Ph. D. Dissertation

Mobility Management Schemes for Performance Enhancement in Heterogeneous Mobile Networks

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AJOU University

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Mobility Management Schemes for Performance Enhancement in Heterogeneous Mobile Networks
Mobility Management Schemes for Performance Enhancement in Heterogeneous Mobile Networks

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A dissertation submitted to the faculty of AJOU University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Electrical and Computer Engineering. The study was conducted in accordance with Code of Research Ethics.

2014. 12. 15.

Approved by

Professor Kim, Jae-Hyun

[Advisor]
이종철 환경의 통신망 성능 향상을 위한
이동성 관리 기법

이 중 희

위 논문은 아주대학교 박사학위논문으로
학위논문심사위원회에서 심사 통과하였음.

2014년 12월 15일

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심사위원 노병희
심사위원 조성현
심사위원 권종형
Abstract

The network densification with dense small cell deployment is one of promising and essential technologies to increase capacity and extend coverage for 5G networks. In this dissertation, a study on network mobility management schemes in heterogeneous mobile networks which are composed of multi-tier small cells overlapping the coverage of macro cells, are proposed. Network mobility procedures cause various overheads including network delay, service interruption time and control message exchanges. These overheads may degrade the performances of network not only on the physical layer but also on the upper layers. This performance degradation may be more serious, especially under complex wireless interference condition in the heterogeneous mobile network (HMN) with dense small cells. In this dissertation, mobility management schemes are proposed to enhance network performance in HMNs which include multi-tier dense small cells overlaying coverage of macro cells.

In the macro cell environment, UEs search neighboring cells by measure the signal strength and receiving synchronization signals. However, UEs need to acquire system information which is essential to connect a certain cell, during neighboring cell search in a dense small cell deployment scenarios; A UE needs closed subscriber group (CSG) information to confirm whether the given cell is available for the UE or not. Moreover, physical ID from synchronization signals is not a unique identity because it can be reused by other base stations. Therefore, UEs have to acquire system information of cells by receiving and decoding the master information block and system information block packets by itself. Moreover, a UE searches multiple neigh-
boring cells up to eight at a neighboring cell search procedure. This system information acquisition causes delay and service interruption times. In the conventional system, UEs acquire system information cell by cell, i.e. serial manner. Therefore, a parallel system information acquisition scheme is proposed to minimize performance degradation due to system acquisition.

Network mobility procedures, for example handovers, cell re-selection, connection re-establishment after a radio link failure, involve network overheads such as control message exchanges, delay and service interruption times as mentioned above. In conventional mobility scheme, cell selection for mobility procedure execution performed mainly according to signal strength; reference signal received power (RSRP) in the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) system. It is unavoidable and inherent characteristic of highly dense HMNs, that frequent network mobility procedures are triggered for mobile UE. Frequent network mobility procedures will cause severe performance degradation. In this dissertation, the time of stay estimation based on users moving speed and transmission power of base stations, is introduced into the cell selection scheme. The time of stay is the duration from the time when a UE associate with a certain base station of certain cell to the time when the UE disconnects from the given base station. Therefore, UEs avoid unnecessary association which may cause very short time of stay.

Since the proposed schemes consider practical heterogeneous mobile networks, and the results show remarkable performance enhancements, it is expected that proposed schemes can be applied to not only 3GPP LTE and LTE-Advanced system but also to the other future mobile network systems.
Abstract .............................................................. i

Contents ........................................................... iii

List of Tables ......................................................... vi

List of Figures ....................................................... vii

List of Abbreviations ............................................... xi

Chapter 1. Introduction ............................................. 1

1.1 Background ..................................................... 1

1.2 Motivation ....................................................... 4

1.2.1 Interferences in HHMs ........................................ 5

1.2.2 Network mobility ............................................. 7

1.2.3 Short Time of Stay Problem ................................. 9

1.2.4 Impact on User Performance ............................... 10

1.2.5 Further enhanced interference coordination schemes ....... 12

1.2.6 Dense HMN adaptable higher-layer protocol design ....... 13

1.2.7 Context centric association policy .......................... 14

1.2.8 Network mobility management schemes for hyper dense and highly mobile heterogeneous network .................... 15

1.3 Contributions ..................................................... 15

1.4 Overview ......................................................... 17
### Chapter 2. Related Works 18

2.1 An Overview of Mobility in 3GPP LTE Network .......................... 18  
2.1.1 Network Architecture .................................................... 21  
2.1.2 Protocol Stack ............................................................ 26  
2.1.3 NAS and RRC States ...................................................... 32  
2.1.4 Measurement and Measurement Report ............................... 34  
2.1.5 Mobility Procedures ...................................................... 38  
2.2 Literature Survey ............................................................ 44

### Chapter 3. System Model 51

3.1 Reference Network Architecture ........................................... 51  
3.2 Mobility Procedures ......................................................... 51  
3.3 L1 and L3 Measurement .................................................... 56  
3.4 Radio Link Failure and Handover Failure ............................... 58  
3.5 Delays and Service Interruptions during Mobility Procedures ....... 59

### Chapter 4. A Fast System Information Acquisition Schemes for Small Cells in 3GPP LTE Networks 63

4.1 System Information for 3GPP LTE/LTE-A System ..................... 64  
4.2 Serial System Information Acquisition Methods ....................... 67  
4.2.1 Scheduled Acquisition with a Large Gap ............................ 68  
4.2.2 Autonomous Acquisition with a Large Gap ......................... 70  
4.2.3 Scheduled Acquisition with Several Small Gaps I ................. 71  
4.2.4 Scheduled Acquisition with Several Small Gaps II ............... 74
List of Tables

1.1 Simulation parameters. .............................................. 8

2.1 Summary of EPC entities. ........................................... 25

2.2 NAS and RRC states. .............................................. 31

2.3 Measurement report triggering conditions. ......................... 37

3.1 Processing delay for RRC procedures .............................. 60

3.2 Control plane latency ............................................. 62

4.1 System information blocks. ........................................ 65

4.2 Simulation parameters. ............................................. 82

5.1 Network Parameters ................................................. 101

5.2 Parameters related to BSs and UEs. ................................. 101
# List of Figures

1.1 Types of small cells. .......................................................... 2
1.2 Illustration of various downlink interferences in a 3-tier HMN; macro
cells, small cells and moving small cells. ................................. 6
1.3 Ratio of time served by each tier (macro and small cells) to total
simulation time. ................................................................. 9
1.4 Association rate (number of UE associations in 1 s). ............... 10
1.5 Average ToS during a Association. ...................................... 11
1.6 Average throughput of the IP-layer and application-layer throughputs
with UDP traffic. ............................................................... 13
1.7 Average throughput of the IP-layer and application-layer throughputs
with FTP traffic over TCP. .................................................. 14
1.8 Contributions of this dissertation. ....................................... 16
2.1 History of 3GPP network technologies. ............................... 19
2.2 LTE network architecture. ................................................ 22
2.3 Protocol stack. ................................................................. 26
2.4 Control plane protocol stack. .............................................. 27
2.5 User plane protocol stack. ................................................ 30
2.6 RRC and NAS states transition. ......................................... 33
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7</td>
<td>Mobility procedures in RRC IDLE state.</td>
<td>39</td>
</tr>
<tr>
<td>2.8</td>
<td>Mobility procedures in RRC connected state</td>
<td>41</td>
</tr>
<tr>
<td>2.9</td>
<td>A3-based handover between macro cells</td>
<td>42</td>
</tr>
<tr>
<td>2.10</td>
<td>A3-based handover between macro and small cells</td>
<td>43</td>
</tr>
<tr>
<td>3.1</td>
<td>The reference network architecture.</td>
<td>52</td>
</tr>
<tr>
<td>3.2</td>
<td>Stretched reference network architecture with a macro cell and three-tier small cells.</td>
<td>53</td>
</tr>
<tr>
<td>3.3</td>
<td>Handover preparation procedure.</td>
<td>54</td>
</tr>
<tr>
<td>3.4</td>
<td>Handover execution procedure.</td>
<td>55</td>
</tr>
<tr>
<td>3.5</td>
<td>Handover completion procedure.</td>
<td>56</td>
</tr>
<tr>
<td>3.6</td>
<td>A simplified mobility procedure model.</td>
<td>57</td>
</tr>
<tr>
<td>3.7</td>
<td>Radio link failure model.</td>
<td>58</td>
</tr>
<tr>
<td>4.1</td>
<td>System information broadcast scheduling in the time domain.</td>
<td>66</td>
</tr>
<tr>
<td>4.2</td>
<td>Procedure of the scheduled acquisition with a large gap scheme.</td>
<td>68</td>
</tr>
<tr>
<td>4.3</td>
<td>An example of the scheduled acquisition with a large gap scheme.</td>
<td>69</td>
</tr>
<tr>
<td>4.4</td>
<td>Procedure of the autonomous acquisition with a large gap scheme</td>
<td>70</td>
</tr>
<tr>
<td>4.5</td>
<td>An example of the autonomous acquisition with a large gap scheme</td>
<td>71</td>
</tr>
<tr>
<td>4.6</td>
<td>Procedure of the scheduled acquisition with several small gaps I scheme</td>
<td>72</td>
</tr>
<tr>
<td>4.7</td>
<td>An example of the scheduled acquisition with several small gaps I scheme</td>
<td>73</td>
</tr>
<tr>
<td>4.8</td>
<td>Procedure of the scheduled acquisition with several small gaps II scheme</td>
<td>75</td>
</tr>
</tbody>
</table>
4.9 An example of the scheduled acquisition with several small gaps II scheme ........................................ 76
4.10 Procedure of the autonomous acquisition with several small gaps scheme ........................................ 77
4.11 An example of the autonomous acquisition with several small gaps scheme ........................................ 78
4.12 An example of the autonomous acquisition with parallel small gaps scheme ........................................ 80
4.13 The mobility model. ........................................ 83
4.14 Delay and service interruption time of scheduled acquisition with a large gap scheme. ........................................ 84
4.15 Delay and service interruption time of autonomous acquisition with a large gap scheme. ........................................ 85
4.16 Delay and service interruption time of scheduled acquisition with several small gaps I scheme. ........................................ 86
4.17 Delay and service interruption time of scheduled acquisition with several small gaps II scheme. ........................................ 87
4.18 Delay and service interruption time of autonomous acquisition with several small gaps scheme. ........................................ 88
4.19 Delay and service interruption time of autonomous acquisition with parallel small gaps scheme. ........................................ 89
4.20 Service interruption time. ........................................ 90
4.21 Acquisition delay (case of six neighboring CSG cells). ........................................ 91
5.1 A reference architecture of an HMN model with $n_{\text{tier}} = 4$.

5.2 Mobility of a UE in a small cell coverage area.

5.3 Number of handovers during one hour with the conventional scheme.

5.4 Number of sToS occurrences during one hour with the conventional scheme.

5.5 Number of HOs during one hour with the ETCS scheme.

5.6 Number of HOs and sToS during one hour with/without the ETCS scheme.

5.7 Circular movement simulation scenario.

5.8 Association rate (number of associations/sec).

5.9 Short time of stay rate (number of sToSs/sec).

5.10 RLF rate (number of RLFs/sec).

5.11 Random waypoint simulation scenario.

5.12 Association rate (number of associations/sec).

5.13 Short time of stay rate (number of sToSs/sec).

5.14 RLF rate (number of RLFs/sec).
### List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3GPP</td>
<td>3rd Generation Partnership Project</td>
</tr>
<tr>
<td>AALG</td>
<td>autonomous acquisition with a large gap</td>
</tr>
<tr>
<td>AAPSG</td>
<td>autonomous acquisition with parallel small gaps</td>
</tr>
<tr>
<td>AASG</td>
<td>autonomous acquisition with several small gaps</td>
</tr>
<tr>
<td>AKA</td>
<td>authentication and key agreement</td>
</tr>
<tr>
<td>AM</td>
<td>acknowledged mode</td>
</tr>
<tr>
<td>AS</td>
<td>access stratum</td>
</tr>
<tr>
<td>ARIB</td>
<td>Association of Radio Industries and Businesses</td>
</tr>
<tr>
<td>ATIS</td>
<td>Alliance for Telecommunications Industry Solutions</td>
</tr>
<tr>
<td>CCSA</td>
<td>China Communications Standards Association</td>
</tr>
<tr>
<td>CDMA</td>
<td>code division multiple access</td>
</tr>
<tr>
<td>CMAS</td>
<td>Commercial Mobile Alert System</td>
</tr>
<tr>
<td>CN</td>
<td>core network</td>
</tr>
<tr>
<td>CoMP</td>
<td>coordinated multipoint</td>
</tr>
<tr>
<td>CQI</td>
<td>channel quality indicator</td>
</tr>
<tr>
<td>CRE</td>
<td>cell range expansion</td>
</tr>
<tr>
<td>C-RNTI</td>
<td>cell radio network temporary identifier</td>
</tr>
<tr>
<td>CSG</td>
<td>closed subscriber group</td>
</tr>
<tr>
<td>CT</td>
<td>core network and terminals</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
</tr>
<tr>
<td>D2D</td>
<td>device-to-device</td>
</tr>
<tr>
<td>eCA</td>
<td>enhanced carrier aggregation</td>
</tr>
<tr>
<td>ECM</td>
<td>EPS connection management</td>
</tr>
<tr>
<td>EDGE</td>
<td>enhanced data rates for GSM evolution</td>
</tr>
<tr>
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<td>enhanced downlink MIMO</td>
</tr>
<tr>
<td>EMM</td>
<td>EPS mobility management</td>
</tr>
<tr>
<td>eNB</td>
<td>evolved nodeB</td>
</tr>
<tr>
<td>EPC</td>
<td>evolved packet core</td>
</tr>
<tr>
<td>EPS</td>
<td>evolved packet system</td>
</tr>
<tr>
<td>E-RAB</td>
<td>E-UTRAN radio access bearer</td>
</tr>
<tr>
<td>ESM</td>
<td>EPS session management</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
</tr>
<tr>
<td>ETWS</td>
<td>Earthquake and Tsunami Warning Service</td>
</tr>
<tr>
<td>E-UTRAN</td>
<td>evolved universal terrestrial radio access network</td>
</tr>
<tr>
<td>FTP</td>
<td>file transfer protocol</td>
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<td>GAN</td>
<td>generic access network</td>
</tr>
<tr>
<td>GERAN</td>
<td>GSM EDGE radio access network</td>
</tr>
<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile</td>
</tr>
<tr>
<td>GTP</td>
<td>GPRS Tunneling Protocol</td>
</tr>
<tr>
<td>GTP-U</td>
<td>GPRS tunneling protocol user plane</td>
</tr>
<tr>
<td>HeNB</td>
<td>home evolved nodeB</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>HLR</td>
<td>home location register</td>
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<td>HMN</td>
<td>heterogeneous mobile network</td>
</tr>
<tr>
<td>HSDPA</td>
<td>high speed downlink packet access</td>
</tr>
<tr>
<td>HSPA+</td>
<td>high speed packet access evolution</td>
</tr>
<tr>
<td>HSS</td>
<td>home subscriber server</td>
</tr>
<tr>
<td>HSUPA</td>
<td>high speed uplink packet access</td>
</tr>
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<td>IETF</td>
<td>Internet Engineering Task Force</td>
</tr>
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<td>IIR</td>
<td>infinite impulse response</td>
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<td>IMS</td>
<td>IP multimedia subsystem</td>
</tr>
<tr>
<td>IMT-2000</td>
<td>International Mobile Telecommunications-2000</td>
</tr>
<tr>
<td>IMT-Advanced</td>
<td>International Mobile Telecommunications-Advanced</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of things</td>
</tr>
<tr>
<td>IP</td>
<td>internet protocol</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MAC</td>
<td>medium access control</td>
</tr>
<tr>
<td>MBMS</td>
<td>multimedia broadcast multicast service</td>
</tr>
<tr>
<td>MB MSR</td>
<td>multi-band and multistandard radio</td>
</tr>
<tr>
<td>MIB</td>
<td>master information block</td>
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<tr>
<td>MIMO</td>
<td>multi input multi output</td>
</tr>
<tr>
<td>MME</td>
<td>mobility management entity</td>
</tr>
<tr>
<td>MOS</td>
<td>mean opinion score</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>MSR</td>
<td>multi-standard radio</td>
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<tr>
<td>MTC</td>
<td>machine-type communication</td>
</tr>
<tr>
<td>NAS</td>
<td>non-access stratum</td>
</tr>
<tr>
<td>NCT</td>
<td>new carrier type</td>
</tr>
<tr>
<td>OFDMA</td>
<td>orthogonal frequency division multiple access</td>
</tr>
<tr>
<td>OSG</td>
<td>open subscriber group</td>
</tr>
<tr>
<td>OTA</td>
<td>Over-the-Air</td>
</tr>
<tr>
<td>PCC</td>
<td>policy and charging control</td>
</tr>
<tr>
<td>PCER</td>
<td>policy and the charging enforcement function</td>
</tr>
<tr>
<td>PCRF</td>
<td>policy and charging rules function</td>
</tr>
<tr>
<td>PDCP</td>
<td>packet data convergence protocol</td>
</tr>
<tr>
<td>PDN</td>
<td>packet data network</td>
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<tr>
<td>PDU</td>
<td>protocol data unit</td>
</tr>
<tr>
<td>P-GW</td>
<td>packet data network gateway</td>
</tr>
<tr>
<td>PLMN</td>
<td>public land mobile network</td>
</tr>
<tr>
<td>PoC</td>
<td>push to talk over cellular</td>
</tr>
<tr>
<td>PSS</td>
<td>primary synchronization signal</td>
</tr>
<tr>
<td>PSTN</td>
<td>public switched telephone network</td>
</tr>
<tr>
<td>QoS</td>
<td>quality of service</td>
</tr>
<tr>
<td>RAB</td>
<td>radio access bearer</td>
</tr>
<tr>
<td>RACH</td>
<td>random access channel</td>
</tr>
<tr>
<td>RAN</td>
<td>radio access network</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>RAT</td>
<td>radio access technology</td>
</tr>
<tr>
<td>RE</td>
<td>resource element</td>
</tr>
<tr>
<td>RLC</td>
<td>radio link control</td>
</tr>
<tr>
<td>RLF</td>
<td>radio link failure</td>
</tr>
<tr>
<td>RNTI</td>
<td>radio network temporary identifier</td>
</tr>
<tr>
<td>RRC</td>
<td>radio resource control</td>
</tr>
<tr>
<td>RS</td>
<td>reference signal</td>
</tr>
<tr>
<td>RSRP</td>
<td>reference signal received power</td>
</tr>
<tr>
<td>RSRQ</td>
<td>reference signal received quality</td>
</tr>
<tr>
<td>RSSI</td>
<td>received signal strength indicator</td>
</tr>
<tr>
<td>SA</td>
<td>service and system aspects</td>
</tr>
<tr>
<td>SAE</td>
<td>system architecture evolution</td>
</tr>
<tr>
<td>SALG</td>
<td>scheduled acquisition with a large gap</td>
</tr>
<tr>
<td>SASG1</td>
<td>scheduled acquisition with several small gaps I</td>
</tr>
<tr>
<td>SASG2</td>
<td>scheduled acquisition with several small gaps II</td>
</tr>
<tr>
<td>SDF</td>
<td>service data flow</td>
</tr>
<tr>
<td>SFN</td>
<td>system frame number</td>
</tr>
<tr>
<td>SGSN</td>
<td>serving general packet radio service support node</td>
</tr>
<tr>
<td>S-GW</td>
<td>serving gateway</td>
</tr>
<tr>
<td>SIB</td>
<td>system information block</td>
</tr>
<tr>
<td>SIM</td>
<td>subscriber identification module</td>
</tr>
<tr>
<td>SINR</td>
<td>signal to interference plus noise ratio</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>SON</td>
<td>self-organizing network</td>
</tr>
<tr>
<td>SSS</td>
<td>secondary synchronization signal</td>
</tr>
<tr>
<td>sToS</td>
<td>short time of stay</td>
</tr>
<tr>
<td>TA</td>
<td>tracking area</td>
</tr>
<tr>
<td>TAI</td>
<td>tracking area identity</td>
</tr>
<tr>
<td>TAU</td>
<td>tracking area update</td>
</tr>
<tr>
<td>TCP</td>
<td>transmission control protocol</td>
</tr>
<tr>
<td>TDD</td>
<td>time division duplexing</td>
</tr>
<tr>
<td>TM</td>
<td>transparent mode</td>
</tr>
<tr>
<td>ToS</td>
<td>time of stay</td>
</tr>
<tr>
<td>TSG</td>
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</tr>
<tr>
<td>TTA</td>
<td>Telecommunications Technology Association</td>
</tr>
<tr>
<td>TTC</td>
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</tr>
<tr>
<td>TTT</td>
<td>time to trigger</td>
</tr>
<tr>
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</tr>
<tr>
<td>UE</td>
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</tr>
<tr>
<td>UHD</td>
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</tr>
<tr>
<td>UM</td>
<td>unacknowledged mode</td>
</tr>
<tr>
<td>UMTS</td>
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</tr>
<tr>
<td>W-CDMA</td>
<td>wideband code division multiple access</td>
</tr>
</tbody>
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Chapter 1. Introduction

An investigation in 2013 by Korean Ministry of Science revealed that 38,160,077 people were using smartphones among 54,514,397 mobile subscribers in Korea. Moreover, 23,993,469 of them are LTE users [1]. This trend may be worldwide trend with consideration of that Korea is one of test market countries for IT products. In 5G era, a large number of mobile smart devices and Internet of things (IoT) devices will generate various kind of traffics from very tiny to gigabytes traffics, for example, small sensing data of IoT networks, and ultra-high definition (UHD) video service which has 7680-by-4320 resolution. It will cause an explosion of tremendous traffic volume with dynamic fluctuation in mobile networks. Many researchers have foreseen that mobile traffic will increase 1,000 times in 10 years. Therefore, it is almost impossible to handle 5G traffics with conventional networks. Moreover, 5G mobile networks should be more flexible because of the various types of network architectures and devices.

1.1 Background

Many researchers and commercial companies have their own vision for 5G wireless networks, and there are some overlapped issues between their prospects as [2–5]:

- HMN for cell densification.
- New carrier type (NCT).
- Massive multi-input and multi-output (MIMO) and array antenna technologies.
- Users / contents / network context-awareness network.
- IoT: machine-type communications (MTC) and device-to-device (D2D) communication.
- Green networks: energy efficiency and cost effectiveness.

![Diagram of small cell types](image)

Figure 1.1. Types of small cells.

The main theme of this dissertation is mobility management of heterogeneous mobile network which is comprised of the macro cells and multi-tier small cells.

A HMN is a cell densification technology created by overlaying multiple tiers of mobile communication network cells; for example, if there are pico cells and femto cells in the coverage of a macro cell, then a three-tier HMN is formed. The Small Cell Forum defines small cells as “an umbrella term for operator-controlled, low-powered radio access nodes” [6]. In other words, the definition of small cells is a low-power mobile network cells that is under the control of a mobile network operators. This is the difference between Wi-Fi access points (APs) and small cells. Additionally, the Small Cell Forum classifies small cells into four classes according
to applications and the size of coverage as shown in Fig 1.1; femtocells with the smallest coverage are used for a home, picocells are used for an enterprise, metrocells and microcells with the largest coverage are used for public hotspots and rural mobile service, respectively.

The features of HMNs are as follows:

- Dense cell deployment with decreased cell size.
- Dynamic deployment and operation.
- Flexible backhaul.
- Access policy: CSG and open subscriber group (OSG) modes.

Dense SCs increase network capacity and extend coverage with lower cost to deploy and to operate. Moreover, SCs can be deployed and controlled adaptively according to certain situations and specific purposes by both of the mobile operators or users, for example, covering a temporal hotspot zone. Additionally, SCs operate regardless of the type of backhaul because they are connected to a core network (CN) of an operator through their own Internet connection. In other words, the backhaul link of an SC can be any Internet link, for example, an Ethernet or an optical cable. This flexible backhaul is one of the most important differences between MCs and SCs because SCs do not require the high-cost backhaul link of a mobile operator. Other important features of SCs are policy modes for mobile subscribers. There are two modes. The first is a CSG mode which allows access only to subscriber group members; thus, only allowed users can be served by a CSG cell. The second
mode is an OSG mode. Therefore, an OSG cell provides service for any users in its coverage. OSG and CSG access policy can be mixed; for example, an SC serves its members with higher priority and serves non-members with the remaining resources after scheduling traffic transmissions of the members.

NCT technology is almost ready for practical use, for example, millimeter-wave technology [5]. The target carrier frequency of NCT is 5 GHz or higher. Therefore, we can expect higher throughput. However, there is a tradeoff. In other words, higher frequency can cause more attenuation. Nevertheless, this will be overcome by various technologies that are being actively studied.

1.2 Motivation

Mobile network systems try to provide seamless connectivity to their users. When a user equipment (UE) is in idle state, the given UE tries to change an association to a better neighboring cell through connection re-selection procedures: neighboring cell search, measurement and evaluation of detected cells, cell system information acquisition, and cell re-selection. When a UE is in connected state, the given UE tries to handover to suitable cells according to leading of serving cell through handover procedures: measurement of signal qualities of the serving and neighboring cells, reporting to current serving cell, handover decision by serving cell, and random access to the target cell. When a UE loses connection because of radio link failure, the given UE tries to re-establish a connection with the target cell through similar procedures with cell re-selection procedures.
Network mobility procedures described above, cause overheads including network delay, service interruption time and control message exchanges. These overheads may degrade the performances of network not only on the physical layer but also on the upper layers. This performance degradation may be more serious, especially under complex wireless interference condition in the HMN with dense small cells.

1.2.1 Interferences in HMNs

There have been many studies to mitigate the interferences in a HMN [7], [8]. In the most previous studies, the main reasons for interferences are the difference in transmission power level between macro and small cell base stations. Interferences will dramatically fluctuate compared with that of a traditional mobile network without small cells. Fig 1.2 shows various types of interferences in a three-tier HMN that is composed of macro cells, small cells and moving small cells. The moving small cell is a small cell with wireless backhaul. In Fig 1.2, wireless link icons with solid lines and with dotted lines represent desired signals from the serving cell and interferences from other cells, respectively.

All interferences in Fig 1.2 are inter-cell interferences. The inter-cell interferences occur between any cells regardless of the tier. All the interferences in the network are inter-cell interferences because currently used and future mobile communication networks may use the orthogonal frequency deviation multiple access (OFDMA) and the OFDMA system does not have intra-cell interferences. If the serving cell and interferer cell are in a different tier, this interference is called inter-
Figure 1.2. Illustration of various downlink interferences in a 3-tier HMN; macro cells, small cells and moving small cells.

tier interference. In particular, if the serving cell is a small cell and the interferer cell is a macro cell like as (b) in Fig 1.2, this interference is critical because of the gap between transmission powers of macro cells and small cells. Various inter-cell interference coordination schemes have been researched [7], [8]. Cell range expansion (CRE) and almost blank sub-frame (ABS) are popular solutions. CRE is a method to give association priority to a small cell tier by adding an offset to the signal quality of small cells during cell selection. However, CRE can cause serious signal quality degradation because a UE is associated with a small cell, even if the signal quality of the small cell is significantly worse than that of a macro cell. Therefore, an ABS scheme is needed. ABS is a resource partitioning scheme; macro cells sacrifice their resources in the time-domain for small cells by scheduling no traffic during certain
sub-frames. However, the resource partitioning scheme causes a decreasing in spectrum efficiency. Intra-tier interference is the opposite of inter-tier interference. If the serving cell and interferer cell are in the same tier, for example, (A) and (C) in Fig 1.2, the interference is intra-tier. Dynamic interference can be considered if a small cell is moving with wireless backhaul. Dynamic interference occurs when at least one of the serving cell and the interferer cell are mobile nodes, for example, (D) and (E) in Fig 1.2. There is a remarkable difference between (D) and (E). The interference (D) will be stronger because the serving cell and the interferer cell will be closer, and vice versa. The semi-static interference is non-dynamic interference. All the interferences in previous studies are semi-static interferences. However, it is not the static interference but a semi-static interference, because of users’ mobility. There can be interferences between wireless backhaul links. Backhaul interference may be similar to common inter-cell interference.

1.2.2 Network mobility

In a traditional mobile network that only has macro cells, most network mobility changes occur at the border of the cells. However, in the HMN, network association changes at any location according to the dense and arbitrary deployment of small cells. The outline of network mobility procedures in current mobile communication network systems, for example LTE are as follows:

1. Neighboring cell search.

2. System information measurement for detected neighboring cells.
3. Cell evaluations and mobility decisions.

4. Mobility execution upon decision.

Therefore, UEs have to perform cell search and measurements for all the neighboring cells that meet the cell detection threshold. Additionally, most of small cells may trigger association changes because of the CRE offset; UEs try to handover to newly detected small cells even if the signal quality of an macro cell is better than that of given small cell. Preliminary performance analysis of network mobility had been performed to motivate my research. Table 1.1 shows the simulation parameters [9].

Table 1.1. Simulation parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>macro cells</th>
<th>small cells</th>
<th>UE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>10 MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrier Frequency</td>
<td>2.110 GHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inter-Site Distance</td>
<td>1732 m (3GPP Case 3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of UE and mPC</td>
<td>3 km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobility Pattern</td>
<td>Random way point model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>19 cells (x3 sectors)</td>
<td>2/4/6/8/10 per macro sector</td>
<td>60 per macro cell</td>
</tr>
<tr>
<td>TX Power</td>
<td>46 dBm</td>
<td>30 dBm</td>
<td></td>
</tr>
<tr>
<td>Path loss</td>
<td>ITU UMa</td>
<td>ITU UMi</td>
<td></td>
</tr>
<tr>
<td>Shadowing</td>
<td>ITU UMa</td>
<td>ITU UMi</td>
<td></td>
</tr>
<tr>
<td>Antenna Height</td>
<td>25 m</td>
<td>10 m / 1.5 m</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Antenna Configuration</td>
<td>2Tx 2Rx</td>
<td>2T x 2Rx</td>
<td>1Tx 2Rx</td>
</tr>
<tr>
<td>Antenna Gain</td>
<td>17dBi</td>
<td></td>
<td>5dBi</td>
</tr>
<tr>
<td>Antenna Pattern</td>
<td>3GPP Case 3</td>
<td>2D Omni-Directional</td>
<td>2D Omni-Directional</td>
</tr>
<tr>
<td></td>
<td>3D Antenna Model</td>
<td></td>
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</tbody>
</table>
1.2.3 Short Time of Stay Problem

The time of stay (ToS) is the service time during an association. We can easily predict that the small cell has a very small ToS from the results shown in Figs. 1.3 and 1.4. Fig 1.5 directly demonstrates this phenomenon. MC and SC indicate macro cells and small cells, respectively. According to the results, UEs experience shorter ToS in a network with higher cell density. A short ToS is a challenging problem that must be solved. It would be better if we do not associate with a given cell that may cause short ToS. There are interruption times for a cell search, random access and association execution during handovers or cell re-selections. For example, the interruption time during a handover procedure in an LTE system is up to 130 ms [10]. The
interruption time during a cell re-selection is more than that of a handover. Moreover, this interruption occurs in bursts. Therefore, a short ToS harms other network performances because frequent association changes lead to bursts of interruptions.

1.2.4 Impact on User Performance

In a HMN, network capacity is enhanced by cell densification. Therefore, physical layer throughput is significantly increased, as shown in previous studies [8], [7]. However, can we say that the goodput which is experienced by users, is also enhanced? The answer is unclear because network mobility may influence the performances of higher-layer protocols. Figs. 1.6 and 1.7 show the throughput results of OPNET simulations according to the number of small cells. Simulations do not
include interference coordination schemes but contains CRE. Therefore, the signal qualities of serving cells are almost the worst case. However, we can see the impact of the highly densely deployed small cells on user throughput with the following results. Moreover, the worst case is also very important. In Figs. 1.6 and 1.7, the left and right bars in each pair, represent the lower-layer and upper-layer throughputs: lower-layer and upper-layer mean the IP and application layers, respectively. In Fig 1.6, we can observe that the gaps between throughputs of the higher-layer and lower-layer are small. However, we are able to observe large differences in Fig 1.7. This phenomenon is mainly due to the TCP behavior. Transmission control protocol (TCP) cannot distinguish between errors in links and congestions in networks.
Therefore, if the link quality of a UE is poor because of CRE offset, the absence of an interference coordination scheme and the bursts of interruption time due to the frequent association changes, the TCP window size will increase until it reaches the maximum. Then, the session will be disconnected and re-established, repeatedly. In the simulation with TCP traffics, although there was a large number of traffic transmissions in lower-layer, most were retransmissions in higher-layer. Moreover, there is another interesting phenomenon. The lower-layer throughput also decreases even if there is a large amount of traffic retransmission. This is because of the duration from the start of the TCP retransmission count to the retransmission timeouts. This duration acts as inter-arrival time of packets. New traffic is transmitted at rare intervals because of continuing TCP retransmission timeouts.

1.2.5 Further enhanced interference coordination schemes

Interference coordination schemes are essential for small cells in HMNs. Additionally, CRE and ABS schemes are key technologies to mitigate interferences in HMNs. A static CRE offset may not be appropriate to handle a highly dense HMN. We can consider a classified adaptation of different CRE offsets for each cell tier or cell, or dynamically optimized CRE offsets in the manner of self-optimizing networks [32], [33]. There are a number of ABS variances in many research papers and technical documents. However, a more dynamic scheme is required to operate effectively.
1.2.6 Dense HMN adaptable higher-layer protocol design

To assure end-to-end user performance in 5G mobile communication networks, further enhanced higher-layer studies are needed as well as lower-layer research. An example is TCP optimization or modification to mitigate frequent short interruptions due to the nature of HMNs with dense concentration of small cells with consideration of cross-layer protocols. Currently, many researchers are focusing on the lower layer because we are still at the beginning of 5G communication research. However, more studies in point of higher layer and cross layer are also urgently needed.

Figure 1.6. Average throughput of the IP-layer and application-layer throughputs with UDP traffic.
Figure 1.7. Average throughput of the IP-layer and application-layer throughputs with FTP traffic over TCP.

1.2.7 Context centric association policy

The small cells are appropriate for application in user- or context-centric network schemes. Therefore, this dissertation is more focusing on it. A context-centric changeable mobile cell is one of our interesting research issues. The user devices and neighboring network elements organize and change their networks by consideration of given user’s contexts while the conventional network cells follow the operational policies of service providers.
1.2.8  **Network mobility management schemes for hyper dense and highly mobile heterogeneous network**

The HMN causes frequent network mobility situations: neighboring cell search, system information measurements, handovers, link failure, and re-association. Moreover, it will be more critical in hyper dense small cell deployment environment. Therefore, 5G HMN requires more advanced mobility management technologies. For example, we can reduce the service interruption and delay for cell search. Or, we can use ToS as a new criterion for cell selection by estimating the ToS. In this dissertation we focused on network mobility management schemes.

1.3  **Contributions**

Mobility management schemes for performance enhancement in HMNs which include multi-tier densely deployed small cells overlaying coverage of macro cells are shown in Fig 1.8. The target system is 3GPP LTE and LTE-Advanced system which are most widely used in mobile communication system.

In the macro cell environment, UEs can acquire system information which is essential to connect the given cell when neighboring cells are detected. However, it may be impossible in a dense small cell deployment scenarios. Therefore, UEs have to acquire system information of cells by receiving and decoding the master information block and system information block packet by itself. Moreover, a UE searches multiple neighboring cells up to eight. This system information acquisition causes delay and service interruption times. In the conventional system, UEs acquire
system information cell by cell, i.e. serial manner. Therefore, a parallel system information acquisition scheme is proposed to minimize performance degradation due to system acquisition.

Network mobility procedures, for example handovers, cell re-selection and connection re-establishment after a radio link failure, involve network overheads such as control message exchanges, delay and service interruption times as mentioned above. In conventional mobility schemes, cell selection for mobility procedure ex-
execution performed mainly according to signal strength; reference signal received power (RSRP) in the 3GPP LTE mobility. It is unavoidable and inherent characteristic of highly dense HMNs, that frequent network mobility procedures are triggered for mobile UE. Frequent network mobility procedures will cause severe performance degradation. In this dissertation, the time of stay estimation based on users moving speed and transmission power of base stations, is introduced into the cell selection scheme. The time of stay is the duration from the time when a UE associate with a certain base station of certain cell to the time when the UE disconnects from the given base station. Therefore, UEs avoid unnecessary association which may cause very short time of stay.

1.4 Overview

The remainder of this dissertation is organized as follows. In Chapter 2, the mobility procedures in the target system (3GPP LTE and LTE-Advanced network) and an overview of previous works on mobility procedures are described. Chapter 3 shows the system model which is used in this dissertation. In Chapter 4, a parallel system information acquisition scheme is proposed to minimize the delay for cell search procedure. And, an estimated ToS based cell selection scheme to avoid unnecessary handovers to possible short ToS occurrence cells is introduced in Chapter 5. This dissertation is concluded in Chapter 6.
Chapter 2. Related Works

2.1 An Overview of Mobility in 3GPP LTE Network

In this section, an overview of mobility management procedures in mobile networks is presented. The target system is the 3GPP LTE system because it is the most widely used mobile network system currently. The 3GPP unites six telecommunication standard development organization: Association of Radio Industries and Businesses (ARIB) in Japan, Alliance for Telecommunications Industry Solutions (ATIS) in USA, China Communications Standards Association (CCSA) in China, European Telecommunications Standards Institute (ETSI) in Europe, Telecommunications Technology Association (TTA) in Korea and Telecommunication Technology Committee (TTC) in Japan. There are four technical specification groups (TSG): radio access network (RAN), service and system aspects (SA), core network and terminals (CT) and Global System for Mobile (GSM) enhanced data rates for GSM evolution (EDGE) radio access network (GERAN). The 3GPP project provides complete system specifications about cellular telecommunications network technologies which include radio access, the core transport network, and service capabilities. The radio access technical specifications have been rapidly developed from 3GPP release 99, wideband code division multiple access (W-CDMA) system in 1999 as shown in Fig 2.1 [11].

Release 99 specifies the first Universal Mobile Telecommunication System (UMTS)
3G networks incorporation a code division multiple access (CDMA) air interface. In specification release 4, 1.28 Mcps time division duplexing (TDD) technology added features including an all IP core network. The IP multimedia subsystem (IMS) and the high speed downlink packet access (HSDPA) technologies were introduced in release 5. Specification release 6 includes high speed uplink packet access (HSUPA) technology, multimedia broadcast multicast service (MBMS), integrated operation with wireless LAN networks, and enhancements to IMS such as push to talk over cellular (PoC) and generic access network (GAN). Release 7 focuses on decreasing latency, improvements to quality of service (QoS) and real-time applications such as VoIP. And, release 7 specification includes high speed packet access evolution (HSPA+), subscriber identification module (SIM) high speed protocol, contactless front-end interface, and the EDGE. LTE and system architecture evolution (SAE)
feasibility studies were started in release 7. The 3GPP specification release 8 is the first LTE release including all-IP Network, SAE. Release 8 changed the existing UMTS as an entirely IP based fourth-generation network. The OFDMA air interface, UMTS femtocells and dual carrier HSDPA technologies are introduced. In the specification release 9, SAE technology was enhanced. multi-standard radio (MSR), dual carrier HSUPA, dual band HSDPA, self-organizing network (SON) and LTE femtocells with home evolved nodeB (HeNB) technologies were introduced. From release 10 onwards, LTE-Advanced has been approved by International Telecommunication Union (ITU) Radiocommunication Sector as ITU-R International Mobile Telecommunications-2000 (IMT-Advanced) radio interface technology. In other words, the 3GPP specifications from release 10, fulfill 4G mobile network requirements. In the release 10 specification, coordinated multipoint (CoMP) technology was studied, and backwards compatibility with release 8 LTE system and multi-cell HSDPA up to 4 carriers are included. Advanced IP interconnection of services and service layer interconnection between national operators and carriers were studied in specification release 11. CoMP enhancement, enhanced downlink (eDL) MIMO for downlink multiple antenna transmission, enhanced carrier aggregation (eCA), MIMO Over-the-Air (OTA), HSUPA transmission with 64QAM MIMO, eight carriers (8C) HSDPA MIMO, and multi-band and multi-standard radio (MB MSR) technologies were included in 3GPP release 11. In the release 12 specification, new carrier type, LTE-Direct and active antenna systems technologies are discussed to be specified.

The basic philosophies of 3GPP specifications are reduction of complexity,
avoidance of fragmentation of technologies, and backward compatibilities. All of the specifications from release 99 to 12 developed to allow existing equipment to be prepared for future technologies and functionalities. Moreover, the evolved packet core (EPC) network is designed as much more simpler form than the core network of prior GSM network.

This chapter comprised of following contents: network architecture, protocol stack, control plane overview, and mobility management procedures in current 3GPP LTE system. The remainder of this chapter is organized as follows. In Section 2.1.1 the network architecture including features of network entities is described. The protocol stack will be explained in Section 2.1.2. The non-access stratum (NAS) and radio resource control (RRC) states which represent connection and mobility conditions of network entities are summarized in Section 2.1.3. The measurement and its reports are essential to perform mobility procedures, and therefore these procedures are described in Section 2.1.4. Section 2.1.5 contains mobility procedures in RRC idle and connected state including the detailed handover procedure.

2.1.1 Network Architecture

The network architecture of 3GPP LTE network is shown in Fig 2.2 [12–14]. The EPC which is core network of LTE system, consists of the mobility management entity (MME), serving gateway (S-GW), packet data network gateway (P-GW), home subscriber server (HSS), and policy and charging rules function (PCRF) with suitable interfaces for each of them. The radio access network (RAN) of the LTE network, evolved universal terrestrial radio access network (E-UTRAN) is very simply.
2.1.1.1 Evolved Packet Core Network

The MME is a main control plane signaling entity of 3GPP LTE and LTE-Advanced network. It connects with eNBs through S1-MME interface. The main functions of MME is similar to that of the serving general packet radio service support node (SGSN) in legacy UMTS network but MME is only control plane entity whereas SGSN is not a pure control plane entity.

Main functions of MME are as follows: non-access stratum signaling for evolved
packet system (EPS) mobility management (EMM), EPS connection management (ECM) and security procedures. The NAS messages which are used for signalling of EMM and EPS session management (ESM), are exchanged between the UE and the MME. User authentication and roaming procedures by inter-working with HSS through S6a interface. The MME checks whether a given subscriber has the right to use the given network, and controls the security functions between the given UE and network. Managements of ECM and EMM states, including paging, tracking area update (TAU), and handover procedures. Location information for UEs is essential to paging procedure. MME stores this location information in unit of tracking area (TA). The MME monitors all mobility procedures of all UEs in its service area. Therefore, it controls the switch of user plane path from S-GW to target eNB during handover procedures. It also act as a anchor point during inter-radio access technology (RAT) handover, for example to GSM or UMTS networks. The MME also manages EPS bearers including bearer setup and modification.

The S-GW is a main user plane entity in the EPC. All user’s IP packets are transferred via the S-GW. It manages the user plane connections and switch them to the suitable network entity in the network. And, it serves as a local mobility anchor for the data bearers during intra-E-UTRAN mobilities of UEs. When an UE perform a handover procedure, the MME asks the S-GW to switch the user plane path toward the new target eNB if the given eNB is under the area of the S-GW. If the target eNB is in the service area of another S-GW, the MME choose the another S-GW which manages the target eNB. The S-GW also serves as a user plane mobility anchor during interworkin with other RATs. The bearer information of a UE stored in the
S-GW even if the given UE is in idle state. Therefore, The S-GW acts as temporal buffer for downlink data while the MME initiates paging of the UE to re-establish radio bearers, and forwards buffered packets after re-establishment.

The P-GW is the gateway to other IP networks. These networks need not be public like the Internet, but may also be private and owned by the operator, like IP multimedia subsystem (IMS). The P-GW allocates an IP address to the UE for each different external network it is connected to. Compared to the UMTS core network, the P-GW has a similar role as the GGSN. The P-GW serves mapping of the incoming IP packets to the correct bearers in the EPC, and forwards them. It also collects charging data. It performs this by packet filters. The service flow can be identified and separated for different users and QoS requirements, for example the voice over IP (VoIP) calls. Since the P-GW is the border side element in the EPS, it is the highest level user plane mobility anchor. Therefore, the P-GW will never be changed regardless of the mobility within the operators network, whereas the S-GW can be changed during a session.

The Home Subscriber Server (HSS) is the similar entity with home location register (HLR) in the legacy 3GPP networks. It maintains the subscribers’ profiles, which contain information such as allowed roaming areas and available packet data network (PDN) connections. It also tracks the location area of UEs with the serving MME. Additionally, the HSS maintains the master security key for each subscription and serves as authentication key server.

The policy and charging rules function (PCRF) is the policy and charging control entity. It makes policy decisions for service data flows (SDFs) and provides the
Table 2.1. Summary of EPC entities.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Features</th>
</tr>
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</table>
| MME    | - NAS signaling (EMM, ESM, Security)  
       | - User authentication and roaming with HSS via S6a interface  
       | - Management of ECM and EMM states (paging, TA, handover)  
       | - Management of EPS bearer |
| S-GW   | - Connection point of E-UTRAN and ETC  
       | - Mobility anchoring point during inter-eNB and inter-EPS handovers |
| P-GW   | - Provide access to a PDN for UEs  
       | - UE IP allocation IP routing and forwarding  
       | - IP routing and forwarding  
       | - Per-SDF and per-user based Packet filtering  
       | - Per-SDF and per-user charging based on the PCC rules provided by PCRF  
       | - Anchoring point during inter-RAT mobility |
| HSS    | - A central database where user profiles are stored  
       | - Provide user authentication information and user profiles to the MME |
| PCRF   | - Policy and charging control entity  
       | - Make policy decision for SDFs  
       | - Provides PCC rules (QoS and charging rules) to P-GW |
policy and charging control (PCC) rules which is rules about QoS and charging, to the policy and the charging enforcement function (PCEF) in the P-GW. The PCRF also serves the QoS class identification and decides data rates for them. In other words, it decides how a certain data flow will be in the PCEF and assure QoS requirement according to the user’s subscription profile. EPC entities and their features are summarized in Table 2.1.

### 2.1.2 Protocol Stack

#### 2.1.2.1 Control Plan Protocols

The protocol structure of EPS is significantly different from that of the previous 3GPP technologies. This results from the packet switched orientation of EPS. The
legacy protocol suite Signaling System number 7 (SS7) has been dropped from the specification. Instead of SS7, EPS relies on the IP architecture already familiar from the Internet to transport the control plane messages. Most of the protocols used in EPS excluding the air interface have been specified by the Internet Engineering Task Force (IETF). Fig 2.4 illustrates the control plane signaling protocol structure from the UE towards the MME. LTE-Uu refers to the air interface, while S1-MME is the interface between an eNodeB and an MME. The protocol structure in LTE-Uu is different from the rest of the links, since it handles the radio transmission and all related aspects. Below is a short description and explanation of the protocols in LTE-Uu.

Layer 1 (L1) indicates the used transmission medium and related functionalities. In this case it includes e.g. multiple access method, modulation, channel coding, etc.

The medium access control (MAC) layer located between RLC layer and L1 layer. It connected with the RLC layer via logical channels, and with L1 layer via transport channels. The MAC layer supports multiplexing and demultiplexing be-
between logical and transport channels. Upper layer use different logical channels according to QoS metrics. The MAC layer in eNBs dynamically allocate resources to UEs, and manage QoS for each bearer.

The radio link control (RLC) constructs RLC protocol data unit (PDU) and provides the RLC PDU to the MAC layer by segmentation and concatenation of PDCP PDUs to transmit data toward MAC layer. It also performs reassembly of the RLC PDU to reconstruct the PDCP PDU when it receive packets from MAC layer. It is responsible for the in-order delivery, duplicate detection of data and retransmission on the air interface. The RLC protocol has three operational modes: transparent mode (TM), acknowledged mode (AM) and unacknowledged mode (UM), and each modes offers different reliability levels.

The packet data convergence protocol (PDCP) layer is responsible for efficient transport of IP packets over the radio link. It performs IP header compression to reduce the overhead. And, the PDCP is responsible for sequence numbering to keep track of the sent or received data. Therefore, it re-order and retransmission packets during handover procedures. PDCP also handles security functionalities such as ciphering and integrity protection for the access stratum (AS) security.

The RRC protocol supports the transfer of the NAS signaling. It also performs functions to manage radio resources efficiently: Broadcasting of system information. The RRC connection setup, reconfiguration, re-establishment and release. The radio bearer setup, modification and release.

The NAS protocol of a UE communicates with that of an MME through the radio link and the LTE-Uu interface. This protocol is responsible for EPS mobility
management and bearer management. The NAS protocol handles attach, detach and tracking area update procedures. The eNB only relays the messages without processing when NAS signaling messages are transmitted between the UE and the MME.

The S1-MME interface follows the IP model.

- L1 is commonly implemented with a fixed cabling for example optical fiber.
- L2 is a medium access technology, such as Ethernet.
- The Internet protocol (IP) routes the signaling and user data messages through the backbone and EPC.
- The stream control transmission protocol is a transport protocol to transport the public switched telephone network (PSTN) signaling messages over IP networks. This protocol provides reliable delivery of application messages.
- S1-AP is an application protocol which supports S1 interface management, E-UTRAN radio access bearer (E-RAB) management, NAS signaling transport and UE context management. It delivers the initial UE context to the eNB to setup E-RABs and manages the UE context. S1-AP is also used to exchange signaling messages between eNB and MME. It includes procedures, for example handover and radio bearer configuration.

2.1.2.2 User Plane Protocols

Fig 2.5 illustrates the interfaces and protocol structure of the user plane. The LTE-Uu interface is similar to the control plane air interface with the exception of IP data packets in place of RRC and NAS signaling.
The user datagram protocol (UDP) is a simple unreliable transport protocol without ordered delivery, duplicate detection and congestion control. Reliable transmission assumed to be conducted by the upper level protocols.

GTP-U (General Packet Radio Service tunneling protocol user plane) is used to tunnel the user IP packets through the EPC. It also carries information related to QoS, charging and mobility.

Unlike the other EPC protocols, GTP is specified by the 3GPP to fit the needs of a mobile core. It was first introduced in the GPRS packet network. GTP faced some resistance during the EPS standardization process, since all the other protocols were IETF standards. The resistance was mostly due to the fact that being a 3GPP protocol, GTP might not perform well with other, non-3GPP access networks. Note that, the UDP/IP protocol block in Fig 2.5 is used for routing only in the EPC. The actual user IP data packet is tunneled on top the GTP-U protocol to the P-GW. From there it is sent onwards to an external network over the SGi interface.
Table 2.2. NAS and RRC states.

<table>
<thead>
<tr>
<th>Layer</th>
<th>State</th>
<th>Entity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMM</td>
<td>EMM-Deregistered</td>
<td>UE, MME</td>
<td>UE is detached and no EMM context has been established in UE and MME. The MME doesn’t know valid location of the UE, and may keep some UE context.</td>
</tr>
<tr>
<td></td>
<td>EMM-Registered</td>
<td>UE, MME</td>
<td>UE has been attached and an IP address has been assigned to the UE. An EMM Context has been established and a default EPS Bearer Context has been activated in UE and MME. The MME knows the location of the UE with the accuracy of a cell or a tracking area (TA).</td>
</tr>
<tr>
<td>ECM</td>
<td>ECM-Idle</td>
<td>UE, MME</td>
<td>There exists no NAS signalling connection (ECM connection) between UE and MME, and no UE context held in E-UTRAN(eNB). The MME knows the location of the UE with the accuracy of a TA.</td>
</tr>
<tr>
<td></td>
<td>ECM-Connected</td>
<td>UE, MME</td>
<td>There exists a NAS signalling connection (ECM connection) between UE and MME. The ECM connection is made up of a RRC connection and a S1 signalling connection. The MME knows the location of the UE with the accuracy of a cell.</td>
</tr>
<tr>
<td>RRC</td>
<td>RRC-Idle</td>
<td>UE, eNB</td>
<td>RRC connection has not been established.</td>
</tr>
<tr>
<td></td>
<td>RRC-Connected</td>
<td>UE, eNB</td>
<td>RRC connection has been established.</td>
</tr>
</tbody>
</table>
2.1.3 NAS and RRC States

Table 2.2 and Fig 2.6 shows NAS and RRC states and transition between them, respectively [15], [16].

- **EMM-Deregistered, ECM-Idle and RRC-Idle states**

When a UE is switched on for the first time after subscription, the UE and MME and eNB is in the EMM-Deregistered, ECM-Idle and RRC-Idle states. If UE is switched on after a long time after the power has been turned off, there exists no UE context in the UE and MME. However, if the UE is switched on within a certain period of time after the power has been turned off or ECM connection is released during communication due to radio link failure, the serving MME and the UE hold contexts to avoid an authentication and key agreement (AKA) procedure. The network entities transit to this state when the UE is detached, attachment procedure is rejected, tracking area update (TAU) is rejected, radio link is failed, or the power of the UE is turned off.

- **EMM-Registered, ECM-Connected and RRC-Connected states**

In this states, UE is attached to the network (MME) and using its necessary services because all the bearers and connections are established. And, the mobility of UE is maintained by handover procedure.

- **EMM-Registered, ECM-Idle and RRC-Idle states**

If the UE is no traffic to transmit or receive, the states are transit to this states. In this states, the UE is connected with an MME, but can not using any services.
2.1.3.1 RRC-Idle state

In the RRC-Idle state, the UE can be identified in EPC and have IP address. The UE can receive a paging message from EPC when downlink traffic is arrived or system information is changed, because the MME also knows the TA of the UE. The mobility management is performed by UE-based cell selection and re-selection after system information acquisitions from MIB and SIB packet broadcasting of eNBs.

2.1.3.2 RRC-Connected state

In the RRC-Connected state, the EPC and the serving eNB have contexts of the UE. And, the location of UE is known on cell level. The serving eNB manages the mobility of the given UE by handover procedures. Therefore, the UE has to perform the channel quality indicator (CQI) feedback, measurement and measurement reporting to the serving cell.
2.1.4 Measurement and Measurement Report

2.1.4.1 Measurement Quantities

- Reference signal received power

The reference signal received power (RSRP) is a metric indicates cell specific signal strength. This measurement is used mainly to rank different candidate target cells according to their signal strength during handovers, cell selection and re-selection procedures. RSRP is defined as the linear average over the power contributions of the resource elements (REs) which carry cell-specific reference signal (RS) from a certain eNB within the considered frequency bandwidth. RSs generally transmitted on the first antenna port.

- Received signal strength indicator

The LTE carrier received signal strength indicator (RSSI) is defined as the total received power observed by the UE from all sources, including co-channel serving and non-serving cells, adjacent channel interference and thermal noise within the measurement bandwidth [10]. LTE carrier RSSI is not reported as a measurement, but is used as an input to measure the RSRQ.

- Reference signal received quality

The reference signal received quality (RSRQ) is a cell-specific signal quality metric. Similarly to RSRP, this metric is used mainly to evaluate the ranks of different LTE candidate target cells according to their signal quality. The RSRQ value is used as an
input parameter for handovers, cell selections and re-selections. For intra-E-UTRAN handover, the RSRP is primary criteria for mobility decisions. However, we can also consider RSRQ if it is required, for example in case for which RSRP measurements do not provide sufficient information to perform reliable mobility decisions. The RSRQ is defined as follows

\[ RSRQ = \frac{N \cdot RSRP}{RSSI} \]  

(2.1)

where \( N \) is the number of resource blocks (RBs) of the LTE carrier RSSI measurement bandwidth. The measurements in the numerator and denominator are made over the same set of resource blocks. While RSRP is an indicator of the signal strength, RSRQ additionally takes the interference level similar to the signal to interference plus noise ratio (SINR). Therefore, RSRQ enables both effects of signal strength and interference to be reported in an efficient way.

- Signal to interference plus noise ratio

The signal to interference plus noise ratio (SINR) is a traditional and popular metric in information theory and telecommunication engineering but not included in 3GPP specifications. It can be represented as follows

\[ SINR = \frac{S}{I + N}, \]  

(2.2)

where \( S \) is the signal strength, \( I \) is the summation of interferences from all sources, and \( N \) is thermal noise. The difference between RSRQ and SINR is that the RSSI
which is denominator of RSRQ, contains signal power term from measurement object, whereas the denominator of SINR does not contains signal power. In practice, RSRQ is more simple to measure than SINR because we have to remove signal power term from total received power within considered frequency band.

- Layer 3 filtering

The measurement quantity, RSRP is measured periodically and filtered by a first order infinite impulse response (IIR) filter as defined in (2.3) [17–19]

\[
F_n = (1 - a) \cdot F_{n-1} + a \cdot M_n,
\]

where \(F_n\) and \(F_{n-1}\) are current and previous updated filtered measurement result, which is used for evaluation of reporting criteria or for measurement reporting. \(M_n\) is the latest measured value of signal. Filtering performs from first measurement in physical layer, \(F_0 = M_1\). And, \(a = 1/2^{k/4}\) where \(k\) is the filter coefficient for the corresponding measurement quantity.

### 2.1.4.2 Measurement Report

UEs report measurement quantities for serving and detected neighboring cells to the serving eNB periodically or by triggering events which are defined in [17]. Table 2.3 shows predefined events for measurement triggering.

A UE enter event A1 when the measured value of its serving cell becomes better than threshold, \(\delta\). \(hys\) is hysteresis parameter to prevent severe fluctuation. Event A2 is when the RSRP or RSRQ of serving cell becomes worse than \(\delta\). Therefore, we
<table>
<thead>
<tr>
<th>Event</th>
<th>Description and condition</th>
</tr>
</thead>
</table>
| A1    | Serving becomes better than threshold  
|       | Entering: $M_s - hys > \delta$  
|       | Leaving: $M_s + hys < \delta$ |
| A2    | Serving becomes worse than threshold  
|       | Entering: $M_s + hys < \delta$  
|       | Leaving: $M_s - hys > \delta$ |
| A3    | Neighbor becomes offset better than serving  
|       | Entering: $M_n + ofn + ocn - hys > M_s + ofs + os - o_{A3}$  
|       | Leaving: $M_n + ofn + ocn + hys < M_s + ofs + os - o_{A3}$ |
| A4    | Neighbor becomes better than threshold  
|       | Entering: $M_n + ofn + ocn - hys > \delta$  
|       | Leaving: $M_n + ofn + ocn + hys < \delta$ |
| A5    | Serving becomes worse than threshold1 and neighbour becomes better than threshold2  
|       | Entering 1: $M_s + hys < \delta_1$  
|       | Entering 2: $M_n + ofn + ocn - hys > \delta_2$  
|       | Leaving 1: $M_s - hys > \delta_1$  
|       | Leaving 2: $M_n + ofn + ocn + hys < \delta_2$ |

can use this event when we decide to handover to better cell. Event A3 is commonly used as handover triggering condition because this event occurs when a UE find neighboring cell which have better signal than the of current serving cell. $M_n$ and $M_s$ are the measured values of neighboring and serving cell, respectively. There are number of offset parameters: $ofn$ and $ofs$ are frequency specific offset for the frequency of the neighboring cell and serving cell, respectively. And, $ocn$ and $ocs$ are cell specific offset for the neighboring cell and serving cell, respectively. $o_{A3}$ is the
offset for A3 event. A UE enter event A4 if the measured value of neighboring cell becomes better than a certain threshold. A5 event is a combination of A2 and A4 event. This event also can be considered as a handover triggering event.

When a UE entered one of event entering condition, the UE start time to trigger (TTT) counter. And, it track the measurement values satisfy the leaving condition of the event. If the given UE stays in the event until TTT counter is terminated, it report the measurement result to the serving eNB. TTT timer parameter is one of following values: 0 ms, 40 ms, 64 ms, 80 ms, 100 ms, 128 ms, 160 ms, 256 ms, 320 ms, 480 ms, 512 ms, 640 ms, 1024 ms, 1280 ms, 2560 ms and 5120 ms [17].

2.1.5 Mobility Procedures

2.1.5.1 Mobility Procedures in RRC IDLE State

UEs do not have active signaling connection to the network when a UE is in the RRC IDLE state. Therefore, mobility procedures in this state are divided into three categories: Public Land Mobile Network (PLMN) selection, cell selection and re-selection, and location management.

- PLMN selection

Once a UE is turned on, it scans all of the E-UTRA carrier frequencies and searches for the strongest neighboring cell. Then, the UE acquire the cell specific system information packets from broadcasting of given cells. The UE selects the best PLMN according to acquired information of neighboring cells and information saved in its subscriber identity module (SIM) card.
Cell selection and re-selection

After the selection of the public land mobile network (PLMN), UEs decide the carrier frequency and cell which it should camp on. This decision is the cell selection in Fig 2.7. If the information about previous carrier usage is available, the UE searches target cells within the carrier frequency. If not, UEs try to scan all possible carrier frequencies and search for the strongest cell in the PLMN by using cell selection criteria. The primary criterion for cell selection or re-selection is radio link quality and can be represented in (2.4) and (2.5) as follow

\[ S_{\text{rxlev}} = Q_{\text{rxlevmeas}} - (Q_{\text{rxlevmin}} - Q_{\text{rxlevminoffset}}) \]  

(2.4)
and

\[ S_{\text{qual}} = Q_{\text{qualmeas}} - (Q_{\text{qualmin}} - Q_{\text{qualoffset}}), \]  

(2.5)

where \(Q_{\text{rxlevmeas}}\) and \(Q_{\text{qualmeas}}\) are the measured cell received signal level value and cell signal quality value; reference signal received power (RSRP) and reference signal received quality (RSRQ). \(Q_{\text{rxlevmin}}\) and \(Q_{\text{qualmin}}\) are the minimum threshold which is required to be served by a given cell. \(Q_{\text{rxlevminoffset}}\) and \(Q_{\text{qualoffset}}\) are offsets may be configured to prevent ping-pong. The parameters for cell selection, \(Q_{\text{rxlevmin}}, Q_{\text{qualmin}}, Q_{\text{rxlevminoffset}}\) and \(Q_{\text{qualoffset}}\) can be obtained by system information block 1 (SIB1). If both of measured values, \(Q_{\text{rxlevminoffset}}\) and \(Q_{\text{qualoffset}}\) fulfill \(S_{\text{rxlev}} > 0\) and \(S_{\text{qual}} > 0\), the given cell is selected by the given UE. The UE capability, the subscriber type, and the cell type can also be considered during cell selection or re-selection.

- Tracking area update

The UE in RRC-idle state, reports its location on the level of TA for the paging procedure from EPC. If UE is also in EMM-Registered state, it will inform its own TA when it crosses to other TA by tracking area update (TAU) procedure. TAU is also performed periodically. Therefore, MME can send paging message to UE by sending it for the tracking area identity (TAI) which the given UE belongs to. A TAI is allocated to a group of adjacent cells.
2.1.5.2 Mobility Procedures in RRC Connected State

UEs have active signaling and data bearers with EPC network. And, the location of UEs registered in a unit of network cell. Therefore, the mobilities of UEs are performed by the handover procedure. A handover can be initiated by handover command from serving cell or signal measurement of serving cell and neighboring cells by UEs as shown in Fig 2.8. Handover procedures can be performed through S1 or X2 interface. S1-based handover procedure is default in 3GPP LTE and LTE-Advanced system. X2-based handover can be performed if X2 interfaces between the serving and target eNB are available. In this section, detailed handover procedure is described with focusing on S1-based handover. X2-based handover is also similar but it is faster than S1-based handover because signaling message exchanges between the serving and target cells are performed directly via X2 interface without delays in the EPC network.
2.1.5.3 Mobility in HMNs

Fig 2.9 shows an example of handover between macro cells based on A3 event. If a UE moves from macro cell 1 to macro cell 2, the RSRP will cross because the transmission power of two eNBs is similar. When the RSRP of macro cell 2 became larger than that of the serving cell by hysteresis, the TTT timer is started. If the RSRP of macro cell 2 is larger than that of the serving cell minus hysteresis during the TTT duration, the handover procedure is initiated by measurement report from the UE to the serving eNB as described in Section 2.1.4. However, there is a critical difference in a HMN because of the imbalance between the transmission powers of macro and small cells. In general, the transmission power of macro cell base station is 43, 46 or 49 dBm according to system bandwidth. And, the transmission power of small cells
Figure 2.10. A3-based handover between macro and small cells

is less than or equal to 30 dBm: 10, 20, 23 or 30 dBm according to the type of small cells [9]. Therefore, the gap between transmission powers is from 20 to 39 in dB scale. This means that the transmission power of a macro cell base station is from 20 to 8000 times stronger than that of small cells. If a small cell is deployed in the coverage of a macro cell as shown in Fig 2.10, the RSRP may not just cross simply. In the example of Fig 2.10, normal A3 event condition can not be satisfied because of huge difference in transmission power. Therefore, the CRE offset is introduced. The CRE offset biases mobilities of UEs toward small cells. We have to adjust the CRE offset value very carefully; if CRE offset is too large, UEs associate with small cells but RLF occurs often. And, UEs can not associate small cells if the CRE offset configured too small. There is also another problem related to the narrow coverage of small cells. The A3-event condition have to fulfilled during TTT duration to perform
handover. However, if the TTT is too large, the condition will be broken before the TTT timer expiration.

2.2 Literature Survey

In this section, previous works related to mobility management in mobile networks including HMNs are presented.

Jansen et al. proposed the weighted performance-based handover parameter optimization (WPHPO) algorithm [20], [21]. They used the number of radio link failures (RLFs), the number of handover failure and the number of ping-pong handovers as performance metrics. And, a handover performance is defined by weighted summation of these metrics as following

$$ HP = \frac{w_{RLF} \cdot RLF + w_{HOF} \cdot HOF + w_{HPP} \cdot HPP}{w_{RLF} + w_{HOF} + w_{HPP}}, $$

(2.6)

where $RLF$, $HOF$ and $HPP$ are the number of RLF, handover failures and ping-pong handovers, respectively. $w_{RLF}$, $w_{HPP}$ and $w_{RLF}$ are weighting parameters for them. WPHPO aims to minimize $HP$ by control parameters, hysteresis and TTT in A3 event based handover. Balan proposed an enhanced WPHPO (EWHPO) to improve the convergence time of WPHPO scheme [22], [23]. The EWHPO changes control parameters only if the $HP$ degrades more than a threshold in the unit of percentage. However, they consider to change of control parameters only if $HP$ decreases. Weight values for each performance metric are not considered to be changed. Moreover, they overlooked that the RLF, handover failures and ping-pong handovers may
have correlations between them.

Lobinger proposed the load balancing (LB) handover to minimize the number of handover failures by admission control of the target cell because of its cell load [24]. In the LB handover scheme, the serving cell estimate the cell load of target cell after handover execution from cell capacity by prediction of SINR and the required resources of the UE. To estimate cell capacity they use the Shannon’s capacity formula. If the predicted cell load of target eNB after the given handover execution is under the pre-configured threshold, the serving cell adjust cell specific offset for handover decision. The serving cell iterates this procedure for all potential target cells to find optimum cell specific offset which may force UEs to handover to the given target cell. And, he also proposed a combination of the WPHPO and LB scheme in [25]. However, they need channel information to predict SINR after handover. Moreover, the predicted cell load from the Shannon’s formula, does not contain cell load information because the 3GPP LTE system use the OFDMA technology. We need the resource which the given UE will be allocated. And, the information of resource usage status and resource allocation and scheduling schemes is required to estimate the possible resource after handover for the given UE.

Munoz introduced a fuzzi-logic-based SON algorithm to optimize mobility parameters in a multi-RAT HMN [26]. In this scheme, the network observes performance metrics: the call dropping ratio, signaling loads and the number of handovers. The objective function is the linear combination of these metrics. The fuzzi-logic-based SON algorithm adjusts threshold for each RAT by Q-learning method to maximize the objective function.

– 45 –
Peng proposed a pico cell fast leaving and attaching limitation schemes to minimize handover to wrong cell [27]. Peng focused on the different types of handovers in HMNs: macro-to-macro, macro-to-small, small-to-macro and small-to-small cell handovers. The fast pico cell leaving scheme reduces the value of TTT parameter if the serving cell is a small cell and the target cell is a macro cell. And, the pico cell attaching limitation scheme prevents to handover to a small cell when the angle between the given UE’s moving direction and line form the UE to the target small cell is larger than a threshold. However, Peng did not consider the speed of UE. Moreover, the reduced TTT may cause frequent handovers or radio link failure.

Peng used the wide-band SINR as handover decision parameter to estimate quality of cell signals in [28]. He formulated the wide-band SINR from measured RSRP of the serving and neighboring cells, as shown in following equation

$$SINR_{WB} = 10 \log \left( \frac{RSRP}{\sum_{k=1, k \neq i}^{k} RSRP + \sigma^2} \right),$$  \hspace{1cm} (2.7)

where $i$ is cell index of the measurement target cell. And, A3 event based handovers are taken according to this wide-band SINR estimation. The number of RLF, handover failure and short ToS occurrences are considered as performance metrics. However, RSRP represent the signal power of the reference signal. Therefore, $SINR_{WB}$ may not show the actual quality of the shared channels which are used for the transmission of user traffics. Moreover, 3GPP LTE specification already defined RSRQ as measurement metric of the signal quality as mentioned in Chapter 2.1 Section 2.1.4. Actually, RSRQ has similar physical meaning with $SINR_{WB}$ except that
it contains the RSRP of the measurement target cell in its denominator.

Jin solved user association problem to maximize the network-wide utility under consideration of the ABS inter-cell interference coordination and a global proportional fairness scheduling schemes [29]. Jin modeled network utility as log scale function of long-term throughput which can calculated from the Shannon’s capacity and SINR. Jin solved this problem by proof that the optimal ABS density is the proportion of the number of vulnerable users and total users.

Bayat proposed a distributed user association and small cell deployment scheme in HMN with an optimization theory [30]. He modeled HMNs as a dynamic matching game between UEs, small cells and service providers. He solved cell selection problem to maximize the sum Shannon’s capacity which is a function of the SINR, of the whole network with consideration of small cells power control and resource allocation to mitigate inter cell interferences. He also modeled satisfaction level of users which increases with their achievable rate and decreases when the minimum required rate is not fulfilled. If the satisfaction rate is low the users move to other service provider. Therefore, the service providers compete to satisfy their subscribers in terms of achievable rate in this model. Nevertheless of the novel network modeling, this study have some limitations such as lack of consideration of real communication system.

Lee proposed a cost-based adaptive handover hysteresis scheme to minimize the number of the handover failures in 3GPP LTE system under consideration of cell loads, the speed of user and the service type which users are served [31]. In this scheme, the hysteresis value of A3 event based handover is dynamically adjusted
according to the equation as follows

\[ H = H_{\text{default}} + \alpha (w_l \cdot N_l + w_v \cdot N_v + w_s \cdot N_s), \]  

(2.8)

where \( w_l, w_v \) and \( w_s \) are weight values for load difference between the target and serving cells, respectively. \( N_l \) is the difference of occupied bandwidth between the target and serving cells which are exchanged through X-2 interface. \( N_v \) is introduced to suppress the handover trials of the slow moving UE, and formatted as

\[ N_v = 1 - 2 \frac{v}{v_{\text{max}}}, \]  

(2.9)

where \( v \) is the speed of user and \( v_{\text{max}} \) is the maximum speed. \( N_s \) indicates the difference between numbers of non-real time and real time services because real-time services are more delay-sensitive.

Munoz introduced a joint control scheme of a hysteresis to minimize ping-pong handovers, and an offset for load balancing in A3 event based handover for load balanced cell association [32]. Three performance metrics are defined. The first is handover ratio as follows

\[ \text{HOR} = \frac{N_{\text{HO}}}{N_{\text{succ}}} \]  

(2.10)

where \( N_{\text{HO}} \) and \( N_{\text{succ}} \) are the number of handovers in the given area and the number of successful calls. And, the second is the call dropping ratio which is the ratio of the number of dropped calls, to the total number of finished calls. Munoz assumed that the call dropping occurs due to low SINR. The last is call blocking ratio which is the number of blocked calls due to a call admission control, over the number of
total offered calls. In the proposed scheme, A3 hysteresis is enlarged when the call dropping ratio exceeds a pre-configured threshold because the network assumes that the high call dropping ratio means the presence of many high-mobility users. And, when the call blocking ratio exceeds a threshold the network assumed that the cell load is too high. Therefore, the handover triggering offset increases. Moreover, the proposed scheme keep the value of one control parameter when the other parameter meets the limitation value to prevent the conflict between ping-pong minimization and load balancing schemes.

Moon focused on the large difference of transmission power between the macro and small cells [33]. Therefore, Moon proposed a handover scheme using combined received power of the serving and target cell as handover triggering value in macro to small cell handovers. The combined received power is as follows

\[ RSRP_{pro} = RSRP_{small} + \alpha RSRP_{macro}, \]  

where \( RSRP_{small} \) and \( RSRP_{macro} \) are RSRP of the target small cell and the serving macro cell, respectively. \( 0 \leq \alpha \leq 1 \). In the proposed scheme, \( \alpha RSRP_{macro} \) term acts similar to the CRE offset in 3GPP LTE system. UEs can handover to small cell although the signal strength of small cell is less than that of the serving macro cell. Moreover, this CRE offset is dynamically adjusted according to the signal strength change of the serving macro cell. Moon also considered the impact of combination factor \( \alpha \).

Xu proposed a wireless transmission loss-based handover algorithm in a macro-to-small cell handover [34]. In this scheme, UEs estimate the channel quality by
comparing the cell transmission power and the received power at a UE, and decision
to handover if the difference of target small cell is smaller than that of the serving
macro cell. This loss represents the pathloss and shadowing term. However, the
RSRP also includes the pathloss and shadowing term.

A Handover optimization scheme considering QoE performance for voice ser-
vice is proposed by Lee [35]. In the paper [35], he estimated mean opinion score
(MOS) by linearizing R-factor in the E-model standard of the International Telecom-
munication Union (ITU), and proposed a linearized R-factor-based handover mecha-
nism. In the proposed scheme, a UE measures SINR of the serving and neighboring
cells and calculates an optimal handover triggering value which maximize the R-
factor based on measured SINR.

Most of previous works are focused on the network or channel capacity which
can be obtained from the Shannon’s formula and SINR; Increasing SINR by control
or optimize parameters. Although most of conventional researches have aimed at
maximize capacity by maximization of SINR, we need only throughput to cover the
given users’ service traffics. This dissertation is focused on the performance those
affect the performance experienced by users, for example the interruption time and
service delay during mobility procedures.
Chapter 3. System Model

3.1 Reference Network Architecture

Figs. 3.1 and 3.2 show the reference network architecture used in this dissertation. As shown in Fig 3.1, interferences from two tier macro cells are considered. Performance evaluation is performed in the cell located at the center which is shown in Fig 3.2. A HMN with multi-tier small cells which are overlaying coverages of macro cell is considered. Fig 3.2 is an example of 3-tier small cells deployed scenario. Although the core network nodes are not explicitly represented in figures the impact of core network entities are reflected as delay and interruption time as described in the Section 3.5 of this chapter.

3.2 Mobility Procedures

The mobility procedure in this dissertation is based on A3 event-based handover procedure in 3GPP LTE/LTE-Advanced system. In this section, detailed procedures and simplified model to performance analysis are described.

Figs. 3.3, 3.4 and 3.5 show the detailed handover procedures. The handover procedure is composed of three phases: handover preparation, execution and completion. A UE continuously measures the RSRP and RSRQ of the serving and neighboring cells. When a measurement report is triggered by events described in Sec-
tion 2.1.4 or periodic triggering, the UE sends a measurement report to the serving cell; the triggering event is A3 event in general. Then the serving eNB evaluates reported measurement and makes decision whether or not to handover. If a handover is decided, the handover preparation phase is started.

In the handover preparation procedure, the serving cell sends a handover required message to the serving MME. Then, the MME performs the admission control procedure with the target cell and S-GW. If the target cell is in the coverage
of another MME, the admission control needs more delays to exchange signaling messages with that MME. A GTP tunnel to forward data traffic during handover execution is also made during the admission control. If the admission control procedure is succeeded, the serving MME sends a handover command to the serving eNB. The handover preparation phase is ended.

The handover execution phase starts with the transmission of RRC connection reconfiguration message including information about mobility control, from the serving eNB to the given UE. After receiving this message, the UE is detached from the
Figure 3.3. Handover preparation procedure.

serving eNB and the serving eNB starts to buffer traffic to the given UE. The serving eNB transmits its status to the MME and the MME transmits MME status to the target eNB. And, the UE tries to synchronize and random access to the target eNB. If the synchronization and random access are successfully finished, the target eNB allocates uplink resources to the given UE and new TA. Therefore, the UE can transmit RRC connection reconfiguration complete message through uplink channel. Now, the UE can be served both of downlink and uplink traffic but the downlink is only by indirect data forwarding from the serving cell. The serving eNB transmits RRC connection reconfiguration message to adjust UE’s measurement parameters and the UE acknowledges with RRC connection reconfiguration complete message.

In the handover completion phase, the target eNB informs that the handover execution is succeeded to the MME by sending a handover notify message. Then,
Figure 3.4. Handover execution procedure.

The MME switches the downlink path by sending modify bearer request to the S-GW. Now, the indirection data forwarding from the serving to the target cell is ended and the UE can be served both of uplink and downlink traffic from the target cell. When the serving cell receives a UE context release command from the MME, it releases the UE context and acknowledges to the serving MME with UE context release complete message. The MME and S-GW delete the GTP tunnel for data forwarding by exchange signaling messages.

The network mobility procedure is simply modeled as shown in Fig 3.6. This simplified mobility procedure model reflects most of procedures described above and in Chapter 2.1 Section 2.1.5.
3.3 L1 and L3 Measurement

In this dissertation, L1 and L3 filtering of measurement values (RSRP and RSRQ) are considered. UEs measure every sampling time, $T_s$. Then, L1 filtering is performed at the physical layer. L1 filtering scheme is simple linear averaging with sliding window which have window size $L_{\text{win}}$. The current value of L1 filtered measurement is as follows

$$M_{L1}(n) = \frac{\sum_{i=n-L_{\text{win}}+1}^{n} M(i)}{L_{\text{win}}},$$  \hspace{1cm} (3.1)

where $n$ is the sample index and $M(n)$ is instantaneous measured value at sampling time $n$. The L3 filter which is applied in this model can be represented as

$$M_{L3}(n) = (1-a) M_{L3}(n-1) + a \cdot M_{L1}(n),$$  \hspace{1cm} (3.2)
Figure 3.6. A simplified mobility procedure model.
where $M_{L3}(n)$ and $M_{L3}(n - 1)$ are current and previous updated filtered measurement result, which are used for evaluation of reporting criteria or for measurement reporting. $M_{L1}(n)$ is the latest measured value of signal. Filtering is performed from first measurement in physical layer, $M_{L3}(0) = M_{L1}(1)$. And, $a = 1/2^k$ where $k$ is 0 if no layer 3 filtering is applied and higher $k$ leads more smooth filtered measurement results.

### 3.4 Radio Link Failure and Handover Failure

In the LTE system, radio link failure is detected and handled as shown in Fig 3.7 [10]. If out of sync indications are received from L1 N310 times consecutively, a UE detects the radio problem and starts $T_{310}$ timer. And, $T_{310}$ is stopped if $N_{311}$ consecutive in-sync indications are reported from physical layer before $T_{310}$ time expired. However, a radio link failure occurs if $T_{310}$ is expired without $N_{311}$ in-sync indications. Then, $T_{311}$ timer is started to decide the RRC state; if a re-establishment procedure is succeeded within $T_{311}$ the UE maintains RRC connected state. Otherwise the UE is disconnected form network and become RRC idle state. In [36], $N_{310}$ out of sync indications are modeled as the condition that the average RSRQ over a sliding window of 200 ms is less than certain threshold, $Q_{\text{out}}$. Similarly, $N_{311}$
in-sync indications modeled as the average RSRQ over a sliding window of 100 ms is more than $Q_{in}$. In the simulation model of this dissertation, radio link problem is detected when L1 filtered RSRQ measurement for serving cell is below the $Q_{out}$. And, a UE detects a radio link failure and triggers re-establishment procedure if the L1 filtered RSRQ is maintains below $Q_{in}$ until $T_{310}$ expiration.

The reasons of handover failures can be divided to two categories: radio link failure and rejection from target base station. A target cell base station can deny handover during admission control procedure because of its cell capacity. In this dissertation, only failures of handover due to radio link state are considered. If the wireless link with serving base station has a radio link failure during handover preparation, the given handover procedure is failed. And, handover failure also occurred when a radio link failure in the link with the target base station during handover execution after the UE is detached from previous serving cell.

### 3.5 Delays and Service Interruptions during Mobility Procedures

The handover delay is defined as total delays for all procedures to decide and command a handover, and can be represented as follows [10], [17]

$$D_{HO} = D_{RRC\ procedure} + T_{\text{interrupt}}, \quad (3.3)$$

where $T_{\text{interrupt}}$ is

$$T_{\text{interrupt}} = T_{\text{search}} + T_{\text{RA}} + 20, \quad (3.4)$$
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Processing delay [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRC connection establishment</td>
<td>15</td>
</tr>
<tr>
<td>RRC connection release</td>
<td>0</td>
</tr>
<tr>
<td>RRC connection reconfiguration (radio resource configuration)</td>
<td>15</td>
</tr>
<tr>
<td>RRC connection reconfiguration (measurement configuration)</td>
<td>15</td>
</tr>
<tr>
<td>RRC connection reconfiguration (intra-LTE mobility)</td>
<td>15</td>
</tr>
<tr>
<td>RRC connection reconfiguration (SCell addition/release)</td>
<td>20</td>
</tr>
<tr>
<td>RRC connection reestablishment</td>
<td>15</td>
</tr>
<tr>
<td>Initial security activation</td>
<td>10</td>
</tr>
<tr>
<td>Initial security activation + RRC connection reconfiguration (RB establishment)</td>
<td>20</td>
</tr>
<tr>
<td>Paging</td>
<td>0</td>
</tr>
</tbody>
</table>

and $T_{\text{search}}$ is the time required to search the target cell when the target cell is not already known when the handover command is received by the UE. If the target cell is known, then $T_{\text{search}} = 0$ ms. If the target cell is unknown and signal quality is sufficient for successful cell detection on the first attempt, then $T_{\text{search}} = 80$ ms. In the interruption requirement, a cell is known if it has been meeting the relevant cell identification requirement during the last 5 seconds otherwise it is unknown. $T_{\text{RA}}$ is the interruption uncertainty in acquiring the first available PRACH occasion in the new cell. $T_{\text{RA}}$ can be up to 30 ms.
Table 3.1 shows RRC processing delay [17]. RRC processing delay indicates the number of 1ms subframes from the end of reception of the message from E-UTRAN to UE on the UE physical layer up to when the UE shall be ready for the reception of uplink grant for the response message from UE to E-UTRAN with no access delay other than the TTI-alignment (e.g. excluding delays caused by scheduling, the random access procedure or physical layer synchronization). Control plane latency which includes random access and processing time is also analyzed as shown in Table 3.2 in [37]. RACH and C-RNTI are random access channel and cell radio network temporary identifier, respectively. In this dissertation, the delay for handover preparation and execution is approximated as 100ms with consideration of Table 3.1 and Table 3.2.
Table 3.2. Control plane latency

<table>
<thead>
<tr>
<th>Description</th>
<th>Latency [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RACH Preamble</td>
<td>1</td>
</tr>
<tr>
<td>Preamble detection and transmission of RA response</td>
<td>5</td>
</tr>
<tr>
<td>(Time between the end RACH transmission and UE’s reception of scheduling grant and timing adjustment)</td>
<td></td>
</tr>
<tr>
<td>UE Processing Delay (decoding of scheduling grant, timing alignment and C-RNTI assignment + L1 encoding of RRC Connection Request)</td>
<td>2.5</td>
</tr>
<tr>
<td>TTI for transmission of RRC Connection Request</td>
<td>1</td>
</tr>
<tr>
<td>HARQ Retransmission (30 %)</td>
<td>$0.3 \times 5$</td>
</tr>
<tr>
<td>Processing delay in eNB (Uu $\to$ S1-C)</td>
<td>4</td>
</tr>
<tr>
<td>S1-C Transfer delay</td>
<td>2 $\to$15</td>
</tr>
<tr>
<td>MME Processing Delay</td>
<td>15</td>
</tr>
<tr>
<td>(including UE context retrieval of 10ms)</td>
<td></td>
</tr>
<tr>
<td>S1-C Transfer delay</td>
<td>2 $\to$15</td>
</tr>
<tr>
<td>Processing delay in eNB (S1-C $\to$ Uu)</td>
<td>4</td>
</tr>
<tr>
<td>TTI for transmission of RRC Connection Setup (+Average alignment)</td>
<td>1.5</td>
</tr>
<tr>
<td>Processing delay in UE</td>
<td>3</td>
</tr>
<tr>
<td>TTI for transmission of L3 RRC Connection Complete</td>
<td>1</td>
</tr>
</tbody>
</table>
Chapter 4. A Fast System Information Acquisition Schemes for Small Cells in 3GPP LTE Networks

Mobile communication has led to the introduction of heterogeneous deployment schemes such as small cells, relays and picocells to enhance both cell coverage and capacity and to mitigate interference. Heterogeneous deployment is one of the key features of 3GPP LTE/LTE-A systems. There are several optional base stations, one of which is the small cell. Femtocells have been the subject of studies. In addition, handover is an important topic in small cell networks [38], [39]. HeNB is a low power base station in the 3GPP LTE network. HeNBs operate only in the CSG mode in release 8. Therefore, only authorized users can access CSG HeNBs.

A UE does not need to acquire system information (SI) from a target cell in the LTE macro handover procedure because the UE can obtain the SI of the target macrocell from the network. However, a UE cannot obtain the SI from the network when performing handover to CSG small cells. Therefore, a CSG inbound handover requires SI acquisition from target HeNBs. However, there is no detailed procedure for SI acquisition for CSG inbound handover in the 3GPP technical specifications [17], [40], [41]. In this chapter, six possible methods for acquiring the SI of a CSG small cell are proposed. This chapter is partly published in the IEEE Communications Letters [42].
4.1 System Information for 3GPP LTE/LTE-A System

The SI includes system parameters required for a UE to connect to the network: the master information block (MIB), system information block type 1 (SIB1) and other SI messages as shown in Table 4.1. An MIB message contains essential information such as downlink bandwidth, hybrid automatic retransmission request (HARQ) channel configuration and system frame number (SFN) information. An SIB1 message contains information related to cell selection, CSG identity (ID) and scheduling information for SIB2–13 [17]. A UE needs MIB, SIB1 and SIB2 to camp on a certain cell. And, traditional macro cell environment do not require system information packets during cell detection because UEs can identify neighboring macro cells by physical cell identity from primary synchronization signal (PSS) and secondary synchronization signal (SSS). However, UEs need to acquire MIB and SIB1 from its neighboring small cells in HMN environment because following reasons; First, we need SIB1 which contains CSG identity if neighboring small cells are CSG cells. And, MIB is needed to acquire SIB1. Second, UEs need to SIB1, even if neighboring cells are OSG cell because the physical cell ID which can be obtained from PSS and SSS is not a unique identifier. The physical cell ID can be re-used due to the fact that it has only 504 different values. Therefore, acquisition of MIB and SIB1 packets is essential for handover of UEs to search neighboring small cells.

MIB and SIB1 messages are periodically broadcast by an eNB. The SI broadcasting scheduling in the time domain is as shown in Fig. 4.1. The length of a sub-
<table>
<thead>
<tr>
<th>SIBs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIB</td>
<td>• Parameters which are essential for a UE’s initial access to the network.</td>
</tr>
<tr>
<td>SIB1</td>
<td>• Parameters needed to determine if a cell is suitable for cell selection.</td>
</tr>
<tr>
<td></td>
<td>• CSG identification.</td>
</tr>
<tr>
<td></td>
<td>• Information about the time-domain scheduling of the other SIBs.</td>
</tr>
<tr>
<td>SIB2</td>
<td>• Common and shared channel information.</td>
</tr>
<tr>
<td>SIB3-8</td>
<td>• Parameters used to control intra-frequency, inter-frequency and inter-RAT cell re-selection.</td>
</tr>
<tr>
<td>SIB9</td>
<td>• Signal the name of a HeNBs.</td>
</tr>
<tr>
<td>SIB10-12</td>
<td>• ETWS notifications and CMAS warning messages.</td>
</tr>
<tr>
<td>SIB13</td>
<td>• MBMS related control information.</td>
</tr>
</tbody>
</table>

Table 4.1. System information blocks.

frame is 1 ms; 10 subframes compose a frame. MIB message packets are generated every four frames and replicas are transmitted for every frame. The time for packet generation and transmission of SIB1 is twice that for MIB. Other SI might be transmitted aperiodically or with their own cycles.

While synchronization between eNBs and HeNBs became mandatory in 3GPP LTE release 9 and 10 [43], the synchronization is an open issue in release 8. There-
fore, LTE small cells can be synchronous or asynchronous. Each cell broadcasts its own MIB and SIB1 at the same time in the synchronous case but at different times in the asynchronous case. In this chapter, six schemes to acquire SI packets are proposed. The first five schemes, introduced in section 4.2, can be used in both synchronous and asynchronous cases. The last scheme, introduced in section 4.3, can only be used in the asynchronous case. Here, I considered only asynchronous LTE small network case in both mathematical analysis and simulation because the results of performance evaluation is obvious for the synchronous case: all the neighboring cells will cause delay about a SI broadcast period. Multiple cells can transmit SI packets at the same time without collision because MIBs are transmitted on a non-colliding channel (Physical Broadcast Channel). SIB packets are carried on a contending data channel (Physical Downlink Shared Channel). However, UEs can obtain timing and channel information of the Physical Downlink Shared Channel from MIB packets. Therefore, there is no collision because the UE already knows about the concurrent broadcasting and acquires one of them at the next time.
4.2 Serial System Information Acquisition Methods

A UE searches for neighboring cells periodically when is still connected to a particular cell. The UE has to disconnect from the serving eNB to acquire SI from the target eNB, and therefore the user cannot be provided any service during this acquisition period. The service interruption time due to this acquisition is called the measurement gap. A UE cannot request a handover decision from its serving cell until the end of SI acquisition for all neighboring cells. In mathematical analysis, the average service interruption time ($T_{\text{gap}}$) and acquisition delay ($T_{\text{delay}}$) are formulated.

Possible SI acquisition schemes can be classified on the basis of two criteria. The first criterion is the presence of scheduling. A UE can acquire SI messages during the measurement gaps scheduled by its serving cell. However, UEs decide their own measurement gaps in autonomous schemes and can interrupt their connection to the serving cell if they find strong neighboring cells. This autonomous acquisition can cause service interruption without negotiation with the serving eNB. However, higher layers (MAC or application) can deal with these interruptions by retransmission or queueing in the serving eNB. LTE specification document contains the autonomous acquisition [17]. However, the details are left completely to implementation issue. The second criterion is the distribution of measurement gaps. A UE can acquire MIB and SIB1 messages from a cell during a long gap or two separate short gaps.
4.2.1 Scheduled Acquisition with a Large Gap

In the scheduled acquisition with a large gap (SALG) scheme, a UE acquires the MIB and SIB1 from a cell during a long measurement gap, $T_{\text{gap}}$ as shown in Fig 4.2 and Fig 4.3. The average of $T_{\text{gap}}$ is

$$T_{\text{gap}} = \sum_{n=0}^{\infty} (p_{e\text{MIB}})^n (1 - p_{e\text{MIB}}) nT_{\text{MIB}} + W_{\text{SIB1}}$$

$$+ \sum_{m=0}^{\infty} (p_{e\text{SIB1}})^m (1 - p_{e\text{SIB1}}) mT_{\text{SIB1}},$$

(4.1)
Figure 4.3. An example of the scheduled acquisition with a large gap scheme

where $T_{\text{MIB}}$ and $T_{\text{SIB1}}$ are the times spent during acquisition of MIB and SIB1 packets, respectively. The average value of $T_{\text{MIB}}$ is 5 ms because of the broadcasting period. The average value of $T_{\text{SIB1}}$ is 1 ms because the RRC message transmission latency is 1 ms [44]. $p_{\text{eMIB}}$ and $p_{\text{eSIB1}}$ are the packet error rates of the MIB and SIB1 packets, respectively. $W_{\text{SIB1}}$ is the waiting time for an SIB1 packet after MIB acquisition; its average value is $W_{\text{SIB1}} = \frac{1}{2} (5 + 15) = 10ms$ because 5 ms and 15 ms are the possible intervals between an MIB and a SIB1 packet, as shown in Fig. 4.1.

The UE requests for scheduling of a measurement gap by transmitting a measurement result message to its serving eNB. Then, the serving eNB returns an RRC connection reconfiguration message with the measurement gap assignment information to the UE. Finally, the UE acknowledges this by sending an RRC connection reconfiguration complete message. $T_{\text{delay}}$ is the time from cell detection to SI acqui-
sition for all neighboring cells; its average value is given by

\[
T_{\text{delay}} = 2 \cdot T_{\text{RRC}} + T_{\text{gap}} + T_{\text{RRC}} + T_{\text{gap}} \\
\quad + \cdots + T_{\text{gap}} + T_{\text{RRC}} \\
= n_{\text{cell}} \cdot T_{\text{gap}} + (2n_{\text{cell}} + 1) \cdot T_{\text{RRC}},
\]

(4.2)

where \(T_{\text{RRC}}\) is the time needed to exchange an RRC message, and \(n_{\text{cell}}\) is the number of detected neighboring cells. We assume that \(T_{\text{RRC}}\) is approximately 10 ms because it is the length of a frame.

### 4.2.2 Autonomous Acquisition with a Large Gap

![Diagram of autonomous acquisition with a large gap scheme](image)

Figure 4.4. Procedure of the autonomous acquisition with a large gap scheme
Figure 4.5. An example of the autonomous acquisition with a large gap scheme

In the autonomous acquisition with a large gap (AALG) method, a UE disconnects from its serving cell when candidate neighboring eNBs are detected without scheduling message exchanges; it then acquires MIB and SIB1 packets. The procedure and an example of AALG scheme is shown in Fig 4.4 and Fig 4.5, respectively. The measurement gap is the same as in (4.1). The average acquisition delay is derived by

\[
T_{\text{delay}} = T_{\text{gap}} + \cdots + T_{\text{gap}} + T_{\text{RRC}}
\]

\[
= n_{\text{cell}} (T_{\text{gap}}) + T_{\text{RRC}}. \quad (4.3)
\]

4.2.3 Scheduled Acquisition with Several Small Gaps I

The scheduled acquisition with several small gaps I (SASG1) method is almost the same as the SALG method. However, in SASG1, a UE acquires MIB and SIB1
Aquisition Delay

- strong neighbor cell detected
- packet data
- initial access control
- HO decision
- Detecting PSS/SSS

[RSS: cell ID, SSS: cell group ID]

- RRC: Measurement Report
  - MeasResults message: rsrpResult, rsrqResult
- MIB: Gap Configuration for MIB
  - RRCConnectionReconfiguration message: measConfig
- Response for the Acquisition
  - RRCConnectionReconfiguration Complete message: rrc-TransactionIdentifier

- acquire MIB on measurement
  - Gap indicated by eNB
- MIB
  - MIB message: systemFrameNumber
- SIB: Gap Configuration for SIBType1 Acquisition
  - RRCConnectionReconfiguration message: measConfig
- Response for the Acquisition
  - RRCConnectionReconfiguration Complete/Failure message

- acquire SIBType1 on measurement
  - Gap indicated by eNB
- SIBType1
  - SIB message: cellIdentity, csg-Identity, schedulingInfoList

- Service interruption

- Service interruption

- initial access control
- RRC: Measurement Report
  - MeasResults message: physCellId, cgi-Info, additionalSI-Info-r9

- HO decision

Figure 4.6. Procedure of the scheduled acquisition with several small gaps I scheme
Figure 4.7. An example of the scheduled acquisition with several small gaps I scheme packets with small measurement gaps for each packet as shown in Fig 4.6 and Fig 4.7. Therefore, the average measurement gap is obtained as

\[ T_{\text{gap}} = \frac{1}{2} T_{\text{acquire.MIB}} + \frac{1}{2} T_{\text{acquire.SIB1}}, \]  

(4.4)

\[ T_{\text{acquire.MIB}} = \sum_{n=0}^{\infty} (p_{e\text{MIB}})^n (1 - p_{e\text{MIB}}) n T_{\text{MIB}}, \]  

(4.5)

and

\[ T_{\text{acquire.SIB1}} = \sum_{n=0}^{\infty} (p_{e\text{SIB1}})^n (1 - p_{e\text{SIB1}}) n T_{\text{SIB1}}, \]  

(4.6)
where $T_{\text{acquire,MIB}}$ and $T_{\text{acquire,SIB1}}$ are the times needed to acquire MIB and SIB1 packets, respectively. The average acquisition delay is given by

$$T_{\text{delay}} = 2 \cdot T_{\text{RRC}} + T_{\text{MIB}} + 2 \cdot T_{\text{RRC}} + W_{\text{SIB1}} + T_{\text{SIB1}}$$

$$+ 2 \cdot T_{\text{RRC}} + \cdots + W_{\text{SIB1}} + T_{\text{SIB1}} + T_{\text{RRC}}$$

$$= n_{\text{cell}} \left( T_{\text{MIB}} + W_{\text{SIB1}} + T_{\text{SIB1}} \right)$$

$$+(4 \cdot n_{\text{cell}} + 1) \cdot T_{\text{RRC}}.$$

(4.7)

### 4.2.4 Scheduled Acquisition with Several Small Gaps II

The SASG2 method is a hybrid method in which a UE requests a measurement gap for MIB acquisition from the serving eNB. After MIB acquisition, the UE acquires SIB1 autonomously as shown in Fig 4.8 and Fig 4.9. The UE knows the time slot when the SIB1 packet will be transmitted and the serving eNB knows that the maximum measurement gap for a single cell is 25 ms. The measurement gap is the same as that in (4.4) and the delay can be represented as

$$T_{\text{delay}} = 2 \cdot T_{\text{RRC}} + T_{\text{MIB}} + W_{\text{SIB1}} + T_{\text{SIB1}}$$

$$+ 2 \cdot T_{\text{RRC}} + \cdots + W_{\text{SIB1}} + T_{\text{SIB1}} + T_{\text{RRC}}$$

$$= n_{\text{cell}} \left( T_{\text{MIB}} + W_{\text{SIB1}} + T_{\text{SIB1}} \right)$$

$$+(4 \cdot n_{\text{cell}} + 1) \cdot T_{\text{RRC}}.$$

(4.8)

### 4.2.5 Autonomous Acquisition with Several Small Gaps

Autonomous acquisition with several small gaps (AASG) involves two or more small gaps, and not a single large gap. When a UE detects strong neighboring cells,
Figure 4.8. Procedure of the scheduled acquisition with several small gaps II scheme
it interrupts the connection with its serving cell until successful acquisition of MIB as shown in Fig 4.10 and Fig 4.11. The UE can predict the time when the target cell will transmit an SIB1 packet, because the UE obtains SFN information from the MIB acquisition. Therefore, the UE needs only one small additional measurement gap to acquire SIB1. The measurement gap is the same as (4.4). And, the delay can be calculated as follows:

$$T_{\text{delay}} = T_{\text{MIB}} + W_{\text{SIB1}} + T_{\text{SIB1}} + T_{\text{MIB}} + W_{\text{SIB1}} + T_{\text{SIB1}} + T_{\text{RRC}} \cdots$$

$$= n_{\text{cell}} (T_{\text{MIB}} + W_{\text{SIB1}} + T_{\text{SIB1}}) + T_{\text{RRC}}. \quad (4.9)$$
Aquisition Delay

strong neighbor cell detected
choose sub-frames autonomously for MIB acquisition
packet data

autonomously for SIB1 acquisition
packet data

Receiving MIB
[MIB message : systemFrameNumber]

Receiving SIB1
[SIB1 message : cellIdentity, csg-Identity]

initial access control

RRC Measurement Report
[MeasResults message : physCellId, cgi-Info, additionalSI-Info-r9]

HO decision

Figure 4.10. Procedure of the autonomous acquisition with several small gaps scheme
Figure 4.11. An example of the autonomous acquisition with several small gaps scheme

4.3 Parallel SI Acquisition Method

In this section, the autonomous acquisition with the parallel small gaps (AAPSG) scheme is proposed. The objective of this method is to acquire the SI of all detected neighboring cells as quickly as possible for asynchronous small cells. This method is a parallel scanning method as shown in Fig 4.12, whereas the other five methods in section 4.2, are serial scanning methods. In other words, a UE acquires the SI of all the neighboring cells in a given amount of time, instead of in a cell-by-cell fashion as in the other schemes. The AAPSG scheme uses the differences in the SI time schedules between small cells. First, the UE acquires the MIB packets from all the target cells. Then, the UE sorts the target cells in the order of the expected SIB1 arrival time. When the UE sorts the target cells, the UE considers consecutive
Algorithm 1 The AAPSG algorithm

1: procedure AAPSG
2:   if strong neighbor cells detected then
3:     for i ← 1, n do  \(\triangleright n\) is the number of strong neighbor cells
4:       acquire (MIB,cell i)
5:   end for
6:   sort (cell list,order of expected SIB1 timing)
7:   for i ← 1, n do  \(\triangleright n\) is the number of strong neighbor cells
8:     acquire (SIB1,cell i)
9:   end for
10:  measurement report (s-cell,cell i)
11: end if
12: end procedure

SIB1 packets transmitted from multiple cells. In other words, if SIB1 packets from two cells are transmitted at the same time, the UE will receive one of the packets at the next transmission time. The UE acquires SIB1 packets in the order of the arrival time. Algorithm 1 is the pseudo code of the proposed AAPSG method. The measurement gap is the same as in (4.4). For AAPSG, the average delay can be derived as follows:

\[
T_{\text{delay}} = T_{\text{MIB.all}} + W_{\text{SIB1}} + T_{\text{SIB1.all}} + T_{\text{duplicate}} + T_{\text{RRC}}, \tag{4.10}
\]

where \(T_{\text{MIB.all}}\) and \(T_{\text{SIB1.all}}\) are the duration required to receive the MIB and SIB1 packets from all neighboring cells, respectively. The mean value of \(T_{\text{MIB.all}}\) is \(n_{\text{cell}} \cdot 1/2 \cdot (1 + 10)\) because the minimum and maximum MIB time differences between cells are 1 ms and 10 ms, respectively. The UE acquires SIB1 packets from all
neighboring cells in the order of SIB1 scheduling time. Therefore, the mean value of $T_{\text{SIB1.all}}$ is $1/2 \cdot (n_{\text{cell}} + 20)$, because SIB1 packets are broadcast every 20 ms. $T_{\text{duplicate}}$ is the delay caused by collision of SI packets when multiple cells transmit SI packets at the same time. We analyze the mean value of $T_{\text{duplicate}}$. For example, if the number of detected neighboring cells is four, $T_{\text{duplicate}}$ is given by

$$T_{\text{duplicate}} = \sum_{i=1}^{\infty} 20 \cdot i \cdot p_{\text{SIB1}}(i), \quad (4.11)$$

where $p_{\text{SIB1}}(i)$ is the probability that the UE needs more time to receive $i$ overlapped SIB1 packet(s) in the time domain. (4.11) contains a constant of 20, because the UE needs $20i$ more milliseconds if $i$ cells broadcast their SIB1 at the same time. We analyze $p_{\text{SIB1}}(i)$ in a case by case manner. For example, if $n_{\text{cell}}$ is 4, $p_{\text{SIB1}}(i)$ is given
by

\[ p_{\text{SIB1}}(1) = \binom{n_{\text{cell}}}{2} \left( \frac{1}{20} \right)^2 \left( \frac{19}{20} \right)^{n_{\text{cell}}-2} , \quad (4.12) \]

\[ p_{\text{SIB1}}(2) = \binom{n_{\text{cell}}}{3} \left( \frac{1}{20} \right)^2 \left( \frac{19}{20} \right)^{n_{\text{cell}}-2} + \binom{n_{\text{cell}}}{2} \binom{n_{\text{cell}} - 2}{2} \left( \frac{1}{20} \right)^2 \left( \frac{18}{20} \right)^{n_{\text{cell}}-4} , \quad (4.13) \]

\[ p_{\text{SIB1}}(3) = \binom{n_{\text{cell}}}{4} \left( \frac{1}{20} \right)^4 \left( \frac{19}{20} \right)^{n_{\text{cell}}-4} , \quad (4.14) \]

where (4.12) indicates the probability that two neighboring cells broadcast SIB1 packets at the same time. In this case, the UE will experience 20ms additional delay to receive a SIB1 packet in next broadcasting period. On the other hand, (4.13) implies the probability that three neighboring cells broadcast SIB1 packets at the same time or, two pairs of neighboring cells broadcast SIB1 packets at the same time. In these cases, the UE needs additional time of 40ms to receive two SIB1 packets in next broadcasting periods. Finally, (4.14) indicates the probability that four neighboring cells broadcast SIB1 packets at the same time. In this case, there will be 60ms additional delay.

### 4.4 Performance Evaluation

Both of mathematical analysis and simulations have been performed to evaluate the performance of the proposed methods. \( P_{\text{eMIB}} \) and \( P_{\text{eSIB1}} \) are assumed to be very small in the mathematical analysis, because RRC messages have a very low error.
Table 4.2. Simulation parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of HeNBs</td>
<td>6</td>
</tr>
<tr>
<td>Number of UEs</td>
<td>1</td>
</tr>
<tr>
<td>Inter-site distance</td>
<td>500 m</td>
</tr>
<tr>
<td>System frequency</td>
<td>2GHz</td>
</tr>
<tr>
<td>System bandwidth</td>
<td>FDD:10+10MHz</td>
</tr>
</tbody>
</table>

**Propagation loss model**
- Inside the same cluster
  \[ L = 127 + 30 \log_{10} R \]
- For other link
  \[ L = 128.1 + 37.6 \log_{10} R \]

**Shadowing model**
- Lognormal shadowing

**Shadowing standard deviation**
- 10 dB for link between HeNB and HeNB UE
- 8 dB for other links

**Penetration loss**
- Inside the same cluster: 0 dB
- All other links: 20 dB

rate. Table 4.2 shows the parameters that were used in both the mathematical analysis and simulation.

The random waypoint model is one of the most popular mobility model [45–47]. In this model, a mobile node randomly chooses destination within the simulation area for every movement. The speed of movement is also chosen randomly. In other words, the mobile node choose random destination and speed until the simulation is terminated. The random direction mobility model is a variant of the random waypoint model [48]. In the random direction model, the mobile node randomly chooses the distance of movement and direction. The random direction model with fixed speed and zero pause time is considered in this dissertation. An example of the random
direction model with two mobile nodes is shown in Fig 4.13

Figure 4.13. The mobility model.

Figs. 4.14, 4.15, 4.16, 4.17, 4.18 and 4.19 show the performance of SALG, AALG, SASG1, SASG2, AASG and AAPSG schemes, respectively. Service interruption time and delay are considered as performance metrics.

Fig. 4.20 shows the average values for the service interruption time. The $x$ and $y$-axes represent the algorithm used and the service interruption time, respectively. Using large gaps can cause service interruption for approximately 14 ms in each measurement gap, whereas using small gaps will cause only approximately 4 ms of interruption during each acquisition, as shown in Fig. 4.20. However, the small gap
Figure 4.14. Delay and service interruption time of scheduled acquisition with a large gap scheme.
Figure 4.15. Delay and service interruption time of autonomous acquisition with a large gap scheme.
Figure 4.16. Delay and service interruption time of scheduled acquisition with several small gaps I scheme.
Figure 4.17. Delay and service interruption time of scheduled acquisition with several small gaps II scheme.
Figure 4.18. Delay and service interruption time of autonomous acquisition with several small gaps scheme.
Figure 4.19. Delay and service interruption time of autonomous acquisition with parallel small gaps scheme.
schemes cause two short service interruptions for each neighboring cell, whereas the large gap schemes cause one service interruption for each cell. In other words, the small gap schemes cause a burst of small service interruptions and the large gap schemes cause a large interruption. However, these interruptions are smaller than the requirements for either conversational or streaming services [49].

Fig. 4.21 shows an example of acquisition delay when there are six neighboring cells. The mathematical analysis and simulation show similar results. Acquisition delay is a major component in the handover delay. In fig. 4.21, the SASG1 and AAPSG schemes show the worst and best delay performance, respectively. However, there is a trade-off: because the autonomous schemes can cause service interruption without agreement between the UE and its serving cell, data packets can be dropped.
in the downlink channel. The performance of practical system might show the same trend with results of performance evaluation in this chapter, although there can be difference in scale because of the different system parameters.

4.5 Summary

SI acquisition is an essential part of handover procedures when a user moves to a CSG cell. In this chapter, six possible SI acquisition schemes are proposed and analyzed. Scheduled methods are appropriate when the user needs highly reliable services, whereas autonomous methods are more efficient when the user needs a fast handover decision because of dynamic environmental changes around the user. The choice between small-gap and large-gap schemes represents a trade-off between
a burst of small service interruptions and a long service interruption. Therefore, we can use a large gap or several small gaps according to the network condition. The results show that the AAPSG scheme shows the best delay and interruption performance. Therefore, the AAPSG scheme can be a good choice when the network conditions are good enough. The proposed schemes can be adopted directly to the LTE asynchronous small cell networks. Moreover, the serial methods can be used also in the LTE synchronous small cell network or LTE-A network.
Chapter 5. Time-of-Stay Estimation-based Cell Selection Scheme in Multitier Heterogeneous Mobile Networks

The handover procedure is one of the most important factors that influences the performance of mobile networks. Specifically, a handover is important in the heterogeneous mobile networks (HMNs) because of the limited coverages of various types of small cells (SCs). Several researchers have studied mobility robustness optimization [50] schemes to optimize the handover procedure. Most of them have focused on the optimization of the handover parameters, e.g., time-to-trigger, offset and hysteresis, according to the measurement results of signal quality [51], [52]. The 3GPP has analyzed the reasons that affect the effectiveness of handovers. Too late handover triggering, too early handover triggering, handover to a wrong cell, and frequent handovers [50] are some of the major reasons. Our argument is that a very short association, which is not sufficient to support users’ service, is a type of wrong handover. In such a case, a given user equipment (UE) may perform frequent handovers with a high probability in HMNs. In this chapter, minimization of the number of such wrong handovers without causing service disruption, is main goal.
5.1 Problem Definition

The ToS can be defined as the period of a connection between a UE and a certain BS [36]. A short ToS (sToS) occurs when a UE associates with a BS for a very short period and therefore service quality may be degraded for the UE. In other words, if the ToS of a user for the given cell is very small, we call this phenomenon as an sToS. The sToS condition can be described as (5.1)

\[
\{\text{short time of stay} \mid T_{oS} < \delta_{sToS}\},
\]

where \(T_{oS}\) and \(\delta_{sToS}\) are the ToS and a minimum threshold to judge by an sToS, respectively.

In conventional mobile networks, for example, LTE networks, the network mobility procedures have following characteristics: Service interruptions may occur during the cell search procedure if the small cell BSs operate at different frequencies with macro cell BSs. Moreover, frequent system information acquisitions and measurement reports are network overheads even though macro cell and small cell BSs operate at the same frequency. Additionally, handover procedures lead to additional service interruptions and delays. An handover failure or a link failure after a handover, requiring roll-back to the previous serving cell or cell re-selection also causes service interruptions and additional delays. An sToS can cause various network overheads related with network mobility procedures because the given UE tries to maintain its connection with the network. Consecutive sToS occurrences mean that the given UE performs frequent handovers including ping-pong handovers. Moreover, each handover procedure contains a cell information acquisition, control message
exchanges between network entities, a service interruption during random access procedure, and a data forwarding between previous and new serving BSs. In other words, sToS associations lead to an increase in the number of handovers, delays, and service interruptions.

Therefore, an sToS avoidance can improve the performance of the mobile network, especially if the network is an HMN. In this chapter, a scheme to minimize the number of sToS HOs by the estimation of the ToS is proposed. Performance comparison of the proposed scheme with that of a conventional scheme, which is used in the 3GPP LTE system, was performed.

5.2 System Model

Fig. 5.1 shows the reference network architecture with the number of cell tiers, \( n_{\text{tier}} = 4 \): macrocell (MC), microcell (MiC), picocell (PC), and femtocell (FC) tiers. We made several assumptions for ensuring the simplicity of the analytic model. Macro cells are traditional hexagonal models with three sectors because macro cells are deployed depending on the service provider’s plan. The coverage area of small cells is circular and depends on the transmission power of the BS, radio channel, and cell selection criteria. BSs in the same small cell tier use the same transmission power. The density of each small cell tier is constant; the density is the number of small cells in a MC sector. The location of nodes are random within a cluster. Nevertheless, the coverage areas of small cells do not overlap because the transmission power of small cell BSs are small enough and the minimum distance between BSs
Figure 5.1. A reference architecture of an HMN model with $n_{\text{tier}} = 4$.

was set according to [9].

We assumed the mobility pattern of users as a random waypoint model [53] with a constant speed to evaluate the performance according to the speed of UEs. A UE moves straight in an SC coverage area because the coverage area of an SC is small enough.
5.3 Proposed Cell Selection Scheme

The objective of this study is to minimize the number of wrong HOs due to sToS. Therefore, an estimated ToS-based cell selection scheme (ETCS) is proposed to avoid sToS HOs. Algorithm 2 represents the ETCS scheme where \( n \), \( q_{\text{serving}} \) and \( q_{\text{min.req.}} \) are the number of detected cells, the signal quality of serving cell BS, and the minimum required signal quality, respectively. In the ETCS scheme, the cell in which the sToS is expected to occur is removed from the candidate cell list, once it is detected during neighboring cell search. However, if the signal quality of the serving cell is poor, the ETCS scheme does not operate to prevent radio link failures. Note that, the ETCS scheme does not influence on a handover to a macro cell because of the large coverage of macro cells.

To estimate the ToS for a detected neighbor cell, UEs need their own mobility information and transmission power of the given neighbor BS. In this scheme, we need only \( v_{\text{UE}} \) to estimate the mobility pattern and it is practical in real world scenarios, for example, by using the global positioning system (GPS). A ToS can be derived by dividing user’s moving distance into speed of UE. If we assume that the direction of a user’s movement is uniform, we can easily estimate the mean ToS using (5.2):

\[
E\{T_{oS}\} = \frac{1}{\pi} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{2r_s \cos \theta}{v_{\text{UE}}} d\theta = \frac{4r_s}{\pi v_{\text{UE}}},
\]

(5.2)

where \( r_s \) and \( \theta \) are the radius of SC coverage and the angle between the horizontal line in Fig 5.2 that contains the center of SC coverage (location of the BS) and the user’s direction, respectively. Now, we can predict the sToS by substituting (5.2) in
Algorithm 2 Estimated ToS-based cell selection

1: procedure ETCS
2:  if strong neighbor cells are detected then
3:    put detected cells in candidate list
4:  for \( i \leftarrow 1, n \) do
5:    if \( q_{\text{serving}} > q_{\text{min.req.}} \) then
6:      estimate \( (T_{\text{os}}) \)
7:      if sToS then
8:        remove cell tier from candidate list
9:      end if
10:   end if
11:  end for
12:  evaluate (candidate & serving cells)
13:  select the best cell
14: end if
15: end procedure

(5.1) as follows:

\[
\frac{4r_s}{\pi \nu_{\text{UE}}} < \delta_{\text{sToS}}. \tag{5.3}
\]

5.4 Performance Analysis

A 3GPP LTE networks with four cell tiers are considered as shown in Fig 5.1:

Cell tier indices are \( k = 1, 2, \cdots, 4 \) for MC, MiC, PC, and FC, respectively. Fig.5.1 shows the system model for analysis when the number of MC sectors is three \( (n_{\text{sector}} = 3) \). Fig.5.1 is an example when \( \rho_2 = 1, \rho_3 = 2 \) and \( \rho_4 = 3 \), where \( \rho_k \) is the density of cell tier \( k \), which means the number of \( k \)-tier BSs in an MC sector.

We evaluated the performance of the ETCS scheme with two performance met-
rics: number of HOs and ToS occurrences. First, the probability that a user is in the coverage area of an SC can be obtained from the ratio of the small cell coverage to the macro cell sector coverage areas, as follows:

$$\Pr(\text{a UE is in an SC coverage}) = \frac{\pi r_s^2}{\frac{1}{\sqrt{3}} r_m^2} = \frac{2\pi r_s^2}{\frac{3}{\sqrt{3}} r_m^2}, \quad (5.4)$$

where $r_m$ is the length of a side of an MC as shown in Fig 5.1. A UE will try to HO if a neighbor cell with strong signal quality is detected and selected. We assume that SCs have higher priority than MCs for cell selection. This assumption makes sense because SCs offer advantages for both users and service providers in terms of costs and offloading; some SC biasing schemes have been introduced recently, for example, the cell-range expansion [54]. Therefore, the expected number of HOs to $k$-tier SC BSs during time $t$ is derived by

$$n_{\text{HO},k}(t) = E\{\text{number of HOs in } k\text{-tier during } t\}$$

$$= 2 \times \frac{2\pi \rho_{\text{UE}} \rho_k r_k^2}{3 \sqrt{3} r_m^2} \cdot \frac{E\{T_{\text{os}}\}}{T_{\text{search}}} \cdot t \cdot \frac{T_{\text{search}}}{T_{\text{search}}}, \quad (5.5)$$

where $T_{\text{search}}$ is the cell search period. (5.5) can be rewritten by substitution (5.2) as
follows:

\[ n_{\text{HO},k}(t) = \frac{\pi^2 \rho_{\text{UE}} \rho_k \bar{r}_k v_{\text{UE}} t}{3 \sqrt{3} r_m^2}. \quad (5.6) \]

Therefore, the number of HOs in the entire HMN overlapped with an MC coverage during time \( t \) can be obtained by

\[
    n_{\text{HO}}(t) = \mathbb{E}\{\text{number of HOs during } t\} = n_{\text{sector}} \sum_{k=1}^{n_{\text{ tiers}}} n_{\text{HO},k}(t). \quad (5.7)
\]

Similarly, the expected number of sToS occurrences in an MC coverage is given by

\[
    n_{s\text{ToS}}(t) = \mathbb{E}\{\text{number of sToS occurrences during } t\} = n_{\text{sector}} \sum_{k=1}^{n_{\text{ tiers}}} n_{s\text{ToS},k}(t), \quad (5.8)
\]

where \( n_{s\text{ToS},k}(t) \) is the expected number of sToS occurrences in \( k \)-tier SCs during time \( t \). The condition of sToS occurrence, (5.3) can be rewritten in terms of the radius of SCs and the speed of users as

\[
    v_{\text{UE}} > \frac{4r_s}{\pi \delta_{s\text{ToS}}}. \quad (5.9)
\]

Equation (5.9) involves the user speed, \( v_{\text{UE}} \). Now, we can estimate the number of expected sToS in an MC sector as follows:

\[
    n_{s\text{ToS},k}(t) = \left[ v_{\text{UE}} > \frac{4r_s}{\pi \delta_{s\text{ToS}}} \right] \frac{\pi^2 \rho_{\text{UE}} \rho_k \bar{r}_k v_{\text{UE}} t}{6 \sqrt{3} r_m^2}, \quad (5.10)
\]

where \([\cdot]\) is the Iverson bracket which denotes a number that is one if the condition in square brackets is satisfied, or zero otherwise.

In the proposed ETCS scheme, UEs eliminate the cell tiers that are expected to
Table 5.1. Network Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System bandwidth</td>
<td>$2$ MHz</td>
<td>2 MHz</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>$f_c$</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Propagation speed</td>
<td>$c$</td>
<td>$3 \times 10^8$ m/s</td>
</tr>
<tr>
<td>Number of RE</td>
<td>$n_{RE}$</td>
<td>1200</td>
</tr>
<tr>
<td>Min. required $P_{RS}$</td>
<td>$P_{\text{min,req.}}$</td>
<td>-70 dBm</td>
</tr>
<tr>
<td>Cell search period</td>
<td>$T_{\text{search}}$</td>
<td>200 ms</td>
</tr>
<tr>
<td>sToS threshold</td>
<td>$\delta_{sToS}$</td>
<td>10 s</td>
</tr>
</tbody>
</table>

Table 5.2. Parameters related to BSs and UEs.

<table>
<thead>
<tr>
<th>Cell type</th>
<th>$k$</th>
<th>$P_{tx}$</th>
<th>$h$</th>
<th>$g_k$</th>
<th>$r_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC</td>
<td>1</td>
<td>46 dBm</td>
<td>25 m</td>
<td>17 dBi</td>
<td>250 m</td>
</tr>
<tr>
<td>MiC</td>
<td>2</td>
<td>30 dBm</td>
<td>10 m</td>
<td>5 dBi</td>
<td>67.1 m</td>
</tr>
<tr>
<td>PC</td>
<td>3</td>
<td>20 dBm</td>
<td>2 m</td>
<td>5 dBi</td>
<td>23.6 m</td>
</tr>
<tr>
<td>FC</td>
<td>4</td>
<td>10 dBm</td>
<td>1.5 m</td>
<td>5 dBi</td>
<td>10.4 m</td>
</tr>
<tr>
<td>UE</td>
<td>N/A</td>
<td>23 dBm</td>
<td>1.5 m</td>
<td>0 dBi</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The parameters used during performance analysis are listed in Table 5.1 and Table 5.2 [36], [9]. $r_k$ for each SC tier is derived as shown in Table 5.2 when $P_{\text{min,req.}} = -70$ dBm. $P_{\text{min,req.}}$ is the minimum required received power to provide services suf-

5.5 Numerical Results

The parameters used during performance analysis are listed in Table 5.1 and Table 5.2 [36], [9]. $r_k$ for each SC tier is derived as shown in Table 5.2 when $P_{\text{min,req.}} = -70$ dBm. $P_{\text{min,req.}}$ is the minimum required received power to provide services suf-

cause the sToS phenomenon, from the candidate target cell list. In other words, UEs do not HO to SCs that satisfy (5.9). Finally, the expected number of HOs is given by

$$n_{\text{HO},k}(t) = \left[ v_{\text{UE}} \leq \frac{4r_s}{\pi \delta_{sToS}} \right] \frac{\pi^2 \rho_{\text{UE}} \rho_k r_k v_{\text{UE}} t}{3 \sqrt{3} r_m^2}. \quad (5.11)$$
Figure 5.3. Number of handovers during one hour with the conventional scheme.

The urban micro channel model is used [9]. The received signal power is derived by

\[ P_{\text{RS}} = P_{\text{tx}} + g_{\text{BS}} \cdot PL + g_{\text{UE}} - 10 \cdot \log_{10}(n_{\text{RE}}), \]  

(5.12)

where \( PL, g \) and \( n_{\text{RE}} \) are the path loss, the antenna gain and the number of resource elements, respectively. \( P_{\text{RS}} \) is a similar index with the reference signal received power in the 3GPP LTE system used for cell selection and HO decision. Now, \( r_s \) can be derived as the radius of coverage area of an SC BS. The boundary of SC coverage is determined by \( P_{\text{RS}} \) and \( P_{\text{min.req.}} \). Therefore, the average cell coverage (\( r_k \)) for each of the cell tiers is calculated as shown in Table 5.2, where the minimum required signal strength for sufficient service is -70 dBm.
The number of HOs in an MC coverage is shown in Fig 5.3. In the analysis, the ratio of SC BS density assumed as fixed value: $\rho_2 : \rho_3 : \rho_4 = 1 : 5 : 10$, and $0 \leq \rho_2 \leq 10$. The speed of the UE ranges from 0 to 65 km/h. The number of HOs increases as the density of SCs becomes high. Moreover, the higher $v_{\text{UE}}$ also increases $n_{\text{HOs}}$ because $T_{\text{oS}}$ decreases according to the increase in the UE’s speed. We calculated the estimated number of sToS occurrences where the sToS threshold is 10 s in a macrocell coverage. Generally, 10 s is the value used when we define the ping-pong HO [51]. The sToS phenomenon does not occur when UEs move at very low speeds. Nevertheless, a UE experiences an sToS when it passes through the coverage areas of BSs with smaller transmission power even if given UEs are moving at lower speeds, while only high-speed UEs experience the sToS when they pass through the higher power SCs. Therefore, Fig 5.4 shows a step-like shape according to the increase of $v_{\text{UE}}$.

In the proposed ETCS scheme, the UE estimates $T_{\text{oS}}$ and eliminates the cells with the possibility of the sToS from the candidate target cell list. Therefore, the number of HOs is reduced as $v_{\text{UE}}$ increases. The peaks in Fig 5.5 appear when $v_{\text{UE}}$ satisfies the sToS condition (5.1). Fig 5.6 shows the cross sections of Fig 5.3, 5.4, and 5.5 when $\rho_2 = 1$, $\rho_3 = 5$, and $\rho_4 = 10$. Note that $n_{\text{HOs}}$ includes HO executions, system information acquisitions, HO preparations, and network overheads related to mobility management that can cause service interruptions and delays.

Simulations have been performed to evaluate more performance metrics. A certain worst case scenario is considered for the feasibility of simulation. Three tiers of small cells are deployed as circle form at the edge of macro cell coverage as shown
Figure 5.4. Number of sToS occurrences during one hour with the conventional scheme.
Figure 5.5. Number of HOs during one hour with the ETCS scheme.
in Fig 5.7: two micro cells, four pico cells and 12 femto cells. The diameter of the circle is 900 m and 1000 m for scenario 900r and 1000r, respectively. During the simulation time, UEs move along the circle.

Simulation results are shown in following figures from Figs. 5.8 to 5.10. The first performance metric, association rate which means the number of associations for one second is shown in Fig 5.8. In the conventional scheme, the association rate increases as the speed of UE increases. However, the proposed ETCS scheme reduces the association rate of UEs that move with high speed because it suppress associations to small cells which are predicted to cause short ToS occurrences. The
(a) Whole network.

(b) Interesting area.

Figure 5.7. Circular movement simulation scenario.
differences between scenarios are due to the density of small cells; the same number of small cells are deployed on the different size of circle line.

The sToS rate is the number of short time of stay occurrences in one second. Fig 5.9 shows the short ToS rate. Short ToS rate also increases with the speed of UE. And, the proposed scheme also prevents short ToS occurrences. Note that, most of short ToS occurrences in the proposed scheme is due to the re-establishment after radio link failures.

The RLF rate is defined as the number of radio link failure occurrences in one second. And, Fig 5.10 shows the results. We can see that the RLF rate is reduced although the proposed ETCS scheme forces UEs to do not associate with small cells.
when the short ToS is predicted. It is natural that the signal qualities of macro cells are mostly better than those of small cells if the UE is in the macro cell coverage because of the imbalance of transmission power as mentioned in section 2.1.5.3: 46, 30, 20 and 10 dBm for macro, micro, pico and femto cells in this simulations as shown in Table 5.2.

Simulations with random waypoint mobility were also performed as shown in Fig 5.11. 19 macro cell base stations and the same num of three-tier small cells are deployed as same as circular movement scenario but small cells are located randomly within interesting area as shown in Fig 5.11b. UEs move with random waypoint mobility pattern during simulation time, six hours [45–47]. An example of user’s
Results shown in Figs. 5.12, 5.13 and 5.14 are The association rate is shown in Fig 5.12. In the random waypoint scenario, the association rate does not increase linearly as the speed of UE increases, but still high enough with the conventional scheme; there is randomness due to the random mobility. Moreover, values of the association rate are less than circular movement scenario because UEs spend more time out of coverages of small cells in random waypoint mobility. The association rate is reduced by the proposed ETCS scheme than that of the conventional scheme. The short ToS and RLF rate also have similar pattern with that of the association rate as shown in Figs. 5.13 and 5.14, respectively.

Figure 5.10. RLF rate (number of RLFs/sec).
Figure 5.11. Random waypoint simulation scenario.
Figure 5.12. Association rate (number of associations/sec).

All the performance metrics are improved by the proposed ETCS scheme. Nevertheless, there might be several trade-offs, for example, in power consumption, offloading or cost of users and/or network service providers: If UEs are forced to associate with macro cells, the distance between a UE and the serving base station becomes longer. Power consumption of the given UE will be increased if the UE controls the transmission power for uplink traffic. Moreover, more traffics from numbers of users can be concentrated into the macro cell base stations and the core network as much as UEs associate with macro cells. It means the increase of the operating cost of service providers. A user’s cost also might be increased with an assumption that the service fee to be served by small cells are less than that of macro cells. However,
Figure 5.13. Short time of stay rate (number of sToSs/sec).

the proposed scheme has advantages to maintain service quality for users. Moreover, the ETCS scheme can create a synergy effect if with dynamic power saving technologies for small cells; if there are numbers of fast moving users on a site, small cells in the given site might reduce their power or simply be turned off according to the condition.

5.6 Summary

The main contribution of this scheme is the introduction of ToS estimation into the cell selection procedure. We proposed the ETCS scheme to minimize the number of unnecessary HOs due to the sToS and compared the performance of the ETCS and
conventional cell selection schemes. Numerical results show that the ETCS scheme shows a smaller number of HOs: The ETCS scheme reduces service interruptions and delays to perform system information acquisitions, HO preparations, and message overheads to support mobility procedures.
Chapter 6. Conclusion

The small cell is one of key technologies for both of increasing network capacity and extending the network coverage with low cost by densifying network cells in B4G and 5G networks. However, there are many challenges to entirely derive the advantages of the heterogeneous mobile network. For example, inter-cell interferences which become more critical because of high density of small cells and the imbalance between transmission powers of macro cells and small cells. Network mobility procedures also heavily influence to the performance of heterogeneous mobile networks. Cell re-selections, handovers and connection re-establishment can be performed more often, and affect on the QoS and QoE as overheads including additional delays and service interruptions. These overheads may degrade the performances of network not only on the physical layer but also on the upper layers. This performance degradation may be more serious, especially under complex wireless interference condition in the HMN with dense small cells. In this dissertation, mobility management schemes to enhance network performance in HMNs which include deployment of multi-tier dense small cells overlaying coverage of macro cells.

In Chapter 4, a fast parallel system information acquisition scheme is proposed. In the macro cell environment, UEs search neighboring cells by measure the signal strength and receiving synchronization signals. However, UEs need to acquire system information which is essential to connect a certain cell, during neighboring cell
search in a dense small cell deployment scenarios because UEs need CSG information in the SIB2 to confirm whether the given cell is available for the UE or not. Moreover, physical ID from synchronization signals is not a unique identity because there can be one or more base stations which use the same physical ID. Therefore, UEs have to acquire system information of cells by receiving and decoding the master information block and system information block packet by itself. Moreover, a UE searches multiple neighboring cells up to eight. This system information acquisition causes delay and service interruption times. In the conventional schemes, UEs acquire system information cell by cell, i.e. serial manner. Therefore, a parallel system information acquisition scheme is proposed to minimize performance degradation due to system acquisition.

In Chapter 5, a cell selection scheme based on the estimated time of stay is proposed. Network mobility procedures, for example handovers, cell re-selection, and connection re-establishment after a radio link failure, involve network overheads such as control message exchanges, delay and service interruption times as mentioned above. In conventional mobility scheme, cell selection for mobility procedure execution performed mainly according to signal strength; reference signal received power (RSRP) in the 3GPP LTE mobility. It is unavoidable and inherent characteristic of highly dense HMNs, that frequent network mobility procedures are triggered for mobile UE. Frequent network mobility procedures will cause severe performance degradation. In this dissertation, the time of stay estimation based on users moving speed and transmission power of base stations, is introduced into the cell selection scheme. The time of stay is the duration from the time when a UE associate with
a certain base station of certain cell to the time when the UE disconnects from the
given base station. Therefore, UEs avoid unnecessary association which may cause
very short time of stay.

The contributions of this dissertation is as follows:

- A general model for multi-tier heterogeneous mobile networks has been pre-
sented.

- System information acquisition schemes has been described and classified which
  are not explicitly mentioned in 3GPP technical documents.

- A parallel information acquisition scheme has been proposed to reduce delay
  and service interruption time during mobility procedures.

- A cell selection scheme to reduce unnecessary associations by estimation of
  the time of stay from the speed of a user and transmission power of eNBs has
  been proposed.

Since the proposed schemes consider practical heterogeneous mobile networks,
and the results show remarkable performance enhancements, it is expected that pro-
posed schemes can be applied to not only 3GPP LTE and LTE-Advanced system but
also to the other future mobile network systems.
References


[49] *Quality of Service (QoS) concept and architecture*, 3GPP TS 23.107.


Summary

Mobility Management Schemes for Performance Enhancement in Heterogeneous Mobile Networks

As the 5G era of mobile communication begins, maintaining high-speed communication across various environments while maintaining high quality of service is crucial. This research explores the use of mobility management schemes to enhance performance in heterogeneous mobile networks.

The proposed schemes are designed to improve the efficiency and reliability of communication services by adapting to the varying conditions of different network environments. This includes optimizing roaming processes, efficient handoff management, and effective resource allocation strategies. The schemes aim to reduce latency, minimize network congestion, and ensure seamless communication across diverse network topologies.

The research paper contributes to the development of robust and versatile mobility management solutions that can be employed in future mobile communication systems. These schemes have the potential to significantly improve the user experience by providing faster and more stable connections, thereby enhancing the overall performance of mobile networks.
(physical cell ID)로는 해당 셀을 인식하는 것이 불가능할 수도 있기 때문이다. 물리 적 셀 아이디는 최대 504개의 값을 가지고 셀을 구분하기 때문에 HMN 환경에서는 다른 셀에서 같은 아이디를 재사용할 가능성이 있다. 최대 8개의 주변 셀이 동시에 탑색되는 LTE 시스템에서는 이러한 절차가 시스템 성능을 저해하는 오버헤드로 작용 가능하다. 본 논문에서는 이러한 환경에서 셀 탐색 시간을 최소화하기 위한 병렬 시스템 정보 획득 방법을 제안하였으며, 다른 여러 방법들과 함께 성능을 수학적 모델링 및 OPNET 시뮬레이션을 통하여 비교 분석하였다. 분석 시나리오는 오버헤드가 최대화 될 수 있는 소형셀 간의 동기화가 이루어지지 않은 환경에서 이루어졌으며, 분석 결과 제안한 병렬 수집 기법이 다른 방법들에 비해 시스템 정보 수집에 걸리는 지연 시간 및 서비스 중단 시간 모두 적게 나타나 성능향상이 있음을 확인 할 수 있었다.

셀 접속 유지 시간이란 단말이 하나의 기지국에 접속을 하였다가 무선 장애로 접속이 단절되거나 다른 기지국으로 핸드오버 하기까지 걸리는 시간을 의미한다. 무선 장애로 접속이 단절 될 경우 네트워크에 재접속 하기 위한 절차가 수행되며 그 동안 서비스를 받지 못할 뿐만 아니라 다시 접속 하기까지 지연 시간이 소요 된다. 또한 핸드오버에도 마찬가지로 주변 셀 탐색 및 기지국으로 보고, 셀 선택, 핸드오버 수행 하는 동안 지연 시간이 발생되며, 랜덤 접속을 위한 서비스 단절 시간 또한 발생한다. 따라서 같은 네트워크 이동 접속 수행은 네트워크 성능에 치명적인 영향을 끼칠 수 있다. 본 논문에서는 이러한 성능 저해를 최소화 하고자, 셀 접속 유지 시간을 고려한 셀 선택 기법을 제안하였다. 단말의 이동 속도 및 탐지된 주변 셀 기지국들의 전송 전력을 기반으로 탐지된 해당 셀 기지국에 접속했을 때 가능한 셀 접속 유지 시간을 추정하여 이를 기반으로 셀 선택 절차를 수행한다. 성능 평가를 위해 수학적 모델링을 통하여 기존의 신호 세기 기반 셀 선택 기법과
제안한 기법의 성능을 비교하였다. 분석 결과, 제안한 기법에서는 핸드오버나 네트워크 재접속 등의 네트워크 이동 절차 수행 횟수가 줄어들었으며, 셀 접속 유지 시간이 특정 값 이하로 발생하는 상황이 발생하지 않았다.

제안한 시스템 정보 획득 기법 및 셀 접속 유지 시간 추정 기반 셀 선택 기법은 실제 이동 통신에서의 현실적인 부분들이 고려되어 있고 성능 분석 결과에서도 기존의 기법들에 비해 괄목할 만한 성능 향상을 확인할 수 있었다. 따라서 제안한 기법들을 현재 널리 사용되고 있는 3GPP LTE 혹은 LTE-Advanced 통신망이나 향후 사용될 새로운 미래 통신망에 적용할 경우, 네트워크 성능 및 사용자 체감 성능 향상에 큰 도움이 될 것으로 기대된다.
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