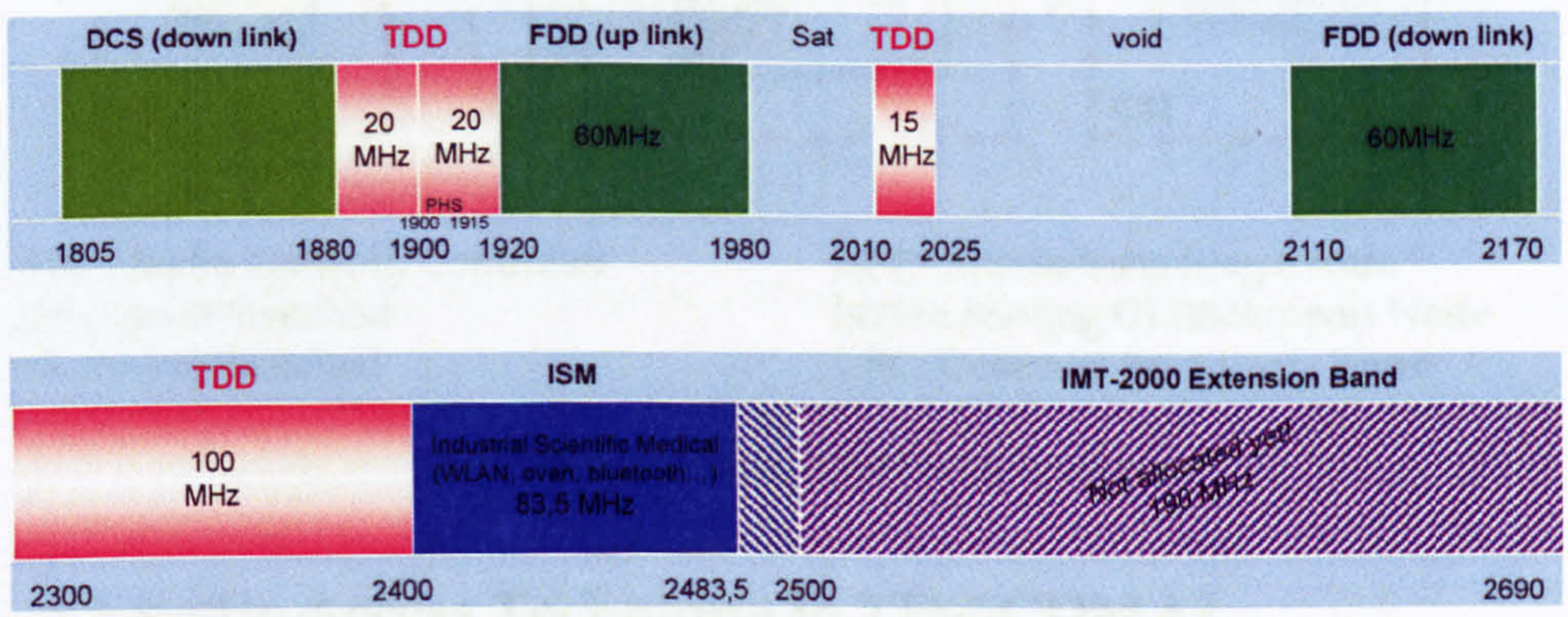
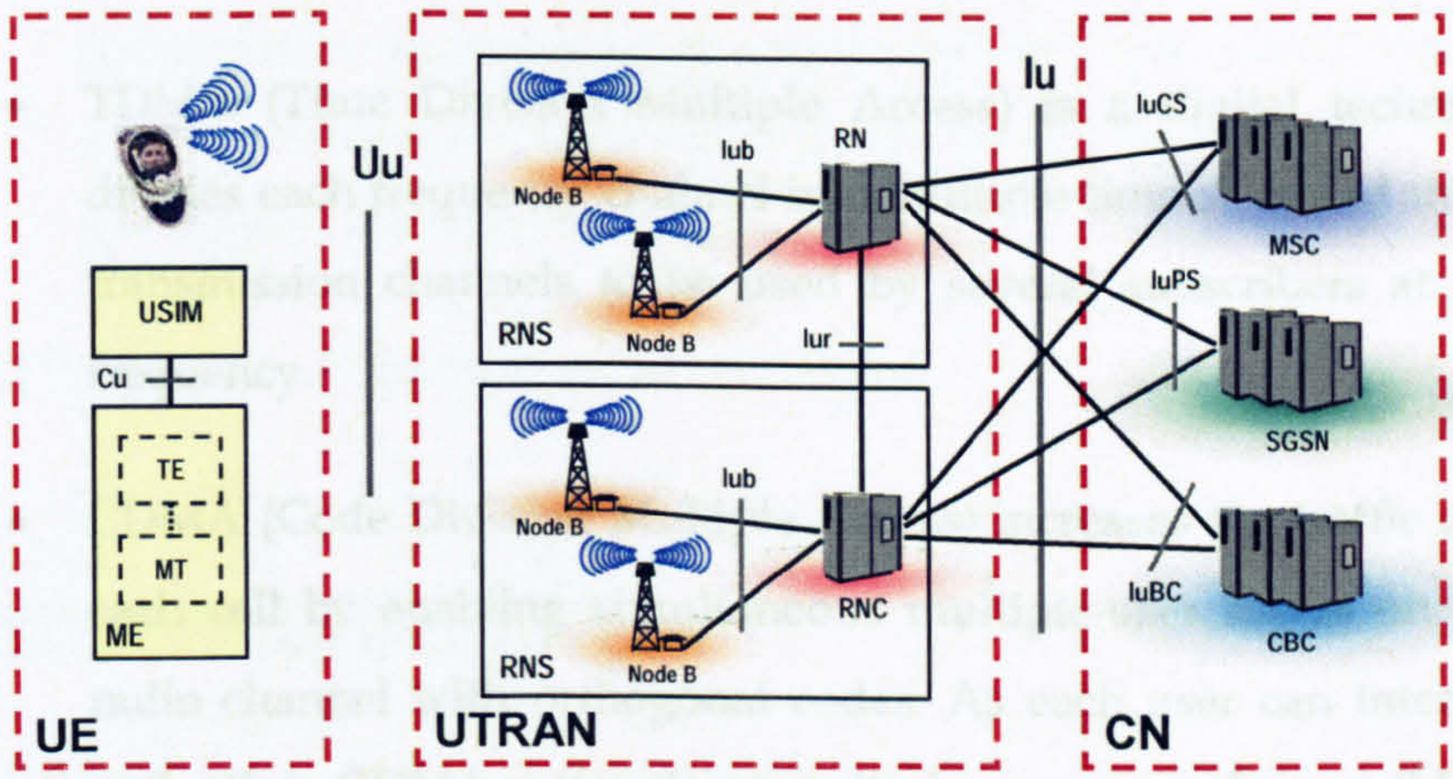


Figure 2-4 Frequency allocation in China for TD-SCDMA (from [TD01])

In the 3GPP specification TR 21.905, the 3G network can be divided into two strata according to the protocol and their area of responsibility. The first one is the access stratum, which contains the protocol handling activities between the User Equipment (UE) and access network. The other is the non-access stratum, which contains protocols handling activities between the UE and Core Network (CN) (circuit-switched or packet-switched). Figure 2-5 shows the general architecture of UMTS. [HH01] [KA01]



RNC: Radio Network Controller
CS: Circuit Switched
PS: Packet Switched

MSC: Mobile Switching Centre
SGSN: Serving GPRS Support Node
CBC: Common Broadcast Centre

Figure 2-5 Overall UMTS architecture

2.2 Radio Access Technique in TD-SCDMA[2]

One of the main challenges for 3G mobile systems is mastering both symmetric circuit switched services (such as speech or video) as well as asymmetric packet switched services such as mobile Internet access. To face this challenge, TD-SCDMA combines two technologies: an advanced TDMA/TDD system with an adaptive CDMA component operating in synchronous mode. [3GPP01]-[3GPP03], [3GPP07]

This section outlines the basic technological principles on which the TD-SCDMA technology is based [SI01]:

- TDD (Time Division Duplex) allows uplink and downlink on the same frequency band and does not require paired bands. In TDD, uplink and downlink are transmitted in the same frequency channel but at different times. It is possible to change the duplex switching point and move

[2] Much of the background description of TD-SCDMA comes from the "Siemens White Paper" [SI01] on the subject. This white paper was written by the author when she was working at Siemens and is now a public document.

capacity from uplink to downlink or vice versa, so improving spectrum utilization. It allows for symmetric and asymmetric data services.

- TDMA (Time Division Multiple Access) is a digital technique that divides each frequency channel into multiple time-slots and thus allows transmission channels to be used by several subscribers at the same frequency.

- CDMA (Code Division Multiple Access) increases the traffic density in each cell by enabling simultaneous multiple-user access on the same radio channel with orthogonal codes. As each user can interfere with each other, CDMA suffers from multiple access interference (MAI).

- Joint Detection (JD) allows the receiver to estimate the radio channel and works for all signals simultaneously. Through parallel processing of individual traffic streams, JD eliminates the multiple access interference (MAI) and minimises intra-cell interference, thus increasing the transmission capacity.

- Dynamic Channel Allocation (DCA): the advanced TD-SCDMA air interface takes advantage of all available Multiple Access techniques. Making an optimal use of these degrees of freedom, TD-SCDMA provides an adaptive allocation of the radio resources according to the interference scenario, minimising inter-cell interference.

- Mutual Terminal Synchronisation: by accurately tuning the transmission timing of each individual terminal, TD-SCDMA improves the terminal traceability, reducing time for position location calculation and search time for handover searching. Because of synchronisation, TD-SCDMA does not need soft handover, which leads to a better cell coverage, reduced inter-cell interference and low infrastructure and operating costs.

- Smart Antennas are beam steering antennas which track mobile usage through the cell and distribute the power for traffic channels only to cell areas with mobile subscribers. Without them, power would be

distributed over the whole cell. Smart antennas reduce multi-user interference; increase system capacity by minimising intra-cell interference, increase reception sensitivity and lower transmission power while increasing cell range. The power for broadcast channels is transmitted over the whole cell.

2.2.1 The Frame Structure of TD-SCDMA

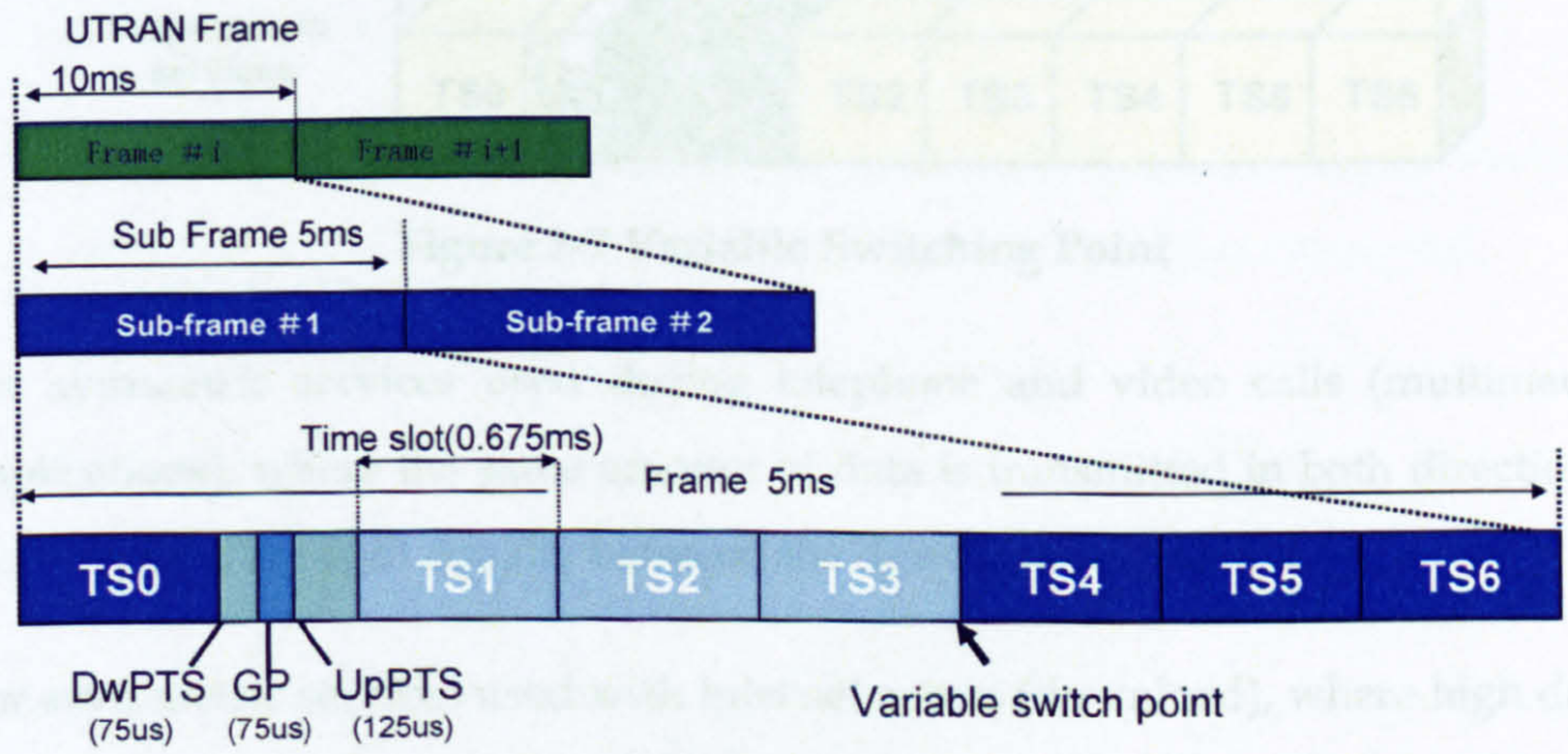


Figure 2-6 TD-SCDMA Frame Structure

TSn (n from 0 to 6): the nth traffic time slot, 864 chips duration

TS0 is always allocated Downlink, and TS1 Uplink

DwPTS: downlink pilot time slot, 96 chips duration

UpPTS: uplink pilot time slot, 160 chips duration

GP: main guard period for TDD operation, 96chips duration

From the sub frame structure it can be seen that the guard period between the downlink pilot timeslot and uplink pilot timeslot is 96 chips and this leads to a theoretical cell radius of 11.25km.

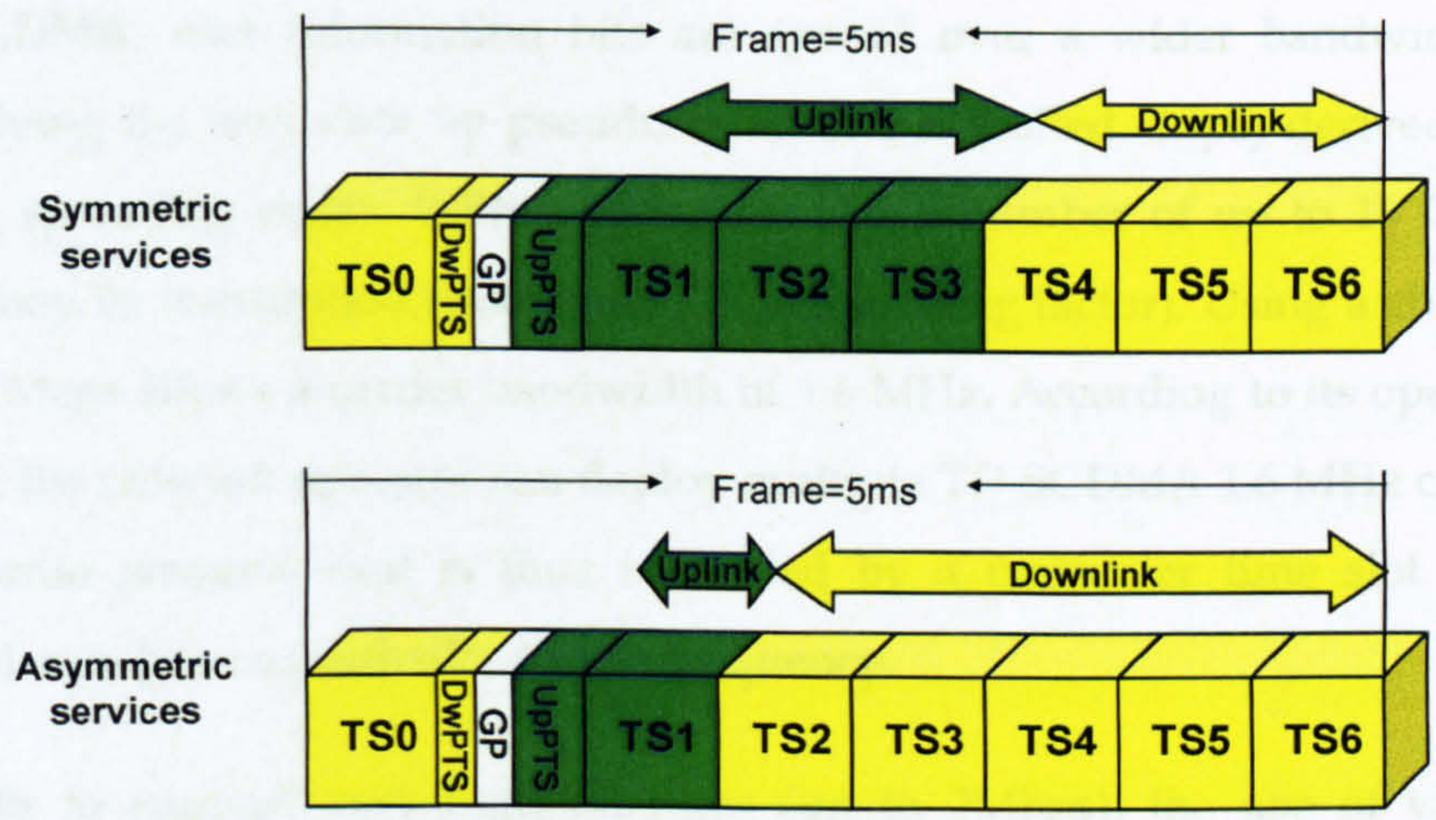


Figure 2-7 Variable Switching Point

For symmetric services used during telephone and video calls (multimedia applications), where the same amount of data is transmitted in both directions, the time slots are split equally between the downlink and uplink.

For asymmetric services used with Internet access (download), where high data volumes are transmitted from the NodeB to the terminal, more time slots are used for the downlink than the uplink.

It is possible to change the switching point between uplink and downlink, depending on the capacity requirement between uplink and downlink.

The ability of adapting the uplink/downlink symmetry and asymmetry according to data load within a single unpaired frequency band optimises the capacity of the air interface, thus utilising the spectrum more efficiently.

Future mobile applications will require an efficient use of the available spectrum and the ability to handle strong asymmetric data traffic: TD-SCDMA fits perfectly these requirements.

2.2.2 Combined TDMA/TDD and CDMA operation

In addition to the TDMA/TDD principle, TD-SCDMA uses CDMA (Code Division Multiple Access) to further increase the capacity of the radio interface. [KK01]

With CDMA, user information bits are spread over a wider bandwidth by multiplying the user data by pseudo-random bits (called chips) derived from CDMA spreading codes. Within each time slot a number of up to 16 CDMA codes may be transmitted (maximum CDMA loading factor). Using a chip rate of 1.28 Mcps allows a carrier bandwidth of 1.6 MHz. According to its operating license, the network operator can deploy multiple TD-SCDMA 1.6 MHz carriers. Each radio resource unit is thus identified by a particular time slot and a particular code on a particular carrier frequency.

In order to support very high bit rates (up to 2Mbps), the use of variable spreading factor and multi-code connections (code pooling) is supported.

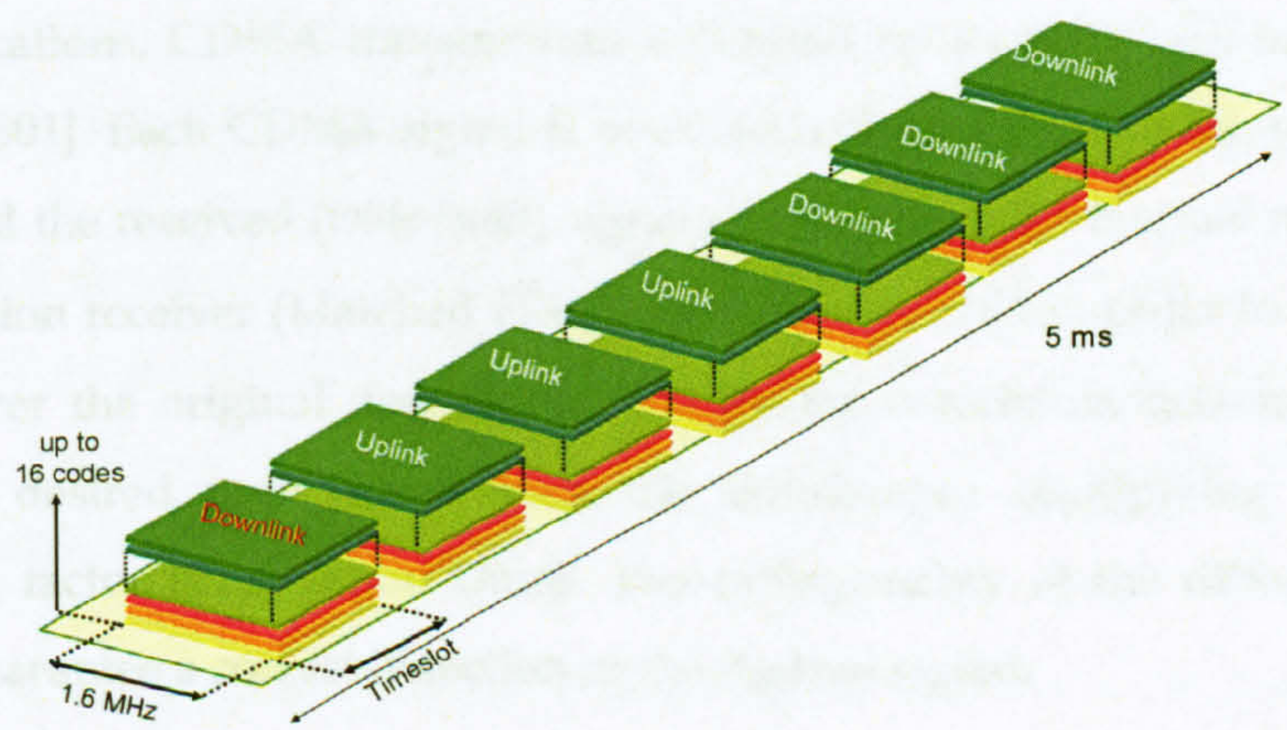


Figure 2-8 Code Division Multiple Access

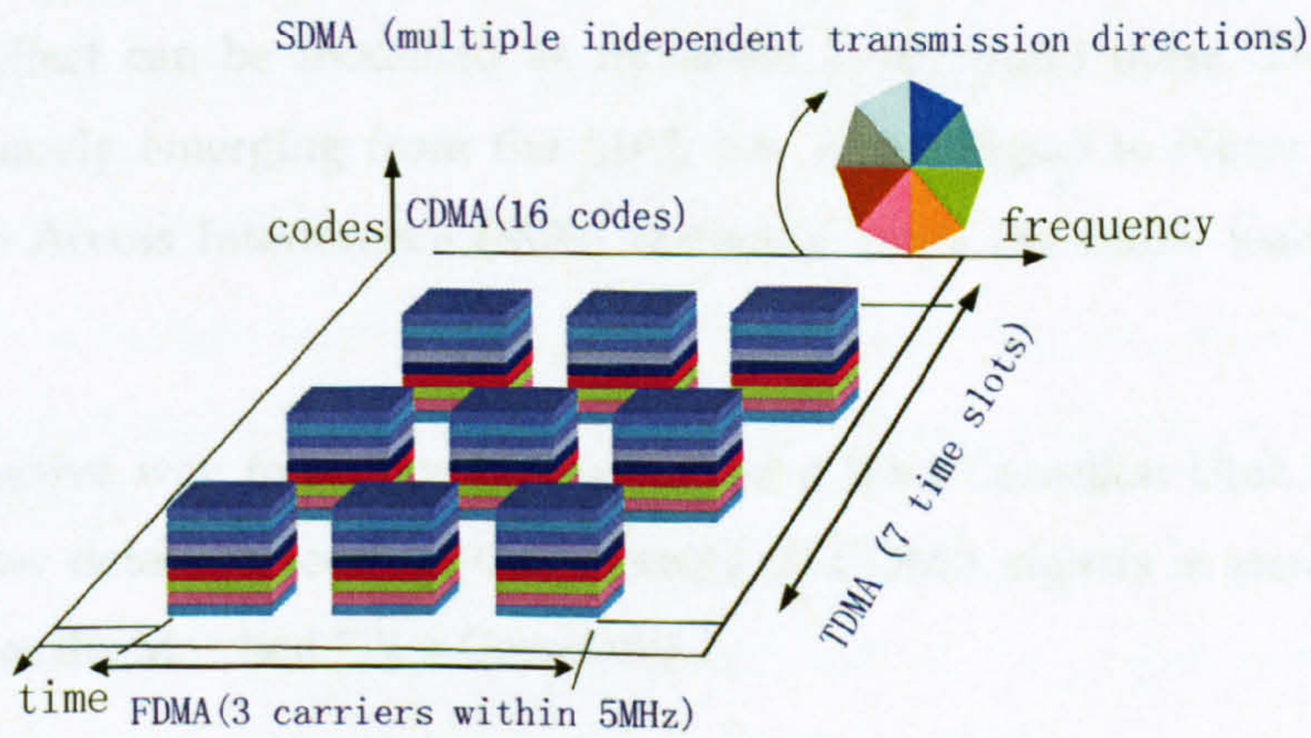


Figure 2-9 CDMA+FDMA+TDMA+SDMA

2.2.3 Joint Detection in TD-S CDMA

Mobile radio propagation is affected by multiple reflections, diffractions and attenuations of the signal energy, caused by normal obstacles - such as buildings, hills and so on - as well as by the mobility of the terminals. The resulting effect is multipath propagation, which generates two different kinds of fading: slow and the fast fading. Fast fading occurs when different delayed paths arrive almost at the same instant; as a result, signal counteraction takes place even if the receiver moves across short distances. During slow fading, mainly caused by shadowing, the signal energy arrives at the receiver across clearly distinguishable time instants

In addition to these signal degradations common to every mobile communications, CDMA transmission is limited by its own "self-interfering" nature [KS01]. Each CDMA signal is overlaid with all others in the same radio carrier and the received (*wide-band*) signal can be below the thermal noise level. A correlation receiver (Matched Filter Correlator) is used in order to de-spread and recover the original user signal. Ideally the correlation detection should raise the desired user signal from the interference multiplying it by the spreading factor (Correlation Gain). The orthogonality of the different codes should guarantee a correct detection of the desired signal.

In fact, in actual CDMA systems the received spreading codes are not completely orthogonal and the correlation process cannot be so efficient. As a result, Multiple Access Interference (MAI) is generated in the receiver: the desired signal does not significantly distinguish itself from interfering users whose effect can be modelled as increased background noise. The detected signal, barely emerging from the MAI, has a low Signal to Noise Ratio. The Multiple Access Interference (MAI) seriously limits the traffic load per radio carrier.

One effective way to reduce MAI is to use a Joint Detection Unit, an optimal multi-user detection receiver that extracts all CDMA signals in parallel; this is used after the Matched Filter Correlator.

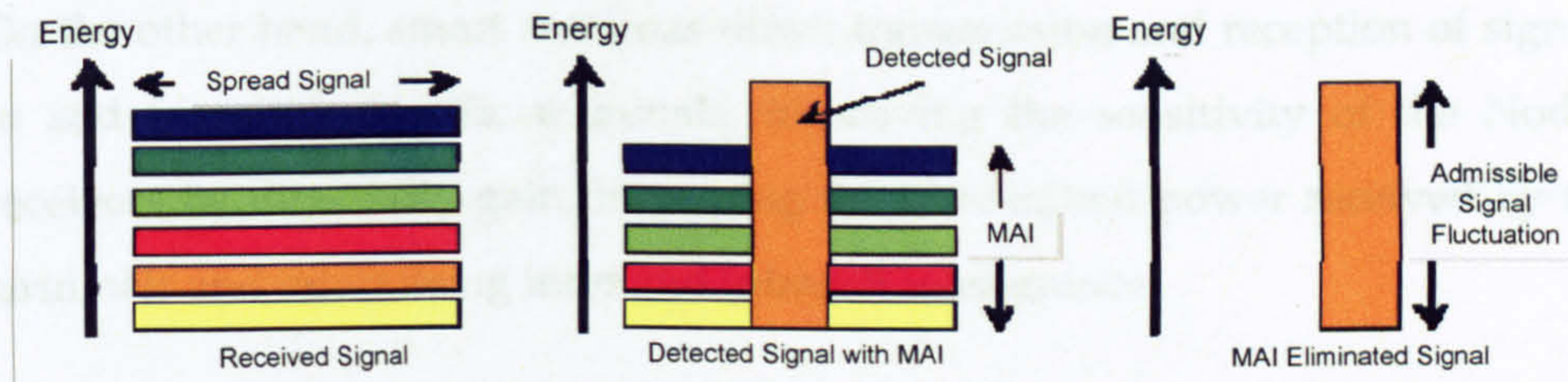


Figure 2-10 Joint Detection

TD-SCDMA technology allows an efficient implementation of Joint Detection receivers in the NodeB as well as in the terminal.

A specific training sequence within each time slot allows the receiver to estimate the parameters of the radio channel. Using a specific algorithm, a DSP extracts all CDMA codes in parallel and removes the interference caused by the residual CDMA codes (MAI). The result is a clear signal (high signal to noise ratio) for each CDMA code.

The result is an increased transmission capacity per MHz of carrier bandwidth (a factor of around 3) and a more efficient use of the available spectrum. Joint detection, therefore, minimises Multiple Access Interference and thus allows higher CDMA loading factors.

The efficiency of the Joint Detection receiver in TD-SCDMA technology is based on the TDMA/TDD operation and on the limited number of codes employed per time slot.

The total number of users per radio carrier is distributed over the different time slots of the basic TDMA frame, so that a maximal number of 16 codes per time slot per radio carrier can be easily processed in parallel and detected.

2.2.4 Smart Antennas

In order to further improve the system robustness against interference, TD-SCDMA NodeBs are equipped with smart antennas, which use a beam-forming concept. [EM01]

Using omnidirectional antennas, the emitted radio power is distributed over the whole cell. As a consequence, mutual intercell interference is generated in all adjacent cells using the same RF carrier.

On the other hand, smart antennas direct transmission and reception of signals to and from the specific terminals, improving the sensitivity of the NodeB receivers by directivity gain, increasing the transmitted power received by the terminals and minimising inter and intracell interference.

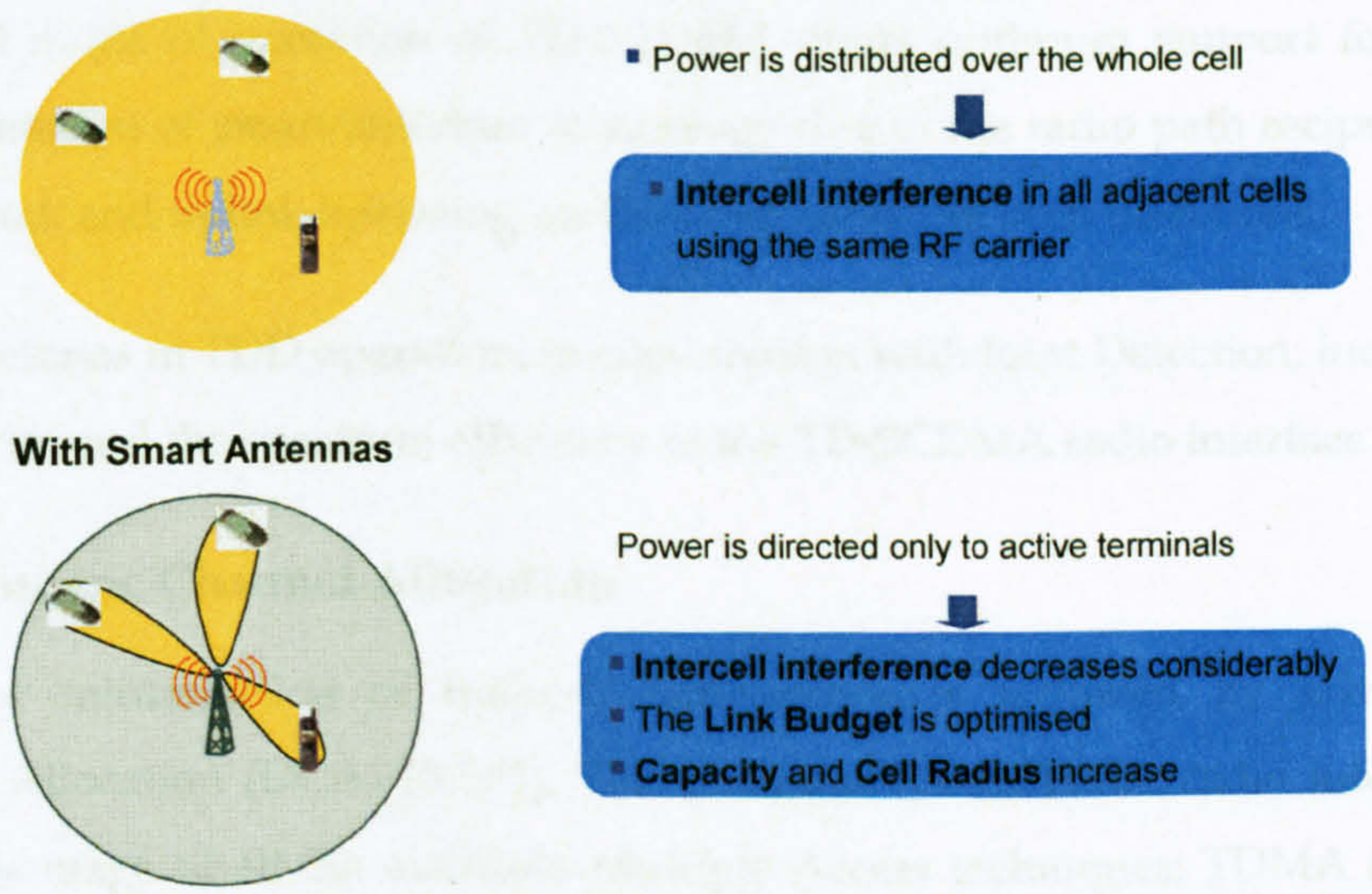


Figure 2-11 Smart Antenna with Beam Forming

Smart antennas employed in TD-SCDMA technology are not conventional diversity beam-switching antennas but advanced beam-forming (and beam-steering) bi-directional adaptive antenna arrays.

The individual directivity between NodeBs and mobile terminals is achieved by a concentric array of 8 antenna elements with programmable electronic phase and amplitude relations. Terminal tracking is performed by fast angle of arrival measurements in intervals of 5 ms 200 times per second.

Figure 2-12 Circle Smart Antenna

In this way the signal-to-interference ratio (C/I) is improved in both directions by about 8 dB, i.e. the interference between cells (*Intercell interference*) is reduced by about 8 dB. This leads to an optimisation of the link budget and a reduction of the power transmitted by mobile terminals.

The TDD mode of operation of TD-SCDMA offers optimum support for the implementation of smart antennas technology due to the radio path reciprocity of downlink and uplink operating on the same carrier in both directions.

Smart antennas in TDD operation, in combination with Joint Detection, increase the capacity and the spectrum efficiency of the TD-SCDMA radio interface.

2.2.5 Dynamic Channel Allocation

A further minimisation of intercell interference is achieved by Dynamic Channel Allocation (DCA) [YC01]. The advanced TD-SCDMA radio interface takes advantage of all the available Multiple Access techniques: TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access), CDMA (Code Division Multiple Access) and SDMA (Space Division Multiple Access). Making an optimal use of these degrees of freedom, TD-SCDMA provides an optimal and adaptive allocation of the radio resources according to the interference scenario, minimising intercell interference.

The following three different methods of DCA are used:

- Time Domain DCA (TDMA operation): Traffic is dynamically allocated to the least interfered timeslots.
- Frequency Domain DCA (FDMA operation): Traffic is dynamically allocated to the least interfered radio carrier (3 available 1.6 MHz radio carriers in 5MHz band).
- Code Domain DCA (CDMA operation): Traffic is dynamically allocated to the least interfered codes (16 codes per timeslot per radio carrier).

TD-SCDMA **minimises Intercell Interference** by dynamically allocating least interfered resources.

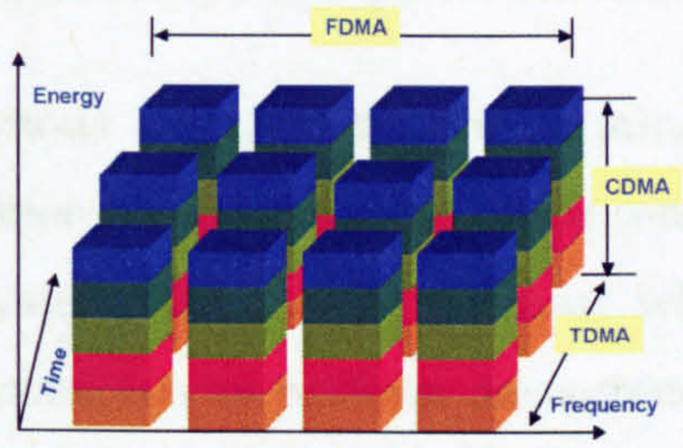


Figure 2-13 Dynamic Channel Allocation

2.2.6 Terminal Synchronisation

Like all TDMA systems TD-SCDMA needs an accurate synchronisation between mobile terminal and NodeB [HH02]. This synchronisation becomes more complex through the mobility of the subscribers, because they can stay at varying distances from the NodeB and their signals have different propagation times.

A precise timing advance in the handset during transmission eliminates those varying time delays. In order compensate these delays and avoid collisions of adjacent time slots, the mobile terminals advance the time-offset between reception and transmission so that the signals arrive frame-synchronous at the NodeB (Figure 2-14).

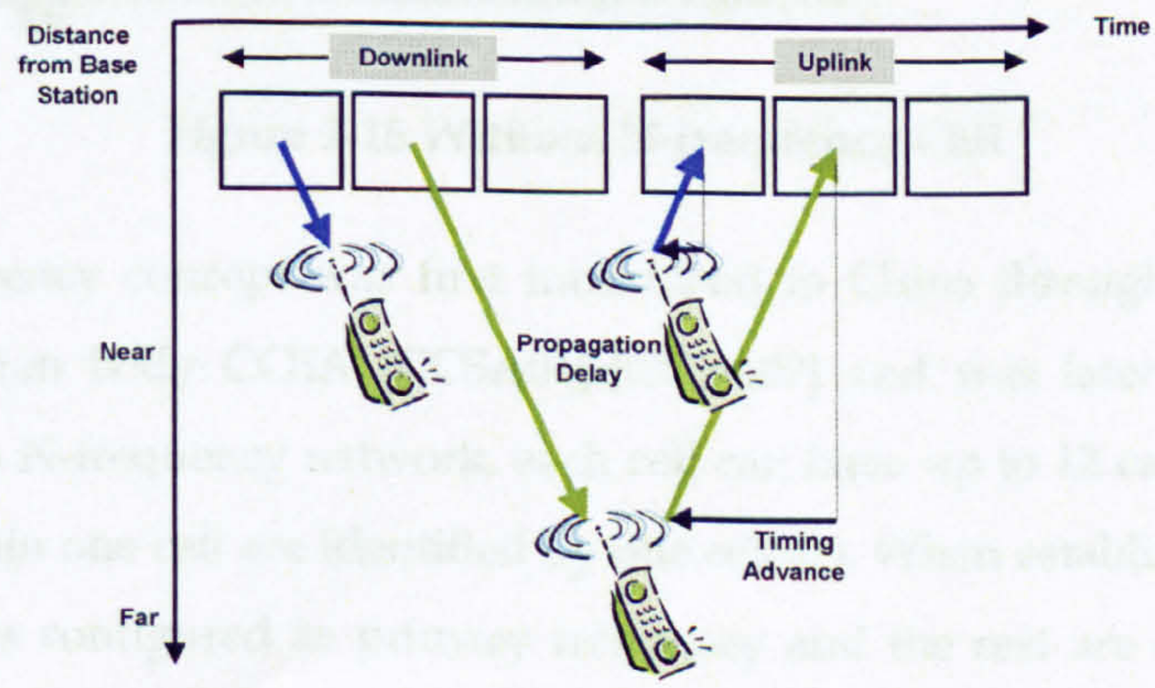


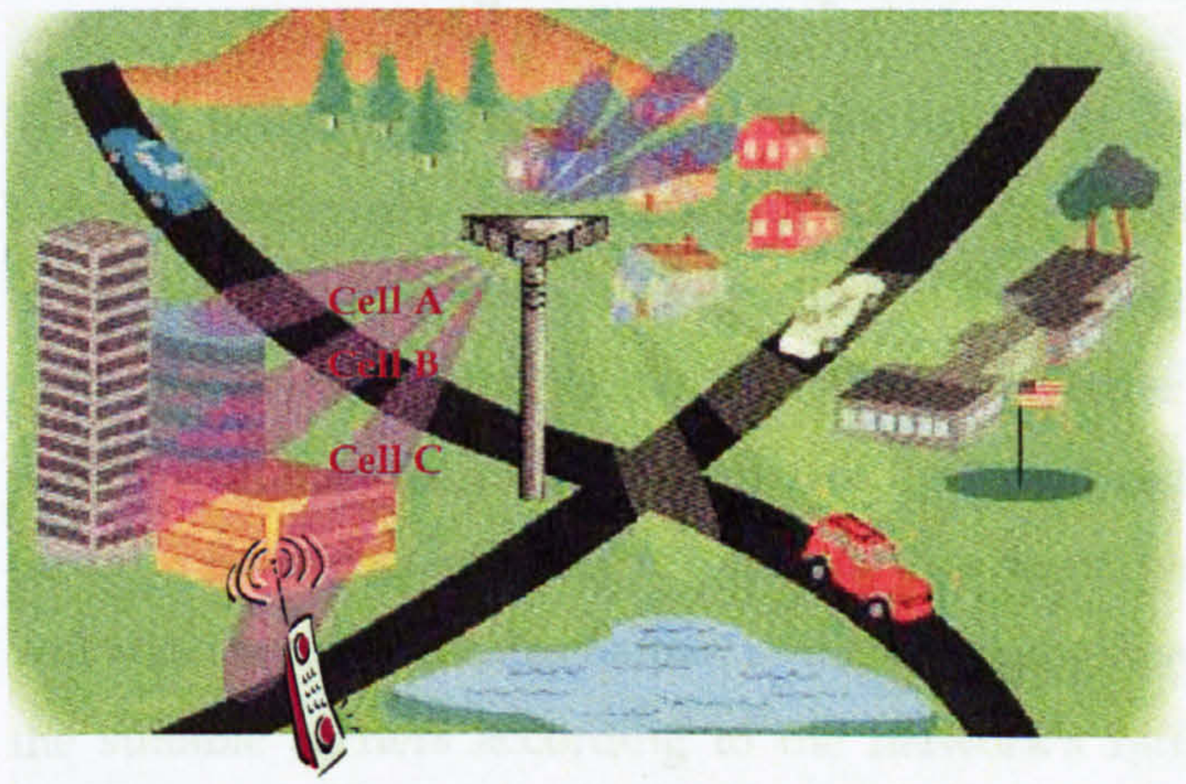
Figure 2-14 Uplink Synchronization

The effect of this precise synchronisation of the signals arriving at the NodeB leads to a significant improvement in multi user joint detection.

By implementing the synchronous deployment, the terminal traceability is improved and the time for position location calculations is sensibly reduced. In addition, in a synchronous system, the mobile terminal when non-actively receiving or transmitting (*idle timeslots*) can perform measurements of the radio link quality of the neighbouring NodeBs. This results in reduced search times for handover searching (both intra- and inter-frequency searching), which produces a significant improvement in standby time.

2.2.7 N-Frequency in TD-SCDMA

As defined in 3GPP, each cell in UMTS networks will contain only one carrier; for WCDMA a 10MHz frequency band (uplink and downlink) is used while TD-SCDMA uses 1.6MHz.



- Each cell can only have one carrier
- N carriers in the same sector means N cells
- UE will be covered by multiple cell broadcast signals with equivalent strength

Figure 2-15 Without N-frequency Cell

The N-frequency concept was first introduced in China through the Chinese standardisation body CCSA [CCSA01]-[CCSA07] and was later proposed to 3GPP. In the N-frequency network, each cell can have up to 12 carriers. All the carriers within one cell are identified by one cell ID. When establishing the cell, one carrier is configured as primary frequency and the rest are configured as secondary frequency (ies).

All carriers will be configured with the same Midamble[3] code ID, scrambling code ID and the N-frequency cell should have a unified uplink downlink switching point. The reason is that all the carriers' signals within one cell are transmitted by one set of smart antennas and the smart antenna system can only perform transmit or receive activity at one time. All the control channels are configured on the primary frequency and TS0 on any secondary frequency is not used by the network. Each individual UE can only work on one carrier at one time under the current N-frequency concept.

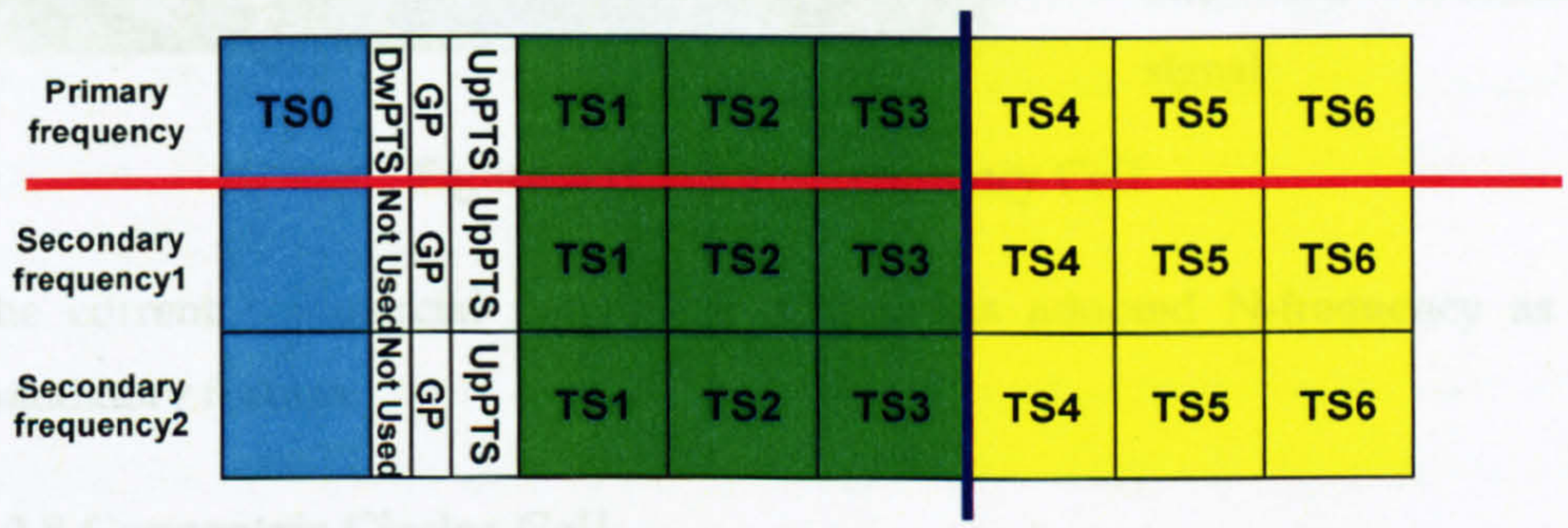
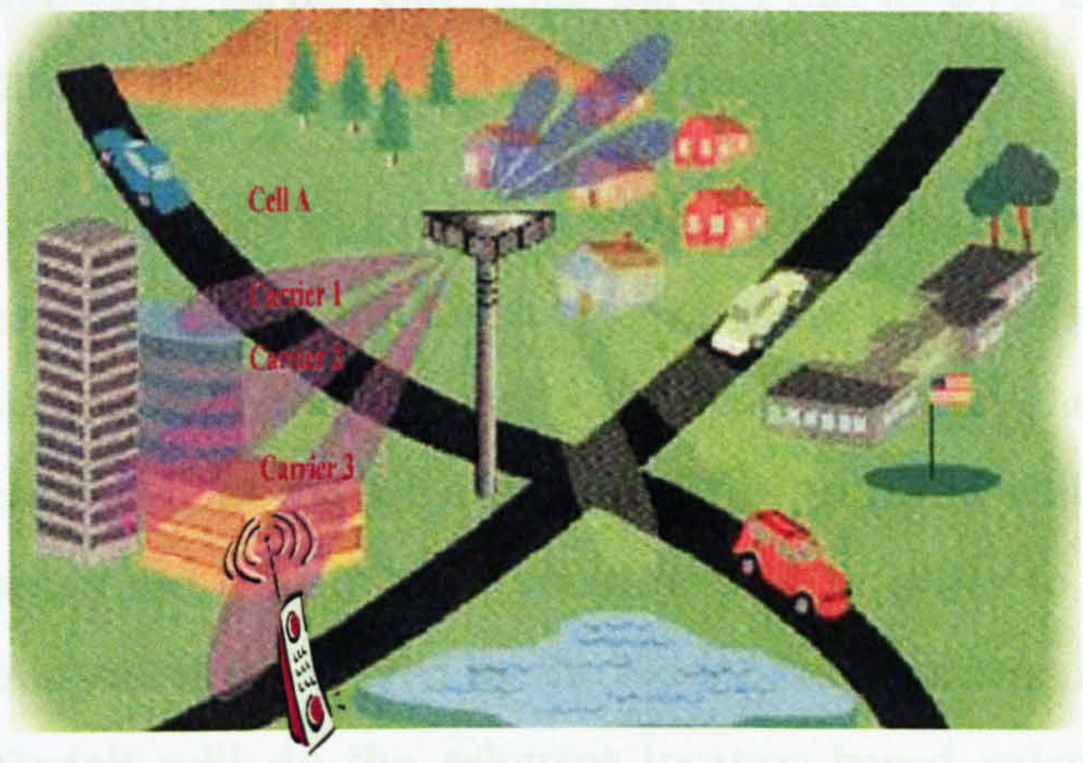


Figure 2-16 N-frequency Cell Structure

When a UE camps on a cell, it firstly listens to the primary frequency for broadcast messages. After successful access, the network will assign the traffic channel to the particular UE according to the radio resource availability and radio environment conditions. During the handover procedure, the terminal will synchronize the primary carrier of the target cell from the serving carrier directly; no matter whether it is primary or secondary carrier. The target cell will allocate the dedicate channel to this incoming handover terminal on any of the suitable carriers according to the network's radio resource management scheme. This research will not cover this radio resource management algorithm.

[3] A burst is the combination of two data parts: a midamble part and a guard period. The duration of a burst is one time slot. Several bursts can be transmitted at the same time from one transmitter. In this case, the data parts must use different OVSF channelization codes, but the same scrambling code. The midamble parts are either identically or differently shifted versions of a cell-specific basic midamble code.



- Each cell can have multiple carriers
- Under one sector there can be one cell with multi-carriers
- UE will be covered by one cell broadcast signal

Figure 2-17 With N-frequency Cell

The current commercial network in China has adopted N-frequency as a mandatory feature.

2.2.8 Concentric Circles Cell

The *Concentric Circles Cell* is a new concept within TD-SCDMA and is proposed by the author as part of this thesis.

The concentric circles cell is under the N-frequency concept umbrella which means that the primary carrier's coverage and the secondary carrier(s)' coverage can be planned differently.

During the cell set up procedure, the network operator will configure the cell parameters via the I_{ub} interface (between NodeB and RNC) messages. Some messages of the NBAP protocol need to be modified; for example, it can indicate the maximum transmission power of each carrier within a cell. [SZ01] gives a proposal on modification of the MAC layer protocol for integrated TD-SCDMA relay network. However, in this research, the modification proposal for the Standard will not be discussed further more because the paper [SZ01] dates from 2007, well after this work was started, and the focus of the research by the author is on network performance.

Basically, the primary carrier's coverage should cover the whole cell (radius r) while the other carriers can cover inner circles of this cell. For example, the first

secondary carrier can cover the cell out to $2r/3$ and the remaining secondary carrier(s) can cover the cell to radius $r/2$.

Normally, the inner circle carriers will serve most of the traffic, and the outer circle will maintain the service of those UEs that are at the edge of the cell. In such a cell, the network can flexibly assign the radio resource to the UE according to the UE's position. The terminal will advance its timing when it sends the signals to the base station in order to make sure all synchronized transmission received by the NodeB from various terminals among the cell. The NodeB will do the relevant location-based calculation to get the terminal's distance. Then the network can adaptively allocate the most suitable radio resource for the terminals.

Advanced radio resource management algorithm adopted in the network will balance the cell traffic and optimize the network efficiency. Meanwhile, the more advanced algorithms of the smart antenna in such a concentric circle cell will improve such aspects as the beam generation and the user location.

For the radio resource management algorithm, how to balance the traffic among inner and outer circles, how to optimize the usage of each carrier are hot topics as well but are outside the scope of this research.

2.2.9 Multi-carrier HSDPA in TD-SCDMA

HSDPA（High Speed Downlink Packet Access）is proposed by 3GPP in its R5 specification [3GPP06][3GPP09][3GPP12] to provide high data rate services in the download direction in the packet domain and to enhance the bearer ability of current 3G system. HSDPA is proposed both in TDD and FDD modes [3GPP06]. Some advanced techniques, such as AMC (Adaptive Modulation Coding) and HARQ (Hybrid Automatic Repeat reQuest), are adopted in HSDPA and the fast packet scheduling function is located in the NodeB instead of the RNC to shorten the round trip times.

In TDD HSDPA, the maximum data rate on one TD-SCDMA carrier is 2.8Mbps with the asymmetric switching point 1:5 (UL: DL).

HSDPA adopts new enhancements especially in the MAC and physical layers, see Figure 2-18 below:

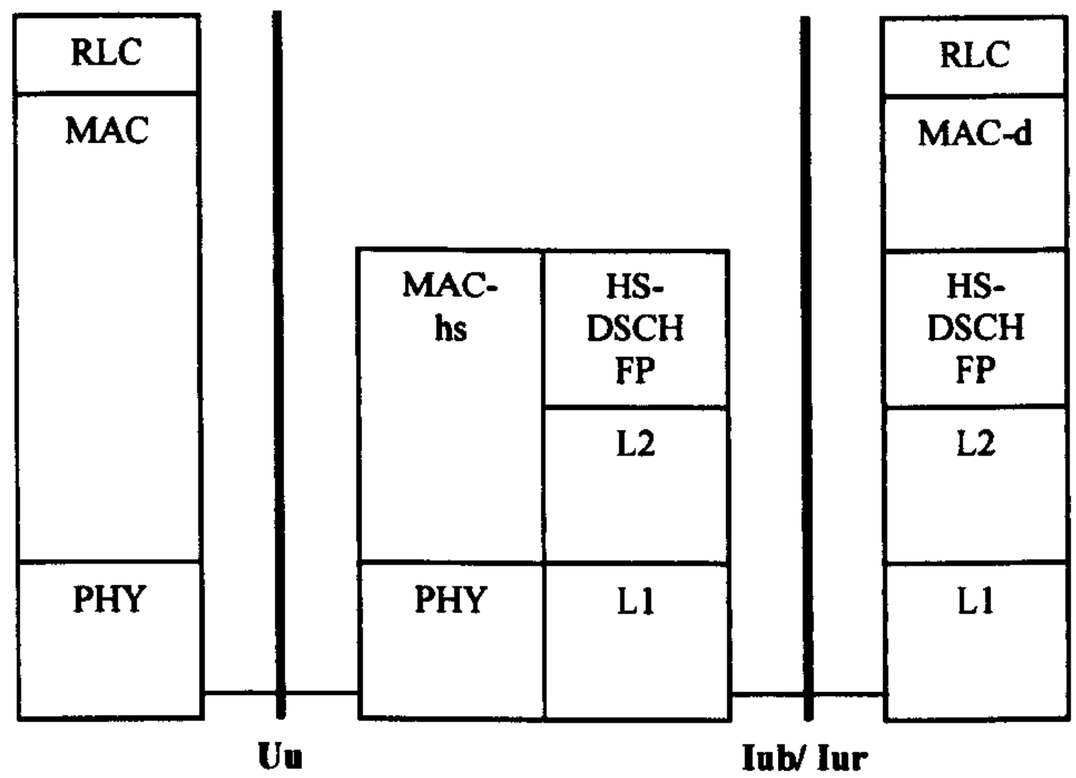


Figure 2-18 Radio Interface Protocol Architecture of HSDPA

- In the MAC layer, a new entity, MAC-hs is added to handle the HSDPA-related tasks such as packet scheduling and HARQ. The transport channel that the HSDPA functionality will use is called HS-DSCH (High Speed Downlink Shared Channel) and is controlled by the MAC-hs.
- In the PHY layer, AMC and HARQ combining are introduced.

According to [3GPP06], for the Node B side, the MAC-hs is responsible for handling the data transmitted on the HS-DSCH. Furthermore it receives configuration parameters from the RRC layer to manage the physical resources allocated to HSDPA. The MAC-hs is comprised of four different functional entities:

- **Flow Control**: This flow control function provides a controlled data flow between the MAC-d and MAC-hs taking the transmission capabilities of the air interface into account in a dynamic manner. This function is intended to limit layer 2 signalling latency and reduce discarded and retransmitted data as a result of HS-DSCH congestion. Flow control is provided independently by priority class for each HS-DSCH.
- **Scheduling/Priority Handling**: This function manages HS-DSCH resources between HARQ entities and data flows according to their

priority class. Based on status reports from associated uplink signalling either new transmission or retransmission is determined.

- **HARQ**: One HARQ entity handles the hybrid ARQ functionality for one user. One HARQ entity is capable of supporting multiple instances (HARQ process) of stop and wait HARQ protocols. There shall be one HARQ process per TTI.

- **TFRI selection**: Selection of an appropriate transport format and resource combination for the data to be transmitted on HS-DSCH.

The MAC-hs, from the UE side, handles the following HSDPA specific functions.

- HARQ: The HARQ entity is responsible for handling the HARQ protocol and there is one HARQ process per HS-DSCH per TTI. The HARQ functional entity handles all the tasks that are required for hybrid ARQ.

- **Reordering**: The reordering entity organises received data blocks according to the received TSN. Data blocks with consecutive TSNs are delivered to higher layers upon reception. There is one reordering entity for each priority class and MAC-identity configured at the UE.

In the HARQ protocol, the network operation performs the following actions:

- **Scheduler**: It includes scheduling all UEs within a cell, services priority class queuing, determining the HARQ Entity and the queue to be served, scheduling new transmissions and retransmissions:

- **HARQ entity** (one per UE): It includes priority class identifier setting, transmission sequence number setting and HARQ process identifier setting

- **HARQ process**: It includes New Data Indicator setting and processes ACK/NACK from the receiver

Meanwhile the UE operation performs the following actions:

- **HARQ entity**: It mainly includes processing HARQ process identifiers
- **HARQ process**: It includes New Data Indicator processing, error detection result processing, status report transmission and priority class identifier processing
- **Reordering entity**: There is one re-ordering entity for each priority class and transport channel configured at the UE. It performs the functions of reordering of received data based on transmission sequence numbers and forwarding data to higher layer

Now multi-carrier TD-SCDMA HSDPA is proposed in the CCSA (China Communication Standard Association) which is the enhanced version of single—carrier TDD HSDPA in 3GPP and much of the standardization work is already completed. Moreover, the multi-carrier TD-SCDMA HSDPA supports backward-compatible to both single-carrier TD-SCDMA HSDPA and N-frequency TD-SCDMA network. So in the multi-carrier HSDPA concept, the basic ideas are the same as in the principle of 3GPP HSDPA, the main difference being that the terminal can work on multiple carriers at the same time in a multi-carrier HSDPA system. Thus the maximum data rate in the multi-carrier HSDPA system is n*2.8Mbps where n is the number of carriers. *This is the combination of N-frequency and HSDPA technologies.*

The standards have been modified to include this combination and the transmitting and receiving capability of the terminals needs to be enhanced greatly. However, the big challenges to efficiently utilizing the network resource are defining the proper channel resource scheduling solutions and re-transmission schemes. With this multi-carrier HSDPA feature, higher bit rate applications can be provided to end users - this is the evolution trend of TD-SCDMA systems.

There are three types of channels newly defined in HSDPA systems: High Speed Downlink Shared Channel (HS-DSCH), High Speed Shared Control Channel (HS-SCCH) and High Speed Shared Information Channel (HS-SICH).

The HS-DSCH is the transport channel which is used to carry the HSDPA related traffic data so the HS-DSCH is downlink only, while the HS-SCCH and HS-SICH are physical channels used for transmitting the HSDPA signalling.

For the downlink, the UE should read the corresponding HS-SCCH channel to get the HS-DSCH related information, such as Transmission Format and Resource Indicator (TFRI), HARQ process identity and redundancy version. Meanwhile the HS-SICH is an uplink control channel shared by UEs for sending the HARD acknowledgement and the Channel Quality Indicator (CQI) to the NodeB. In CQI, the information about the proposed modulation type, recommended Transmission Block size are included.

Figure 2-19 gives one example of multi-carrier TD-SCDMA HSDPA resource allocation. The HSDPA downlink control channels can only be configured on the primary carrier and the TS0 timeslots on secondary carriers are not used. If the UE supports multi-carrier receiving, the HSDPA resource of one particular UE can be assigned on different codes, different timeslots and different carriers.

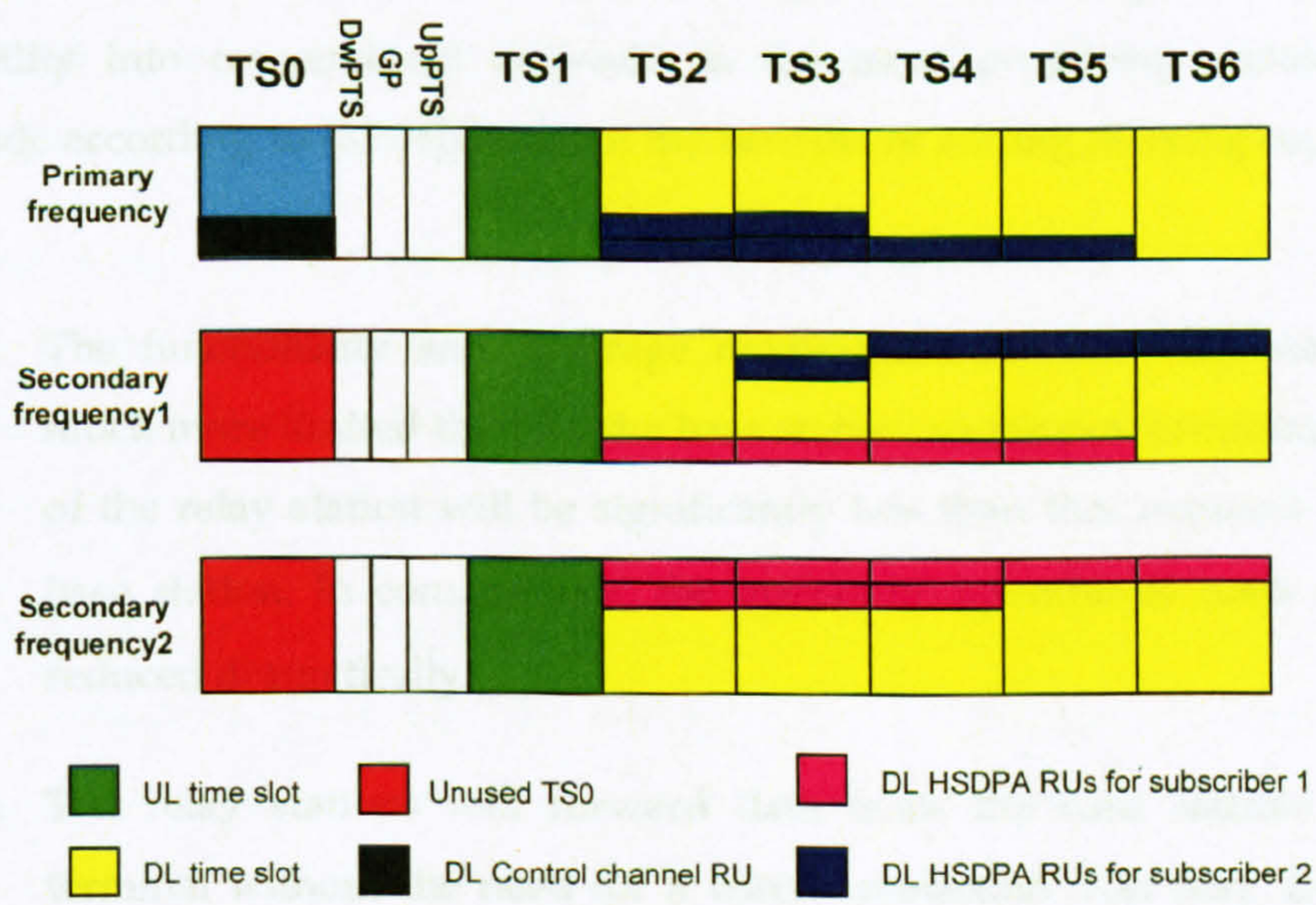


Figure 2-19 Multi-Carrier HSDPA Structure

In this research, the multi-carrier HSDPA concept will be adopted for the capacity analysis in the hybrid TD-SCDMA relay network and comparison with it in the genuine TD-SCDMA network. So the multi-carrier HSDPA technology itself will not be considered further.

2.3 Relay Networks

The concept of multihop wireless networking was originally studied in the context of ad hoc and peer-to-peer networks. However, this topic later became more and more popular for cellular networks. The first system based on time-division multiplexe (TDM) and relays connecting mobiles to the fixed network was proposed in 1985 [BW01]. Another method, reusing a frequency channel from a neighbouring cell was proposed for frequency/time-division-multiplex system in [VS01]. Relaying in the cellular code-division multiple access-based systems has been investigated by Zadeh in [AZ01].

As mentioned in Chapter 1, the demand of high data rates became one of the core requirements when investigating the mobile network evolution. However, such demands in wireless networks results in high power consumptions as it is well known that for a given transmit power level, the symbol energy decreases linearly with the increasing transmission rate. With the desire for high throughput and satisfactory seamless coverage in mobile networks some fundamental network enhancements are required. The integration of relay capability into conventional networks is the most promising architectural upgrade according to [RP01]. Some of the benefits of adding relaying capability are:

1. The functionality and coverage requirement for the relay station is much more limited than for the base station, so the power consumption of the relay station will be significantly less than that required for the base station. In consequence, the operators' operational costs will be reduced dramatically.

2. The relay stations will forward data from the base station to the terminal without the need for a wired connection. Not only does this give the possibility of solving coverage problems, but the investment needed for network construction investment can be reduced.

3. The capacity gains may also be achieved by either exploiting reuse efficiency or spatial diversity.

Furthermore, time-division multiple access-based systems are especially well suited to introducing relays as this scheme allows for easy allocation of resources to the mobile-to-relay and relay-to-BS links.

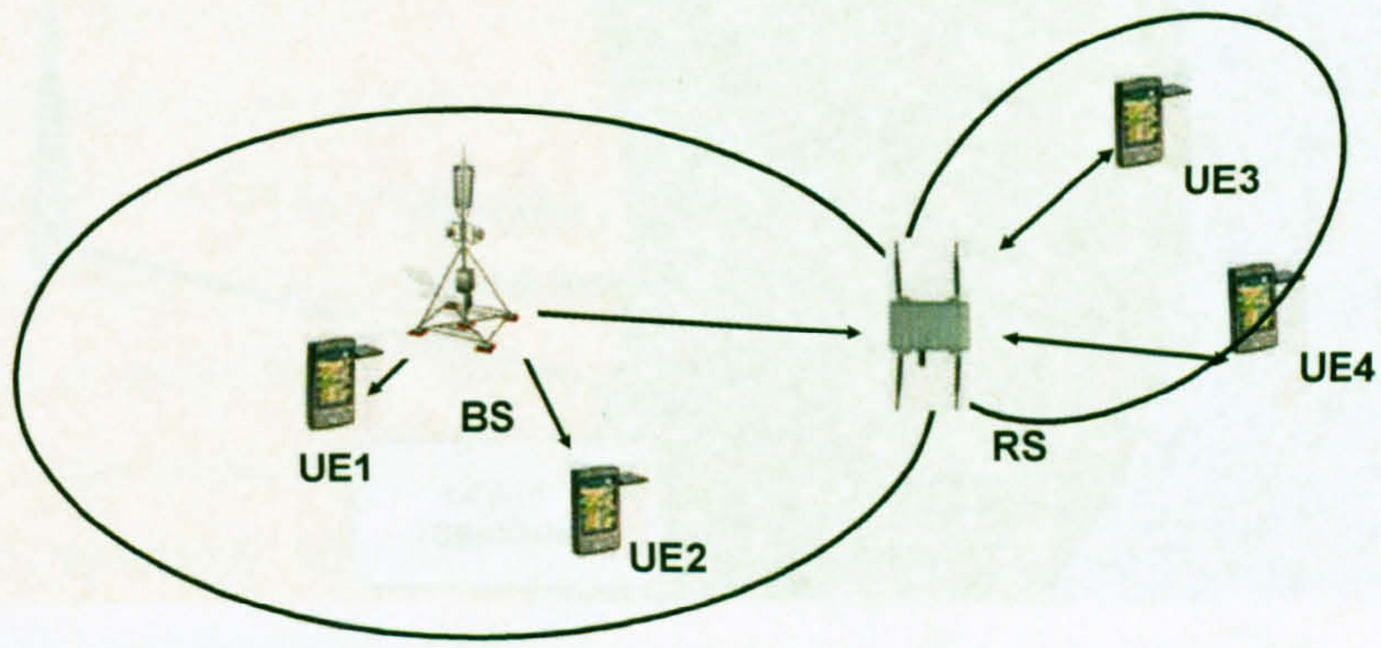


Figure 2-20 Relay Network

Figure 2-20 shows the principle for a simple 2-hop relay network. Here, the Base Station (BS) provides the services to UE1 and UE2 as both terminals are within its coverage. However the UE3 and UE4 are out of the coverage but can receive the signals from the Relay Station (RS). As there is also a link between BS and RS, these two UE3 and UE4 then connect directly to the RS instead of the BS so their signals can be relayed.

In general, the relay network can be categorized into two schemes – decode-and-forward system and amplify-and-forward system. In this research, the first scheme is considered as the majority of proposed concepts are of this category and they are more viable for implementation.

The Opportunity Driven Multiple Access (ODMA) introduced in [3GPP14] is a relay protocol designed for UMTS TDD. One of the aims of ODMA is to increase the capacity and efficiency of radio transmissions towards the boundaries of the cell. However ODMA works only for the area within the TDD coverage to extend the range of the high rate data coverage - Figure 2-21. The research work in this thesis will consider the border region without the TDD coverage.

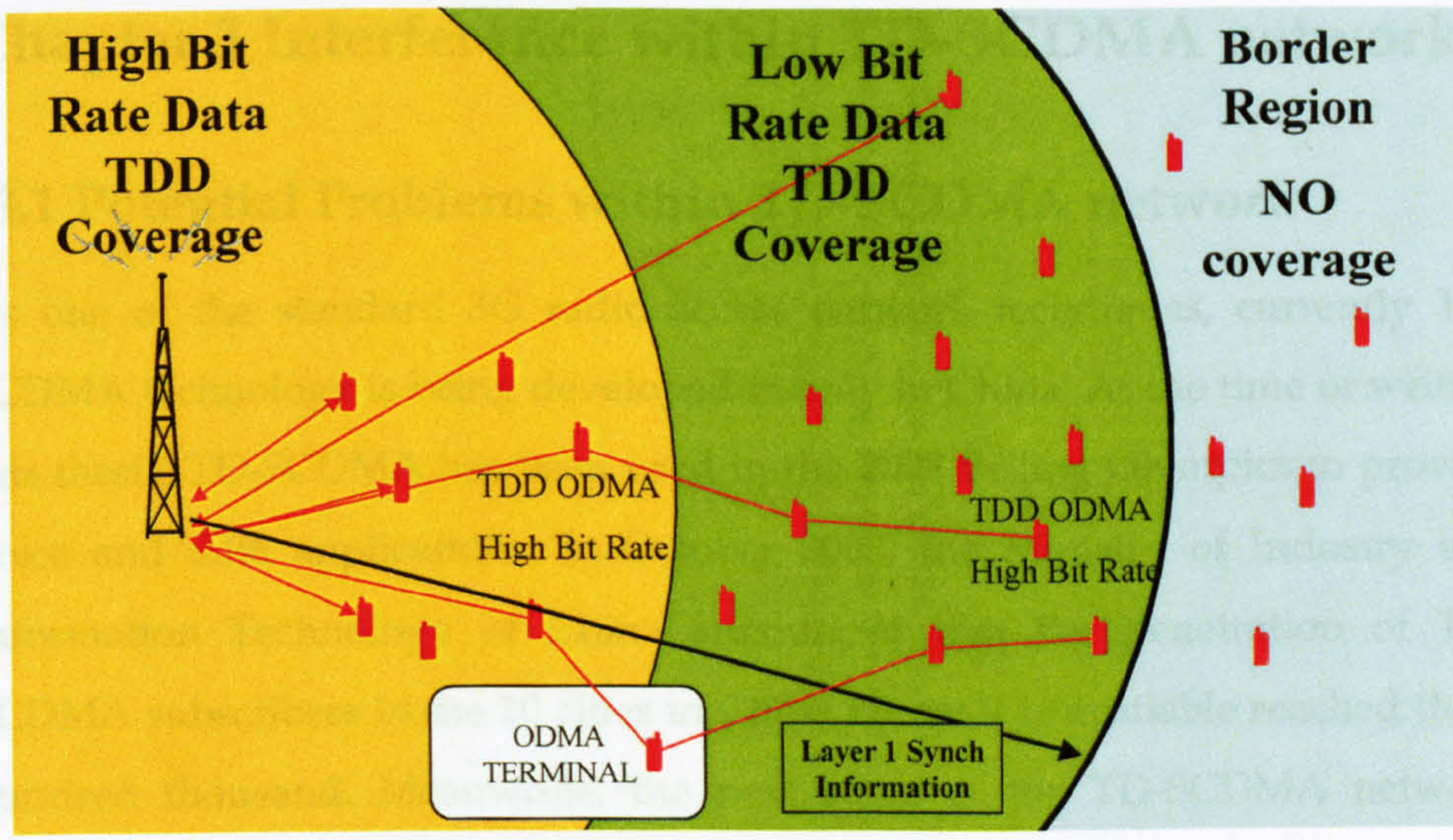


Figure 2-21 ODMA Border Coverage [Figure 1 in [3GPP14]]

The main reason why ODMA started from TDD is because of the advantage of TDD in that the signals are transmitted and received on the same frequency band; there will be less hardware impact on the TDD terminal with the introduction of the relay network and there fewer additional frequency bands will be needed. In the project "FLEETNET" in Germany [MH02], a modified air interface based on UTRA TDD was proposed for car-to-car communication; the work in [MW01] gave a detailed proposal about how to use the common air interface (CAI) for both TD-SCDMA and ad hoc network. In [PJ01], the work showed that by introducing an underlying TDD relay network, the WCDMA FDD network performance was been improved by up to 50%.

2.4 Summary

This Chapter presented an overview of 3G mobile network technology, in particular TD-SCDMA that is used in this research. It also briefly introduced relay networks.

The next Chapter discusses why this research is necessary and how it is possible to introduce a relay network addition to TD-SCDMA.

Chapter 3 Interference within TD-SCDMA networks

3.1 Potential Problems within TD-SCDMA network

As one of the standard 3G radio access network techniques, currently TD-SCDMA technology is being developed mainly in China. At the time of writing this thesis, TD-SCDMA has been used in the 2008 Beijing Olympics to provide voice and data applications. In October 2008, the Ministry of Industry and Information Technology of China announced that the penetration of TD-SCDMA subscribers in the 10 cities in China where it is available reached three hundred thousand. Meanwhile, the next stage of the TD-SCDMA network expansion is continuing as planned. According to the plan, there will be another 28 cities covered by TD-SCDMA. The overall amount of TD-SCDMA subscribers has reached 2 million after 2008 Beijing Olympic and it optimized estimation is till 2012, the total TD-SCDMA subscribers might be 50 million.

Although the launch of TD-SCDMA is in its initial phase across China, it is expected to grow rapidly, as witnessed by the current heavy advertising. This research is focussing on topics such as the network's performance under heavy traffic conditions in cities and in large rural areas. One particular area of concern to network operators is what should be the proper cell radius for TD-SCDMA networks under different conditions.

As with all CDMA technologies, interference is a key aspect when doing the network planning as well as the propagation model; many interference factors can influence the coverage.

For example, the multiple DwPCH signals from different cells within one geographical area will cause inference. Two possible solutions for this are:

- the N-frequency technology addressed in the previous chapter;
- using "DwPTS blanking".

DwPTS blanking means that the DwPCH signal of one cell is not continuously transmitted, but uses a scheduling scheme to determine when the different DwPCH signals from different cells should be transmitted to avoid interference

among them. Although that might introduce more difficulties for a mobile terminal searching cells to determine which to camp to, it is possible, by using repeated attempts, for the terminal to finally capture the best cell in its cell list. [3GPP13]

Besides the downlink pilot interference, the uplink pilot interference is another issue since all the terminals attempting to gain service are accessing the UpPCH. If this UpPCH is interfered by other signals, the cell access success rate will drop dramatically. This problem becomes more serious when adopting the N-frequency technology because all the carriers within the cell share a single time slot. In addition, downlink DwPCH signals from other cells can interfere with the UpPCH signal because the extra propagation delay means they overspill their time slot and if this overspill is greater than the guard period then interference occurs - remembering that uplink and downlink channels are on the same frequency.

One possible method to solve the problem of DwPCH / UpPCH inter-cell interference is to allow the network to dynamically allocate the UpPCH in any uplink time slot. Then, via broadcasting the allocation, all the terminals within this area will adjust their sub frame structure accordingly.

At the edge of the cell, these problems will be more serious when there are more users. This research will focus on solving the coverage problems at the edge of the cell or the black hole in the network.

3.2 Coverage problems within TD-SCDMA network

As shown in Figure 3-1, the delay will be further at the edge of the cell. If the terminal is near the cell edge, after receiving the signals from the network, it will adjust its timing to advance the signals it transmits to make sure they arrive at the NodeB simultaneously with those from other terminals all around the cell. The further the terminal is away from the NodeB, the more it should advance its signal timing. The following diagram shows the normal status of signalling transmission and receiving between the NodeB and one terminal at the edge of cell (the x axis is time):

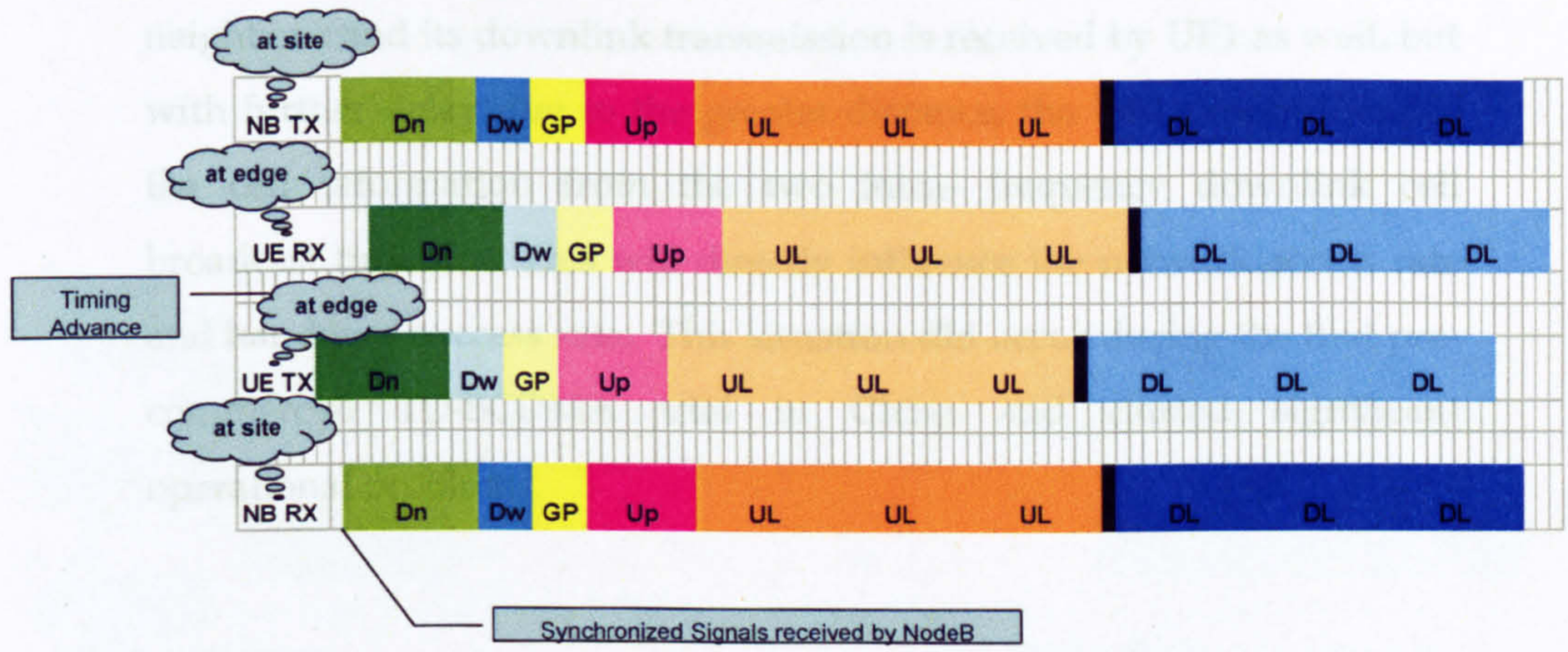


Figure 3-1 Cell Edge Normal Case

Dn: Downlink Timeslot 0, which is always configured as downlink, mainly to do the cell broadcasting

Dw (DwPTS): downlink pilot time slot, for downlink synchronization

GP (Guard Period): main guard period for TDD operation,

Up (UpPTS): uplink pilot time slot, for uplink synchronization

UL: the Uplink Time Slot, while the TS1 is always allocated Uplink

DL: the Downlink Time Slot

NB TX: The Signals transmitted from the NodeB

UE RX: The signals received by the terminal

UE TX: The signals transmitted from the terminal

NB RX: The signals received by the NodeB

However, even with a carefully designed network, there are still more possibilities to introduce interference in the network. The majority of interference cases exist at the edge of the cell and two of the interference scenarios are described below:

Scenario 1: If the terminal is at the edge of the cell, it might get interference from the neighbouring cell. As shown in the following slot diagram, the UE1 is within the NodeB1's coverage and is receiving the delayed signals from NodeB1. However, with the timing advance scheme, UE1 can still camp on NodeB1, but, as NodeB 2 is NodeB1's

neighbour and its downlink transmission is received by UE1 as well, but with further delay due to the greater distance, the UE1 cannot identify the cell information from the two intra- frequency downlink cell broadcast time slot. This will directly influence the network access rate and handover success rate. This situation did occur during the first pre-commercial TD-SCDMA trial in China and caused significant operational problems.

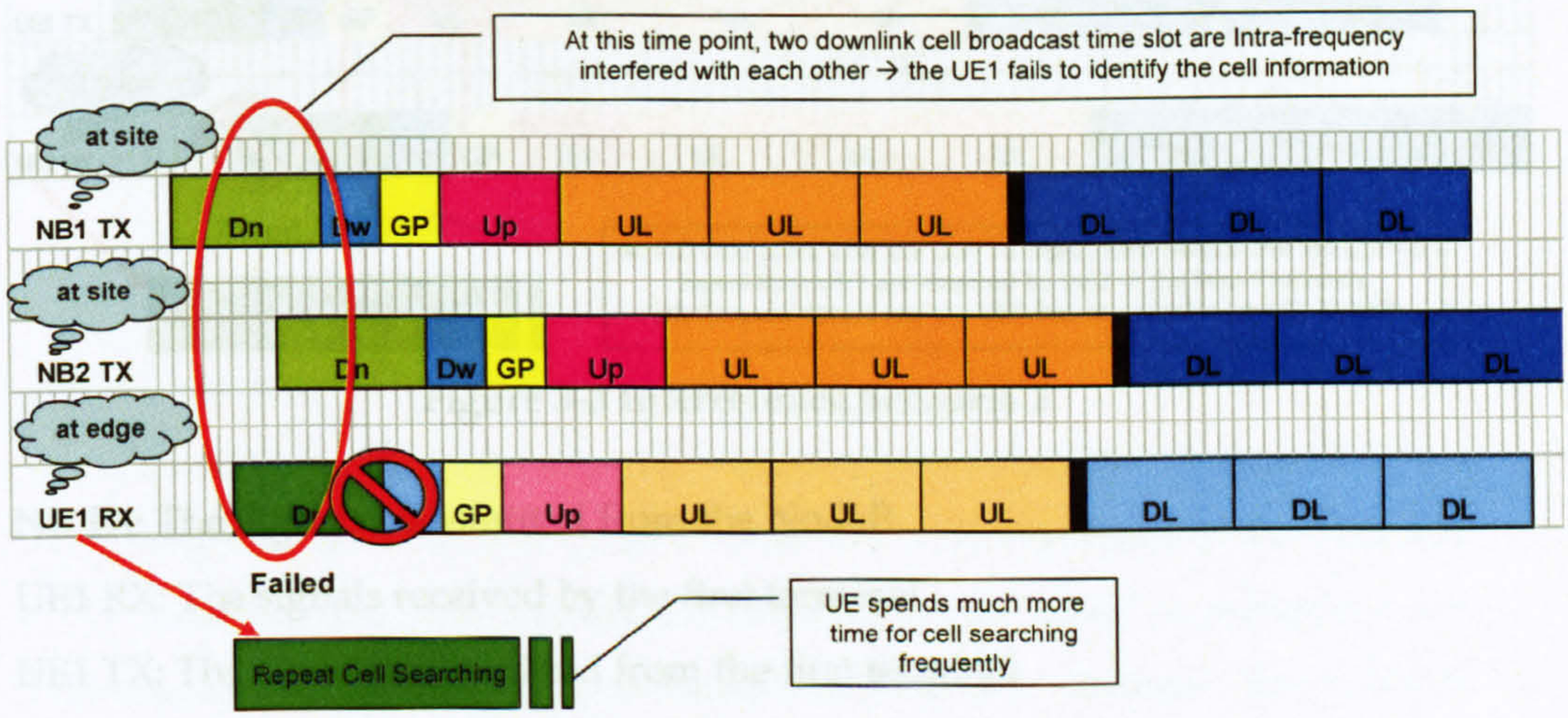


Figure 3-2 Interference Scenario 1

NB1 TX: The Signals transmitted from the NodeB1

NB2 TX: The Signals transmitted from the NodeB2

UE1 RX: The signals received by the first terminal

Scenario 2: There also exists another interference scenario, this time with two users near to each other at the edge of the cell who will have interference problems particularly when one is searching and the other is sending: the terminal searching is looking for downlink synchronized signalling but will also see the heavy intra-frequency interference from another terminal sending on the uplink. The more terminals there are, the heavier the interference will be.

As shown in the following slot diagram, the first terminal's uplink pilot signals interfere with the second terminal's downlink pilot Pilot signals.

Therefore, having a heavier noise figure, the second terminal cannot decode the cell synchronization information carried on the DwPTS, even if it is located in the coverage of this cell.

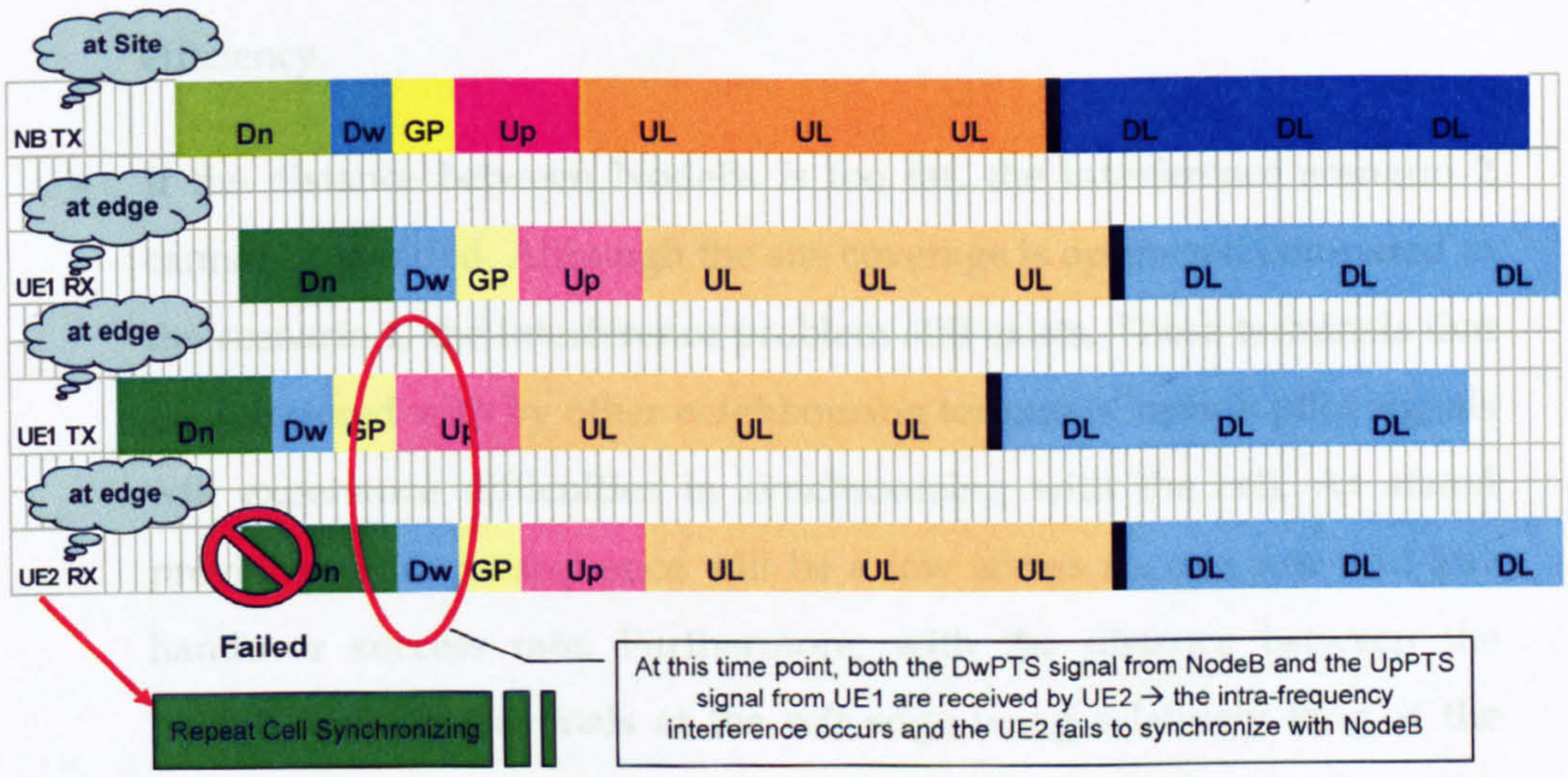


Figure 3-3 Interference Scenario 2

NB TX: The Signals transmitted from the NodeB

UE1 RX: The signals received by the first terminal

UE1 TX: The signals transmitted from the first terminal

UE2 RX: The signals received by the second terminal

NB RX: The signals received by the NodeB

The distance between NodeBs is an important element of network planning:

- If the NodeBs are too close, the interference scenario 1 is more likely to happen. If the terminal is, by chance, in the position where the signals are coming from more than two NodeBs, the problem will be even worse. On the other hand, with such interference in the network, the terminal will repeatedly search the cell information, even it is not very far away from the desired serving NodeB; this will lead to a waste of the battery and delay in camping on to the cell. The cell access success rate will be lower than in the normal case. Meanwhile, because the terminal will monitor the neighbouring cells regularly to be prepared for any handover, the interference on the downlink cell broadcast timeslot will lead to bad neighbouring cell selection and consequentially low

handover success rate. Remember that the small cell coverage will cause frequent handover activities. The result is that there will be an adverse impact on the network capacity as fewer users will be served by the network. The above two aspects can lead to a lower network utility and efficiency.

- If the distance between NodeBs is too far, the interference scenario 2 cannot be avoided. Although the site coverage is optimized compared to the scenario 1, the interference problem still exists. Those terminals that are interfered with by other neighbouring terminals' uplink pilot signals will experience difficulties in synchronizing with the cell. As stated previously, the consequence will be a low access success rate and low handover success rate. Furthermore, with the distance between the NodeB and the terminals at the cell edge being relatively long, if the handover attempts fail because of the bad synchronization, the handover call drop rate will increase greatly. Besides the negative user experience, those users will attempt to connect repeatedly and will also interfere with other terminals. Similarly to the result of scenario 1, the failure call attempts and handover attempts decrease the network capacity.

From the above analysis, this research proposes a new network structure with the intention of improving TD-SCDMA cell coverage suggestion and optimizing the capacity of the TD-SCDMA network via lowering the interference at the cell edge.

3.3 Adding relay to N-frequency TD-SCDMA

If coverage is to be extended in a TD-SCDMA network then either more NodeBs have to be added (which is costly) or the power has to be increased - which can be self-defeating as it can increase the problem of interference.

By using the concept of relay networks, introduced in the previous chapter, the flexibility that they offer can benefit the network a lot while extending the coverage and enhancing the capacity.

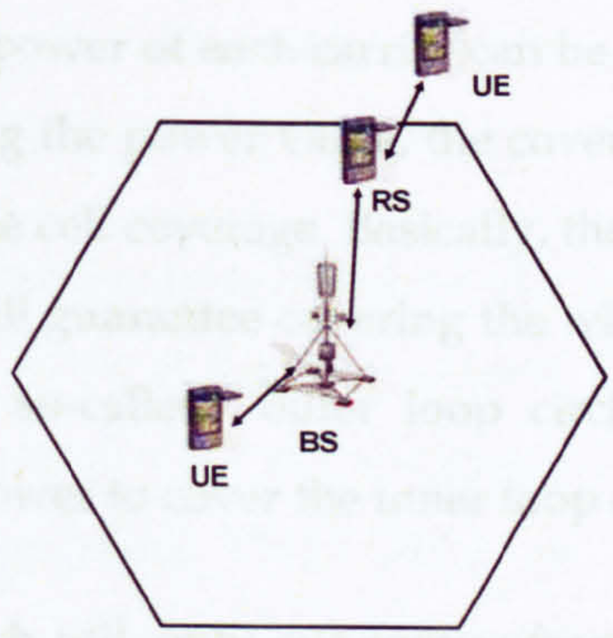


Figure 3-4 Relay sketch map

The principle is illustrated in Figure 3-4. Within the relay network, the client terminal just needs to contact a nearby terminal that is acting as a relay station. By keeping a low transmission power, compared with that for normal cellular communications, over the relatively short distance, this does not add significant extra interference for other terminals.

In addition, the establishment of the relay connection is *application driven*: this means that the relay element is only introduced if such a service is required by the client terminal and there is no need to extend the fixed infrastructure - an important consideration in rural scenarios especially.

Taking advantage of the N-frequency network introduced in chapter 2, in the same geographical cell coverage area, there can be more than one carrier belonging to one logical cell. In other words, all the cell broadcast information is transmitted on the primary carrier only and all the secondary carriers are regarded as the traffic carriers of an individual cell. The N-frequency technology significantly reduces the interference which is introduced by DwPCH and download Timeslot 0 because less DwPCH and cell broadcast information is required in the network. Moreover, from the network planning point of view, adopting the N-frequency allows the primary carrier frequency plan to be more flexible. For example, the primary frequency can be allocated in a cluster concept while the secondary carrier can be assigned with frequency reuse factor of 1. So it is obvious that the N-frequency network will be of great benefit for reducing the network interference. The concentric circle cell complies with the N-frequency network structure perfectly

- The transmission power of each carrier can be allocated according to the needs; by adjusting the power value, the coverage of each carrier can be different within the cell coverage. Basically, the transmitted power of the primary carrier will guarantee covering the whole planned cell coverage all the time (the so-called "outer loop circle") while the secondary carriers use less power to cover the inner loop circle.

- At the edge of each cell, only one carrier from an individual cell might cause interference any other inner circle carriers will definitely have no overlap with neighbouring cells' inner circle carriers. Therefore the interference at the cell edge will reduce to a certain extent.

This research, therefore, combines the N-frequency technology and the concentric circle cell concept with relay network technology, applying the same radio access technology -TD-SCDMA to all the air interfaces, to solve the coverage problems at the edge of the cell or the "black holes" in TD-SCDMA networks.

[HN01] investigated the work about introducing a relay network into a WCDMA network. Similar to the proposal in this research, the air interface is the same for both the WCDMA and relay networks. However as stated in [HN01], TDD is more suitable for this relay combination as in a WCDMA FDD system the terminal cannot transmit and receive signals on the same frequency band, which makes the radio more complicated for relaying.

When importing another network into the TD-SCDMA network, the most important issue is to avoid introducing more interference. The N-frequency and concentric circle cell make the TD-SCDMA network more suitable for combining with relay network where the hybrid network structure will extend the coverage and reduce the interference greatly. The main advantage is that the terminal acting as a relay station in the relay network will be covered only by the cell primary carrier, so this terminal can take any of the secondary carriers of the cell as the working frequency between itself and the client terminal. This selected frequency has no intra-frequency interference with the primary carrier in TD-SCDMA network.

This approach extends the coverage, therefore, without adding extra interference.

Adding a relay network into a conventional cellular network has attracted quite a lot of research interest. Most of the work related to TD-SCDMA has focused on developing a suitable protocol for the integrated TD-SCDMA relay network. [LX01] presents the appropriate TD-SCDMA air interface modification to include ad hoc operations without changing the TD-SCDMA frame structure. Corresponding radio resource management schemes are provided to ensure the new air interface will apply to the hybrid system. Based on the work that brought out one common air interface for both TD-SCDMA and relay network parts [MW01], researchers from the same "National Mobile Communications Research Laboratory, Southeast University" investigated the modification on the MAC layer protocol to utilize the channel allocation efficiency in the TD-SCDMA relay network [SZ01].

As stated in previous sections, this work is different, focusing on the performance analysis of the TD-SCDMA relay network under the combination of N-frequency and concentric circle cell concepts, which has not yet been considered by any other work.

3.4 Approach

A normal ad hoc relay network structure will dynamically construct and de-construct itself with the activities of the terminals comprising that network, including as they move location. However, when considering the hybrid TD-SCDMA relay network, a frequently changing network structure will cause severe problems, with large increases in signalling traffic and non-guarantee in service quality. Therefore, in this research, the approach taken stabilises the hybrid network structure as much as possible.

The outline of the approach is:

- User terminals will act as the relay stations in the relay network to provide access services to other users who are out of the TD-SCDMA network's coverage. Since this will benefit the network operator, at least from the coverage point of view, the operator should set up promotional

schemes to encourage the users to work as the relay station in the relay network, such as free traffic rewards or free application rewards. Promotional schemes have been successfully used before in the mobile industry, such as that currently adopted in China which is used to encourage the "friendly users" in the TD-SCDMA pilot network. Within 2 months, there were more than 20,000 users using the TD-SCDMA network in 5 cities. By using such schemes in the hybrid TD-SCDMA relay network, the network operator can maximise the probability of there being sufficient relay stations within the coverage area to provide an adequate quality of service to those outside. Of course, a scheme could exist where all users could act as relay stations whether they wanted to or not, but in a competitive environment this might not be good marketing, It should also be noted that acting as a relay station will impact adversely on battery life as it will be transmitting even when the subscriber is not using it, so the user should have some incentive.

- In order to avoid the relay network structure changing frequently (called "floating" here), the TD-SCDMA network must have a strategy for establishing the relay network and monitoring its performance. In this research the approach is:
    - It will always be the terminal that initiates the move to act as the relay station in the relay network. If the terminal is in idle mode, the user can manually send the "act as relay station request" to the TD-SCDMA network in order to claim rewards.
    - When the TD-SCDMA network receives the request, the network will evaluate the terminal's "credit" (such as current location, recent movement statistics, previous service quality, application capability) - the criteria for choice of relay station will be set by the operator depending on its business plan. As this research focuses on the coverage and interference influence of the hybrid TD-SCDMA relay network, the criteria choices will not be discussed further.

- If the request meets the criteria, the TD-SCDMA network will send a response to the terminal together with necessary parameters (such as which secondary frequency of the serving TD-SCDMA cell the terminal should use as a relay station for broadcast and what kind of packet data services that can be forwarded by the terminal).
- When the response is received successfully by the terminal, it will adjust its transmitter and receiver accordingly and start working as a relay station in the relay network.

- Both the terminal and the TD-SCDMA network can terminate the relay network based on certain rules. For example, if the TD-SCDMA network discovers that the terminal acting as a relay station is active with its own communication it will terminate the relay station role since continuation of relay services will interfere with the TD-SCDMA network. Another case is where the user wants to stop acting as a relay station, or the terminal realises that the relay station role will adversely affect its own performance, a message can be sent to the TD-SCDMA network to terminate the role.

How this will work in different scenarios is discussed in the next section.

3.5 Research Scenarios

In GSM networks, the main type of service carried was voice, but after the evolution to 2.5G or 2.75G, with GPRS and then EDGE, both voice and data application are common and the trend is that data services are getting more and more important. In this research, only packet data services are considered. The reasons are:

- Normally uses who are running data application on their terminals are not moving as frequently or as fast as voice users. This lower mobility makes them a more suitable candidate for constructing a relay network; this applies to both acting relay station and client terminals.
- The quality requirements for data services are generally not so stringent as those for voice; users can bear more delay or jitter in the application.

This aspect is very important for the relay network which needs the users to be more tolerant about the quality.

- The duration of a typical data application connection is much longer than a voice application, which will introduce less signalling traffic in the TD-SCDMA relay network.

Furthermore, according to [3GPP08], each TD-SCDMA carrier can serve only one 384kbit/s user or three 128kbit/s users, which will not be the majority business model in the real network. The reason for this is the scrambling code limitation in TD-SCDMA. At the initial stage of constructing a new network, the main intention of the operator is to attract as many users as possible to utilise the network investment. So in this research, the non-HSDPA service model is assumed to be packet switched 64kbit/s, which is the most likely wide used packet date-rate. Meanwhile, HSDPA, which further optimises the network resource usage via adopting the shared channel among all severing users, is analyzed as well for further comparison between these two packet data service technologies. The HSDPA user in this work is configured with peak data rate 384kbit/s and mean date rate 64kbit/s.

The normal objective for the cellular mobile network structure is consistent coverage to provide seamless services; basically each cell will be surrounded by six neighbouring cells and between them the handover management is implemented.

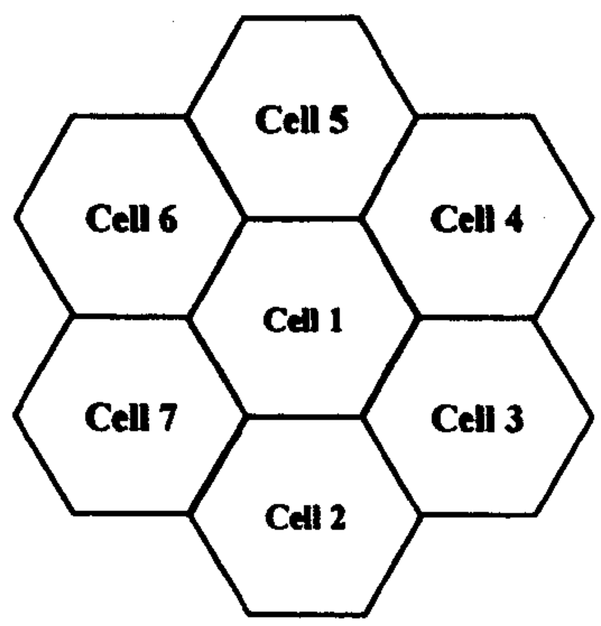


Figure 3-5 Cellular Mobile Network

For an individual cell in the non-N frequency network, the coverage of each carrier is the same. If the frequency reuse factor = 1, the more carriers adopted by one NodeB, the heavier the intra-frequency interference there will be.

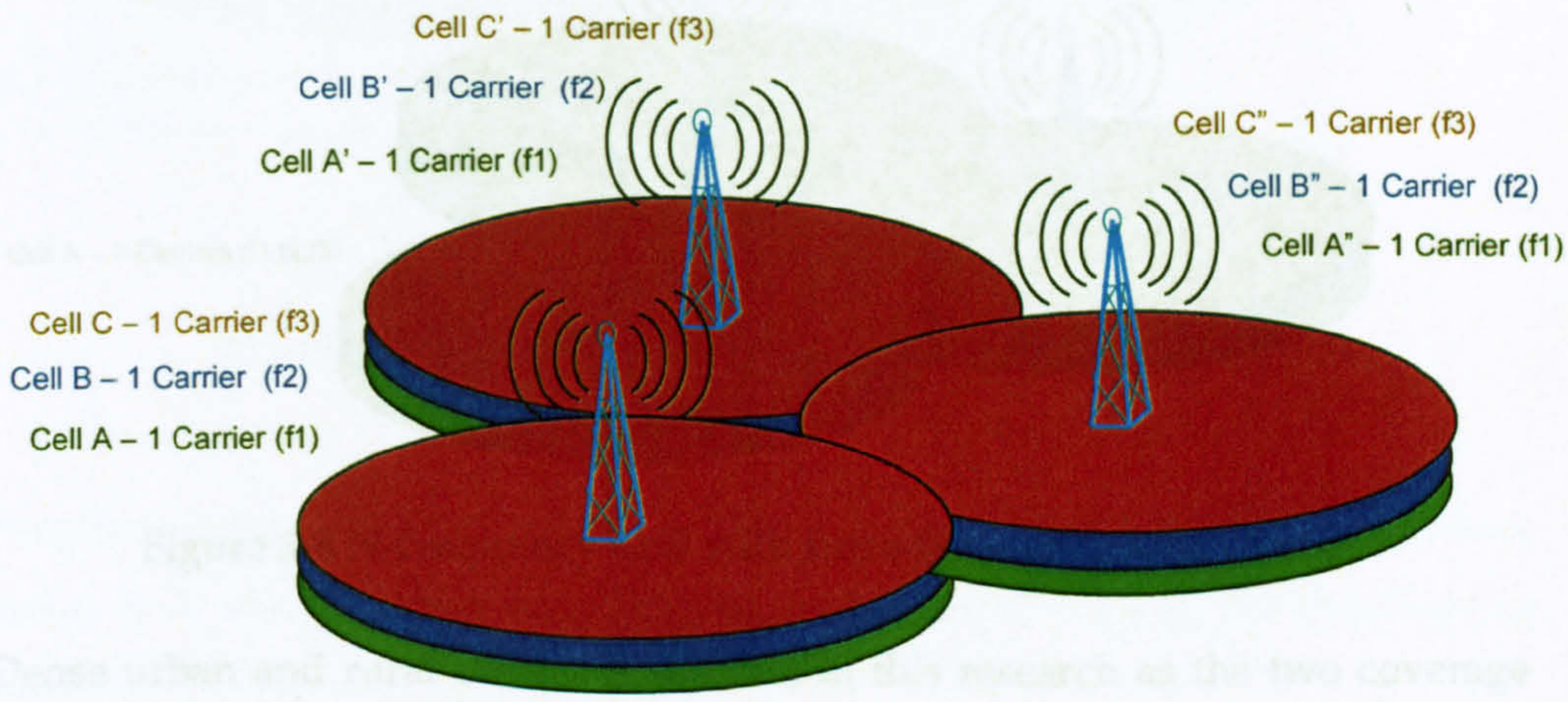


Figure 3-6 non N-frequency Cell with intra-frequency Interference

Otherwise, if it is required to establish an inter-frequency network, the requirements of the bandwidth will depend on the cluster's size. For example, if the cluster contains 3 NodeBs and each NodeB has 3 carriers, the total bandwidth requirement is up to 10MHz.

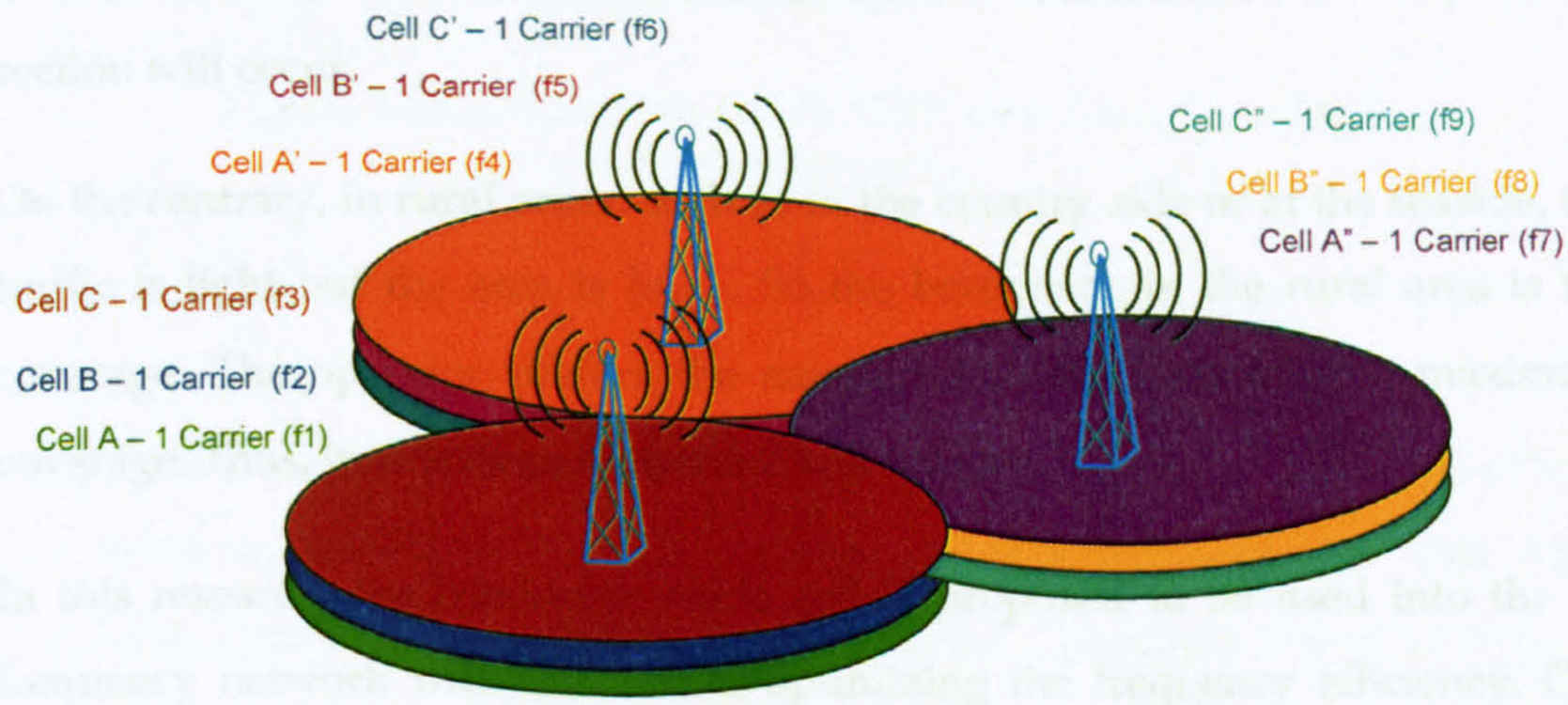


Figure 3-7 non N-frequency Cell with inter-frequency Interference

With the N-frequency technology, there will be only one set of downlink pilot and broadcast channels in each cell. So the DwPTS and TS0 will have less inter-frequency interference compared to non N-frequency network. But unless the

primary carrier's frequency of each cell is allocated differently, the intra-frequency interference can not be avoided.

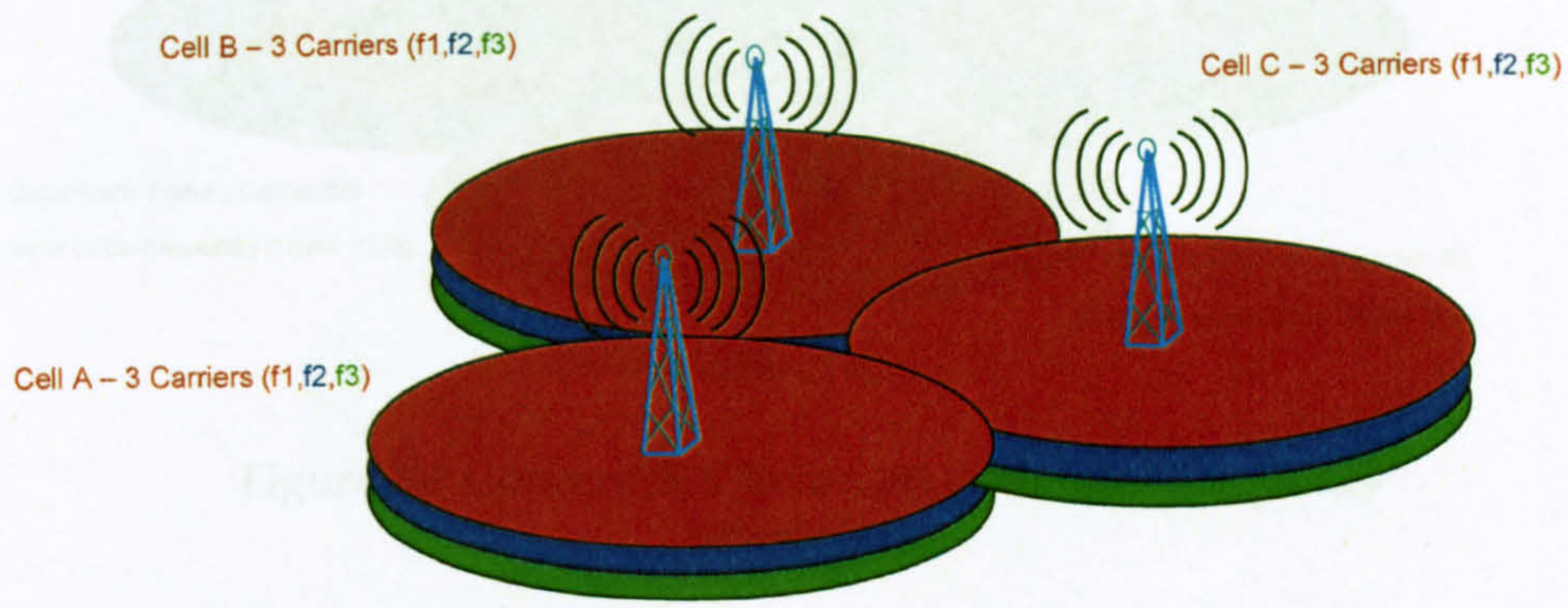


Figure 3-8 N-frequency Cell with intra-frequency interference

Dense urban and rural areas are selected in this research as the two coverage objects for analysis.

Most big cities, such as Beijing and Shang Hai have heavy mobile traffic due to the large population and high usage profiles. The bottleneck in network establishment is not the coverage but the capacity in dense urban areas. In another words, the distance between two sites in big cities is very close in order to make sure there is enough network resource to serve the heavy network load. In such circumstances, the interference scenario 1, mentioned in the previous section will occur.

On the contrary, in rural areas, such as in the country side or at the seaside, the traffic is light but the area is huge. So the bottleneck in the rural area is the coverage. The operator prefers the smallest number sites for the maximum coverage. Thus, interference scenario 2 will happen.

In this research, the concentric circle cell is proposed to be used into the N-frequency network with the aim of optimizing the frequency efficiency. One solution is that apart from the primary carrier, which uses a different frequency for every cell within a cluster, the first secondary carrier of each cell can use the same frequency and the second secondary carrier can adopt another frequency, including the same as the primary in another cell. So within a 5MHz allocation, the frequency reuse factor is between 1 and 3, yet there is no heavy intra-frequency interference on DwPTS and TS0 channels.

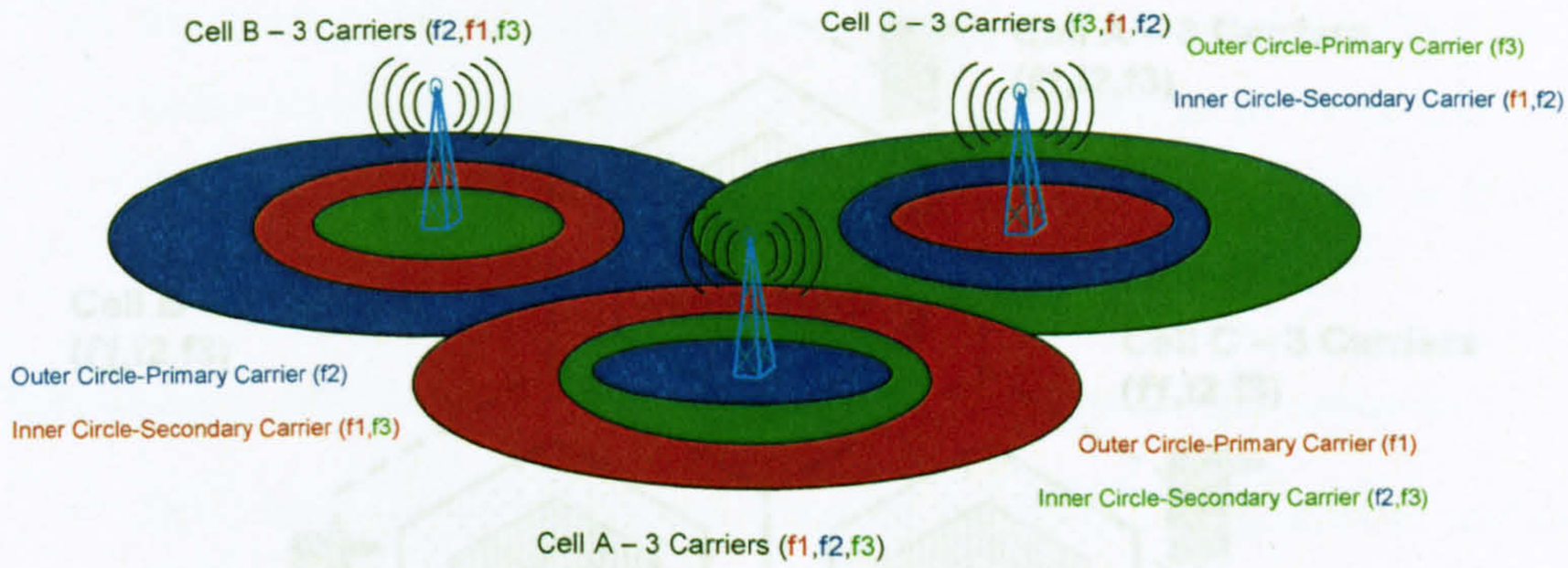


Figure 3-9 Concentric Circle Cell with Inter-frequency Interference

However, with the most frequency efficient scheme where the frequency reuse factor is 1, the intra-frequency interference will still exist in the overlapping areas.

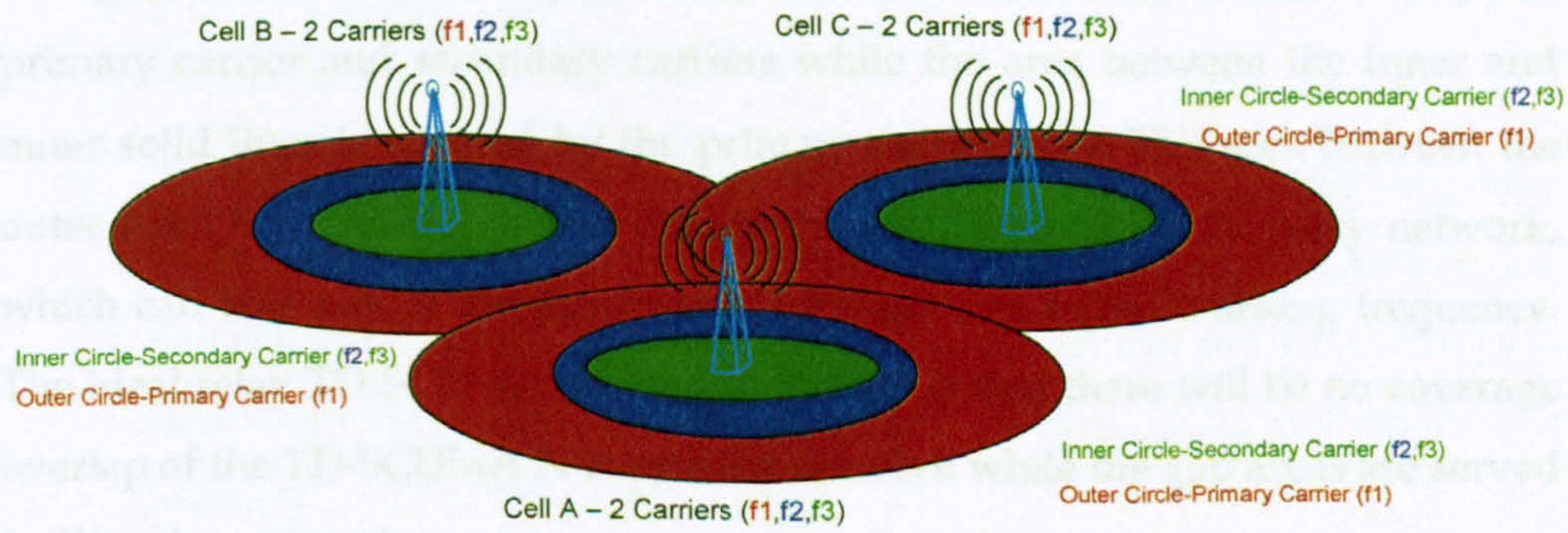


Figure 3-10 Concentric Circle Cell with Intra-frequency Interference

The central shaded areas of each cell in Figure 3-10 above are covered by the primary carrier and secondary carriers while the area beyond that is covered by the primary carrier only. It is obvious from Figure 3-10 that at the edge of each cell there are overlapping areas for the primary frequency, so that intra-frequency interference cannot be totally avoided. Therefore, the relay network is implemented here.

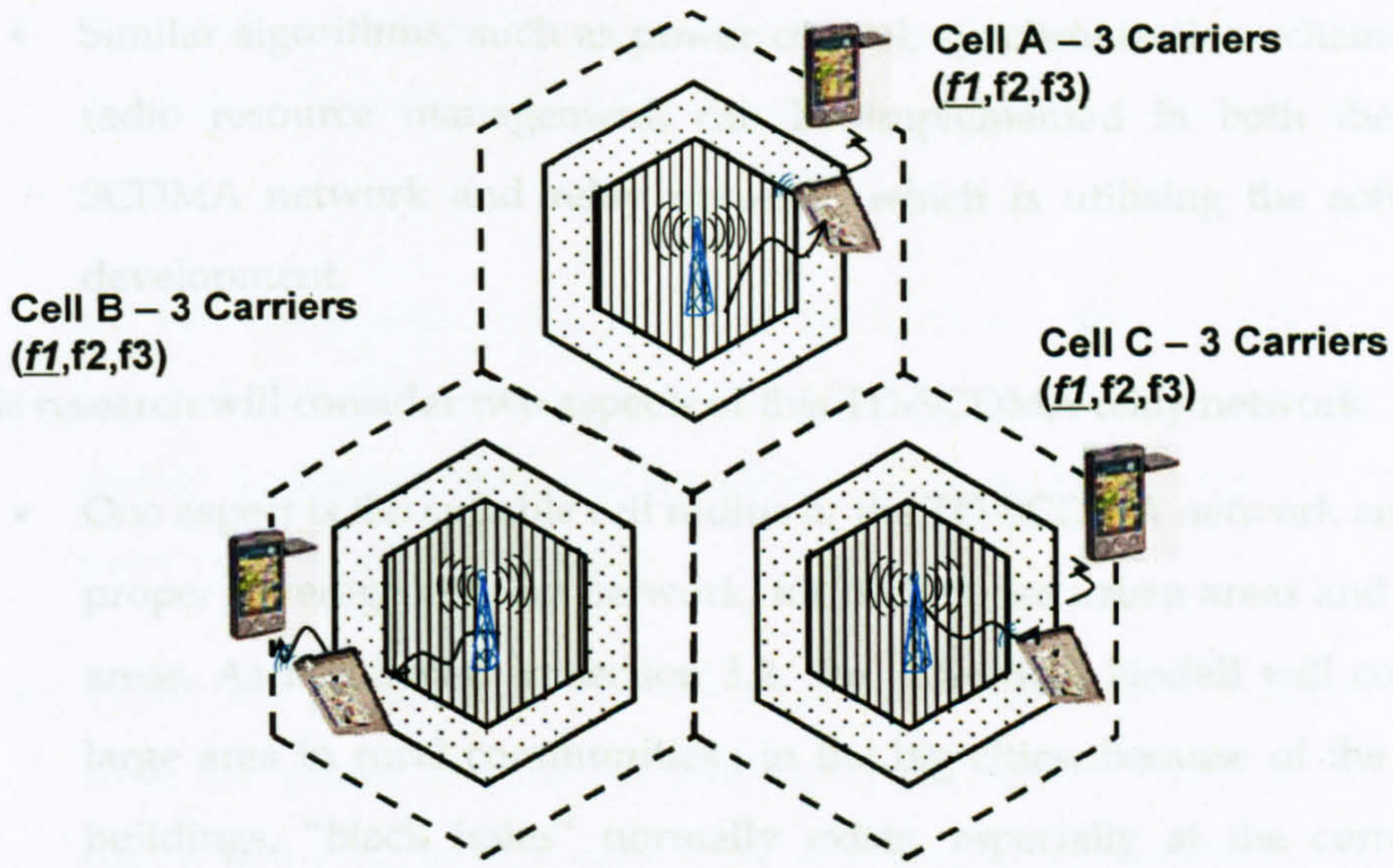


Figure 3-11 Hybrid TD-SCDMA relay Network

In Figure 3-11, the shaded area within the inner solid line is covered by the primary carrier and secondary carriers while the area between the inner and outer solid lines is covered by the primary carrier only. The area between the outer solid line and the dashed line is the area covered by the relay network, which can take any of the inner circle's frequencies as the working frequency. The ideal relay TD-SCDMA network structure is that there will be no coverage overlap of the TD-SCDMA N-frequency network while the gap areas are served by the relay network.

The radio access technology for the relay network segment is proposed to be TD-SCDMA [LX01]-[DS01]. The reasons are:

- The terminals within the TD-SCDMA and relay network only have to support one kind of access technology which is the simplest way to develop the product.
- The same frame structure can shorten the translation processing time in the relay station acting terminal node.
- Applications from the terminal acting as a relay station and client terminal combination are easier to implement because the same air interface is used.

- Similar algorithms, such as power control, synchronization scheme and radio resource management, can be implemented in both the TD-SCDMA network and relay network, which is utilising the software development.

This research will consider two aspects of this TD-SCDMA relay network.

- One aspect is the suitable cell radius of the TD-SCDMA network and the proper coverage of relay network, for both dense urban areas and rural areas, As mentioned in section 3.2, the individual NodeB will cover a large area in rural communities.; in the big cities, because of the thick buildings, "black holes" normally exists, especially at the corner of buildings. This research will, therefore, verify to what extend the relay network can enlarge the TD-SCDMA network's coverage in rural areas or whether the relay network can help avoid "black holes" in dense urban areas.
- The other aspect is to analyze the influence of the TD-SCDMA/relay combination on interference and capacity. As mentioned in section 1.2, two different scenarios in different types of area that bring out different aspects are considered for the interference and capacity analysis in this research:
    - HSDPA data service in dense urban
    - Non-HSDPA data service in rural

Both have the same rationale: *the adoption of the concentric circle cell in the hybrid network structure will dramatically minimize the intra-frequency interference in TD-SCDMA networks with the aim of increasing the capacity and coverage of the hybrid network than the non-concentric circle cell configuration.*

These are considered below.

HSDPA service in dense urban areas

- The primary frequency is used by the network to broadcast to all the terminals in the outer circle cell areas while secondary frequencies serve the inner circle cell.

- One of the secondary frequencies is used by the relay station in the relay network to broadcast to all the terminals positioned in the relay network only.

- Because in multi-carrier HSDPA applications, the downlink traffic transmission channels are shared by HSDPA users, and neither the relay station acting terminal nor the client acting terminal will occupy the network resource continually.

- Under the multi-carrier HSDPA structure, each NodeB supports more than one carrier but the terminal in this research supports only one carrier at a time, which reflects the situation of the current TD-SCDMA terminals as it is the most cost effective solution for the terminal vendors and the end users.

Non-HSDPA data service in rural areas

- The primary frequency is used by the network to broadcast to all the terminals in the outer circle cell areas while secondary frequencies serve the inner circle cell(s).

- One of the secondary frequencies is used by the relay station in the relay network to broadcast to all the terminals positioned in the relay area only.

- The relay station will receive and send the client's data to the TD-SCDMA network via the primary carrier in one frame and communicate with the client via the secondary carrier in the following frame with the continuous resource allocation within a packet call.

3.6 Summary

This chapter showed how the TD-SCDMA network could in principle be extended by a relay segment in order to address some of the problems such as interference limiting the coverage and capacity of a conventional network. This is a new concept for TD-SCDMA networks,

In the next chapter, the link budget of the TD-SCDMA network and relay network will be calculated and using that result, the cell coverage of this hybrid TD-SCDMA relay network will be determined. The simulation method for capacity and interference will then be introduced in the subsequent chapter together with the simulation results.

Chapter 4 Link Budget

4.1 Introduction

In this section, the link budgets for the TD-SCDMA network and the relay network are calculated. This is necessary in order to calculate the coverage area of the combined hybrid network and the work on extending this link budget to the hybrid segment is new.

In a TD-SCDMA network, both the control channel and the traffic channel should be taken into account when considering the network planning and cell coverage. In the product realization from industry, the power of NodeB downlink control and traffic channel are treated differently while the terminal uplink control and traffic channel are treated similarly

Considering these in turn:

<u>NodeB downlink control and traffic channel</u>

- The NodeB will always transmit the control signals, especially the cell broadcast signals, with maximum power without any power control. This is unlike the traffic channel where power control is used to lower the interference within the network.

- The total transmission power of each timeslot is set by the NodeB's power amplifier and all the timeslots have the same signal power before being sent to the antenna.

- Furthermore the antenna will treat all the timeslots the same. As all the cell broadcast channels are allocated in TS0 only and no traffic channel will be allocated in TS0, the TS0 power will be fully used by the cell broadcast signals. On the other hand, as TD-SCDMA inherits the code division multiple accesses from CDMA system, the more terminals that camp onto a certain timeslot, the lower the downlink transmission power that will be seen from the NodeB by each terminal since CDMA is used *within* the timeslot. Also, in order to make sure all the terminals on

the same timeslot can be served properly, the NodeB will use the transmission power relevant to the service type in use.

- The major difference between the downlink control channel and the traffic channel is that there is 8dB smart antenna beam forming gain on the traffic channel but not on control channel. The reason is that the control channel has to cover the whole cell areas so there can be no directed beam on the control channel.

So from the downlink point of view, the power in the control channel will always be lower that that in the traffic channel.

<u>Uplink Control and traffic Channel</u>

- The UpPCH is a solo timeslot in the TD-SCDMA frame structure so there is no transmission power limitation on it. A multi-access attempt scheme is implemented here to ensure the terminal can continually synchronize with the network if conflicts occur due to too many attempts.

- The uplink access channel can be allocated to any of the uplink timeslot which normally occupies 2 codes. The rest of the codes are used as uplink traffic channel. So the uplink control channel and traffic channel will share the total transmission power within each timeslot

- On the Uplink, the smart antenna diversity and joint detection are performed both for uplink access channel and traffic channel

Based on the above information, in this research only the uplink traffic channel and downlink control channel are considered for the uplink and downlink link budget calculation.

4.2 Traffic Channel Parameters

The values from these tables have been taken from [HX01][WQ01], [3GPP04] and [3GPP05],

Table 4-1 Uplink Traffic Channel Parameter Table

		DCH
Transmitter__Terminal		
Max Tx Power	a	24 dBm
Tx Antenna Gain	b	2 dBi
Connector loss	c	0 dB
Body Loss	d	0
EIRP	e = a+b-c-d	26 dB
Reciever__NodeB		
NodeB Noise Figure	f	5 dB
Thermal Noise	g	-113 dBm
Interference Margin	h	2 dB
Interference Floor	i = f+g+h	-106 dB
Service Eb/No	j	3 dB
Service PG	k	3 dB
Receiver Sensitivity	l = i+j-k	- 106 dB
Single Antenna Gain	m	15 dBi
Beamforming Gain	n	8 dB
Rx Antenna Gain	o = m+n	23 dB
Cable Loss	p	1 dB
Isotropic Power Required	q = l-o+p	-128 dB
Allowed Prop. Loss	r = e-q	154 dB

Table 4-2 Downlink Control Channel Parameter Table:

		TS0
Transmitter - NodeB		
Max Tx Power (Total)	a	33 dBm
Max Tx Power (per Radiolink)	b	33 dBm
Cable Loss	c	1 dB
Single Antenna Gain	d	15 dBi
Beamforming Gain	e	0 dB
Tx Antenna Gain	f = d+e	15 dBi
EIRP	g = b-c+f	47 dBm
Receiver - Handset		
Handset Noise Figure	h	7 dB
Thermal Noise	i	-113 dBm
Interference Margin	j	1.5 dB
Interference Floor	k = h+i+j	-104.5 dB
Service Eb/No	l	5 dB
Service PG	m	3 dB
Receiver Sensitivity	n = k+l-m	- 102.5 dBm
Rx Antenna Gain	o	0
Body Loss	p	0
Isotropic Power Required	q = n-o+p	- 102.5 dB
Allowed Prop. Loss	r = g-q	149.5 dB

Table 4-3 Parameters for relay connection

		DCH
Transmitter__Terminal		
Max Tx Power	a	24 dBm
Tx Antenna Gain	b	2 dBi
Connector loss	c	0 dB
Body Loss	d	0
EIRP	e = a+b-c-d	26 dB
Receiver - Handset		
Handset Noise Figure	f	7 dB
Thermal Noise	g	-113 dBm
Interference Margin	h	1.5 dB
Interference Floor	i = f+g+h	-104.5 dB
Service Eb/No	j	5 dB
Service PG	k	3 dB
Receiver Sensitivity	l = i+j-k	- 102.5 dBm
Rx Antenna Gain	m	0
Body Loss	n	0
Isotropic Power Required	o = l-m+n	- 102.5 dB
Allowed Prop. Loss	p = e-o	128.5 dB

4.3 Propagation models

In order to calculate the cell radius it is necessary to choose an appropriate propagation model and generally in wireless telecommunication network the planning considers macro cells. Here, since the emphasis is on extending coverage, it is necessary to consider macro cells.

The common propagation models are shown in Table 4-4.

Table 4-4 Macro cell model compare in common use

Models	Frequency range	BS antenna height	MS antenna height	Coverage radius
Okumura model [YO01]	150~1920MHz	30~200m	1~10m	1~20km
Okumura-Hata [MH01]	100~1500MHz	30~200m	1~10m	1~20km
Cost231-Hata [COST23101]	1500~2000MHz	30~200m	1~10m	1~20km
Cost231 Walfish-Ikegami [COST23101]	800~2000MHz	4~50m	1~3m	0.02~5km

China has allocated three frequency segments for TD-SCDMA with a total available bandwidth of 155MHz:

- 1880-1920MHz (bandwidth of 40MHz)
- 2010-2025MHz (bandwidth of 15 MHz)
- 2300-2400MHz (bandwidth of 100 MHz)

Among the above band, the cord bands assigned by ITU for TDD usage are 2010-2025MHz and 1900-1920MHz, so the first step of the manufacturer is to support these two bands in order to enable the global roaming. However, currently in China, the 1900-1915MHz is widely used by the PHS system; a certain period is, therefore, required for the operator to clear the frequency band for another TDD system. Hence, all TD-SCDMA equipment vendors are developing their first commercial products to support the 2010-2025MHz band. In this thesis that frequency band will be adopted for the analysis.

4.3.1 Infrastructure part

In a real wireless network, the height a NodeB is normally from 30m to 60m and the height of a mobile terminal is around 1.5m in the majority of cases; with these values the Cost231-Hata propagation model is the most suitable one for macro cell coverage, and is the one normally used in the industry [MJ01]. Meanwhile the Cost231- Walfish-Ikegami is the most suitable one for micro or pico cell coverage. Those two propagation models are adopted in the TD-SCDMA network and the relay network separately in this research.

As the Hata model is expanded effectively at 2GHz, we can get: [COST23102]

$$L_{urban}(dB) = 46.3 + 33.9\log_{10} f_c - 13.82\log_{10} h_{te} - a(h_{re}) + (44.9 - 6.55\log_{10} h_{te})\log_{10} d + C_M$$

Where:

- L_{urban} is allowed propagation loss
- f_c is the carrier frequency and in this research, 2010MHz is chosen as the system's working frequency.

- h_{te} is the effective height of the NodeB antenna, which is the gap between the NodeB antenna height above sea level and the mean ground height above sea level of the NodeB and is normally between 30m and 200m; in this research 30m is used;
- h_{re} is the effective height of the MS antenna, which is the height of antenna above the ground and the height is generally between 1m and 10m; in this research 1.5m is used.
- d is the distance between the BS antenna and MS.
- $\alpha(h_{re})$ is the effective antenna modified factor:
- $\alpha(h_{re}) = [1.1\log_{10} f_c - 0.7]h_{re} - [1.56\log_{10} f_c - 0.8]$
- C_M is the modification factor for the type of scenario
    - Dense urban (city centre): 3dB
    - Urban: 0dB
    - Suburbs: -12.28dB
    - Rural: -22.52 dB

Calculating the propagation loss for each type of scenarios gives the following:

When f_c =2010MHz:

- $L(denseurban) = 140.85 + 35.2\log_{10} d$
- $L(rural) = 115.33 + 35.2\log_{10} d$

4.3.2 Relay part

In the relay network, the height of the mobile relay station is lower than the NodeB in an infrastructure network and the coverage radius is smaller than a macro cell, so the Cost231 Walfisch-Ikegami [COST23103] [COST23104] is adopted in the relay part of network for the link budget calculation.

The Walfisch-Ikegami propagation model is:

For rural areas, the formula for Line of Sight is adopted as below:

$$L_a(rural) = 42.6 + 26\log_{10}d + 20\log_{10}f_c$$

For dense urban, the Non Line of Sight formula is adopted as below:

$$L_a(denseurban) = L_o + L_{rts} + L_{msd}$$

Where:

L_o represents Free Space Loss,

$$L_o = 32.4 + 20\log_{10}d + 20\log_{10}f_c$$

L_{rts} is the rooftop-to-street diffraction and scatter-loss

$$L_{rts} = -16.9 - 10\log_{10}w + 10\log_{10}f_c + 20\log_{10}(h_r - h_m) + L_{ori}$$

L_{ori} is the street-orientation-loss

$$L_{ori} = 0.01$$

L_{msd} is the multi-screen diffraction loss

$$L_{msd} = L_{bsh} + k_a + k_d\log_{10}d + k_f\log_{10}f - 9\log_{10}b$$

L_{bsh} is the NodeB antenna – building loss

$$L_{bsh} = 0, (h_b \le h_r)$$

k_a represents the increase of the path loss for NodeB antennas below the roof tops of the adjacent buildings.

$$k_a = 54 - 0.8(h_b - h_r) \ (d \ge 0.5 \text{ and } h_b \le h_r)$$

$$k_a = 54 - 0.8(h_b - h_r)(d/0.5) \ (d < 0.5 \text{ and } h_b \le h_r)$$

k_d and k_f control the dependence of the multi-screen diffraction loss versus distance and radio frequency, respectively.

$$k_d = 18 - 15(h_b - h_r)/h_r, (h_b \le h_r)$$

$k_f = -4 + 1.5(f/925 - 1)$

Where the terms have the following definitions and values for this research:

- h_r is the height of the buildings: 30m;
- h_m is the height of the MS:1.5m;
- h_b is the height of NodeB antenna[4]: 2m;
- b is the building separation: 30m;
- w is the width of the streets: 15m;
- f_c is the frequency: 2010MHz and 2300MHz;
- d is the distance between transmitter and receiver (in km).

Substituting gives the relay network propagation path loss for each scenario:

When f_c =2010MHz

$$L_a(rural) = 108.66 + 26\log_{10} d$$

$$L_a(denseurban) = 165.25 + 52\log_{10} d + 44.8d$$

4.4 Conclusions from link budget

Besides the propagation model considered before, the Morphology parameters for path loss should also be taken into account. Those parameters are shown in the table below:

Table 4-5 Morphology parameters

Morphology	Shadow Margin (dB)	Penetration Loss (dB)
Dense Urban	10.1	8 (outdoor)
Rural Area	4.4	8 (outdoor)

So the maximum allowed path loss is the allowed propagation loss, which is calculated in Table 4-1, Table 4-2,Table 4-3 minus the Shadow Margin indicated in Table 4-5. The final result is shown in the below:

[4] Possibly hand-held for the terminal acting as a relay station, but maybe not on the ground floor if possible, so a value between floors is used.

Table 4-6 Maximum Propagation Loss Table

Morphology	TD-SCDMA Uplink (dB)	TD-SCDMA Downlink (dB)	relay Network (dB)
Dense Urban	135.9	131.4	110.4
Rural Area	141.6	137.1	116.1

From the above result, it indicates that the TD-SCDMA cell radius is restricted by the downlink control channel's maximum propagation loss. Referring to [3GPP06] and [3GPP07], the downlink control channel's characteristics for normal data application and HSDPA application are the same. For relay network, the parameter Table 4-3 is the same for normal data application and HSDPA application because according to [3GPP07] and [3GPP09], modifications for HSDPA are more scheduling and modulation related and those changes do not affected those parameters in Table 4-3. Therefore, the following cell radius' result applies to both service types.

Calculating the effective maximum cell radius in each direction:

<u>Uplink:</u>

Data service in dense urban areas:

$$L(denseurban) = 135.9 = 140.85 + 35.2\log_{10} d \quad (f_c = 2010\text{MHz})$$

Data service in rural areas:

$$L(rural) = 141.6 = 115.33 + 35.2\log_{10} d \quad (f_c = 2010\text{MHz})$$

<u>Downlink</u>

Data service in dense urban areas:

` $L(denseurban) = 131.4 = 140.85 + 35.2\log_{10} d \quad (f_c = 2010\text{MHz})$

Data service in rural areas:

$$L(rural) = 137.1 = 115.33 + 35.2\log_{10} d \quad (f_c = 2010\text{MHz})$$

Table 4-7 Maximum TD-SCDMA Cell Radius Table

Scenario	Frequency Band	TD-SCDMA Uplink Cell Radius (L)	TD-SCDMA Downlink Cell Radius (L)
Dense Urban	2010MHz	0.72 km	0.54 km
Rural Areas	2010MHz	5.58 km	4.15 km

Table 4-8 Maximum TD-SCDMA Cell Coverage Table

Scenario	Frequency Band	TD-SCDMA Cell Distance (L √3)	TD-SCDMA Hexagonal Cell Coverage
Dense Urban	2010MHz	0.93 km	0.76 km^2
Rural Areas	2010MHz	7.19 km	44.7km^2

From these results in Table 4-7, it can be seen that TD-SCDMA data service is limited in the downlink direction, so the downlink value gives the cell radius, which means for a dense urban area the cell radius is 0.54km for 2010MHz and for rural areas the cell radius is 4.15km for 2010MHz.

This result fits the real network situation as, for instance, in the centre of big city the distance between two macro cells is normally around 300m-500m.

Using these values, the cell coverage of each environment is 0.76km^2 (dense urban) and 44.7km^2 (rural area) in 2010MHz frequency band, see Table 4-8.

For the relay network, the results for the maximum distance between the relay station and the client are:

Data service in a dense urban area:

$$L_a(denseurban) = 110.4 = 165.25 + 52\log_{10} d + 44.8d \quad (f_c = 2010\text{MHz})$$

Data service in rural areas:

$$L_a(rural) = 116.1 = 108.66 + 26\log_{10} d \quad (f_c = 2010\text{MHz})$$

Table 4-9 Maximum Relay Cell Radius Table

Scenario	Frequency Band	ad hoc Cell Radius (L)
Dense Urban	2010MHz	0.076 km
Rural Areas	2010MHz	1.93 km

Table 4-10 Maximum Relay cell coverage

Scenario	Frequency Band	ad hoc Cell Distance (L √3)	Hexagonal Cell Coverage
Dense Urban	2010MHz	0.132 km	0.015 km^2
Rural Areas	2010MHz	3.34 km	9.67 km^2

The maximum extension to the TD-SCDMA effective cell radius is when the relay station is at the edge of the infrastructure cell and the client is the maximum distance away in a radial direction. So the maximum radius of the hybrid network in the two scenarios is:

Table 4-11 Maximum hybrid TD-SCDMA relay Cell Radius

Scenario	Frequency Band	hybrid TD-SCDMA relay Cell Radius	Hybrid Hexagonal Cell Coverage
Dense Urban	2010MHz	0.54+0.076=0.616 km	0.986 km^2
Rural Areas	2010MHz	4.15+1.93=6.08 km	96.0 km^2

- Dense Urban: around 14% extension compared with the pure TD-SCDMA network
- Rural Area: around 47% extension compared with the pure TD-SCDMA network

Furthermore, this leads to a reduction in NodeB sites of up to 23% for the dense urban environment and 54% for rural areas.

Of course, there is no guarantee that a mobile terminal outside the TD-SCDMA radius can connect with a relay station inside – but the probability of connection is something the operator can weigh up against saving in equipment costs when formulating the business plan.

4.5 Summary

In this chapter, the coverage areas for the hybrid TD-SCDMA relay network are constructed by obtaining the cell radius based on the link budget calculation. With this new concept for TD-SCDMA networks, the coverage of TD-SCDMA network can be dramatically expanded in rural areas and some black holes in the dense urban can be covered without adding more NodeBs. This will benefit the network operators with a big saving in network investment.

In the next chapter, the current conclusion at this stage of the work and future work to complete the PhD are given and the simulation method for capacity and interference will be introduced. The further work about the capacity and interference will be based on this chapter's results on coverage. The final target of this research will demonstrate the hybrid TD-SCDMA relay network's overall effects on the construction of TD-SCDMA networks.

Chapter 5 TD-SCDMA Relay for HSDPA Services

5.1 Introduction

HSDPA is becoming the most widespread data service in mobile networks as the higher bit rate in the downlink is suited to asymmetrical applications like live multimedia broadcasting. Before the Beijing 2008 Olympics, China Mobile TD-SCDMA pre-commercial networks in the 10 pilot cities were all upgraded to multi-carrier HSDPA networks to provide more attractive data services.

The maximum bit rate available in the downlink is 2.8Mbit/s per carrier with a 1:5 switch point. Since the most likely number of carriers per cell is 3 (absolute maximum is 6 [CCSA08]) the maximum bit rate available would 8.4Mbit/s downlink. However, in a real system this would not leave much capacity for symmetrical services like voice so a 2:4 split would be more likely giving 2.2Mbit/s per carrier in theory. This is the ratio adopted in this research.

It must also be remembered that the same switch point must be used on each carrier for the whole network.

5.2 Simulation Modelling

In order to simulate the HSDPA scenario, the research uses a TD-SCDMA HSDPA system-level simulator written in OPNET by Beijing University of Posts and Telecommunications (BUPT) [DJ01] but modified by the author.

This platform is used as a fundamental research tool for TD-SCDMA HSDPA systems with the implementation of TD-SCDMA physical layer functions, smart antenna functions and HSDPA techniques and applications. Other necessary simulation elements, such as simulation environment and radio link fading, are covered as well. Figure 5-1 shows the simulator's structure, including the three logical network entities, RNC, NodeB and UE, and other models, such as traffic generation model, UE mobility management model.

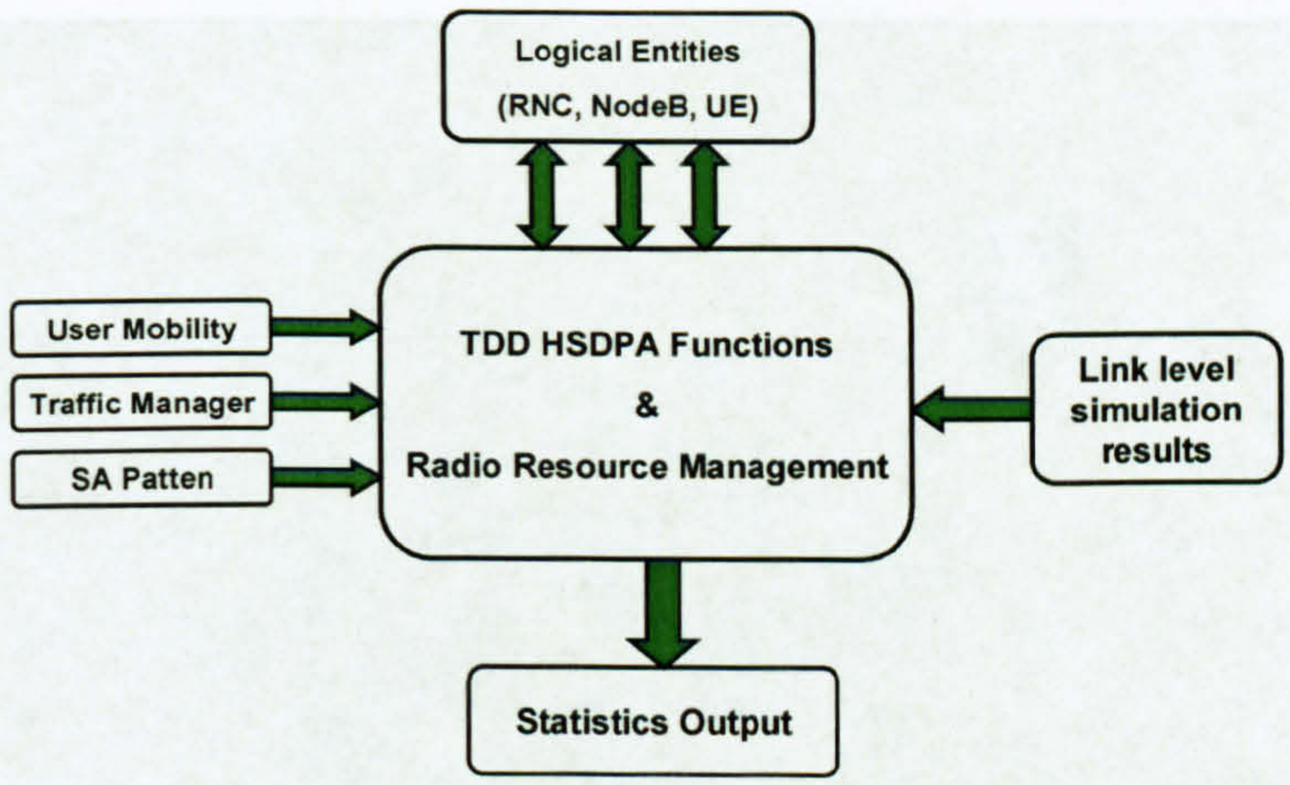


Figure 5-1 Simulator Structure (Fig 1 from [DJ01])

The author had to modify this simulator to adapt the initialization and cell-selection phase to the new structure, adding in the concentric circle cell concept. The whole procedure for using relays in this simulator was written completely by the author. Details are given in section 5.4.7.

Functions are realized in different modules and global variables are used as input/output parameters between each module. Figure 5-2 shows an example of the simulation scenarios which contain the three main objects in the simulation: RNC, NodeBs (Base Stations) and UEs (Terminals).

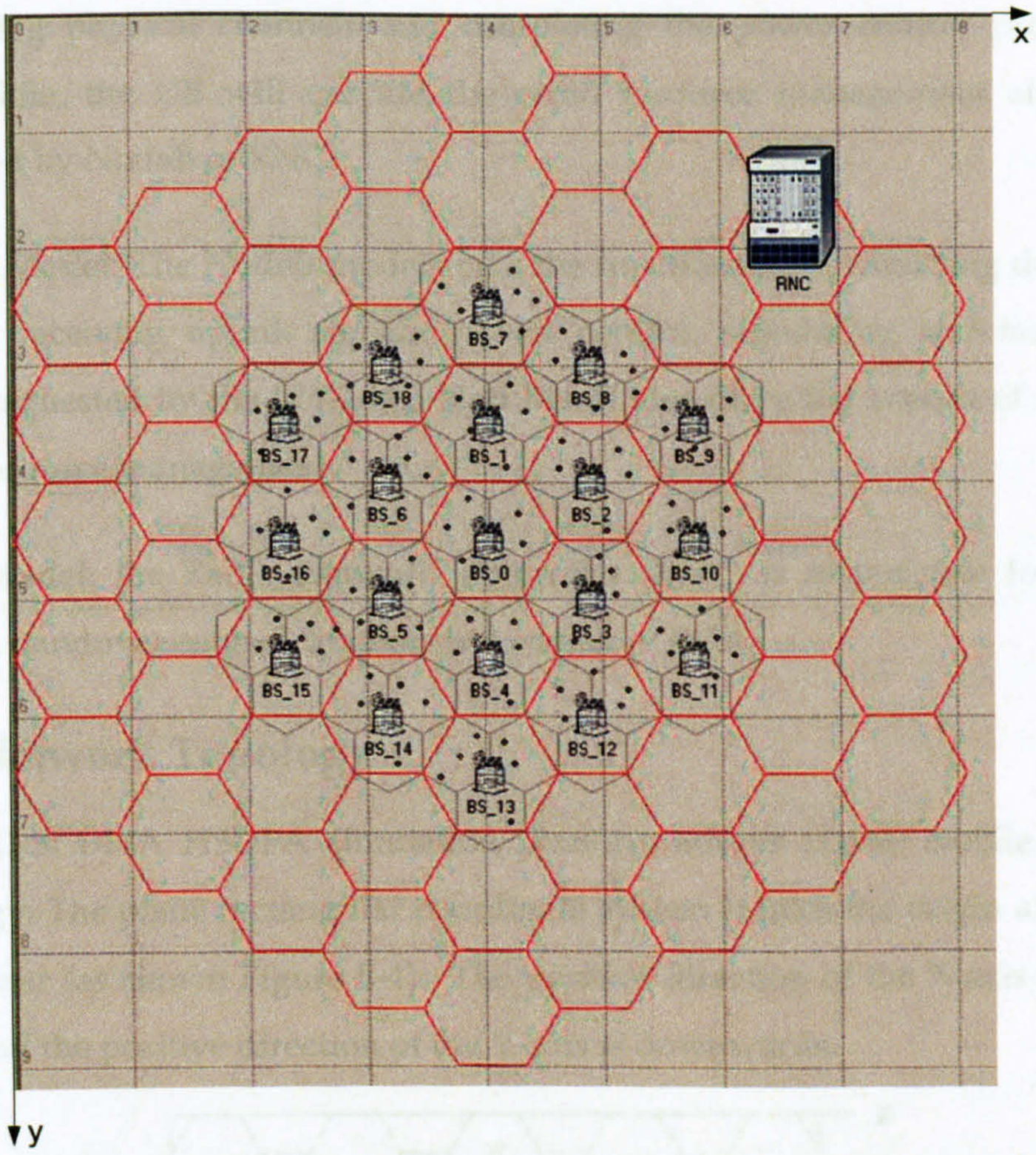


Figure 5-2 Simulation Scenario Example

These three objects construct the whole TD-SCDMA radio access network in this simulation as shown in Figure 5-3

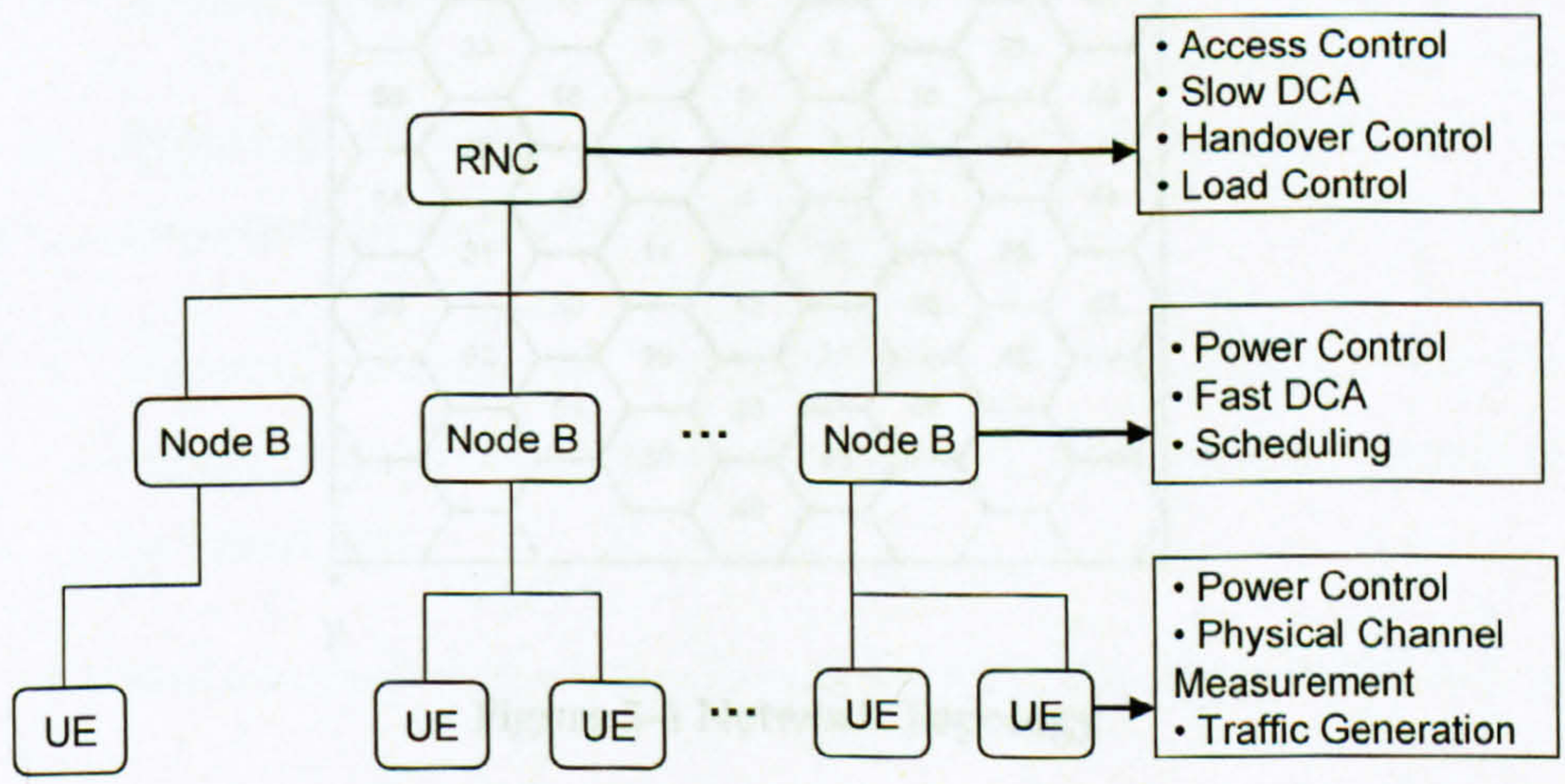


Figure 5-3 Model Functions

UE Model: The user equipment (UE) models realize the functions of generating designed traffic, transmitting the uplink signals, receiving the downlink signals,

measuring physical channels and completing the power control procedure. Meanwhile, the UE will execute the radio resource management algorithm informed by NodeB or RNC.

NodeB Model: The NodeB models take the functions of transmitting downlink signals, receiving uplink signals, power control, scheduling and fast DCA. When requested by the RNC, the Nod B will also carry the actions of relevant radio resource management.

RNC Model: the Radio Network Controller (RNC) is responsible for access control, handover control, load control and slow DCA.

5.3 Network Topology

This TD-SCDMA HSDPA simulation platform adopts classic mobile cellular topology. The plane rectangular coordinate system locates the origin at the left top corner (as shown Figure 5-4). The positive direction of the X-axis is to the right and the positive direction of the Y-axis is downwards.

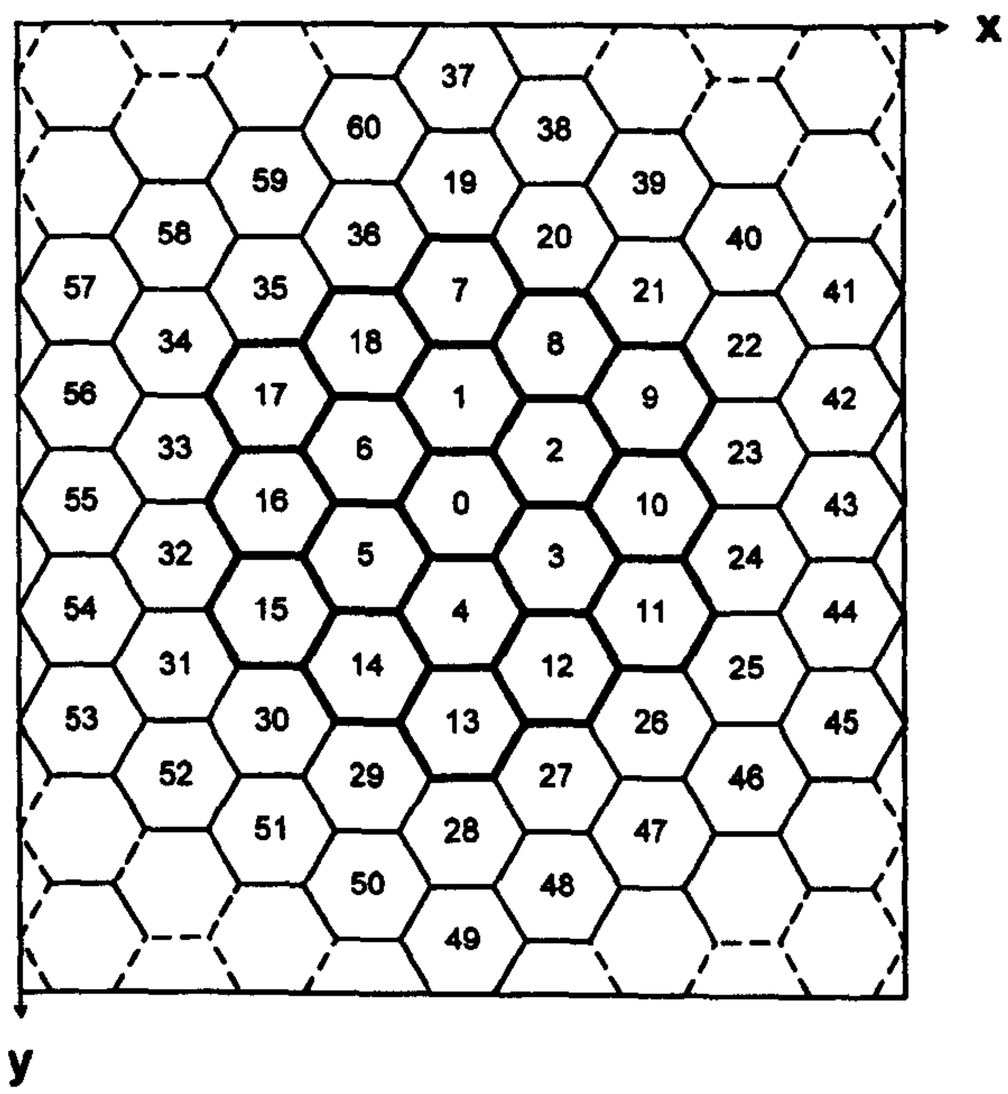


Figure 5-4 Network Topology

The distribution of UE has two options in this platform: manually and randomly. The OPNET network model editor provides a visual interface to the programmer to manually locate the UE's positions at the initial phase, although the programmer should make sure that all the terminals are within the network

scope; otherwise, the simulator will produce an error message and abort the simulation procedure. Another method used in this simulation tool is that the system will automatically generate a certain number of UEs and randomly distribute them into the network scope.

"Wrap-around" is used in the simulator. The intra-frequency interference from neighbouring cells will impair the signal quality of the serving NodeB so when doing simulations there should, ideally, be at least two additional layers of cells surrounding the cell being observed to simulate the interference situation. However, the simulation scope cannot be expended to infinity; there will always be certain cells that will have the "boundary effect" as they are not surrounded by two layers. The wrap-around approach is widely adopted in the wireless telecom research work to eliminate the "boundary effect".

Several concepts are adopted in the wrap-around approach and these are illustrated in Figure 5-5.

- **Real cells**: the real network scope, where the NodeB and terminals are located. None of the UEs can be generated outside the scope and these are shown in Figure 5-5 as coloured areas.

- **Virtual cells**: the cells positioned outside the real network scope, shown as white cells in Figure 5-5.

- **Referring cell**: the real cell which are under observation and measurement during the simulation.

- **Mapping cells**: the cells corresponding to the real cells after the wrap-around action. Note here that the mapping cells can be either real cells or virtual cells.

- **Real coordinates**: the network coordinates of the objects in the real cells

- **Mapping coordinates**: the coordinates of the objects in the mapping cells. Note that when the mapping cell is the real cell itself, the mapping coordinates are the real coordinates.

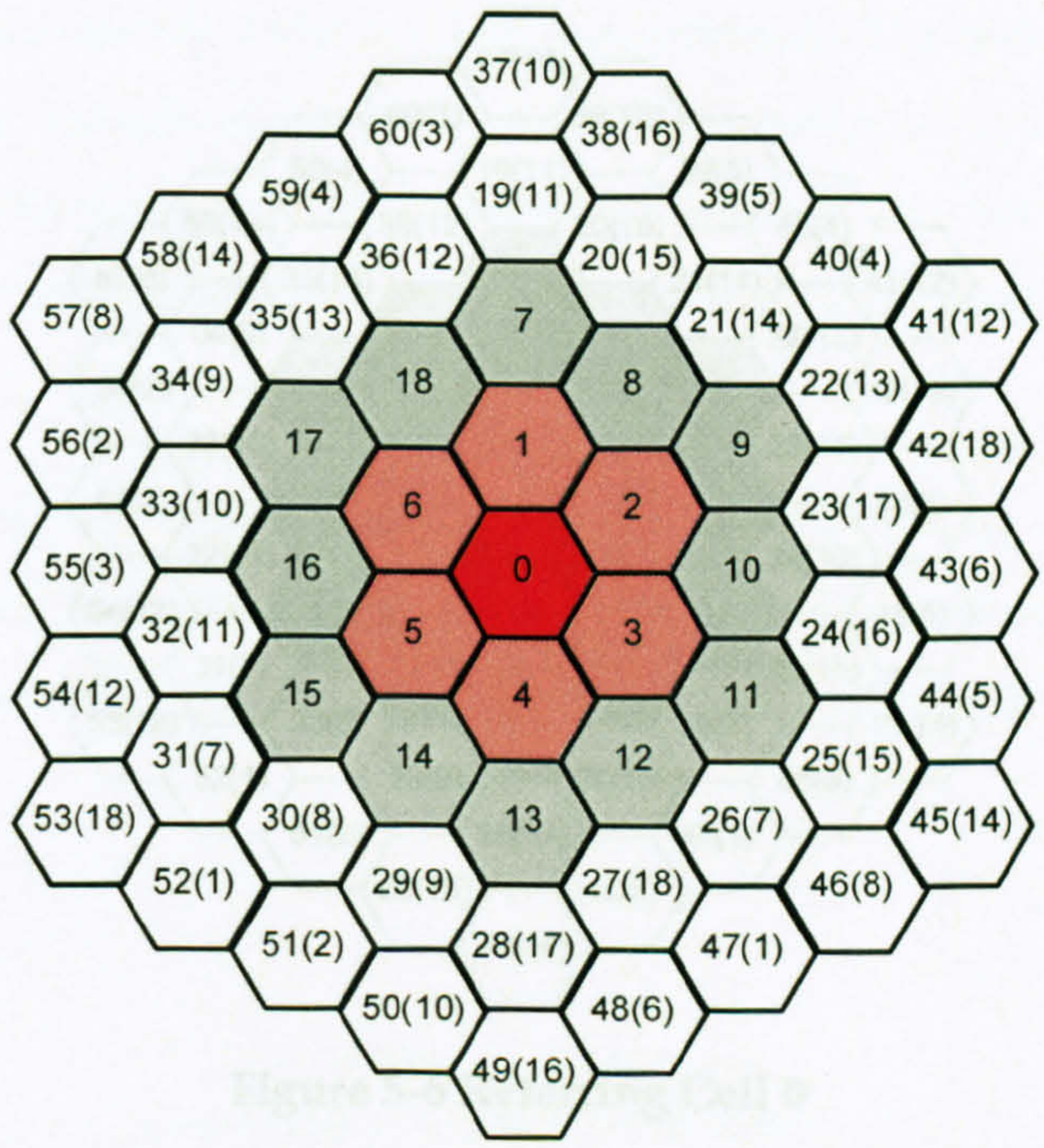


Figure 5-5 Wrap-around Principle

The principle of the wrap-around skill is while shifting the 19 real cells, it is guaranteed that when observing any of the network objects, the 19 real cells are surrounded by another two neighbouring cell-layers; there is no overlap among the 19 real cells to cover the corresponding areas. In Figure 5-5, those numbers in the brackets are the numbers of the real cells corresponding to the virtual cells. If there are virtual cells among the two neighbour cell-layers of the real cells, the real cells that are corresponding to the virtual cells have to be mapped to the virtual cells' locations. Afterwards the interference situation in the virtual cells will be measured according to the corresponding real cells' situation, including the network objects' distribution and configuration.

The following few figures give some examples of using the wrap-around mapping approach.

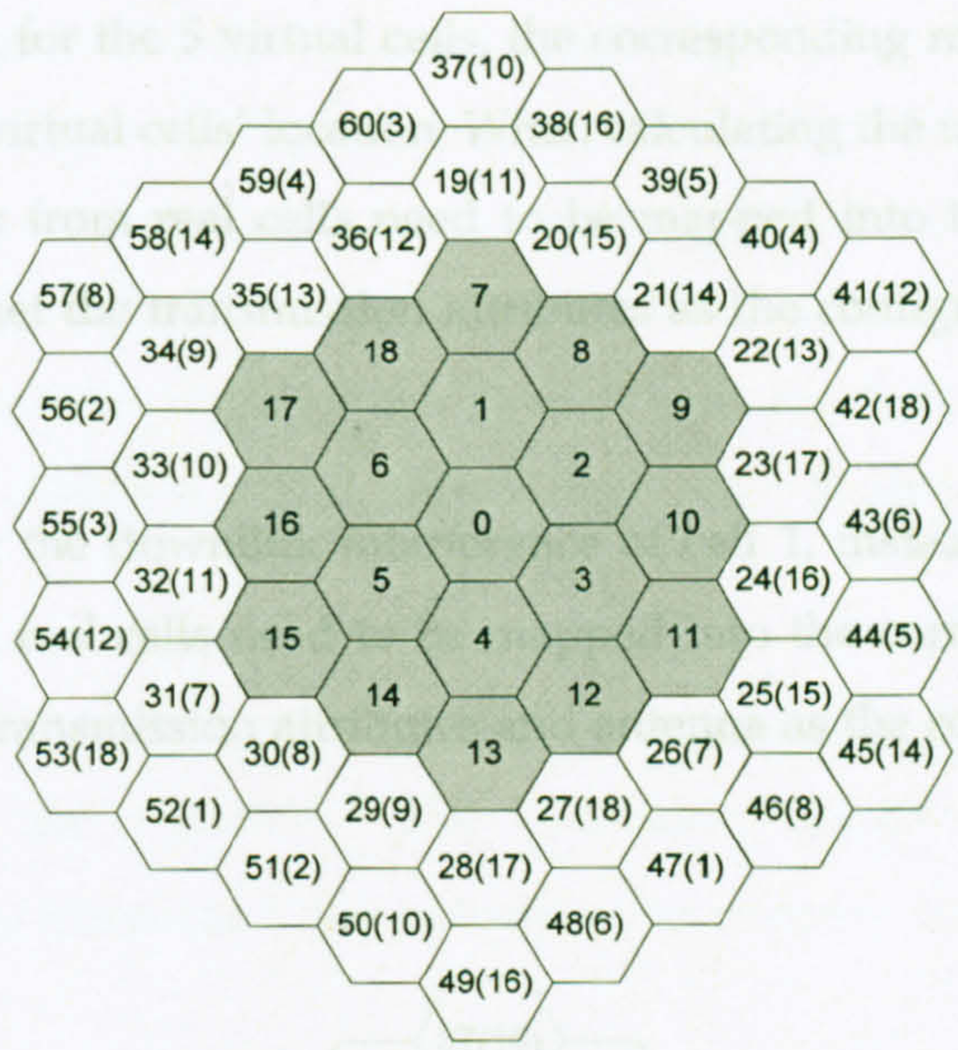


Figure 5-6 Referring Cell 0

In Figure 5-6, the real cell is cell 0. As there are no virtual cells among the neighbour two cell-layers, there is no need to do the wrap-around mapping.

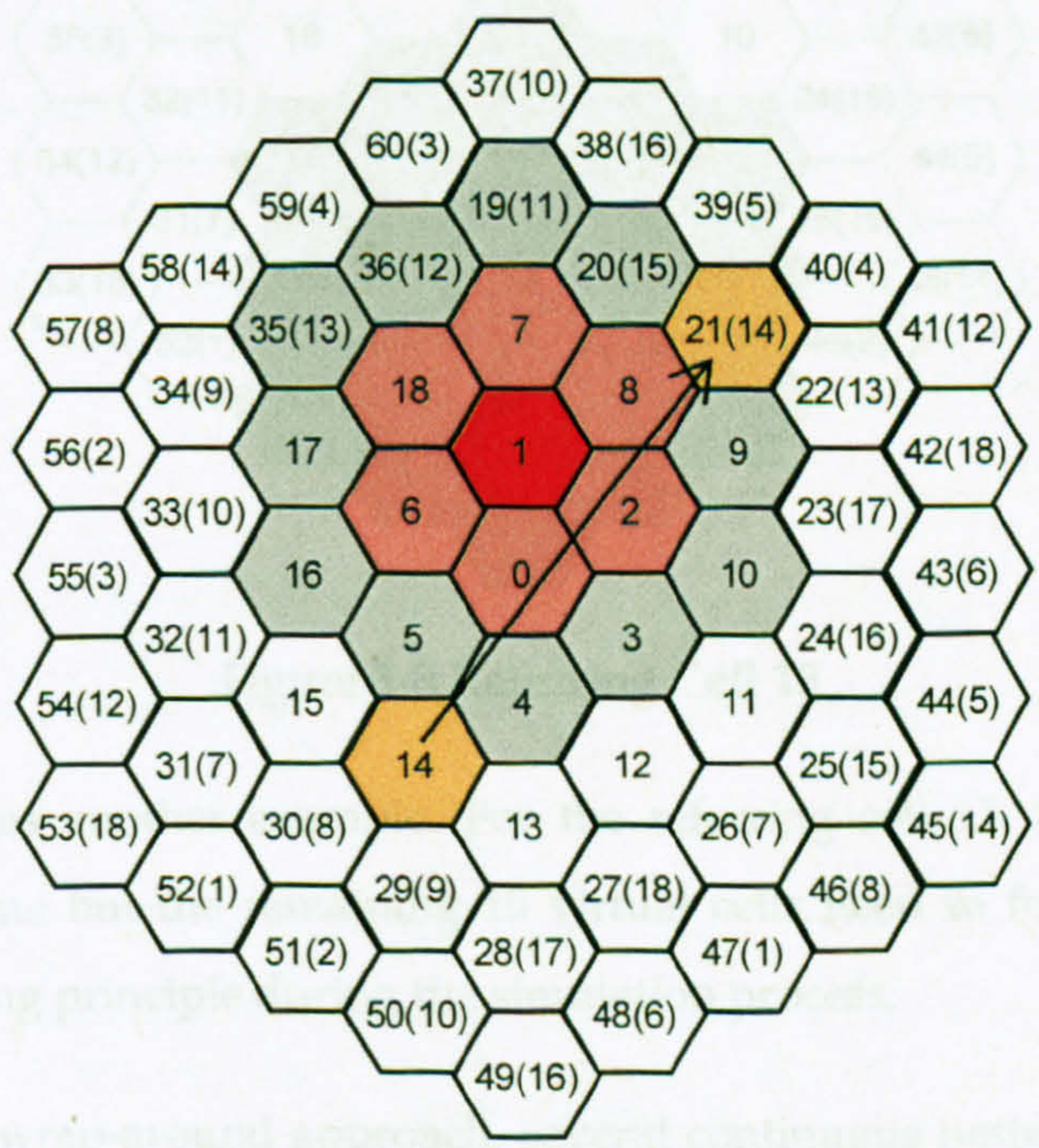


Figure 5-7 Referring Cell 1

In Figure 5-7, the real cell is cell 1. Now there are 13 real cells and 5 virtual cells among the two neighbour cell-layers. According to the wrap-around principle

mentioned above, for the 5 virtual cells, the corresponding real cells should be mapped into the virtual cells' location. When calculating the uplink interference of cell 1, the UEs from real cells need to be mapped into the corresponding virtual cells and set the transmission attributes as the configuration in the real cells.

When calculating the downlink interference of cell 1, instead of the UEs, the NodeBs from the real cells need to be mapped into the corresponding virtual cells and set the transmission attributes and antenna as the configuration in the real cells.

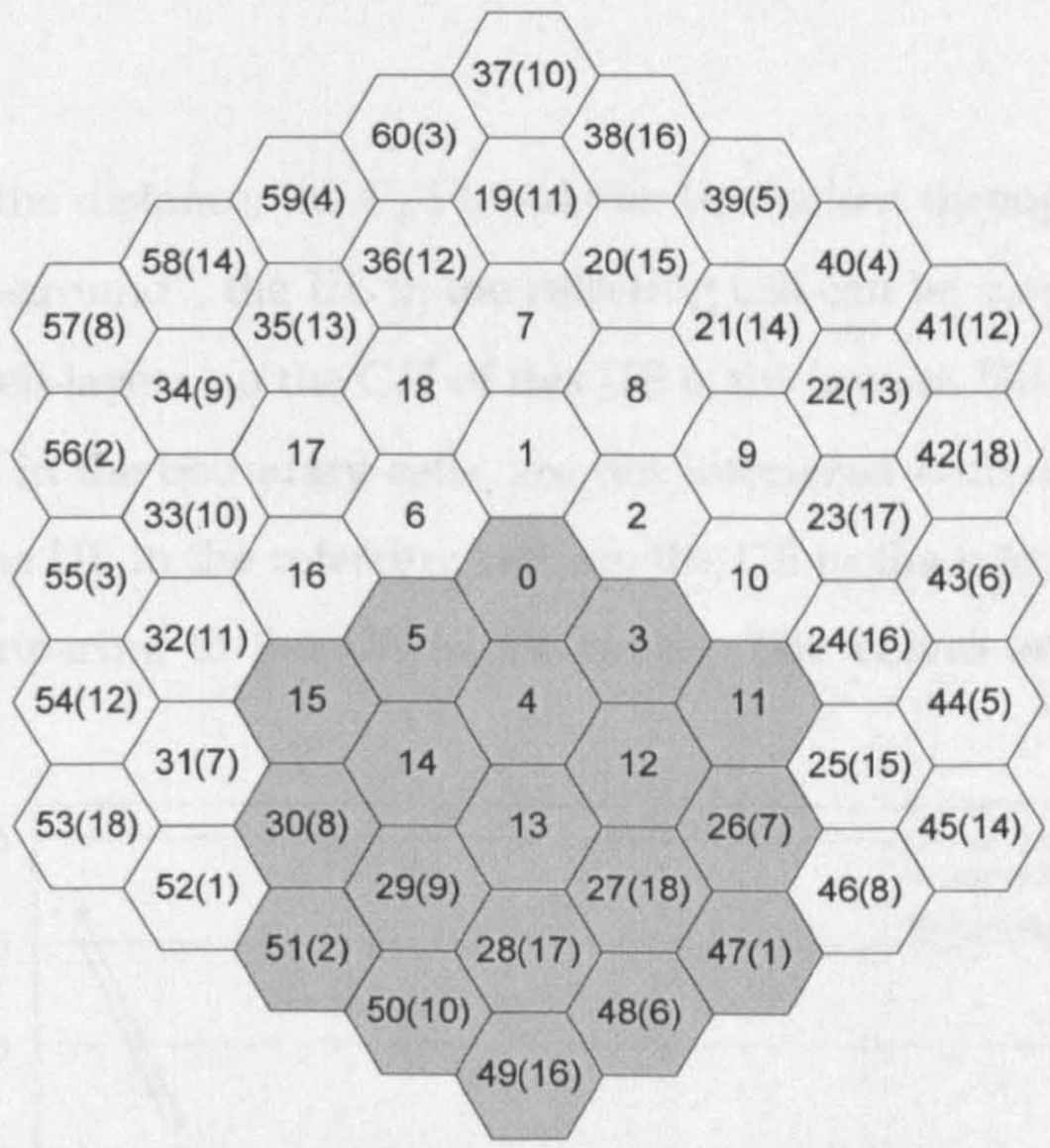


Figure 5-8 Referring Cell 13

Figure 5-8 gives another example. For the referring cell 13, 8 real cells can remain the same but the remaining 10 virtual cells need to follow the wrap-around mapping principle during the simulation process.

To realize the wrap-around approach, several continuous nested call functions are used in this simulation platform for the conversion between the real coordinates and the mapping coordinates. As this part is not the focus of this research work, the details of the mapping functions will not be discussed further.

To verify the wrap-around function, a test case is set in this simulation: the cell radius is 577m which is the typical range in dense urban GSM system. All the NodeBs are using omni antennas for transmitting and the transmission power are set as the same value. There is only one UE in each cell and the distance between the UE and the NodeB is the same as well. For the UE, only the signal from the serving NodeB is useful, signals from other NodeBs will be regarded as interference.

In order to simply the test scenario, the shadow fading, fast fading and the thermal noise are ignored. The pathloss model is adopted as $L_{fs} = 38.12 + 20\lg(R)$ where R (in metres) is the distance between the UE and the NodeB.

While altering the distance, the C/I trend can be tracked through the platform. Without "wrap-around", the UE in the referring cell can be surrounded by two neighbouring cell-layers, so the C/I of this UE is the lowest. However, the other UEs, especially in the boundary cells, are not interfered with equally from the NodeBs as is the UE in the referring cell: so, the UE in the boundary cells have higher C/I comparing to the UE in the centre. The values are shown in the Figure 5-9.

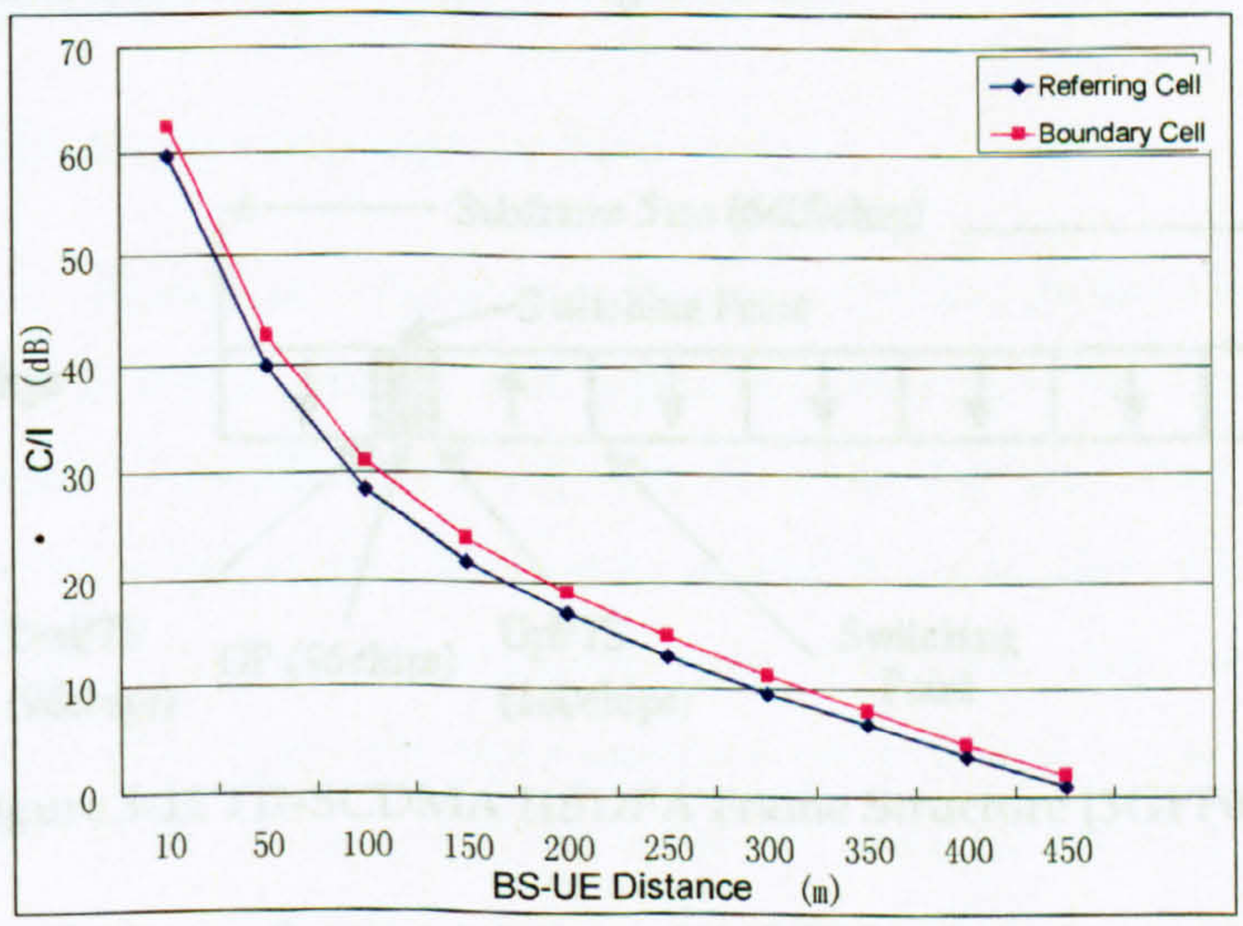


Figure 5-9 C/I without wrap-around [Figure 2.28 from [TD02]]

With "wrap-around", after mapping the real cells to the virtual cells, all the UEs are guaranteed to be surrounded by two neighbouring cell-layers, so the C/I of

each UE is as the same as the UE in the referring cell. In such a situation, the C/I values, see Figure 5-10, are exactly the same as the values of the UE in the referring cell shown in the Figure 5-9.

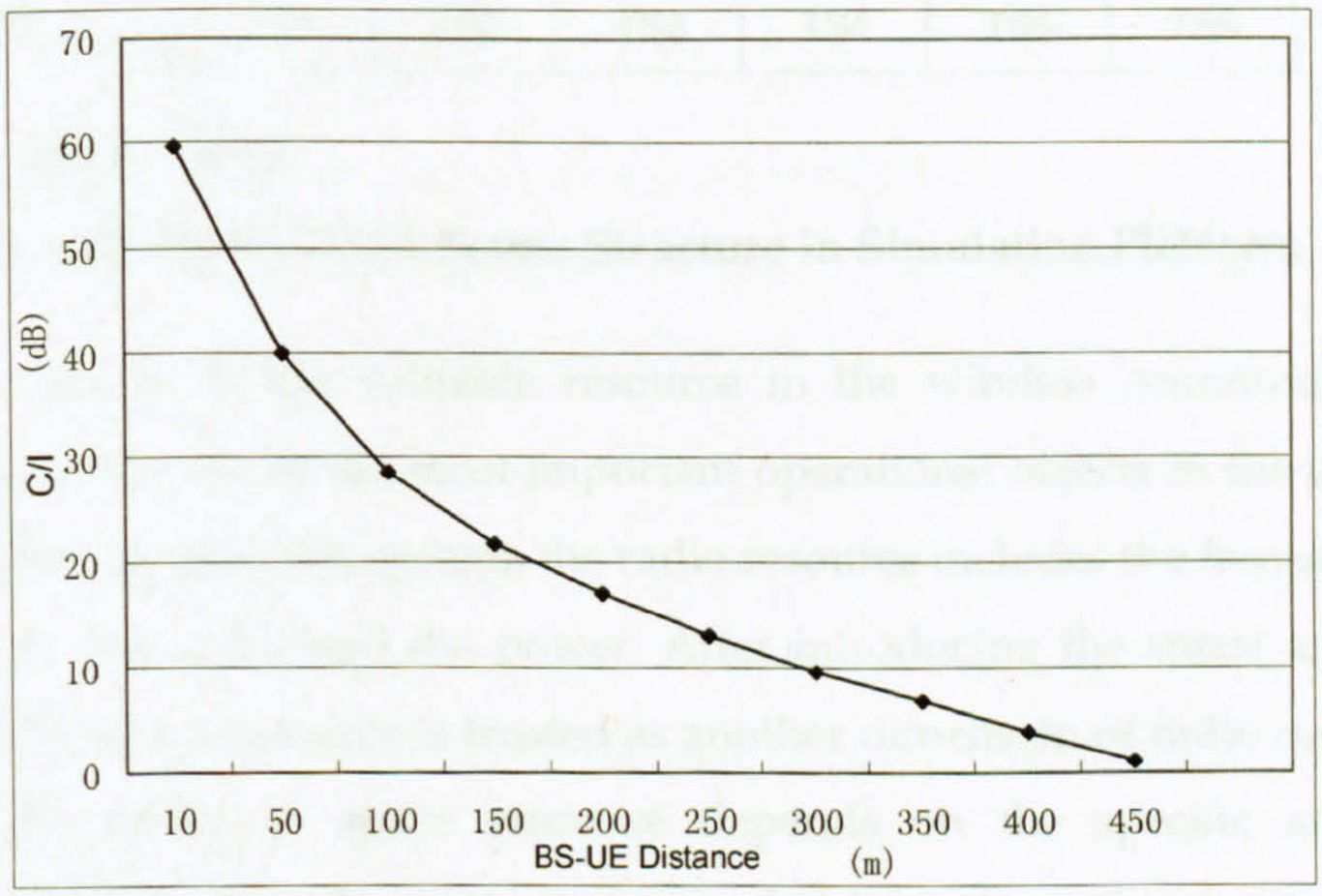


Figure 5-10 C/I with wrap-around [Figure 2.29 from [TD02]]

5.4 Radio Resource Management

The TD-SCDMA Frame structure was introduced in previous sections. The TD-SCDMA frame used for HSDPA services is exactly the same as the ordinary TD-SCDMA frame which is illustrated in Figure 5-11.

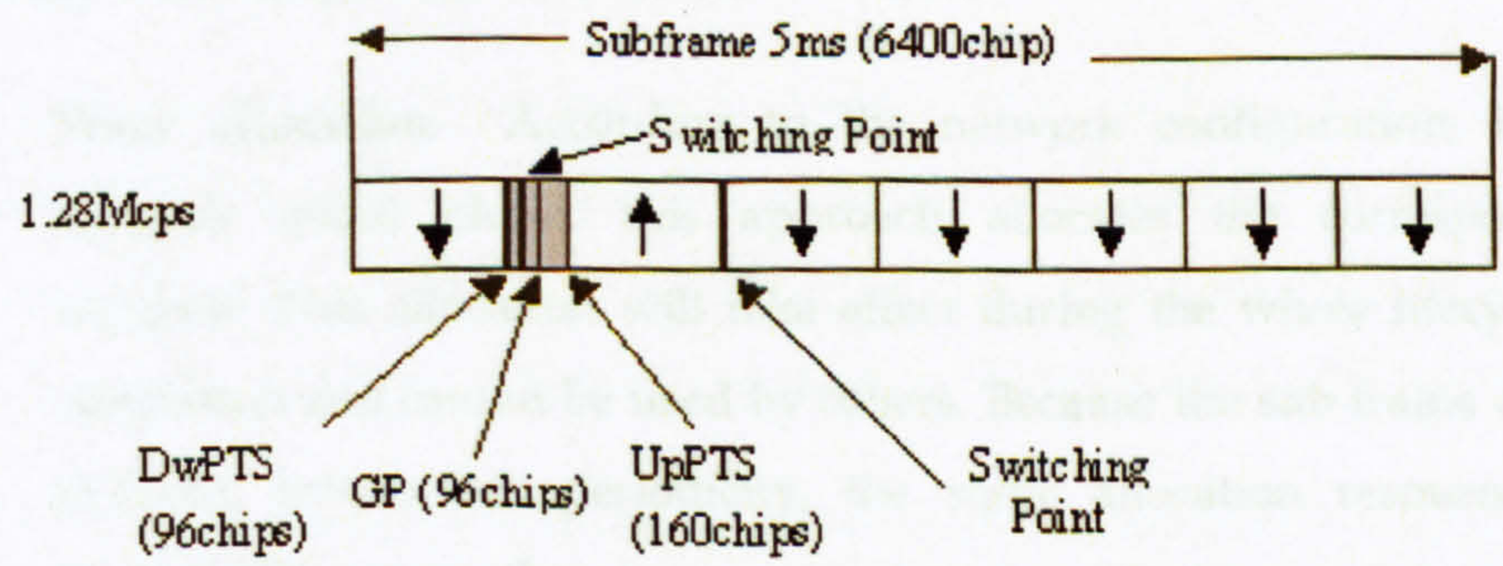


Figure 5-11 TD-SCDMA HSDPA Frame Structure [3GPP01]

As mentioned above, the special time slot "GP", takes the responsibility of "protecting" the uplink and downlink switch. That "guard" function has no other actions so in order to reduce the events during the simulation, the "GP" is divided into two parts, one part merging with the DwPTS and the other one

merging with the UpPTS. Therefore, the simplified TD-SCDMA HSDPA frame structure used in this simulation platform is shown in Figure 5-12.

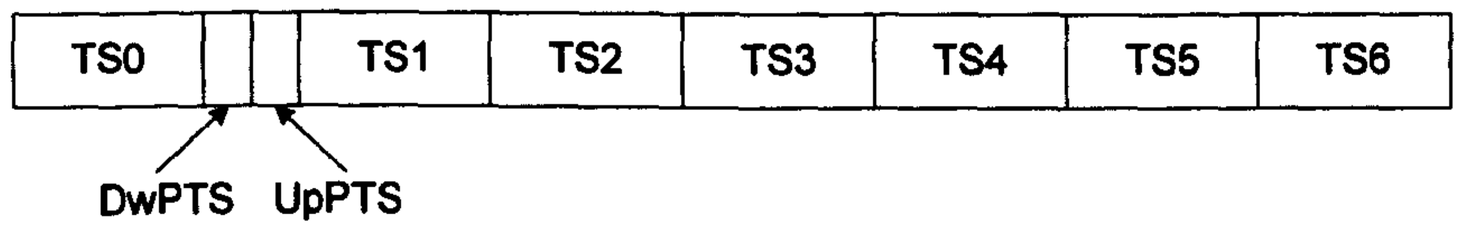


Figure 5-12 TD-SCDMA Frame Structure in Simulation Platform

The radio resource is the valuable resource in the wireless communication networks and so is one of the most important operational objects in the system simulation. For TD-SCDMA system, the radio resource includes the frequencies, the time slots, the codes and the power. After introducing the smart antenna techniques, the space resource is treated as another dimension of radio resource. However, the utility of space resource depends on the specific antenna technologies used, unlike the codes or power that have theoretical limits. So in the current simulation platform, only the frequencies, time slots, codes and power are regarded as the core radio resource to be considered in the research.

The basic operations for resources consist of: resource allocating, resource releasing and resource usage observing.

Resource allocation

Generally the resource allocation methods include:

- **Static allocation**: According to the network configuration, in the network initial phase, this approach allocates the corresponding resource. This allocation will take effect during the whole lifecycle of simulation and cannot be used by others. Because the sub-frame of TD-SCDMA system has periodicity, the static allocation resource will periodically occupy the same assigned resource in every sub-frame and there will be no changes of the location within the timeslots. During the whole simulation process, the static resource allocation does not need to be released at all, resources such as P-CCPCH.

- **Semi-static allocation**: According to the network configuration, the radio resource is dynamically allocated for certain usage and this

allocation will be valid only until the end of the application. During the application, the semi-static allocation is treated as a static allocation, but when the application is over, the resource assigned by semi-static allocation should be released for other usages; an example is DCH.

- **Dynamic allocation**: According to the application request, certain resources are allocated on specified timeslots of specified sub frames. Those resources (such as HS-PDSCH) will be immediately released after being used once.

- **Reservation**: According to the network configuration, in the initial phase, certain resources (such as HS-SCCH) are reserved for special usage. Even if they are not being used as planned, they cannot be used for anything else.

To summarise, the radio resource management model design should consider the above four types, including the usage allocation and the resource release. Moreover, the resources have to be allocated based on the current resource availability status. Those resources that have been allocated cannot be duplicated before they are released and for this reason, the real-time resource monitoring function is necessary as well.

5.4.1 Resource Pool

Considering there will be no resource overlap among different timeslots, it is wise to build an individual data structure for each timeslot to record the resource allocation. With the resource pools for codes and power on each timeslot, it turns out to be convenient to manage the resource on a timeslot basis.

The size of the resource pools are configured at the simulation initial phase based on the configuration profile or configuration attributes. The resource pools remain the same during the whole process of the simulation, which can be treated as the static allocation for the network or network objects. Another benefit of using the resource pools in this simulation is that they are set as the upper threshold of the resources during the allocation, which can simulate the codes limitation or power limitation scenarios.

5.4.2 Codes Resource Pool

Regarding the codes within the TD-SCDMA HSDPA cell, they are shared resource, no matter whether uplink or downlink: so the usage allocation of the codes is within the scope of the cell. As each cell will map to a solo NodeB in this simulation platform, the codes resource pool of the cell can be designed as one of the NodeB's attributes. The uplink/downlink switch point will affect the total amount of codes for uplink and downlink. Furthermore, the codes for HS-PDSCH are independent from other physical layer channels, these two resource categories have to be separated. There is an explicit definition for the codes of HS-PDSCH.

On each timeslot, the parameters link_direction, HSDPA_code_num and nonHSDPA_code_num will be configured according to the cell profile in the simulation initial phase. As stressed in the background chapter, the uplink/downlink switch point for the whole network should be set the same to avoid uplink/downlink overlap interference (if certain protection mechanisms are executed, the interference influence might be optimized - but this is not the focus in this research work so there will be no more discussion on this item), so the link_direction for all the cells should be the same. However, the configuration of HSDPA_code_num and nonHSDPA_code_num can be different to simulate the co-existence of HSDPA cell and non-HSDPA cell. Note that the HSDPA_code_num here only covers the codes for downlink HS-PDSCH, not including the codes for HS-SCCH or DPCH. It neither covers the downlink non-HSDPA DCH. The HSDPA_code_num is always set as 0 for TS0 (which is not used for HS-PDSCH defined in the standard), uplink timeslots and TD-SCDMA special timeslots.

5.4.3 Power Resource Pool

Within each timeslot, the NodeB power resources are shared by multiple UEs' multiple channels. Meanwhile the total power for HS-PDSCH is separated from the total power for other physical layer channels. The usage of these two categories is independent.

Within each timeslot, the UE power resources are shared by multiple channels.

In the simulation platform, the power resource pools are created separately for NodeB and UE. For NodeB, the downlink HSDPA_power means the total power for HS-PDSCH; in the uplink the HSDPA_power and the non-HSDPA_power are always 0.

For a UE that is not acting as the relay station, there is no need to configure the HSDPA power for the uplink so the HSDPA_power for uplink timeslots is always 0. But the non-HSDPA_power is decided by the UE's capability and both the downlink HSDPA_power and non-HSDPA_power are always 0 for the UE.

For the UE acting as a relay station, there will be two sets of resource allocation: one follows the rule for the NodeB's (communicating with a relayed UE) and the other follows the UE rule (communicating with the NodeB). The system will call the corresponding configuration based on the role during the packet call.

5.4.4 Resource allocation list

The resource allocation status has to be recorded all the time. The remaining resources can be determined after subtracting the already allocated resources, so the upper limit can calculated for further resource allocation. Based on the current allocation of resources allocation, the simulation system can use the corresponding codes and power to transmit the signals.

The four different resources allocation methods mentioned above bring more complexity to the modulation in the simulation platform. For example, the resources might not only be used in the current sub frame, but also the following sub frames. Besides, the occupation on the following sub frames might be permanent (static allocation), or be valid for certain period (semi-static allocation), or just be valid once (dynamic allocation). Therefore the data structure should not only record the resource usage of the current sub frame but the following sub frames. Additionally it needs to have the capability of recording the different resource allocation methods and keep updating the data when the resource allocation status changes. Because the period of static allocation and semi-allocation occur on every timeslot, an individual resource allocation list is designed for every timeslot.

To realize that requirement, the "List" type of OPNET is used here. One of the advantages of using "List" here is that the resource record number for every timeslot can be different. Furthermore, it is easy to carry out the operations on adding or deleting the resource allocation to reflect the updates of the resource allocation.

5.4.5 General Process

Figure 5-13 gives the overall view of the simulation flow chart. The external interface allows the user to set common parameters for the simulation scenarios, such as AMC, HARQ and scheduling schemes. Meanwhile the NodeB configuration, smart antenna configuration and HSDPA resource configuration are defined in the profile as well.

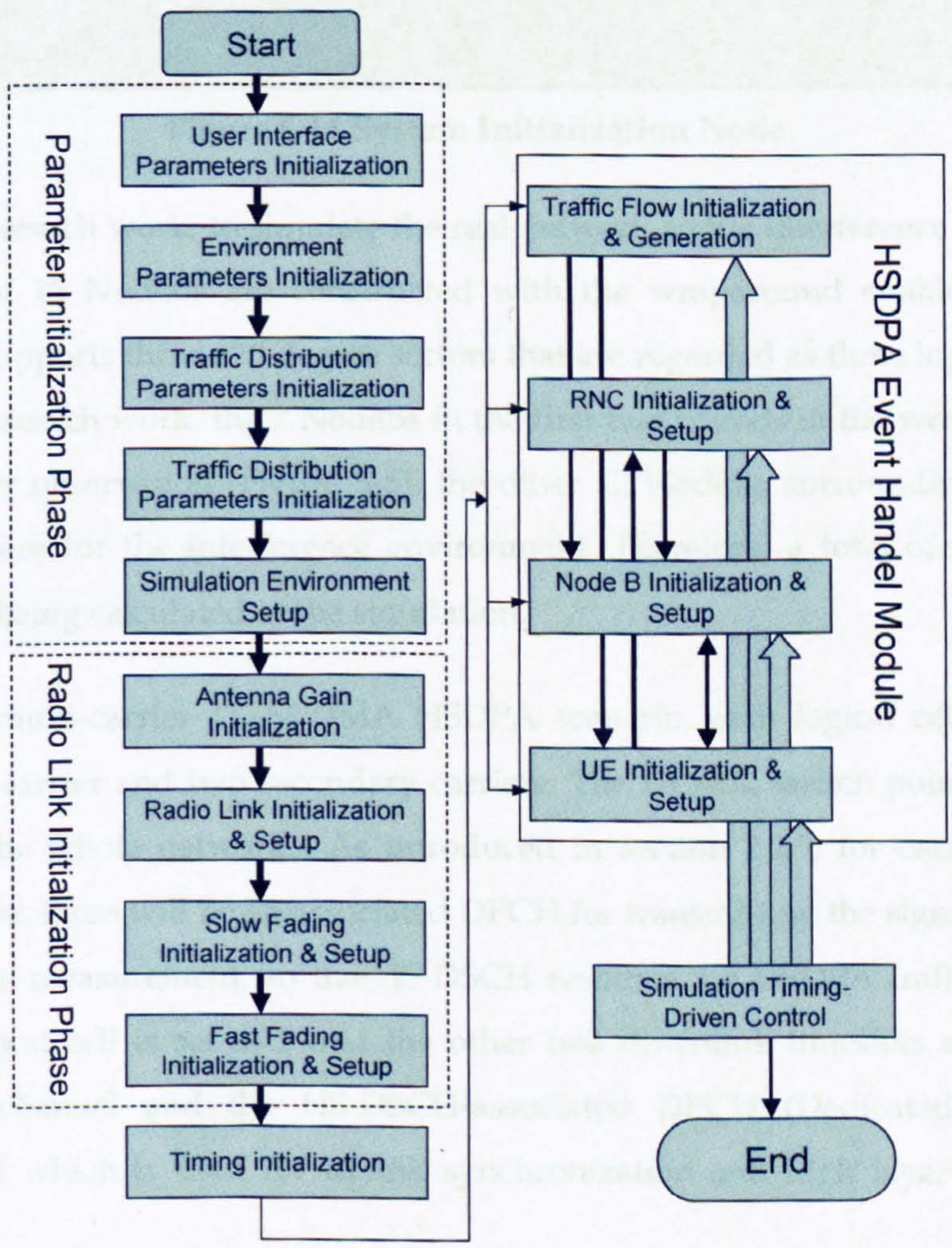


Figure 5-13 Simulation Platform Flow Chart [Fig2 from [DJ01]]

The whole system consists of two parts, initialization of system parameters and radio link, and HSDPA event handling. When the simulation starts, it first enters the parameter initialization models to set the initial value of simulation relevant parameters and then initialises the radio link model to configure the links and channels; it will also complete reading the external profiles at this stage.

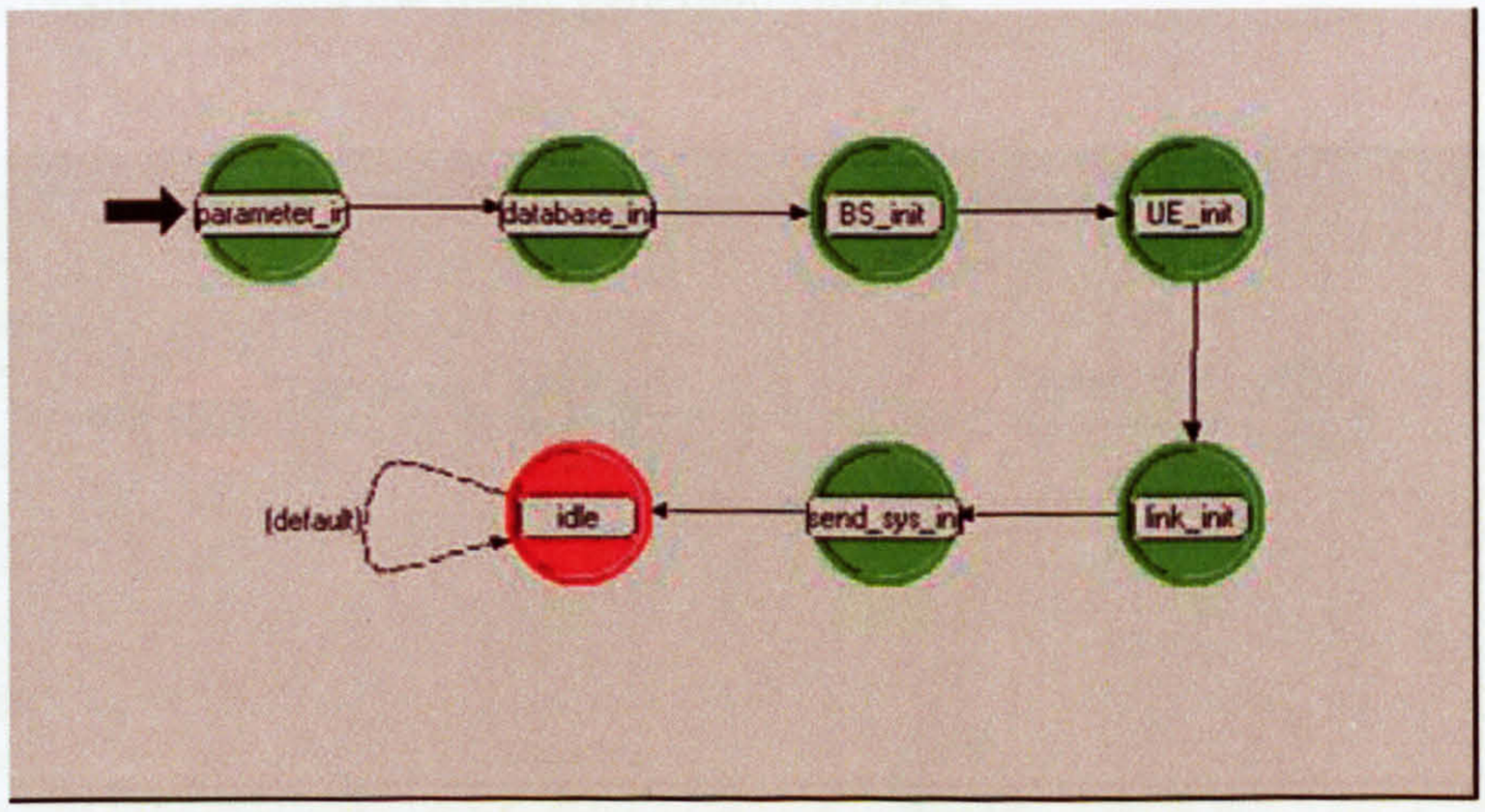


Figure 5-14 System Initialization Node

In this research work, to simulate the real network traffic interference situation, a total of 19 NodeBs are constructed with the wraparound enabled. Each NodeB supports three 120 degree sectors that are regarded as three logical cells. In this research work, the 7 NodeBs in the first two rounds in the wrap-around are under observation (Figure 5-5); the other 12 NodeBs surrounding these 7 NodeBs are for the interference environment. Therefore, a total of 21 logical cells are being calculated in the simulation.

For the multi-carrier TD-SCDMA HSDPA scenario, each logical cell has one primary carrier and two secondary carriers. The UL/DL switch point is set as 2:4 for the whole network. As introduced in section 2.2.9, for each HSDPA subscriber, there will be an associated DPCH for transmitting the signalling and doing the measurement, so the HS-DSCH resource for HSDPA traffic data in each logical cell is set as 2 and the other two downlink timeslots are set for control channel and the HS-DSCH-associated DPCH (Dedicated Physical Channel) which is used for uplink synchronization and high layer signaling

transmission purpose. The HSDPA related uplink and downlink signalling channel HS-SICH and HS-SCCH are configured as 4 for each logical cell.

When all the initialization work is done, the whole simulation will enter the global timing initial stage. In this phase, the timing-control logical model (Global Timer) will send the global timer signalling to the three main nodes: RNC, NodeB, UE and the traffic generation model.

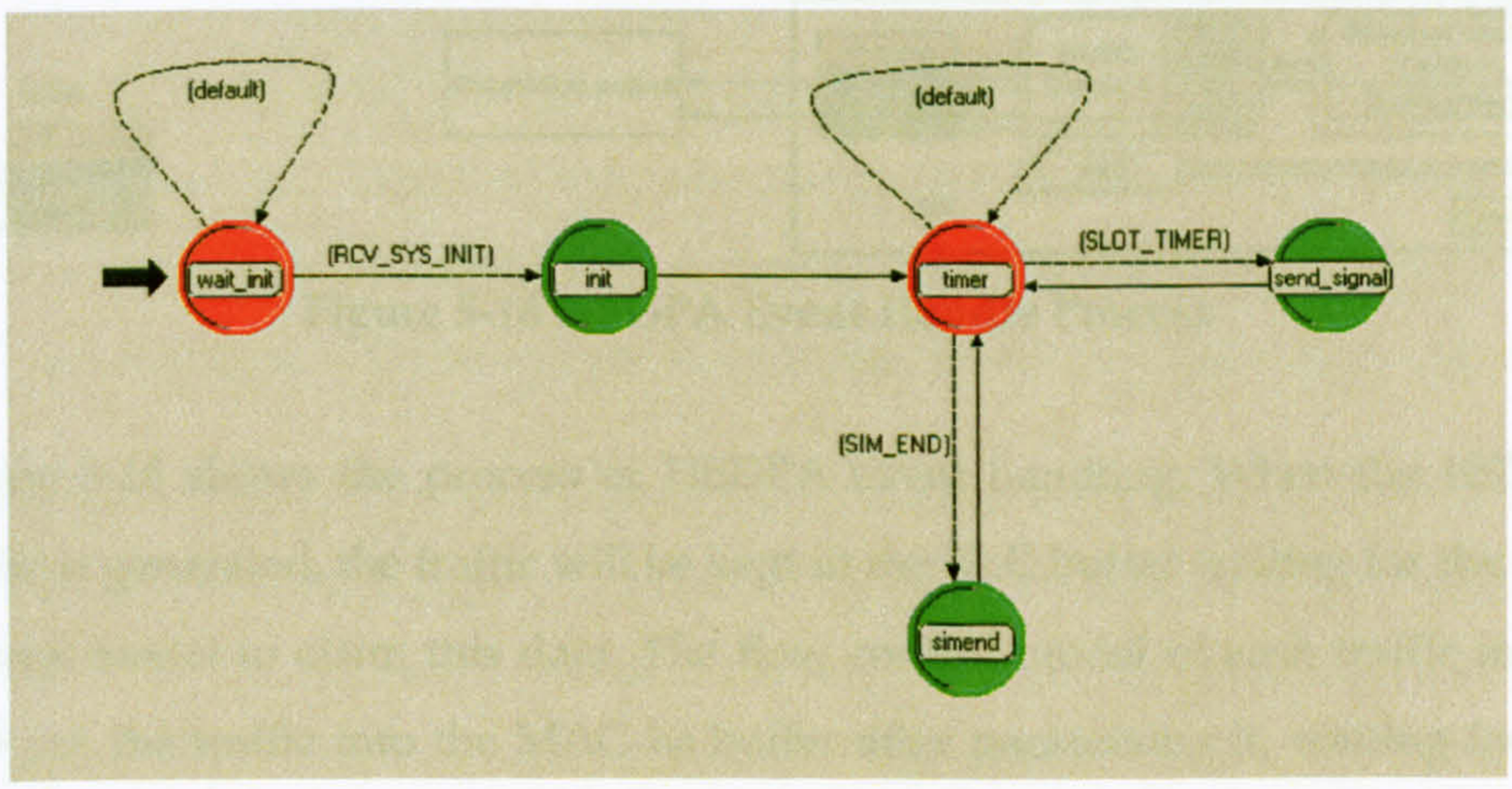


Figure 5-15 Global Timer Node

This interrupt will trigger those modules to do parameter initialization. Afterwards, they will enter the "wait" state until another interrupt from an inner node or outer node to trigger the new operation. Thereafter, the event-driving mechanism will keep driving the progress of the simulation until the end of the simulation time.

5.4.6 HSDPA Event Handling Process

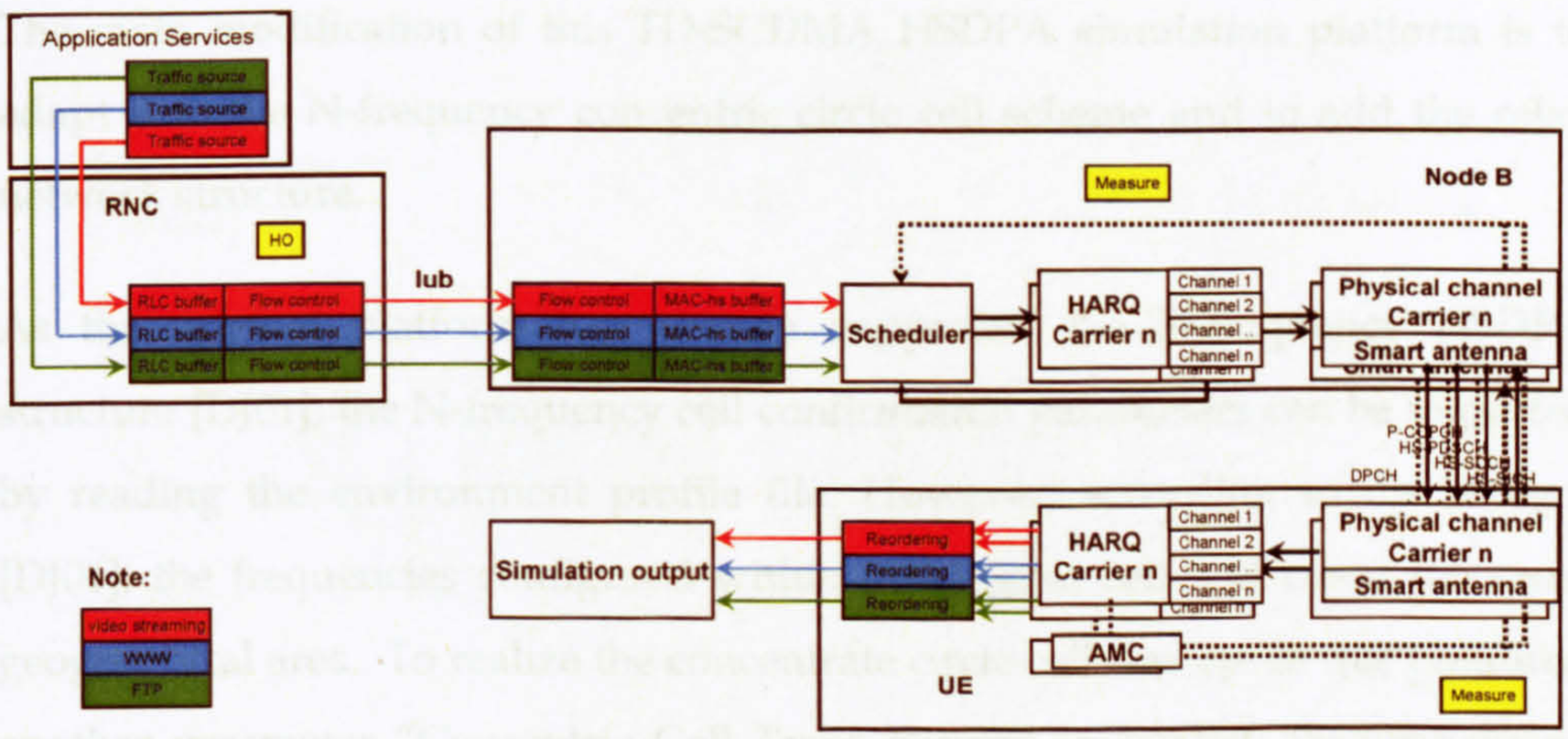


Figure 5-16 HSDPA Event Handle Process

Figure 5-16 shows the process of HSDPA event handling. When the HSDPA traffic is generated, the traffic will be kept in the RLC buffer waiting for the flow control model to claim this data. The flow control model of each traffic model will put the traffic into the MAC-hs buffer after packetizing it, waiting for the scheduled time from the scheduling model.

Every frame, the scheduling model will adjust the UE transmission and UE retransmission scheme based on the feedback of UE channel quality, UE HARQ channel quality and scheduling algorithms. The UE will receive the signals on the HS-PDSCH (HS-PDSCH is the HS-DSCH channel mapped to the physical layer) channel indicated by the HS-SCCH channel. Then the UE will forward the received information to the corresponding re-ordering model for the unpacking process to retrieve the HSDPA data.

The scheduler scheme adopted in this research work is Round Robin. Although it is not the most optimum scheduling algorithm, it is fair to every UE in terms of the chances of being served by the NodeB. Introducing the relay network to extend the network coverage means that those terminals that are working under the relay network as relay stations are sitting in the poorer radio conditions compared to other TD-SCDMA UEs as they are at the cell edge. By using the Round Robin scheme, every UE will be served equally, independent of channel quality.

5.4.7 Modification for TD-SCDMA relay network

The main modification of this TD-SCDMA HSDPA simulation platform is to adapt it to the N-frequency concentric circle cell scheme and to add the relay network structure.

As the original platform has already supported the N-frequency HSDPA structure [DJ01], the N-frequency cell confirmation parameters can be imported by reading the environment profile file. However, according to the design, [DJ01], the frequencies configured within one logical cell will cover the same geographical area. To realize the concentrate circle cell concept in this platform, another parameter "Concentric Cell Trans Power" is created. By configuring different maximum power values, the coverage of each carrier will be different.

As stated in the previous chapter, the primary carrier (shown as the italic frequency number in Figure 5-17) of each logical cell has to cover the whole TD-SCDMA cell area (shown as the area within the outer solid hexagonal coverage in Figure 5-17). The original parameter "Max. NodeB Trans Power" in the system here is only for the primary frequency configuration. The maximum transmission power for the secondary frequencies in the logical cell is configured according to the figure of the new parameter "Concentric Cell Trans Power" (shown as inner solid hexagonal coverage in Figure 5-17). In this simulation scenario, the NodeB maximum transmission power for the two secondary frequencies of each logical cell is configured as 3dB less than that for the primary frequency. Here the 3dB is the figure used in practice for GSM concentric circle cells. This part is added in the parameter initialization phase.

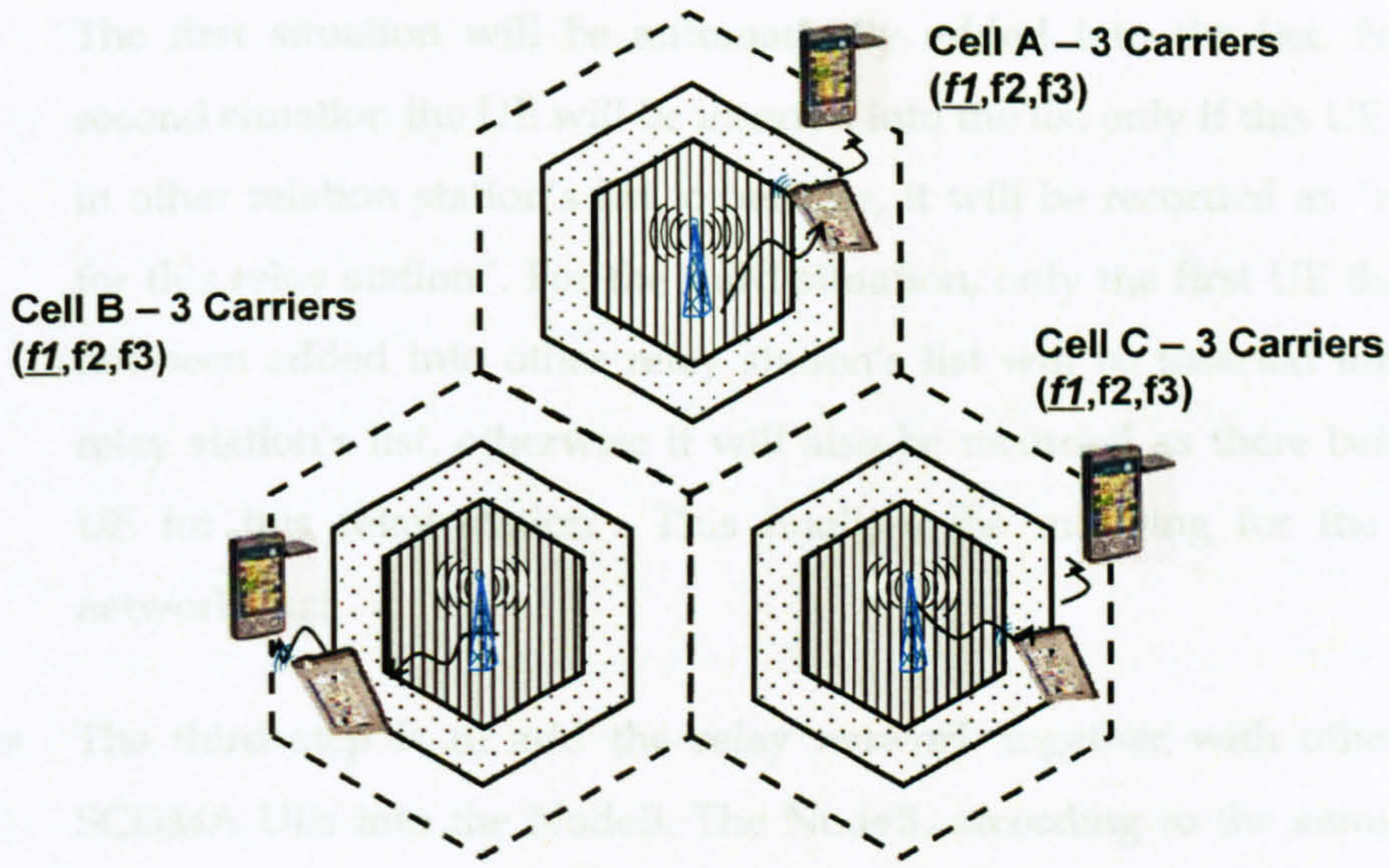


Figure 5-17 TD-SCDMA Relay Network

By adjusting the UE selection procedure, the relay network is added into this simulation platform.

The UEs are generated randomly by the platform (see Figure 5-18). The UE selection phase is divided into three steps.

- The first step is to select potential relay stations for the system. During the generation of every UE, the distance between every UE and NodeB is known by the system. By referring to the value of the parameters "TD cell radius" and "Relay cell radius", those UEs that are only under the coverage of the primary carrier will be added into one "potential relay station list". Those UEs that are under all the three carriers' coverage will be inserted into another list "potential TD UE list".

  Based on the distance between these UEs and NodeB, the relation between the UE and serving NodeB is fixed as well. Here the "serving NodeB" means the UE is within the coverage of this NodeB.

- The second step is to select the UEs for the relay network. Under every relay station's coverage, another list will be generated to record the relationship between the relay station and the UE in the relay network. Within the coverage there may exist three possibilities: (i) there is no UE, (ii) only one UE or (iii) more than one UE for the specific relay station.

The first situation will be automatically added into the list. For the second situation the UE will be inserted into the list only if this UE is not in other relation station's list, otherwise, it will be recorded as "no UE for this relay station". For the third situation, only the first UE that has not been added into other relay station's list will be inserted into this relay station's list, otherwise it will also be recorded as there being no UE for this relay station. This finalises the mapping for the relay network part.

- The third step is to add the relay network together with other TD-SCDMA UEs into the NodeB. The NodeB, according to the simulation scenario configuration, will first select those relay stations that have one UE in its relay network coverage into NodeB serving UE list. By adding these relay stations, the one-to-one relationship between the relay station and the UE in the relay network is also being added into the NodeB records. Then the NodeB will select the rest of the UEs within the TD-SCDMA cell coverage.

Based on the above steps, the simulation will generate enough random UEs so that the NodeB will get the desired number of relay stations and UEs for every round of the simulation.

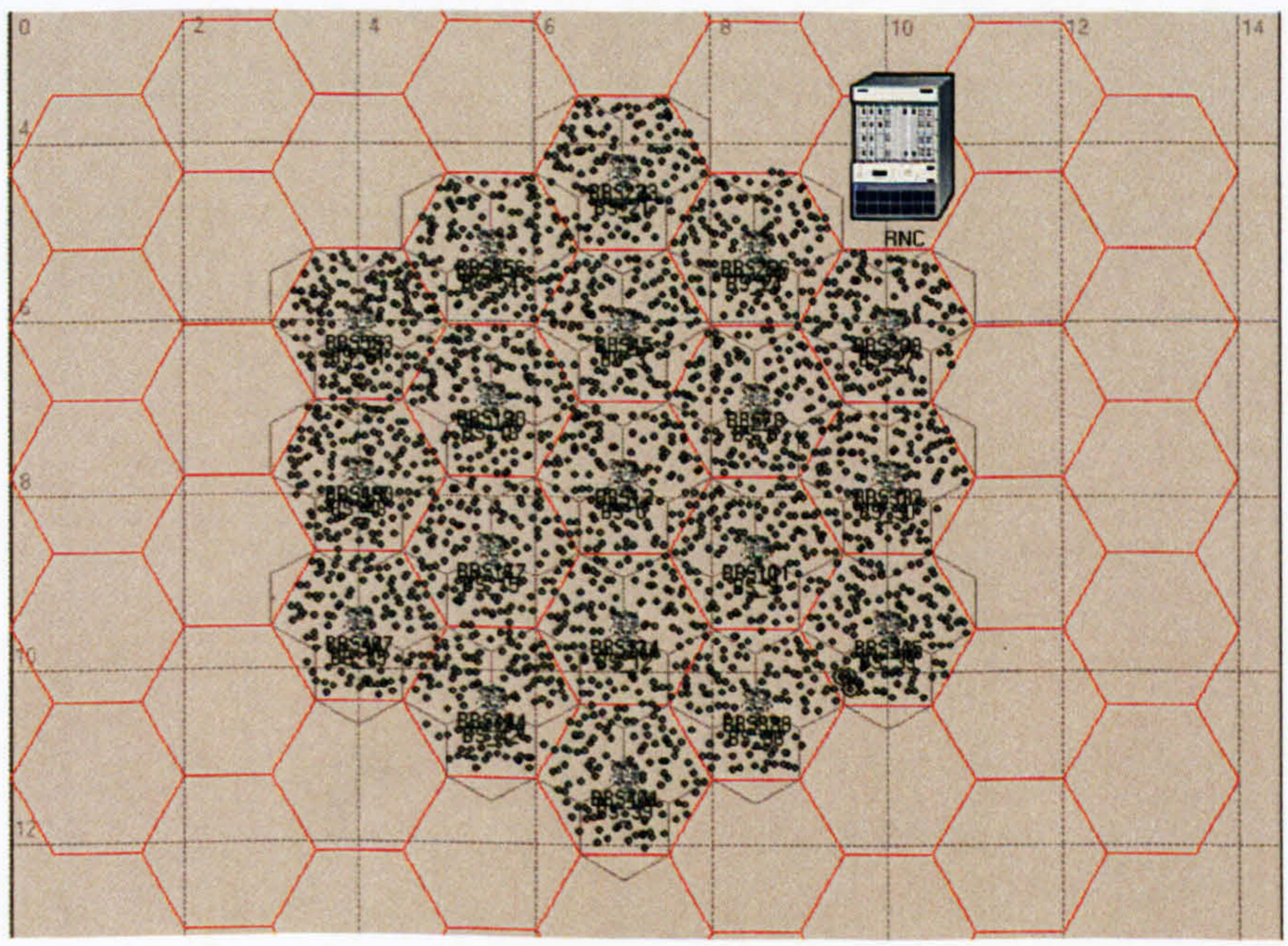


Figure 5-18 UE Generation

After fixing the UE-NodeB relationship, the resource of every NodeB and UE can be allocated accordingly.

The radio resource management scheme in this simulation platform applies to both TD-SCDMA network and relay network and the NodeB will treat the relay station as the same as other TD-SCDMA UEs. The only modification here for the TD-SCMDA network part is the NodeB will allocate the corresponding frequency resource for the TD-SCDMA UEs. In other words, if the UE is within the coverage of inner circle cell under the concentric circle cell concept, the NodeB will allocate the secondary carrier resource to the UE; otherwise, the NodeB will assign the UE to use the primary carrier resource.

For the relay network part, as stated in 3.3, the radio access technique in the relay network air interface is also TD-SCDMA, so the resource assigned for the relay station is easily mapped to the UE in the relay network. The main change is the frequency used between the relay station and the UE in the relay network: the relay station will select one of the secondary frequencies as the transmission carrier for the UE in the relay network, instead of using the primary frequency which the relay station is using to communicate with the NodeB.

Table 5-1 shows the main common parameters of all the simulation scenarios.

Table 5-1 Simulation Scenario Parameters

Item	Assumption
System	TD-SCDMA
Environment	19 Macro NodeBs in Wraparound
Cell Structure	Each Hexagonal Macro NodeB contains three 120 degree sectors (so called logical cells)
TD Cell Radius	540m
Relay Cell Radius	616m
Mobility	3 km/h
Antenna Type	Smart Antenna (8 elements each set)
No of carriers/sector	3
No. of HSDPA timeslots /carrier	2
Fast Fading Model	ITU Pedestrian 3 km/h
Max. BS Transmission Power	33(dBm)
Max. UE Transmission Power	24(dBm)
Thermal Noise	BS: -113.0 dBm UE: -113.0 dBm
Maximum transmission times	3
HARQ channel number	4

5.4.8 TCP modelling

The basic traffic models for non-real time services are introduced in UMTS 30.03 [3GPP10]. The typical traffic model structure consists of three layers: (i) session (ii) packet calls (iii) packets.

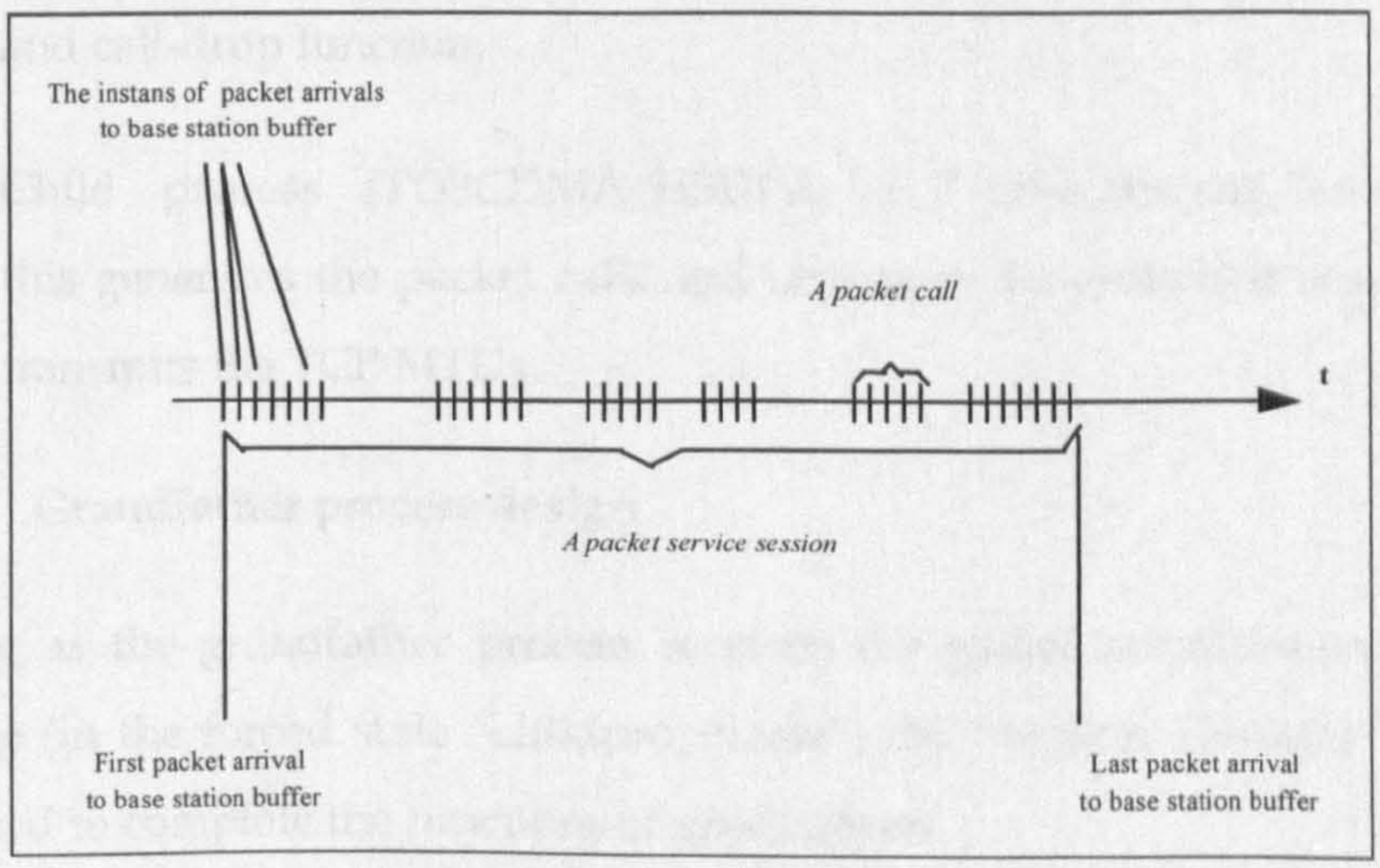


Figure 5-19 Typical characteristic of a packet service session

In this TD-SCDMA HSDPA simulation platform, the three-layer traffic architecture is adopted. As for HSDPA services, all the traffic modelling is for downlink only. The non-real time service "WWW application" is implemented in this simulation; the details of the model are introduced in [3GPP11].

The protocol used for the transport layer for the WWW application is the TCP protocol and that is reproduced as far as possible in the simulation model. To reduce the complexity of the simulation platform without significantly affecting the simulation result, a simplified TCP model is used; this modifies the TCP protocol flow control and congestion control, the TCP Slow-Start data transmission procedure and the TCP set-up and clear-down.

For internet traffic, the MTU for TCP has two options: 1500B and 576B [CR01] and within one packet call, the MTU will remain the same, which means for one packet call all the objects (files) use the same MTU value.

5.4.9 Traffic model design

The whole traffic model is a three-process-layer design, the layers being grandfather process, father process and child process.

- Grandfather process (TDSCDMA_HSDPA_UE_Traffic_Manager): this generates the Session Manager for different application types.

- Father process (TDSCDMA_HSDPA_UE_Traffic_Session_Manager): this completes the traffic offered, generation of next session, access function and call-drop function.

- Child process (TDSCDMA_HSDPA_UE_Traffic_Session_Generation): this generates the packet calls and objects in the particular session and transmits the TCP MTUs

5.4.9.1 Grandfather process design

As long as the grandfather process receives the global initialization success message (in the forced state "childpro_create") the "Session Manager" will be generated to complete the functions of applications.

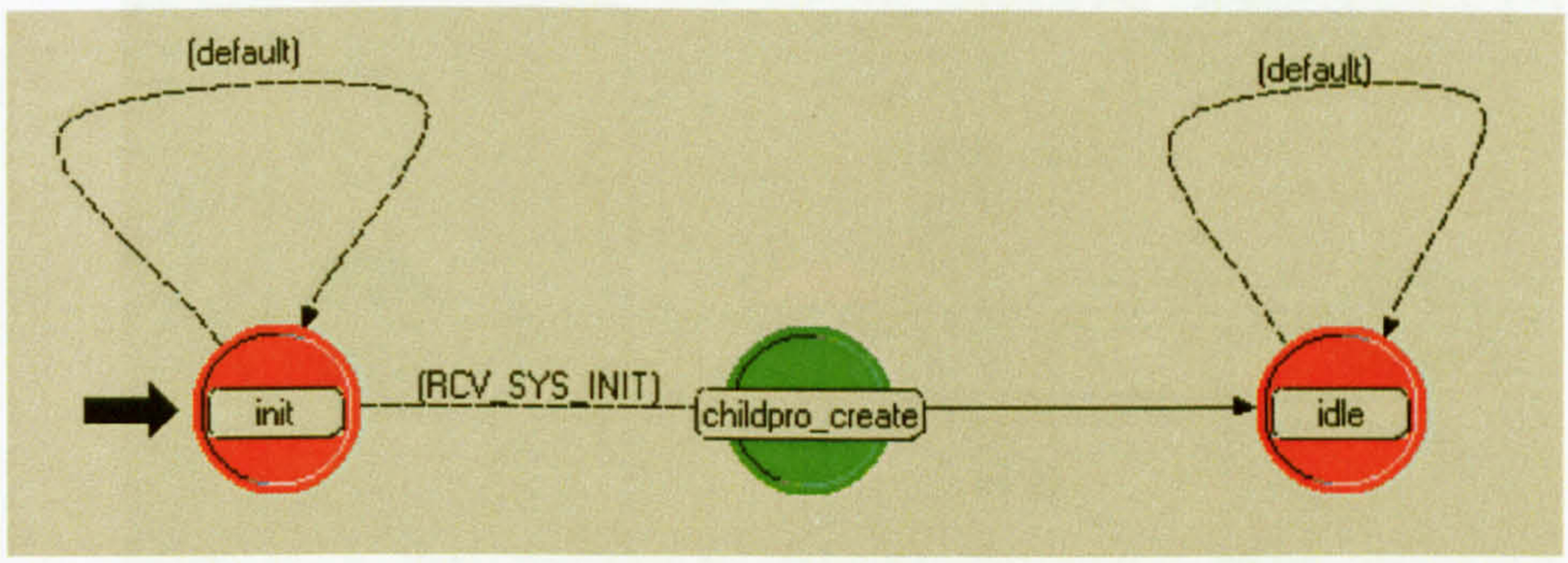


Figure 5-20 Grandfather Process Finite State Machine Design

5.4.9.2 Father process design

When the father process has been called (in the forced state "Virt_Traffic") the traffic will be generated according to the required traffic types. The forced state "Session_Schedule" will generate the duration of next session.

When the next session arrives, it will send the access request to the NodeB radio resource management model. The simulation will enter this state when a session ends, or the previous session fails to access, or the previous session drops.

If the service accesses successfully, the simulation will enter the forced state "PA_Success" and a child process will be created immediately to generate the session itself and record the number of successful accesses.

If the service access fails, the simulation will enter the forced state "PA_Fail". No child process will be created but the number of the access failure will be recorded. Then the progress will transfer to the forced state "Session_Schedule".

If the call-drop occurs during the session generation procedure, the child process will be destroyed but the number of call-drop will be recorded. Then the progress will transfer to the forced state "Session_Schedule".

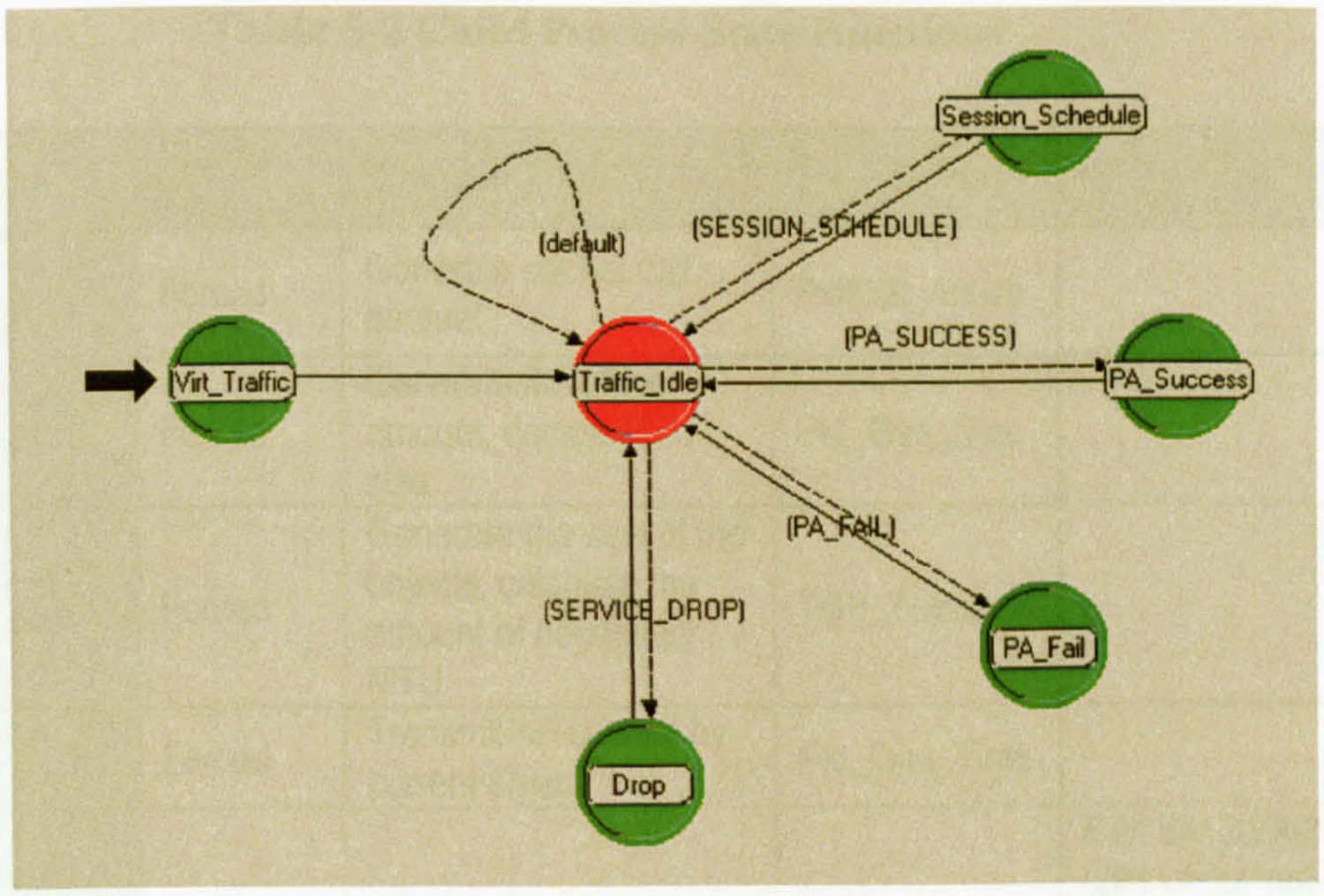


Figure 5-21 Father Process Finite State Machine Design

5.4.9.3 Child process design

The functions of the child process are: generating the packet calls, files and MTUs in the session.

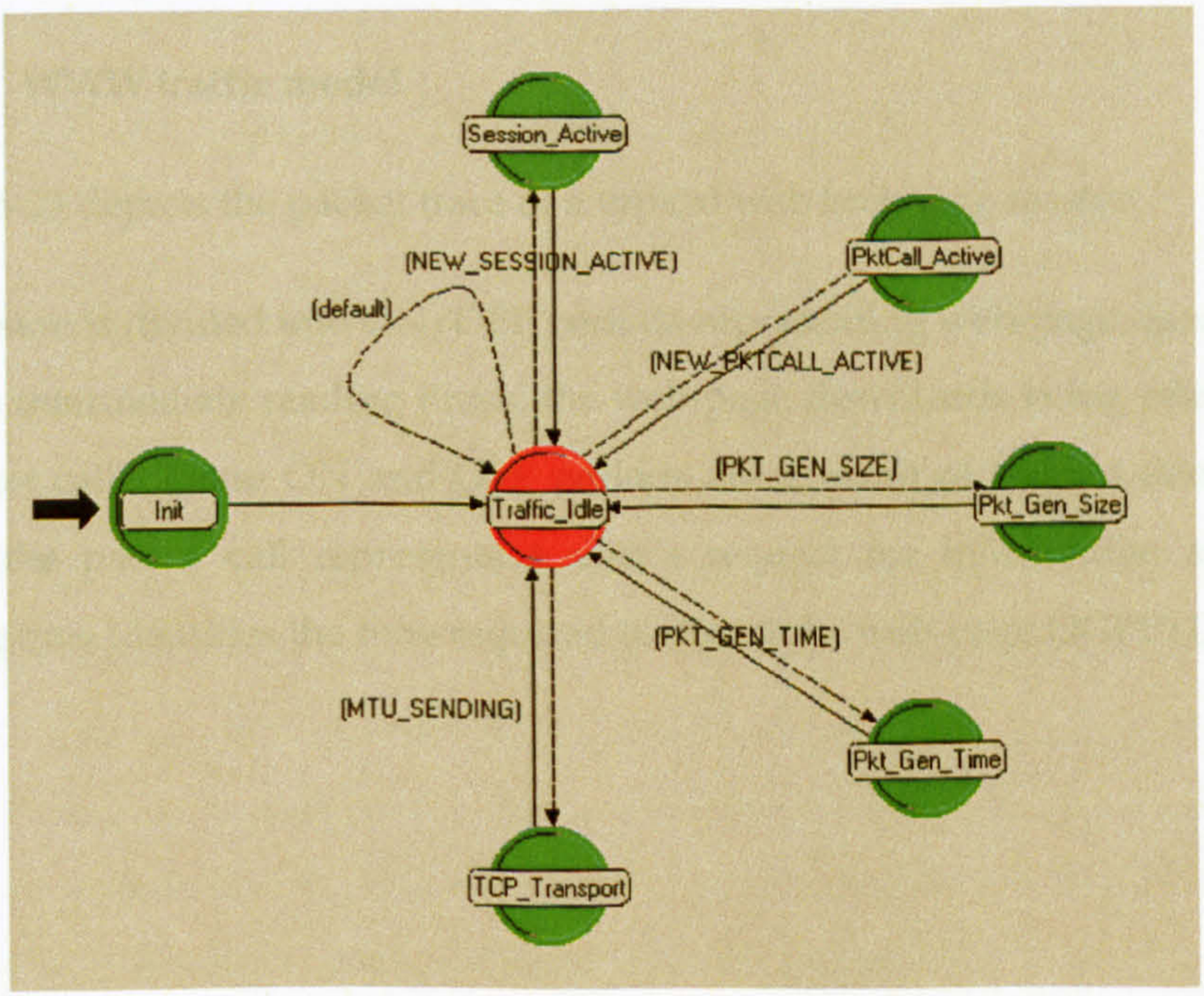


Figure 5-22 Child Process Finite State Machine Design

Table 5-2 gives the details about the functions of each state in the child process.

Table 5-2 Child Process State Functions

State Name	State Type	State Function	Transfer to	Notes
Session_Active	Forced	Generate packet call amount	PktCall_Active	
PktCall_Active	Forced	Generate the object amount, decide MTU size	Pkt_Gen_Size	
Pkt_Gen_Size	Forced	Generate the size of the objects, calculate the amount of necessary MTU	TCP_Transport	
TCP_Transport	Forced	Transmit MTU used by current object	Pkt_Gen_Time	
Pkt_Gen_Time	Forced	Generate the next object or the duration of next packet call	Pkt_Gen_Size Or PktCall_Active	If all the packet calls of current session are sent out, the child process will notify the father process and self destroye. The current session is over normally.

5.4.9.4 WWW traffic model

Figure 5-23 depicts the packet trace of a typical web browsing session.

The session is divided into ON/OFF periods representing web-page downloads and the intermediate reading times, the web-page downloads being referred to as packet calls. These ON and OFF periods are a result of human interaction where the packet call represents a user's request for information and the reading time identifies the time required to digest the web-page.[3GPP11]

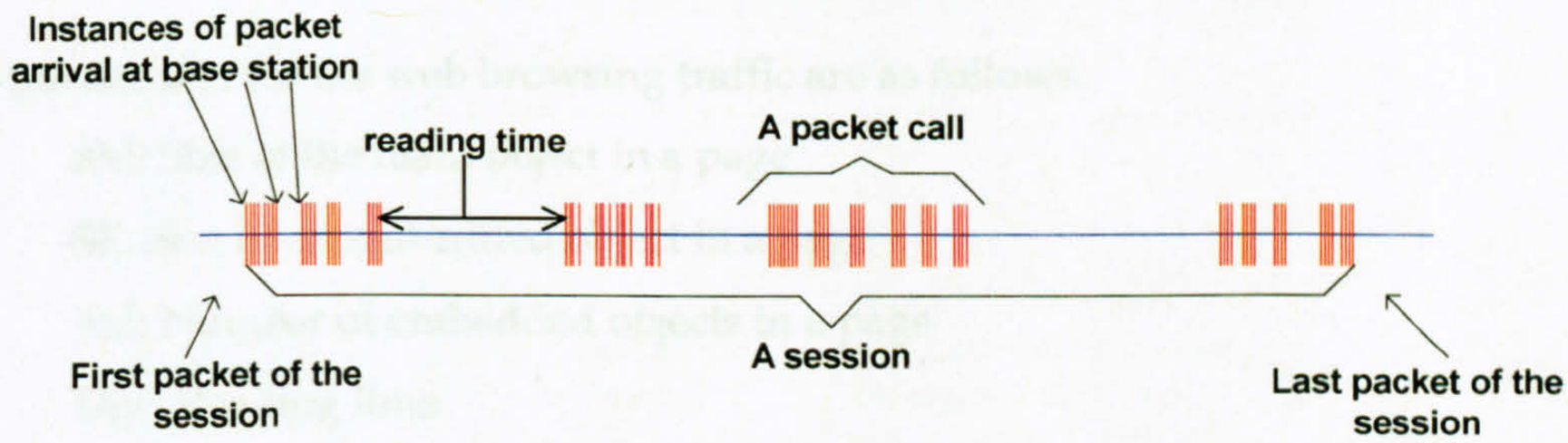


Figure 5-23 WWW Traffic Model

As is well known, web-browsing traffic is self-similar: in other words, the traffic exhibits similar statistics on different timescales. Therefore, a packet call, like a packet session, is divided into ON/OFF periods as in Figure 5-24, which also includes a series objects and the time intervals between every two objects.

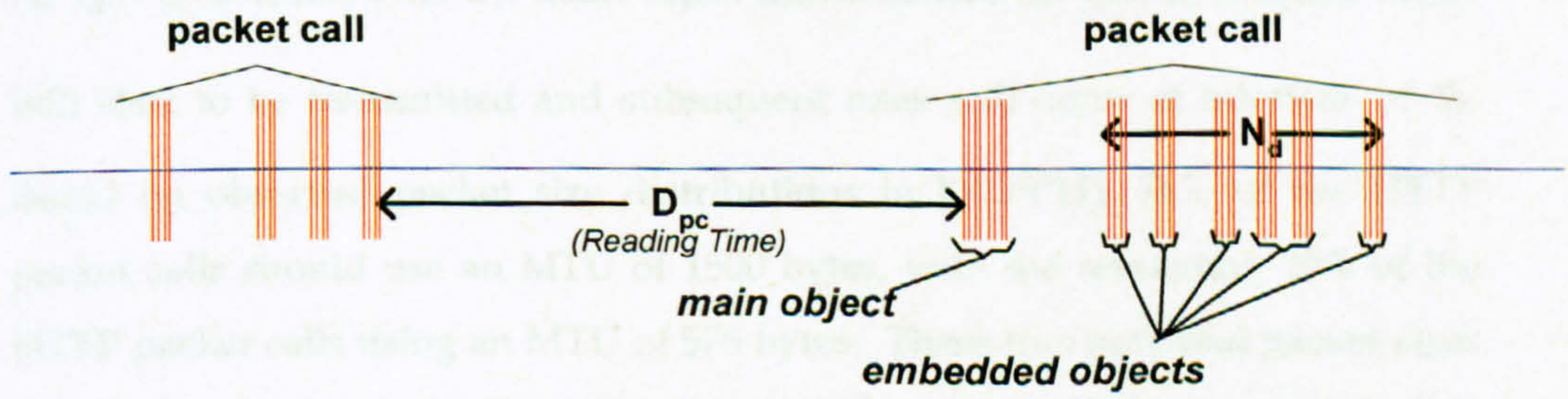


Figure 5-24 Contents in a Packet Call

This WWW traffic model is suitable for HTTP/1.1 persistent mode. In most cases, the webpage includes a single basic HTML file and several embedded objects. Therefore, within every downloaded webpage (one packet call), there are two types of packet: main object and embedded object. The main object refers to the basic HTML page while the embedded objects can be a JPG image, GIF image, JAVA application programme, or voice clip, etc.

Although the two packet types obey the same distribution, they have different parameters. When a UE seizes the main object, it needs time to parse the

hypertext markup language to get the webpage configuration information. The duration is so called "Parsing Time".

The parameters for the web browsing traffic are as follows:

SM: Size of the main object in a page

SE: Size of an embedded object in a page

Nd: Number of embedded objects in a page

Dpc: Reading time

Tp: Parsing time for the main page

TS: Time interval between sessions

NC: Number of the packet calls within this session

$\tau_{c.}$: Transmission interval of the embedded object, which is the sum of the duration of ACK from the client to the relay station and the duration from the packet data server to the NodeB router.

tpi: Duration of transferring every MTU

At Tp +$\tau_{c.}$ seconds after the main object transmission, the first embedded object will start to be transmitted and subsequent ones will occur at intervals of $\tau_{c.}$ Based on observed packet size distributions in [3GPP11], 76% of the HTTP packet calls should use an MTU of 1500 bytes, with the remaining 24% of the HTTP packet calls using an MTU of 576 bytes. These two potential packet sizes also include a 40 byte IP packet header (thereby resulting in useful data payloads of 1460 and 536 bytes, respectively)

The distributions of the parameters for the WWW traffic model are described in Table 5-3 [3GPP11]

Table 5-3 WWW Traffic Model Parameters

Component	Distribution	Parameters
Session Interval (TS)	Exponential	Mean = 60 sec
Number of Packet Call (NC)	Geometric	Mean = 30 Max. = 50 Min. = 20
Main object size (SM)	Truncated Lognormal	Mean = 10710 bytes Std.dev. = 25032 bytes Minimum = 100 bytes Maximum = 2 Mbytes
Embedded object size (SE)	Truncated Lognormal	Mean = 7758 bytes Std.dev. = 126168 bytes Minimum = 50 bytes Maximum = 2 Mbytes
Number of embedded objects per page (Nd)	geometric	Mean = 6 Max. = 53
Reading time (Dpc)	Exponential	Mean = 6 sec
Parsing time (Tp)	Exponential	Mean = 0.13 sec
Embedded object Interval（τ_c）	Exponential	Mean = 0.05 sec
MTU Interval（tpi）	Exponential	Mean = 0.0033 sec

The parameters used in the simulation are given in Table 4-1, Table 4-2, Table 4-3 and Table 4-11

5.4.10 Simulation Statistics

To verify the performance of the proposed network structure in this research work, four statistical performance indicators will be considered in the WWW traffic model simulation environment.

- **Average CIR** (dB): a network statistic on the OPNET global statistic scale. It is a time-average statistic of the whole network's downlink carrier/interference rate in dB. Because the two interference scenarios considered in Chapter 3 are both from the point of view of the UE, it makes sense to only consider the downlink CIR in this research work. The "Average CIR in dB" is the total contribution of every individual UE's average CIR within the simulation network.

  First, each UE in the simulation will calculate its own HS-PDSCH averaged CIR. The UE will treat the received signal power on the

allocated timeslot and the frequency from the serving BS as the carrier signals; the received power from all the other resources is treated as interference. The average CIR is the total CIR of this UE divided by the number of timeslots used by this UE. The value of this statistic is a proper indicator of the whole network's performance, which reflects the status of the signal power against the interference. The individual averaged CIR is one of the most important factors for improving the radio resource management algorithm.

- Average Retransmission: a UE statistic on the OPNET global statistic scale. The maximum retransmission of each MAC_hs_PDU block which is configurable in this simulation platform is set as 3. The statistics shown in the result sheet are the average figure within the simulation time of all the UE's.

- BLER (%): a UE statistic on the OPNET global statistic scale. The BLER is the MAC_hs_PDU block error rate statistics from the UE aspect. When the maximum retransmission of each block is reached, if the network still has not received the ACK from the UE, the "UE_pkt_received_wrongly" number will be incremented; if the ACK is received, the "UE_pkt_received_correctly"will be incremented. Then at the end of the simulation, the BLER is the rate of UE_pkt_received_wrongly/ UE_pkt_received_correctly based on each UE and traffic type.

- **Cell Throughput** (bit/s): it is also a network statistic on the OPNET global statistic scale. It is an average per NodeB per frequency statistic of the whole network's downlink throughput. In addition to the interference level, the network capacity is another important network performance factor that concerns network operators. This is measured for each NodeB so that statistics can be collected across the whole network.

  This statistic has a close relationship with the previous "Average CIR" as the NodeB will automatically adjust the allocated transmitted block

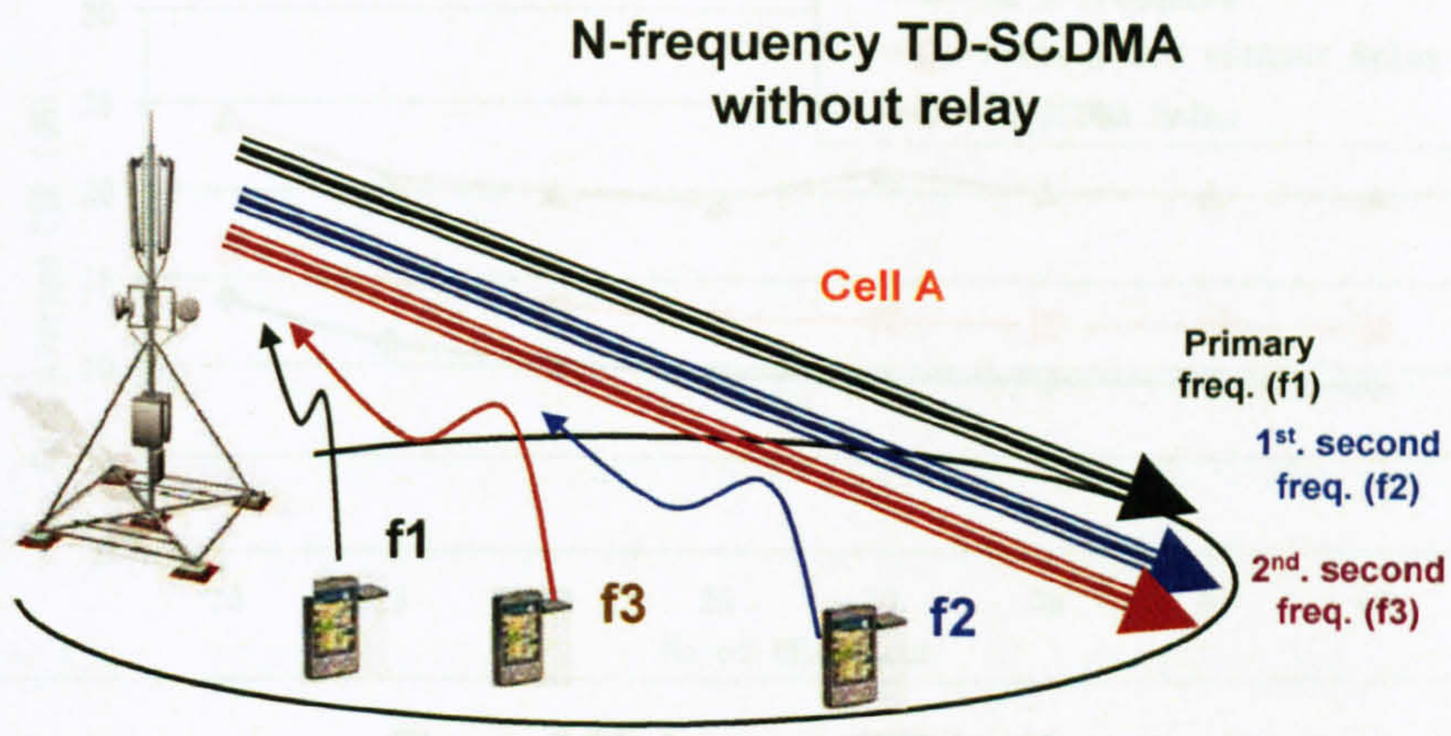


Figure 5-26 N-frequency TD-SCMDA without relay

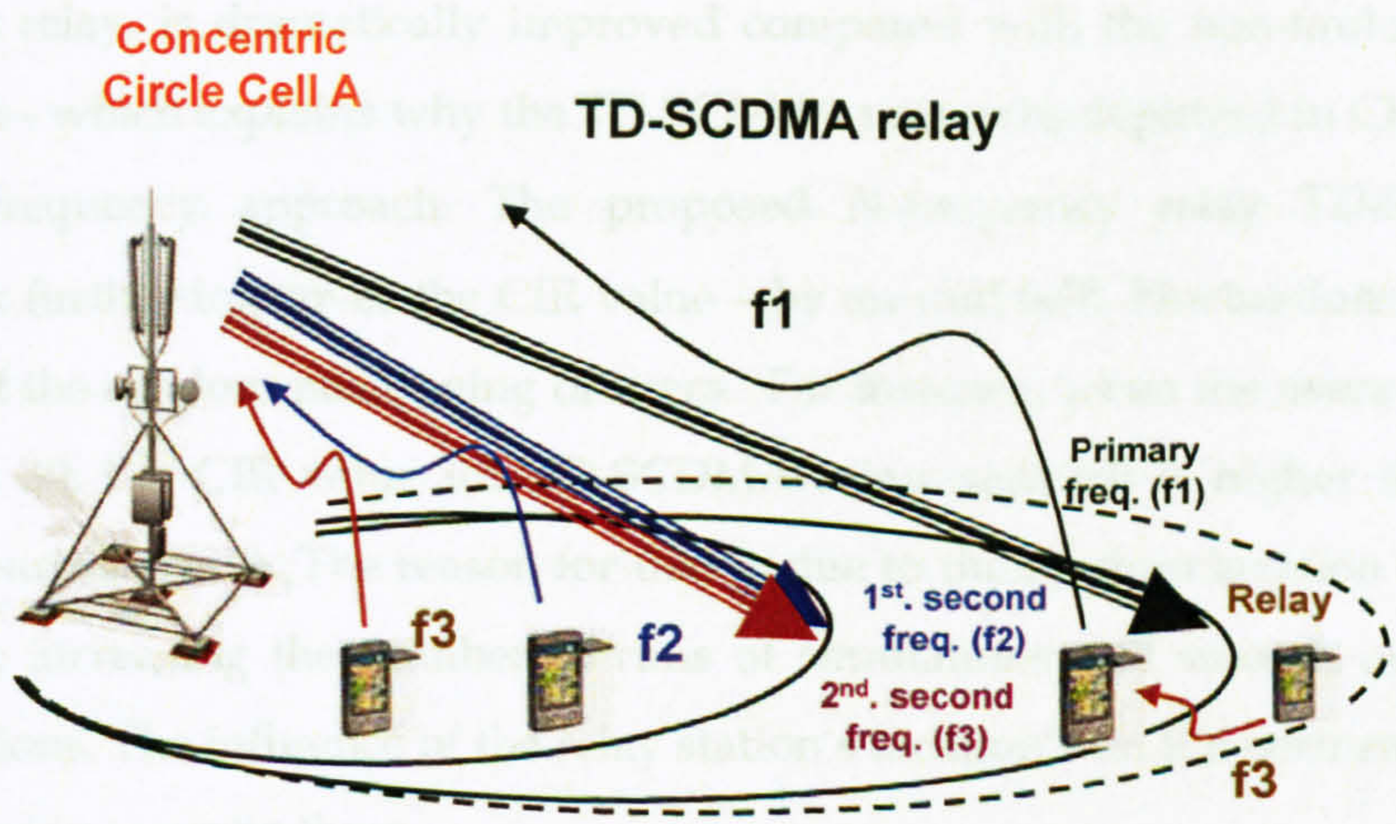


Figure 5-27 TD-SCDMA Relay Network

The UEs are randomly distributed within the whole simulation area. For every desired number of subscribers, the simulation is run 5 times with different random seeds and the average value of the results is calculated.

By increasing the number of subscribers in each logical cell with a fixed proportion of 25% relay users, the network performance is studied in terms of the interference and capacity. The results from the UE aspect are shown in Figure 5-28, Figure 5-31 and Figure 5-29.

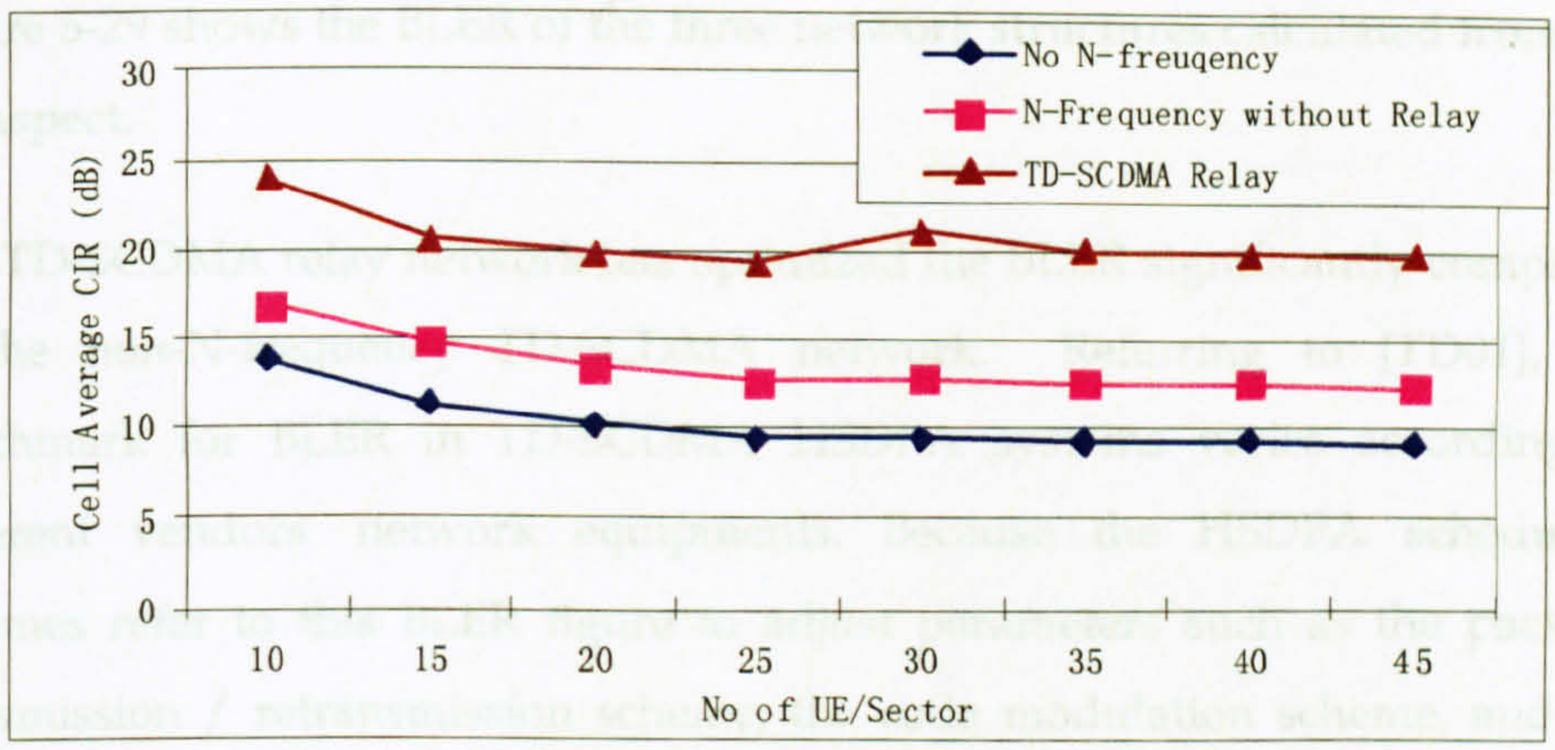


Figure 5-28 Average CIR in dB

The network interference when N-frequency is deployed, both with and without relay, is dramatically improved compared with the non-multi-carrier network - which explains why the TD-SCDMA networks deployed in China use the N-frequency approach. The proposed N-frequency relay TD-SCDMA network further improves the CIR value – by around 6dB. Fluctuations are the result of the random positioning of users. For instance, when the users per cell reached 30, the CIR value for TD-SCDMA relay network is higher than the neighbouring points. The reason for that is due to the random location of relay stations; increasing the number of runs of simulations will smooth out these fluctuations. The influence of the relay station's location's on the performance is discussed in scenario three.

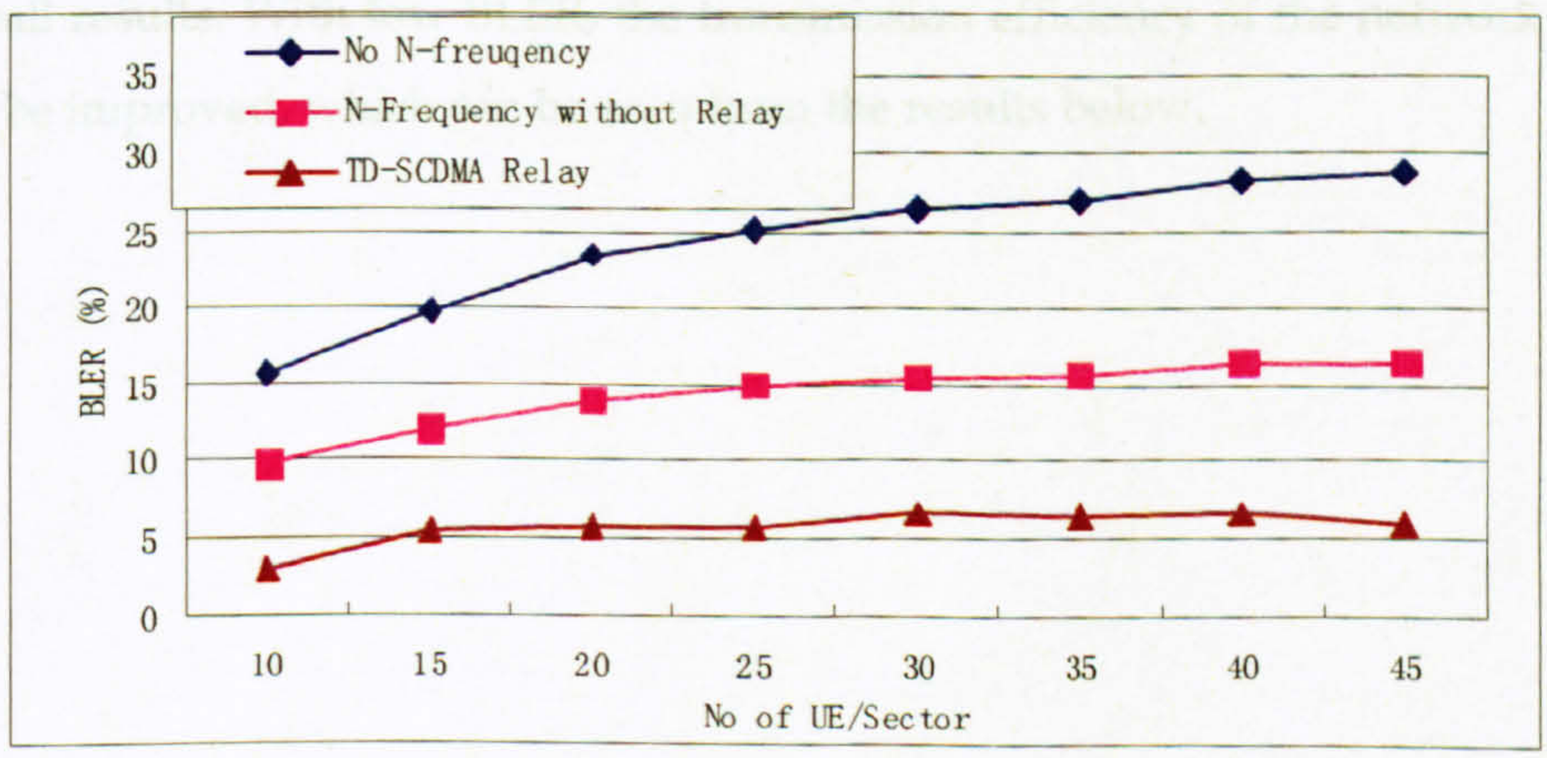


Figure 5-29 BLER (%)

Figure 5-29 shows the BLER of the three network structures calculated from the UE aspect.

The TD-SCDMA relay network has optimized the BLER significantly compared to the non-N-frequency TD-SCDMA network. Referring to [TD01], the benchmark for BLER in TD-SCDMA HSDPA systems varies according to different vendors' network equipments. Because the HSDPA scheduling schemes refer to this BLER figure to adjust parameters such as the package transmission / retransmission scheme, the code modulation scheme, and the traffic package size, a vendor will optimize their own system with advance scheduling algorithms to enlarge the network performance tolerance. However, the common range for that figure reference is between 10%-20%

This means that as long as the BLER is in that range, the TD-SCDMA HSDPA network performance is generally acceptable. The non-N-frequency TD-SCDMA network's BLER is in a very bad condition when the number of subscribers increases and cannot really satisfy the users in such a situation. That supports the fact again that only the N-frequency TD-SCDMA network is adopted in the current early commercial TD-SCDMA network in China.

Both N-frequency TD-SCDMA and TD-SCDMA relay networks' BLER are in the common range which can meet the general network performance requirements. Furthermore, the TD-SCDMA relay network gives the best overall results. With low BLER, the transmission efficiency of the network will also be improved, which can be seen from the results below.

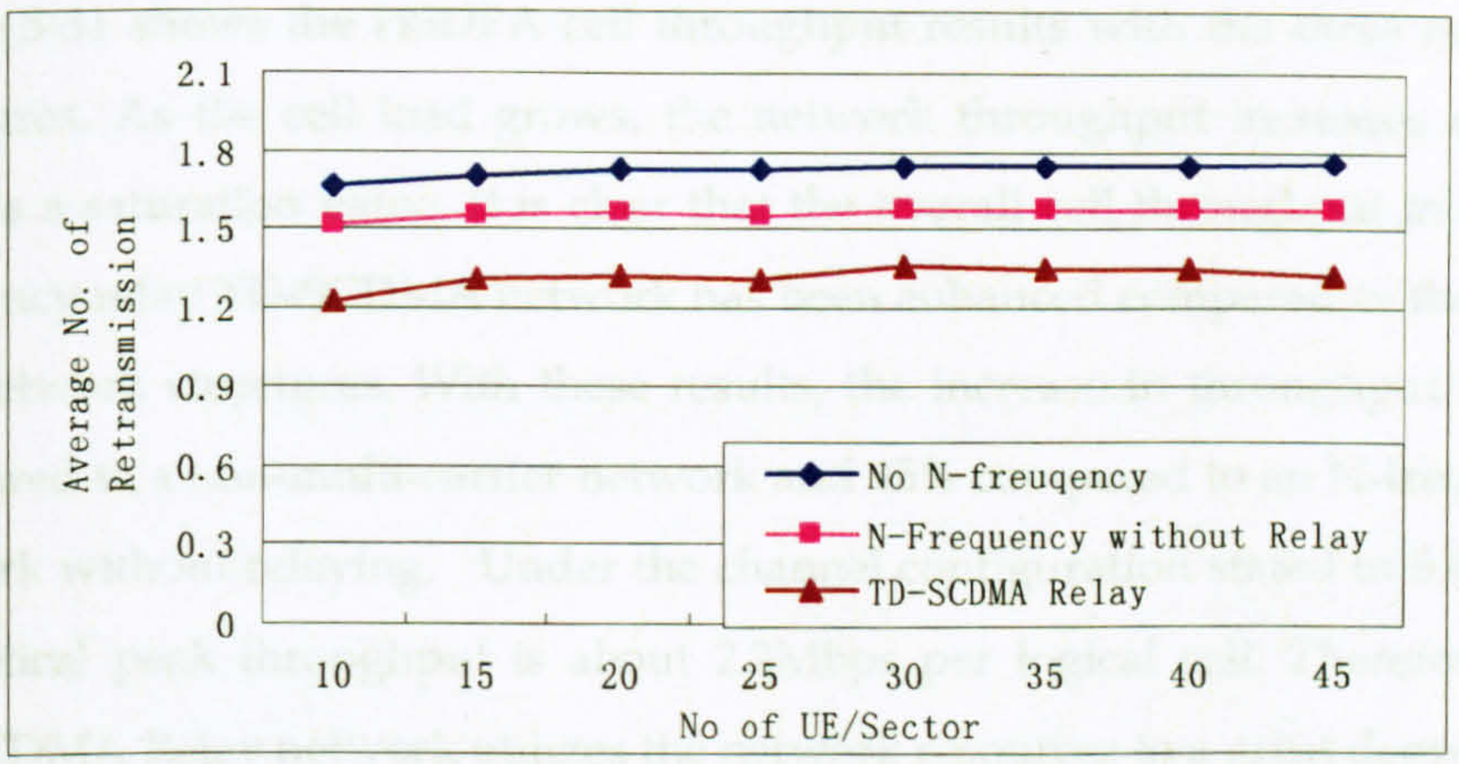


Figure 5-30 Average Number of Retransmission

Figure 5-30 indicates the average retransmission, another statistic from the UE aspect. From the above figure, it is easy to tell that the retransmission slightly increases as the number of subscribers increases. Although the TD-SCDMA relay network cannot avoid that trend, it still improves the situation about 15% compared to the N-frequency TD-SCDMA network.

The slight reduction in the retransmission rate for the relay network when there are 45 subscribers is purely down to the randomness of the simulation – averaging of a larger number of runs would improve the averaging.

The above three results indicate the great improvement for the network downlink performance. The research also investigates the cell throughput from the NodeB point of view.

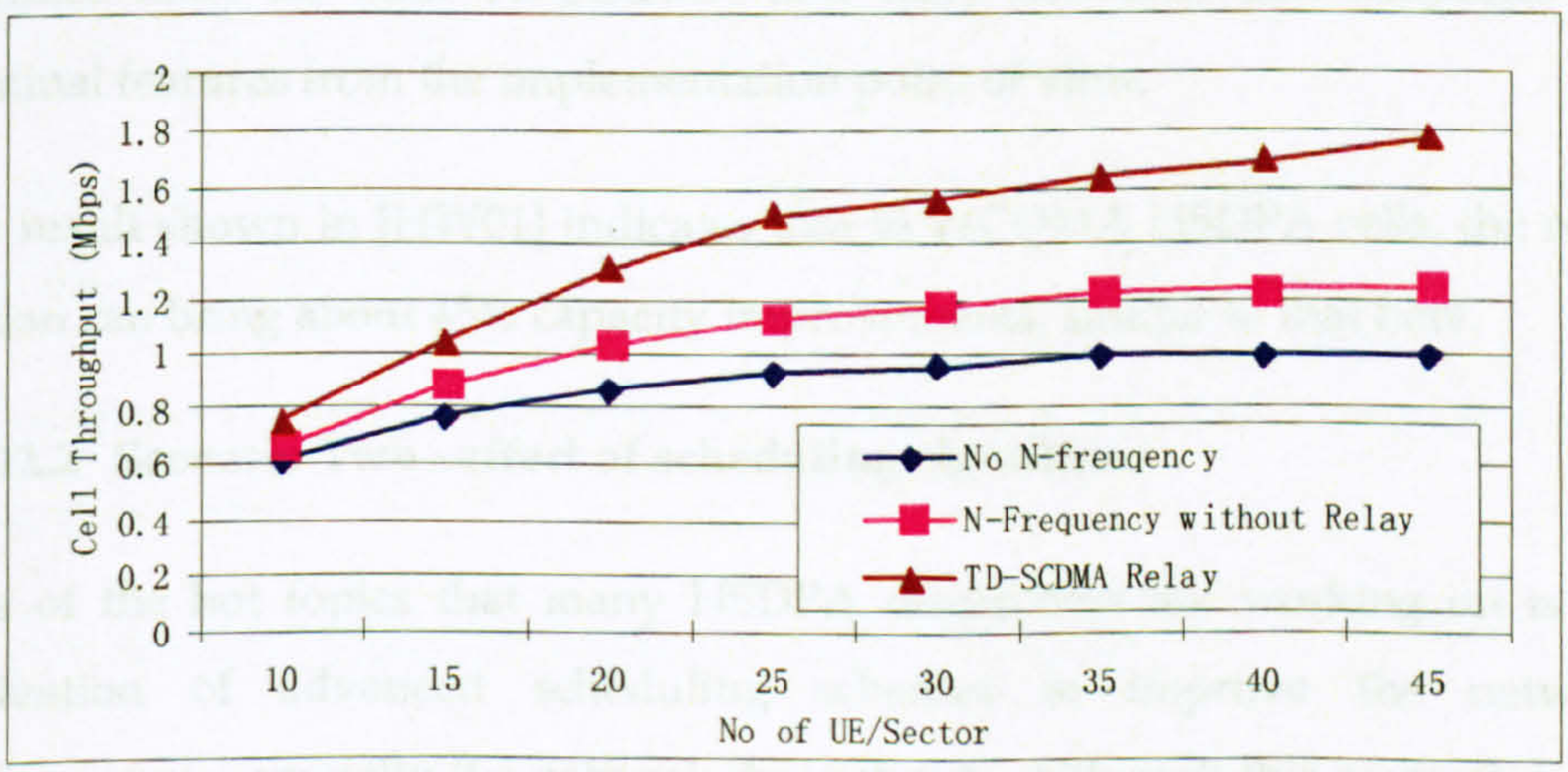


Figure 5-31 Cell Throughput (Mbps)

Figure 5-31 shows the HSDPA cell throughput results with the three network structures. As the cell load grows, the network throughput increases until it reaches a saturation value. It is clear that the overall cell throughput in the N-frequency relay TD-SCDMA network has been enhanced compared to the other two network structures. With these results, the increase in throughput is 77% compared to a non-multi-carrier network and 45% compared to an N-frequency network without relaying. Under the channel configuration stated in 5.4.5, the theoretical peak throughput is about 2.2Mbps per logical cell. Therefore, the TD-SCDMA Relay network utilizes the network resources to a great degree.

From those results, the advantages of the proposed TD-SCDMA relay network are obvious. The combination of the concentric circle with N-frequency and relay network contributes reduces the network interference greatly, leading to a consequent increase in the overall network throughput. Therefore, the proposed TD-SCDMA relay network not only benefits the coverage extension but also the network capacity.

The WCDMA relay system study introduced in [HW01] also investigated the HSDPA data service capacity improvement of the proposed WCDMA relay network. A major difference between the work in [HW01] and here is the air interface for the ad hoc relay network adopted in [HW01] is 802.11 a/b/g based WiFi technology so the requirement for the terminal is stricter as it needs to support dual modes. Here, in this research, it is the single TD-SCDMA air interface node for both TD-SCDMA and relay networks that simplifies the terminal features from the implementation point of view.

The result shown in [HW01] indicates that in WCDMA HSDPA cells, the relay station can bring about 45% capacity improvements, similar to that here.

5.4.11.2 Scenario Two - effect of scheduling algorithms

One of the hot topics that many HSDPA researchers are working on is the derivation of advanced scheduling schemes to improve the network performance, especially the network throughput. Although this research is not discussing the algorithms itself, the author is still running the simulations based on the existing mature scheduler schemes to show the effect on TD-SCDMA

relay network, see below Table 5-4. The similar results in WCDMA [from [HW01]] are also listed for reference. The same relay station percentage (4%) among the overall subscribers per logical cell is adopted for both WCDMA relay network and TD-SCDMA relay networks.

Table 5-4 Scheduling Algorithms Effect Results

	PFair (Mbps)	RR (Mbps)	C/I (Mbps)
WCDMA HSDPA	8.108	5.409	10.58
WCDMA HSDPA Relay	9.508	7.856	10.58
Improvement	**17.26%**	**45.24%**	**0%**
TD-SCDMA HSDPA	1.316	1.179	1.632
TD-SCDMA HSDPA Relay	1.517	1.410	1.767
Improvement	**15.27%**	**19.59%**	**8.27%**

Figures from the table show that the throughput of the TD-SCDMA relay network improved under all three algorithms rather than only two algorithms as was the case with WCDMA. Although the Max. C/I scheme only improves the throughput by less than 10%, it is still much better than the zero improvement in WCDMA.

On the other hand, the advantage brought by the Round Robin (RR) in WCDMA is more than double that for TD-SCDMA. The main reason for this is that the HSDPA peak rate for an individual WCDMA subscriber is theoretically nearly 5 times as much as that for TD-SCDMA.

For the PFair algorithm, the improvement after introducing a relay network is similar for both WCDMA and TD-SCDMA.

In a summary, after adding the relay network into TD-SCDMA, the throughput is optimized by 10%-20% compared to the standard TD-SCDMA.

The next two simulation scenarios are to study the TD-SCDMA relay network's performance itself.

5.4.11.3 Scenario Three – Location of the Relay station

In this simulation scenario, the location of the relay station and how it may affect the TD-SCDMA relay network's performance are studied. Based on the result from Table 4-11, it can be seen that the location of the relay station can

vary within a certain range in the TD-SCDMA network. So, in this scenario, the relay coverage range is divided into three sub ranges: near, middle and far, which categorise the distance between the relay station and the NodeB in the TD-SCDMA network.

The distance between the relay station and UE in the relay network is always randomly decided by the simulation system. Before starting the simulation, the preferred location range of the relay station will be specified by the input parameters then the UE selection procedure will choose the relay station accordingly. Remember that no matter at which distance the relay station is located, it has to be within the coverage of the TD-SCDMA primary frequency.

Figure 5-32 and Table 5-5 illustrate the three location ranges for the relay stations. The primary carrier covers the whole hexagonal area within the black solid line and the area between the outer solid line and the dashed line is the relay network.

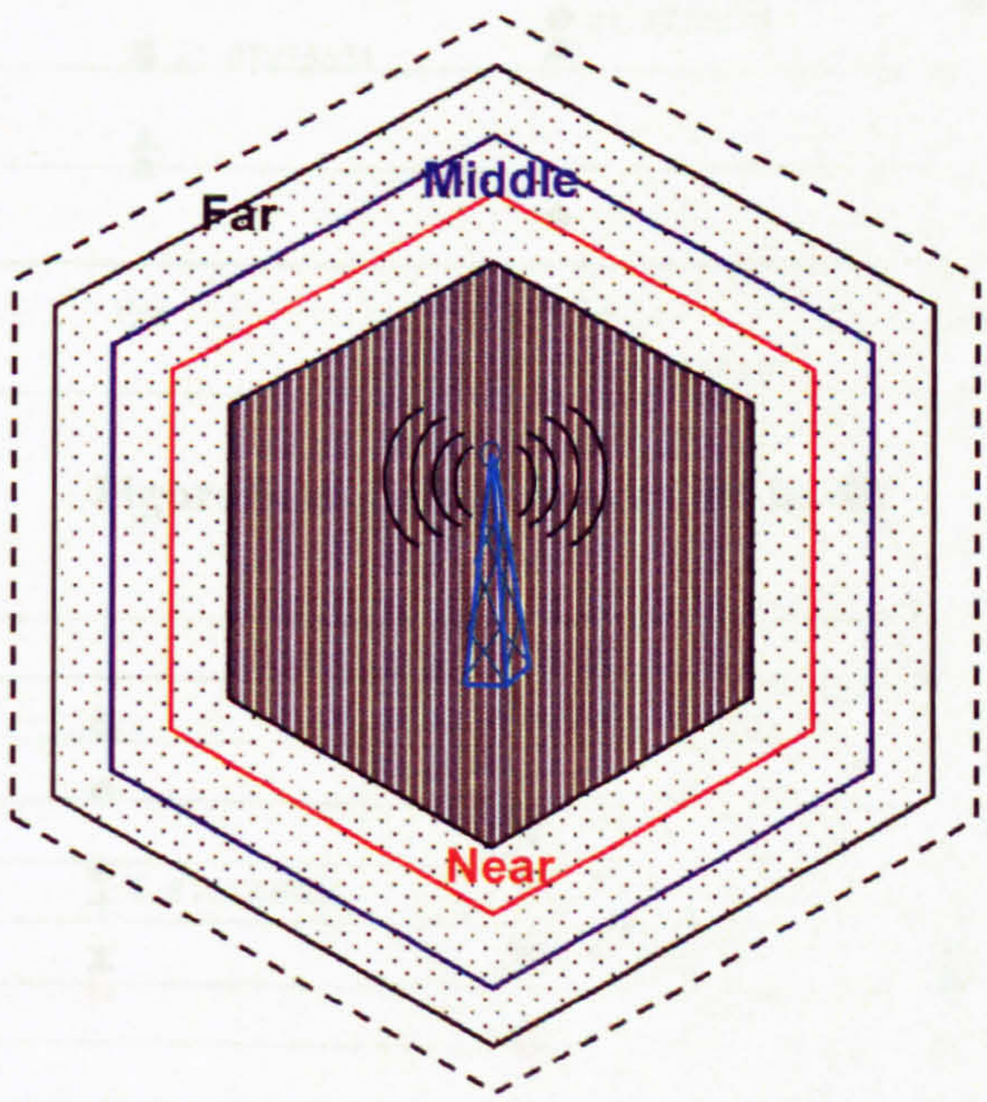


Figure 5-32 TD-SCDMA Relay Location

Table 5-5 Distance range between NodeB and Relay Station

Relay Station Location Category	d (m)
Far	530≤d≤540
Middle	497≤d≤507
Near	464≤d≤474

The number of subscribers in each logical cell in this simulation is set as 30 while the number of relay station is fixed as 10. For every location range, 5 runs are simulated for UE random distribution. All the values of every run and the average of the 5 runs are marked in the following results.

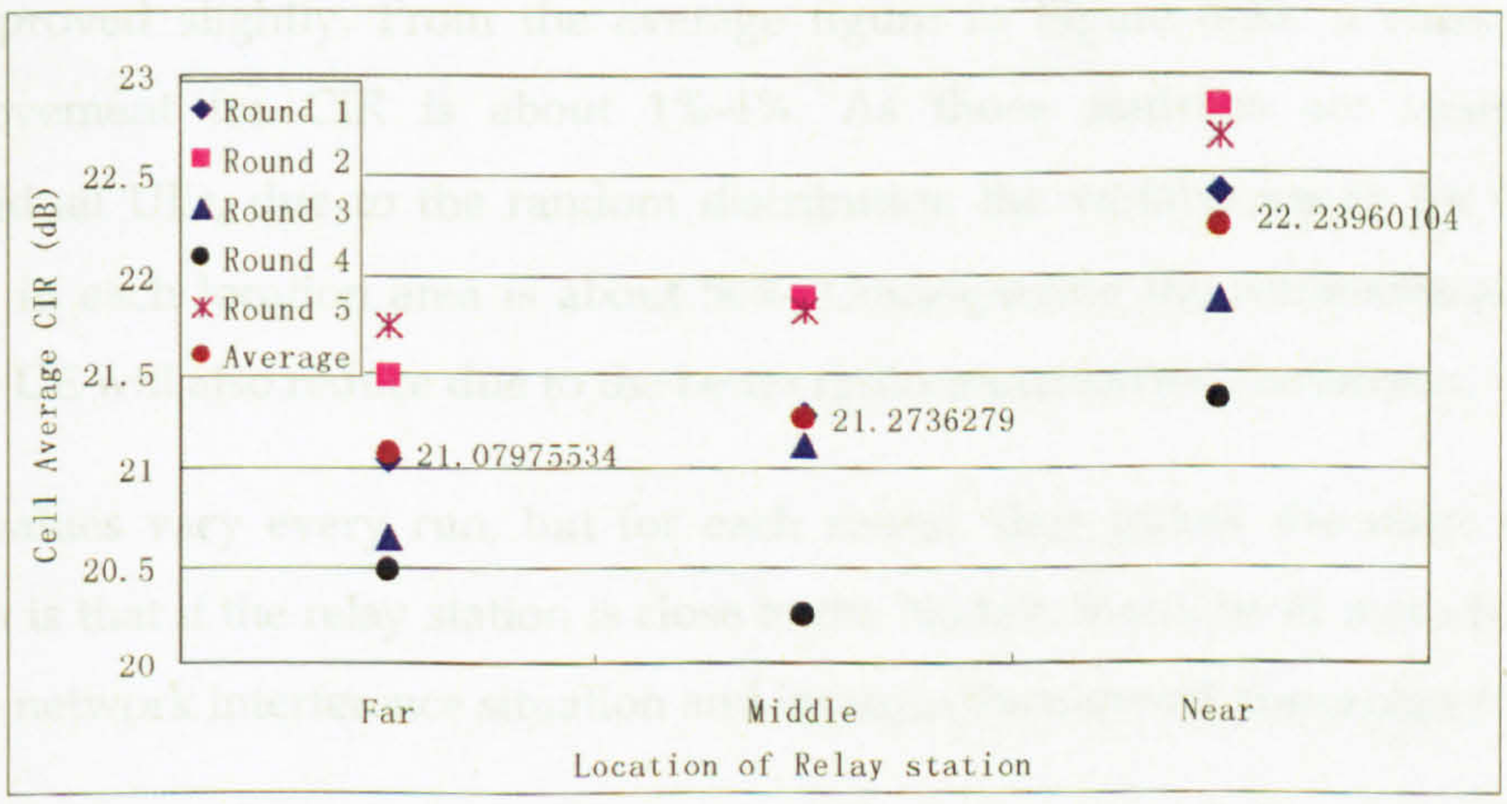


Figure 5-33 Cell Average CIR in dB

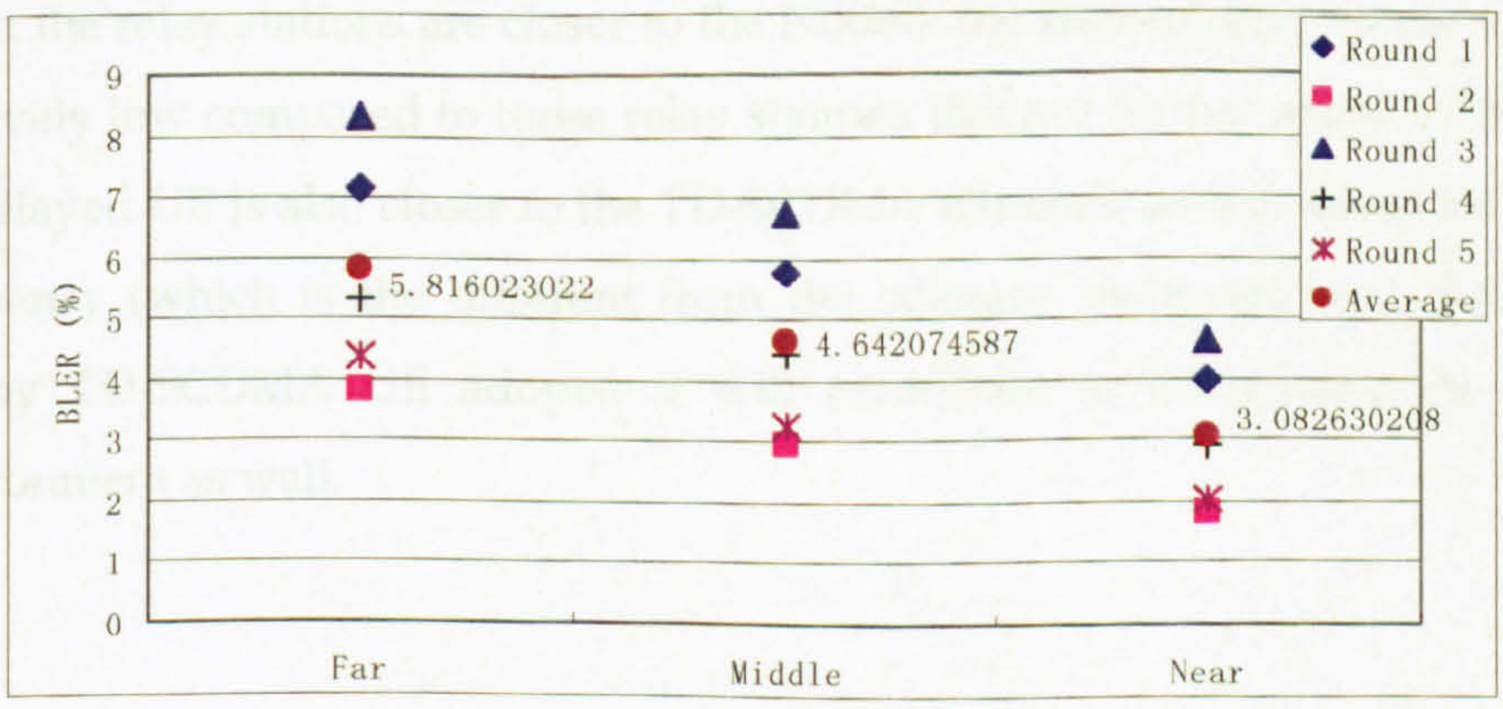


Figure 5-34 BLER (%)

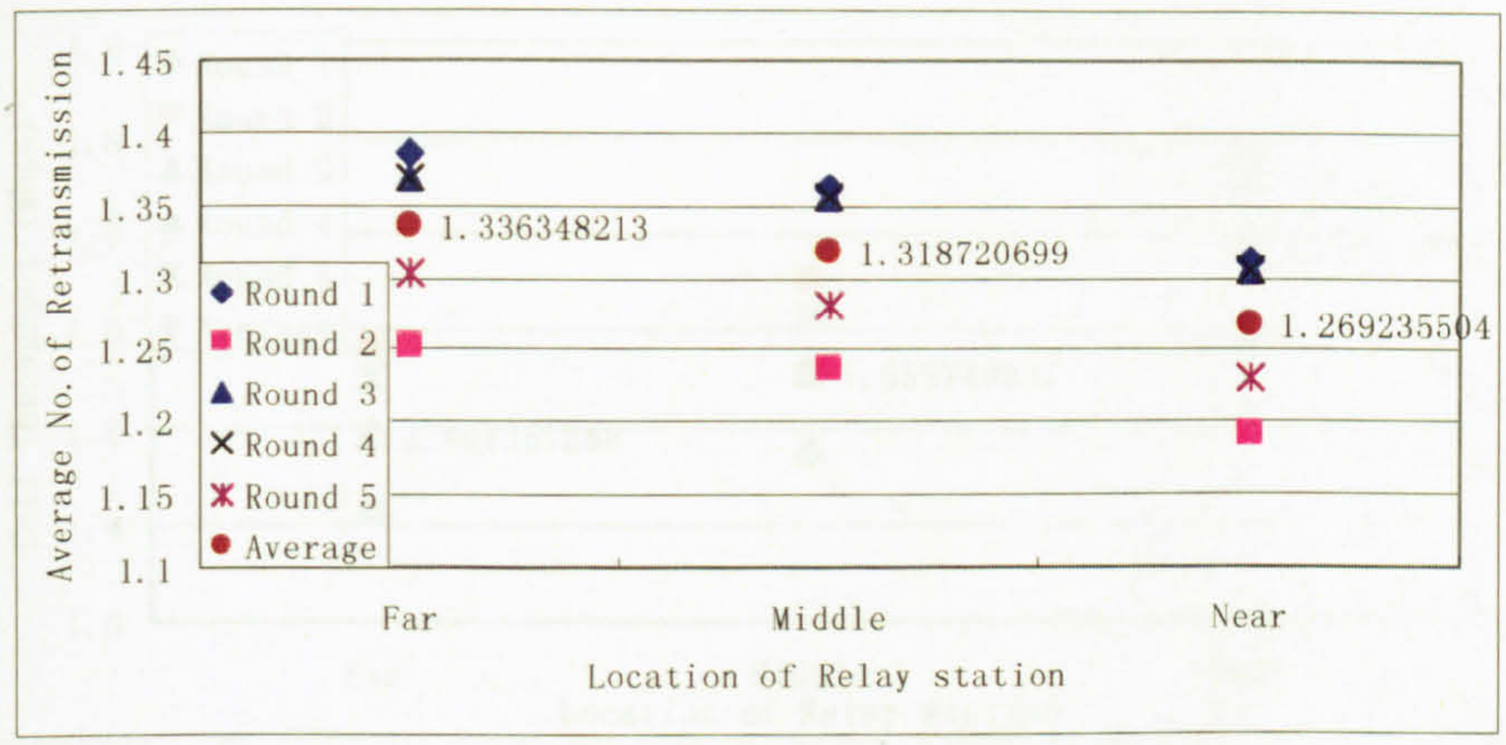


Figure 5-35 Average Number of Retransmission

Figure 5-33, Figure 5-34 and Figure 5-35 reflect the downlink conditions for different relay station locations. It can be seen that the downlink signal quality is improved slightly. From the average figure in Figure 5-33, it shows the improvement for CIR is about 1%-4%. As those statistics are based on individual UEs, due to the random distribution the variable range for BLER value in each location area is about 50%. Consequently the retransmission of every UE will also reduce due to the better radio transmission conditions.

The values vary every run, but for each round, they follow the same trend which is that if the relay station is close to the NodeB, it will be of more benefit to the network interference situation and increase the network throughput.

The main reason for such results is that the distance between the relay station and NodeB is one of the main factors in determining the transmitting power. When the relay stations are closer to the NodeB, the transmitting power will be relatively low compared to those relay stations that are further away. Although the relayed UE is also closer to the TD-SCDMA network, as it is using the relay frequency (which is the different from the primary frequency that the other nearby TD-SCDMA UE adopts) it will contribute to optimizing the radio environment as well.

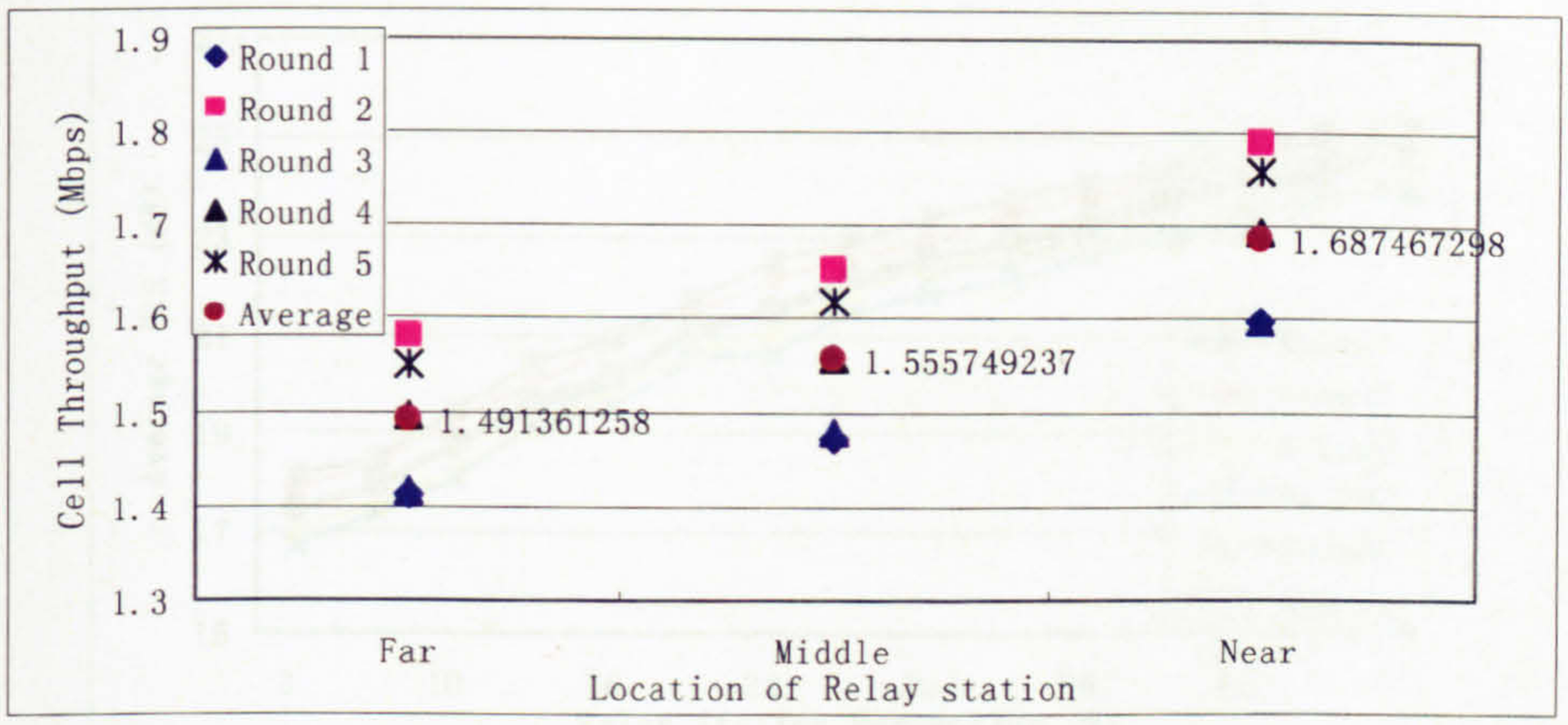


Figure 5-36 Cell throughput (Mbps)

Figure 5-36 indicates the effect of the relay station location from the network aspect, which shows the cell throughput, has been improved by about 4%-9%.

5.4.11.4 Scenario Four – Relay station Percentage Effect

The following simulation scenario is to investigate the situation with a different percentage of relay subscribers in the TD-SCDMA relay network. The total number of subscribers in each logical cell is set as 30 and the overall number of the subscribers served by the primary carrier (who are the potential relay stations) is fixed for all the rounds as 15.

The variable is the real number of relay stations for every percentage. Those that are not picked by the network as relay stations will act as normal TD-SCDMA subscribers communicating with the NodeB via the primary carrier. The results are shown in the following charts.

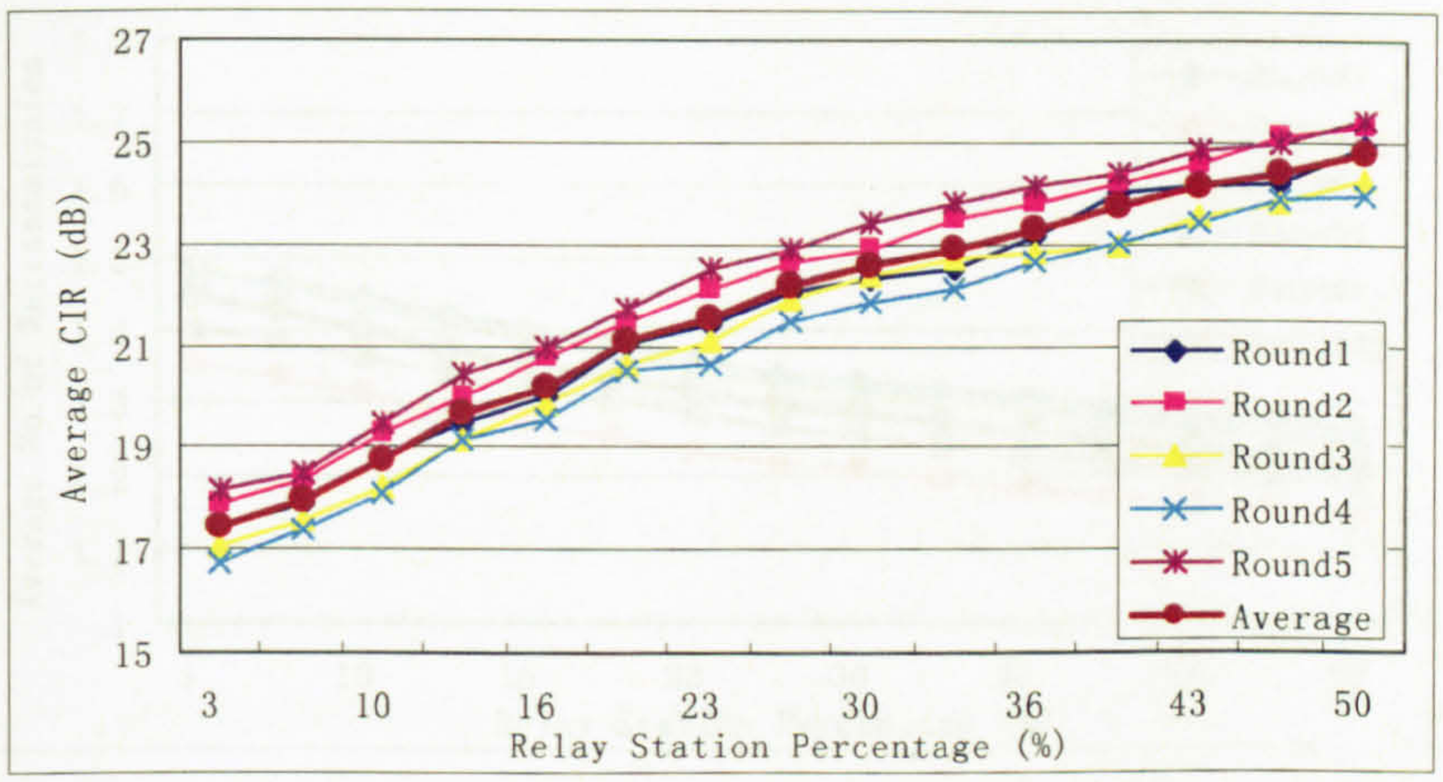


Figure 5-37 Average CIR in dB

As in the previous simulation, this figure shows the downlink condition when the number of relay stations increases. The more relay stations there are in the system, the better CIR situation the system obtains. When half of the subscribers within the TD-SCDMA cell act as the relay stations, the CIR is optimized as 42% compared with only 1 relay station.

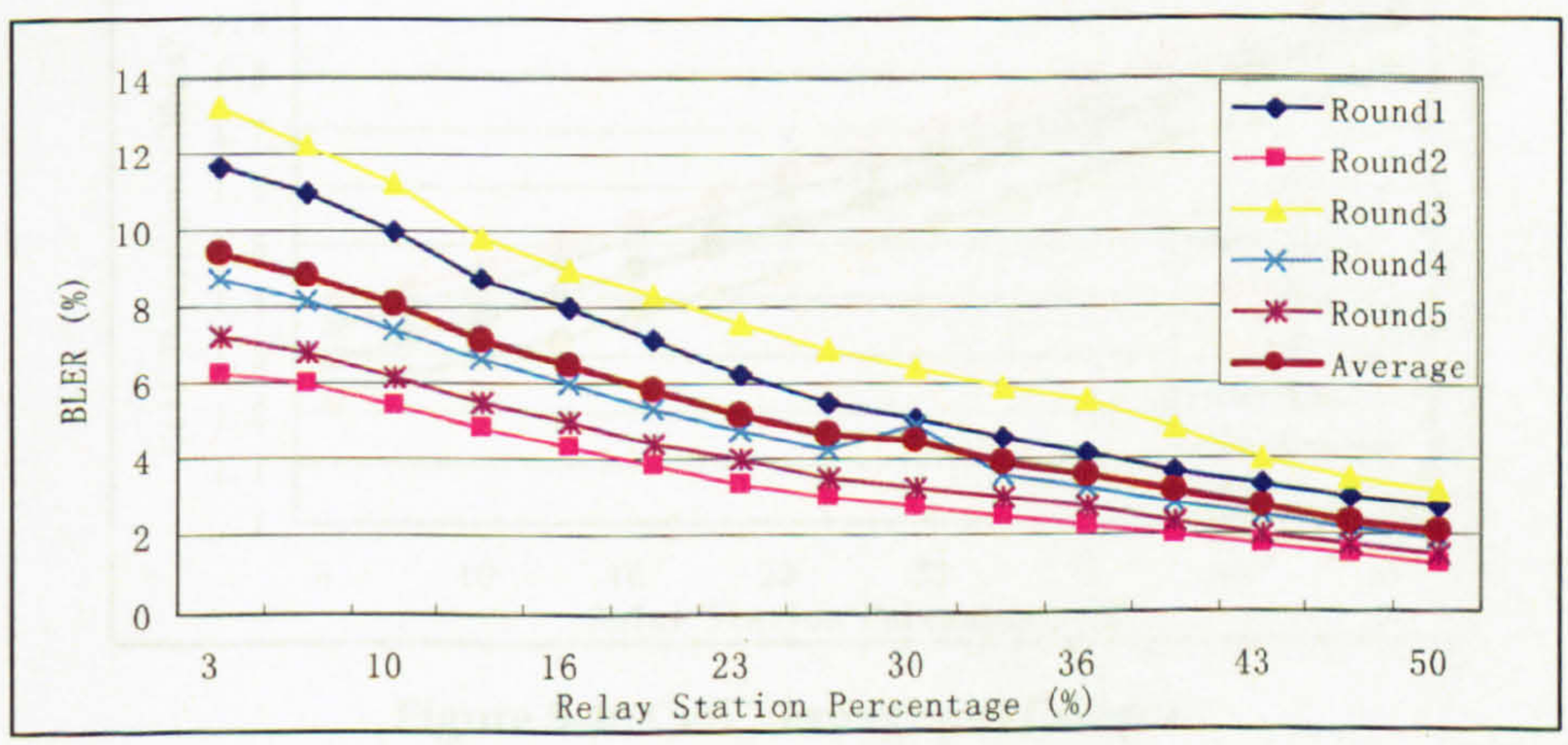


Figure 5-38 BLER (%)

The result of Figure 8 in [HW01] indicates that in WCDMA HSDPA cells, as the number of relay nodes increases from 2 to 15, the system interference situation is optimized greatly, which results in the minimum rate threshold going up from 1Mbps to 10Mbps. As WCDMA systems are more interference sensitive than TD-SCDMA, the interference improvement in TD-SCDMA is comparatively less, an improvement in BLER of about 4 times.

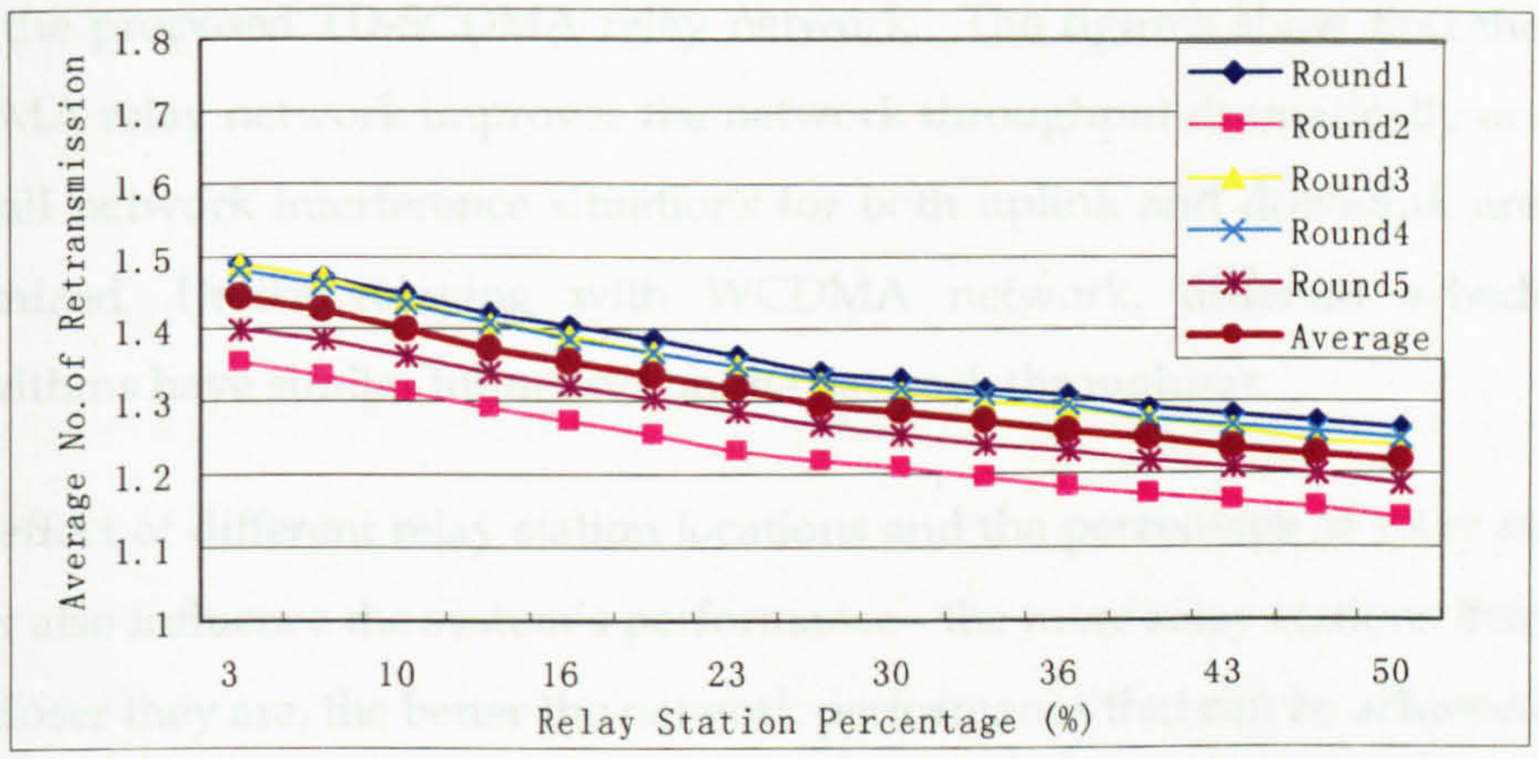


Figure 5-39 Average Number of Retransmission

As defined in this simulation scenario, as the number of relay stations increases, the number of TD-SCDMA subscribers served by the primary carrier only will decrease. With the improvement of the interference situation within the TD-SCDMA HSDPA cell, the average retransmission of all the terminals improves better, as shown in Figure 5-39.

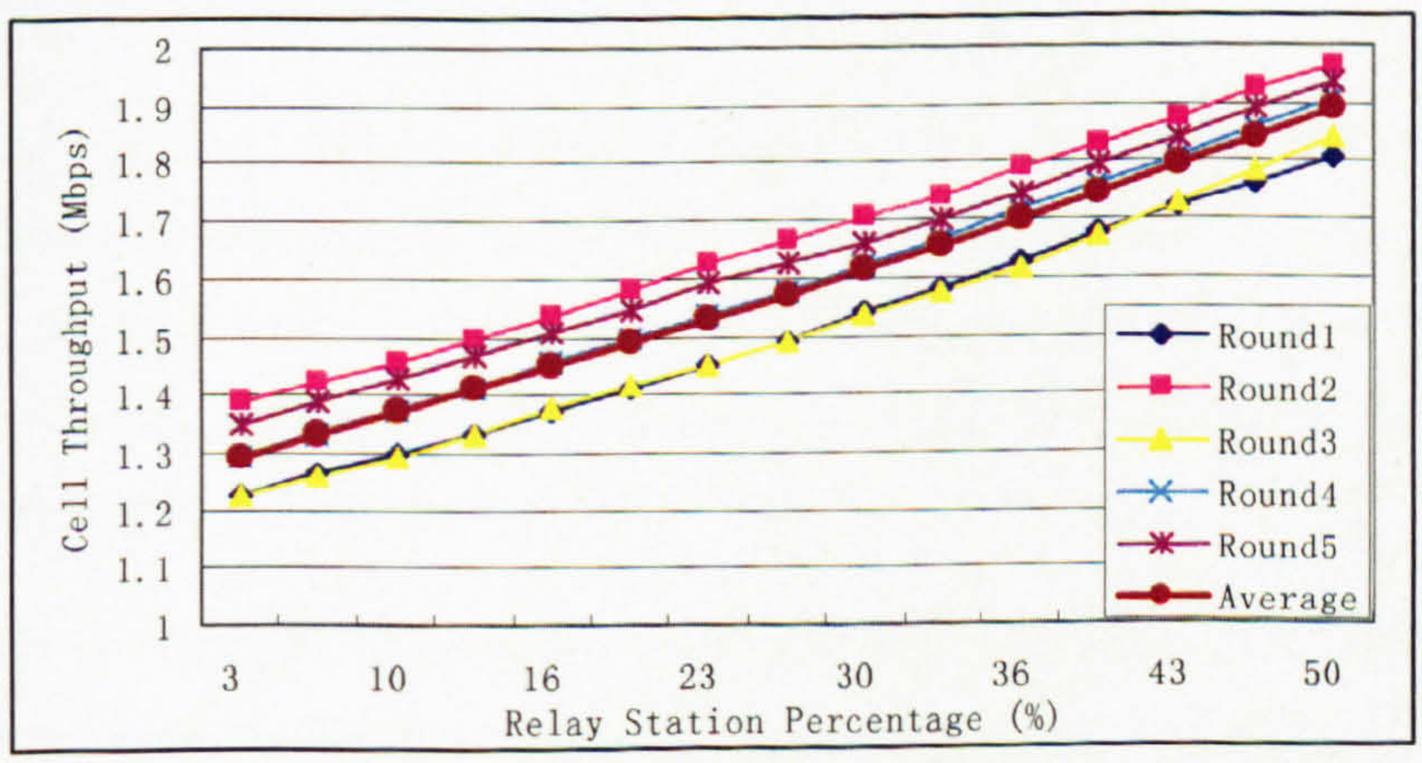


Figure 5-40 Cell Throughput (Mbps)

The cell throughput is increased about 46% when the relay station percentage increases from 3% to 50%. This result shows that with the proposed TD-SCDMA relay network structure, the network resource utility has been dramatically improved.

5.5 Summary

In this chapter, a detailed introduction to the simulation has been given and the results analysis are given for HSDPA services in both the standard TD-SCDMA

and the proposed TD-SCDMA relay network. The figures show that the TD-SCDMA relay network improves the network throughput dramatically and the overall network interference situations for both uplink and downlink are also optimized. Unlike relaying with WCDMA network, different scheduling algorithms have similar influences on the network throughput.

The effect of different relay station locations and the percentage of relay station users also influence the system's performance - the more relay stations there are, the closer they are, the better the network performance that can be achieved.

In the next chapter, the non-HSDPA services scenario is investigated.

Chapter 6 TD-SCDMA Relay for 64k Non-HSDPA Services

6.1 Simulation Modelling

Although non-HSDPA is no longer the main stream data application in the developing TD-SCDMA networks, non-HSDPA services will have a role in many rural areas. The reasons for this are that (i) it will be a cost effective solution for rural areas as the traffic density is very low compared to the dense urban areas and (ii) the cell coverage for the rural areas is relatively large compared to the urban areas so it is more likely there will be weak link conditions in the rural areas.

By adopting non-HSDPA data services in TD-SCDMA, the subscriber will have dedicated channels transmitting their traffic which can, to a certain degree, guarantee the service quality to satisfy the end user. Remember, that in the rural areas the problem is *coverage*, not capacity.

For this research, the non-HSDPA packet data simulation uses a static simulation tool that adopts the Monte Carlo simulation method [HM01]. The original platform was developed in the Wireless Signal Processing and Network Lab at Beijing University of Posts and Telecommunications (BUPT) and modified here to fit the simulation requirements in this work.

The platform from BUPT supports single frequency for each NodeB so multi-frequency capability had to be added.

As the network structure here uses the concentric circles cell and relay network, these two structures are also added to the platform.

These two modifications are included in the "initialization" function block shown in Figure 6-1

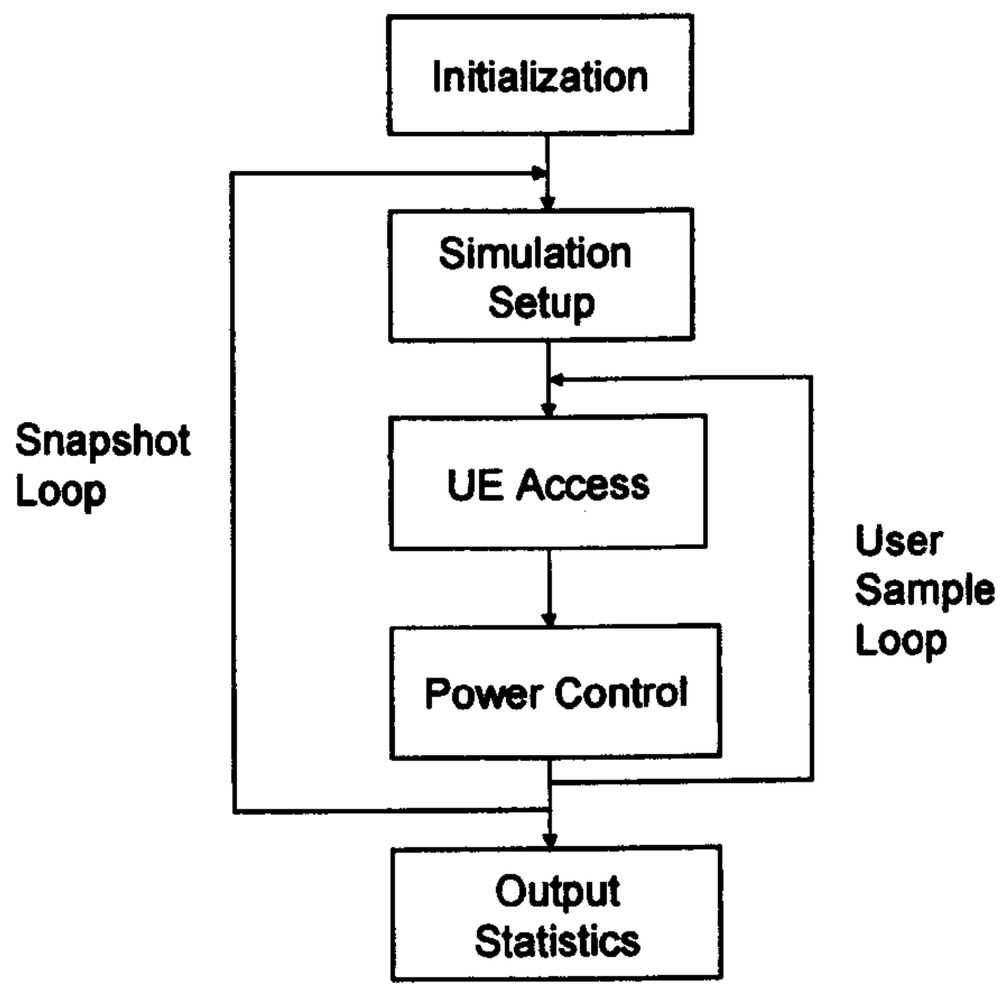


Figure 6-1 Non-HSDPA Simulation Platform Overall Flowchart

In this research only macro cells are considered since, in a real network, the only top-layer cell structure is the macro cell; micro cells and pico cells are used underneath a macro cell in order to provide extra capacity in high demand areas. For micro and pico cells where coverage or capacity might be a problem the most likely course of action would be to hand over to the overlaying macro cell rather than use relaying.

The macro cell network structure is set up in the initialization block as are the concentric circle cells.

Once the NodeBs are set up, there will be two cell radiuses as input parameters for each simulation scenario, one for the original TD-SCDMA network and another for the new TD-SCDMA relay network. The TD-SCDMA NodeB can only serve those terminals whose position is located within the coverage of the original TD-SCDMA cell; the rest of the terminals are only possibly served by the relay network part. The uplink and downlink switch point is configured as 3:3 which means that from the total of six TD-SCDMA traffic timeslots, the first three are for uplink and the following three are for downlink. The reason for doing this is that non-HSDPA data services are designed as being symmetric.

Table 6-1 and Table 6-2 show the main configuration for the network initialization; other parameters are given in the relevant tables in chapter 4. To

construct the concentric circle cell, the initial phase of the initialization automatically assigns different a maximum downlink transmission power for each carrier to realise the idea of different frequencies having different coverage ranges. Here 3dB, which is typically used as the default value in the network planning at the initial phase, is the gap between primary and secondary frequencies. In a real network environment, the RNC will judge the distance between the subscriber and the NodeB via "timing advance" calculation; as a consequence, the RNC will assign corresponding radio resource to the terminal according to the access control algorithms. Here in the simulation, as the system is aware of the distance between each terminal and NodeB, the terminal will automatically use the appropriate frequency within the relevant coverage.

Table 6-1 Non-HSDPA Simulation Network Assumptions

	Downlink	Uplink
Maximum transmit power	BS: 33dBm	24 dBm
Receiver sensitivity	-102.5dBm	-106dBm
Thermal Noise	-113 dBm	-113 dBm
Shadow fading deviation (dB)	10.1 (dense urban) and 4.4 (rural areas)	
Power control	On	On
Noise figure (dB)	7	5
User distribution	randomly distributed	randomly distributed
Smart Antenna	On	On

Table 6-2 Non-HSDPA Simulation Network Configuration Parameters

Parameters	Assumptions/Value
NoofBSs	61
NoofBSs_Wrap	19
NoofFrequency	3 /per cell/per sector
Freq_reuse_factor	1
NoofSlots	1
NoofChannels	2
Frequency (MHz)	2010
TD Radius (km)	4.15
TD ad Radius (km)	6.08
C/I Target	-0.5dB

Defining the parameters as below:

- **NoofBSs_Wrap& NoofBSs**: In this simulation, the NodeBs are set out as wraparound topology. The observing NodeBs are set to 19, the first three inner rounds, and these are surrounded by two more rounds (making 61 cells in total) to make sure the observing set do not suffer any boundary effect.

- **NoofFreque**: This value shows how many frequencies each logical cell can support. In the system, each omni NodeB has only one sector while each sector NodeB has three sectors and for both cases, each sector maps into one logical cell. During the NodeB construction step in the initialization phase, every logical call will regard the first frequency as the primary carrier for the whole cell range coverage and the remaining two are secondary carriers acting as the inner circle carriers for the concentric circle cell. The system will take one of the secondary frequencies as the working carrier in the relay network part.

- **Freq_reuse_factor**: For the N-frequency TD-SCDMA network here, the frequency reuse factor is 3 to reduce the intra-frequency interference on the primary carrier. Therefore, three neighbouring logical cells will be grouped as a cluster and each of the three frequencies within the 5MHz band will be configured as a primary carrier for each logical cell.

- **NoofSlots**: The principle of TD-SCDMA is that, by taking advantage of uplink synchronization, smart antenna and joint detection, the interference for the traffic channel can be optimized within a single time slot. So in this simulation, each timeslot of one TD-SCDMA frame will be treated equally. The "NoofSlots" is then set to 1 and the overall system capacity is based on the multiple of all the TD-SCDMA traffic channels.

- **NoofChannels**: This parameter means how many subscribers one timeslot can support depending on different application types. In the TD-SCDMA system each timeslot has up to 16 codes and each code is regarded as the resource unit (RU). For example, according to [3GPP08],

every voice service will take 2RU for uplink and 2 RU for downlink. Consequently for voice applications, the "NoofChannels" should be configured as 8, the maximum number of voice users for each timeslot. With the research scenarios mentioned in chapter 3.5, 64kbps is considered for non-HDSPA data application which will use 8 RU. Therefore the "Noofchannels" here is set for 2.

- **Frequency**: 2010MHz is simulated here.

- **TD Radius& TD ad Radius**: The TD Radius gives the original TD-SCDMA network cell radius shown in Table 4-7 and the TD relay Radius is the proposed hybrid network cell radius shown in Table 4-9. Those terminals, whose positions are in the gap between the two radiuses can only be served by the relay network.

- **C/I Target**: Normally different service types have different values of this parameter and the target is also specific for the equipment. The value used here is quoted from [TD01] which is used by the majority of the TD-SCDMA equipment vendors.

In the following "Simulation Setup" step, the original system will generate the pathloss matrixes which store all the pathloss values between each terminal and each NodeB while the improved scheme is introduced in this work to optimize the system. Unlike the previous BUPT design, the new system has added one "comparison step" before calculating the pathloss between NodeB and terminals. The "comparison step" has the function of comparing the distance between a NodeB and a terminal with the system-configured original TD-SCDMA cell radius. Three options will be covered by the following rules:

- If the terminal is within the original TD-SCDMA network cell coverage, the pathloss between the terminal and NodeB will then be calculated and the terminal will be added into the TD candidate list of the NodeB together with the pathloss.

- If the the terminal is not covered by the TD-SCDMA NodeB or TD-SCDMA relay network, there will be no pathloss calculation or any other actions processed between this particular NodeB and terminal.

- If the terminal is in the range of the relay network area, instead of calculating the pathloss between the terminal and the NodeB, this terminal will be directly put into the relay candidate list of the NodeB.

Another additional modification that has been done in this phase is to calculate the pathloss between the potential client-terminal and relay station-terminal in the relay network part. Taking the the previous results of NodeB and terminal pathloss calculation, those terminals that have been added into the relay candidate list have the possibility to work as the client-terminal in the relay network part. To pair the relay station, each particular client-terminal will seek all the nearby terminals to determine which fulfils the criteria below:

- the nearby terminal is in the TD candidate list of the same NodeB; and

- the distance between the two terminals is within the range of the pure relay network cell radius (refer to Table 4-9).

As long as the above two items are satisfied simultaneously, the pathloss between these two terminals will be calculated according to the equations in chapter 4.3.2 and the paired relay client-terminal and relay station will also be inserted into the paired relay terminals table for the next step's use.

There is a risk with using randomly generated subscribers that the location of the users is not guaranteed to fit the simulation scenarios. Aiming to solve this problem, each time before starting the simulation, the overall UE amount is configurable. Theoretically, the full load of the system for uplink/downlink 64kbps users is fixed. However, in order to make sure that at each snapshot there is a relay station and paired relayed UE in each cell, the total number of randomly generated subscribers is more than the theoretical capacity of the whole network to guarantee the feasibility of UE selection scheme, but of course the number of active users must not exceed the maximum capacity.

The core functions in this Non-HSDPA packet date application simulation environment are "UE Access" and "Power Control". Figure 6-2 shows the logical flows.

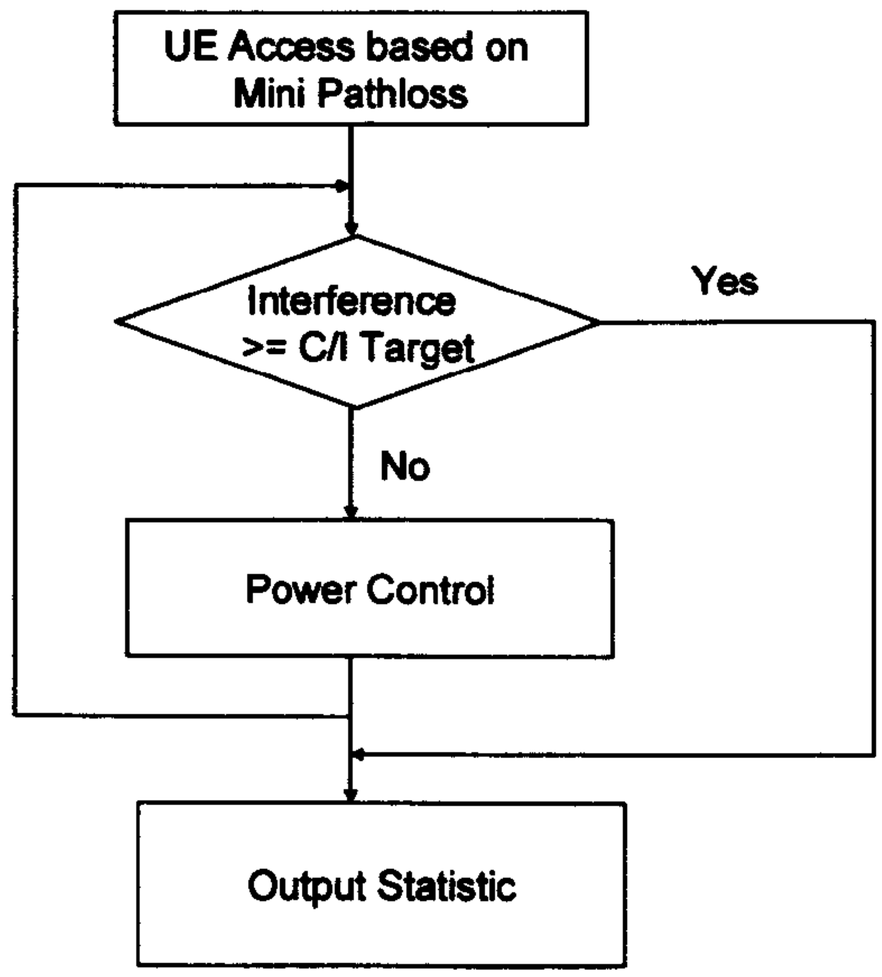


Figure 6-2 UE Access and Power Control Function Flowchart

Referring to most of the cases in the real mobile network for the "call setup" procedure, the minimum pathloss is taken as the "UE Access" criteria. As addressed in previous sections, the maximum number of the uplink/downlink 64k packet-data users per timeslot defined in the 3GPP TD-SCDMA standards is 2; therefore to verify the proposed TD-SCDMA relay hybrid network in which the paired client-terminal and relay station has to be counted as one 64k user, the user selection rule in the NodeB is set to choose one TD relay paired user and another regular TD-SCDMA user.

The rest of the terminals will be regarded as blocked UE with the reason of "No radio resource available" and contribute nothing to the system's performance. The "UE Access" function blocks complete the following steps:

- The client-terminal in the relay network area will seek the minimum pathloss from the UE-UE pathloss table and fix the paired relationship with the relay station.

- The relay station then will access the corresponding NodeB through being assigned the proper radio resource units for carrying UL/DL 64kbps application

- The NodeB then will randomly pick another terminal from the TD candidate list as the pathloss between them has been guaranteed as the minimum pathloss for this particular terminal. The relevant radio resource units are configured as well.

- The rest of the terminals will continue trying to access the NodeB in the designed system but will fail with the reason of "Not enough radio resource" in this UL/DL 64kbps case.

At this point, the whole system performance has been initialized. However, allowing the users just to access the network is not the goal for commercial network operators but to deliver services with good network performance, so the next few steps contribute more on that aspect.

In general, to maintain a good experience to the mobile user means consuming the minimum power to provide the satisfied quality of service given the level of interference. The three key factors - power, service quality and interference - are used to evaluate the proposed network's performance.

Unlike the real network's complicated performance management scheme, in this simulation platform, the simplified power control function is used to optimize the system's overall transmission power and interference level, reflecting the network's performance. The principle of the simulation is

1. Given a certain number of subscribers to access the network, calculate the C/I for each successfully accessed user.

2. Compare the initial terminal's C/I status to the system defined C/I target.

3. Generate power control decisions based on the comparison result.

4. Perform the power control according to the specified power control step.

5. Calculate the C/I again then repeat the loop from step 2 to step 5 until the satisfied user rate reaches the target defined by the system

6. Keep increasing the total amount of subscribers then go to the loop from step 1 to 5 until the satisfied user rate drops below the designed target

7. Record the user amount as the maximum subscribers supported by this system with guaranteed service type.

8. Calculate statistics for the average noise rise for the overall network as the network interference is considered in the C/I calculation together with the maximum capacity. In this system, another network performance indicator is the average noise rise which shows the increase in overall system noise after each snapshot. A lower noise increase of the whole system will benefit the overall system power consumption and the interference situation.

In this research, only the intra-frequency interference is counted as interference to the frequency used and the C/I target is defined as -0.5dB for both the proposed TD-SCDMA relay network and the original TD-SCDMA networks (as stated in Chapter 4).

6.2 Simulation Result and Analysis of 64K Data Application

6.2.1 Capacity analysis

Simulation was carried out following the steps introduced in the previous section; the number of users was increased until the rate of satisfied subscribers no longer reaches 100% (100% means that all the user C/I targets were satisfied with full data rates).

The results below show the number of users able to be satisfied for each frequency carrier for all the 19 under-observed NodeBs.

Table 6-3 No of subscribers of NodeB

NodeB Type in rural area	Omni-NodeB	Sector NodeB
No. of Subscribers in TD-SCDMA	342	1026
No. of Subscribers in TD-SCDMA Relay	342	1026
Improvement	0%	0%

Table 6-3 shows the capacity simulation results of Omni and Sector NodeBs for the 2010 MHz band for rural TD-SCDMA (no relay and radius 4150 m) and TD-SCDMA with relay (radius 6080m). The Y axis is the total subscriber numbers on one frequency of the 19 NodeBs.

Although the proposed TD-SCDMA relay network is different from the original TD-SCDMA network, the number of subscribers remains the same for both systems: here the theoretical capacity as, for each frequency carrier, the maximum number of non-HSDPA UL/DL 64k data users is 2 (per timeslot) * 3 (timeslots) * 3 carriers and the 19 Omni-NodeBs will support up to 342 users in total. The main difference between Omni NodeB and Sector NodeB is each Sector NodeB will have 3 logical cells while the Omni NodeB only has 1 logical cell: the theoretical full capacity for each frequency carrier is hence three times that of the Omni cell.

The reasons for such results are:

- For each TD-SCDMA timeslot, the maximum codes are 16 (unlike WCDMA which has up to 512 codes) for downlink. Meanwhile, according to the TD-SCDMA standard definition, one non-HSDPA 64kbps data user will occupy the 8 dedicated codes for uplink and another 8 dedicated codes for downlink which means the maximum users per timeslot for this service is only 2. This characteristic is not changed in the new TD-SCDMA relay system. Therefore the code limitation affects both original TD-SCDMA and new TD-SCDMA relay networks equally.

- In the new TD-SCDMA relay network, the terminal acting as a relay station in the relay network is still regarded as a normal user in the TD-SCDMA

network. Although the paired client-relay terminals are using different frequencies in the relay network compared to the frequency used in a normal TD-SCDMA network, with the unchanged TD-SCDMA frame structure, a terminal can only either transmit or receive within one timeslot period, so the overall timeslot capacity remains unchanged.

Similar work in WCDMA systems introduced in [HN01] also studied the non-HSDPA data service capacity improvement of the proposed WCDMA relay network. The best case in that work shows that with introducing the relay stations, the overall number of uplink active users per cell has been significantly improved by 82%, from 28 to 51. So it is quite obvious that WCDMA is more sensitive to the interference than TD-SCDMA systems, but TD-SCDMA is strictly limited by the code resource of each time slot.

To summarize the capacity impact, in terms of the non-HSDPA 64kbps data applications, the proposed new TD-SCDMA relay network has no impact on the overall system's capacity as it is still a code limited system compared with WCDMA.

6.2.2 Average noise rise analysis

Table 6-4 Average noise rise of NodeB

NodeB Type in rural area	Omni-NodeB	Sector NodeB
Average Noise Rise in dB in TD-SCDMA	5.58	6.43
Average Noise Rise in dB in TD-SCDMA Relay	5.57	6.37
Improvement	1%	6%

Table 6-4 shows that the average noise rise is more or less the same, showing a very slight improvement.

6.3 Summary

The significance of these results is that the addition of the relay network allows the cell coverage to be extended with no penalty either in terms of number of subscribers or increase in interference.

Chapter 7 Conclusion and Future Work

7.1 Conclusion

The thesis has proposed a hybrid TD-SCDMA relay network that is constructed under the umbrella of the combination of the TD-SCDMA N-frequency technology and the concentric circle cell concept.

The results of cell radius calculations in the hybrid network show that the coverage of the original TD-SCDMA network in rural areas can be extended by introducing the relay network rather than by adding more NodeBs. For non-HSDPA customers this can be done without penalty in terms of number of subscribers that can be satisfied or by any increase in noise level. This gives opportunities for network operators to save large amounts of investment in network establishment and to better utilize the network equipment in areas where the limiting factor is coverage not capacity.

The results from the HSDPA application simulation show that after introducing the relay network to a standard TD-SCDMA network by adopting the common TD-SCDMA radio frame structure, the network throughput can be improved dramatically, which is about 77% compared to the non N-frequency TD-SCDMA network and 45% compared to the N-frequency TD-SCDMA network without relay.

Moreover, the downlink interference at the cell boundary is optimized significantly as well. Therefore, the overall results of the HSDPA application part show the very positive aspects of the proposal.

7.2 Further work

In the last few years, more and more people are making use of the high speed data applications that are now being developed. The TD-SCDMA network in China is also developing quickly with full support from the Chinese Government and more and more manufacturers. However at the same time the whole telecom world keeps moving forward. Nowadays LTE is the new hot topic for all the 3G techniques; the advantages of LTE include higher peak data rate, lower latency, quicker response and strong forward compatibility. TD-

SCDMA standardization groups also regard TDD LTE as the future for current TD-SCDMA HSDPA system. Adding relay into TDD LTE will soon become one of the attractive interests and further network improvements should be studied as the next stage work.

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