Performance Analysis of Long Term Evolution (LTE) Network

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Ramprasad Subramanian declare that this thesis, is submitted in fulfilment of the requirements for the award of Master of Engineering by Research, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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ABSTRACT

The demand for high speed network has led to the development of LTE. The LTE replaced circuit switched legacy systems into packet switched network. The high speed simultaneous transmission of data is achieved by using Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink. To achieve high speed multimedia services in the downlink various packet scheduling algorithms have been proposed in the past. The LTE architecture has been simplified compared to 2G or 3G systems to a greater extent. The network elements namely Base Station Controller (BSC) and Radio Network Controller (RNC) have been replaced with eNodeB. The Radio Resource Management (RRM) functionality has been confined to eNodeB. To enable end users to achieve high data rates Heterogeneous Networks (HetNets) are used. In HetNets, the pico cells and femto cells work alongside the macro cells to deliver the required QoS. The objective of this thesis is to study the performance of LTE network through simulation and by observing the KPIs from real-time network.

The thesis starts with the performance analysis of downlink scheduling algorithms through simulations. The scheduling algorithms were simulated using NS-3 and LTE-Sim and various performance factors were studied. Thereafter, a model HetNet was simulated with a macro cell and pico cells. In the simulated LTE network environment, impact of pico cells on macro has been studied along with the scheduling algorithms.

After simulations, a more practical approach has been taken to study the performance of the LTE network. The performance analysis of Proportional Fair (PF) scheduler has been made in the real-time LTE network. In this study, the end users were classified as Gold, Silver and Bronze based on the subscription plans. A combination of various scenarios has been was tested to analyse the throughput of the scheduler. Then the performance of RAN and Evolved Packet Core has been made by observing the Key Performance Indicators (KPIs). To obtain RAN KPIs drive tests were made in various modes such as walking around the city centre, travelling in train, driving in the car and in indoor environments. The KPIs were collected using Nemo Handy RF planning tool. The final part of the thesis covers the performance analysis of EPC. The KPIs such as accessibility, retainability, traffic, mobility, and Automatic Neighbour Relations (ANR) were collected

for three months and the EPC performance was analysed. In the analysis, a critical issue in retainability was identified and this issue was impacting the accessibility of the network. After thorough analysis of KPIs, the root cause of the issue was identified as the Mobility Management Entity (MME) sending fake Serving Gateway (SGW) relocation request to eNodeB when there is only one SGW configured. This issue was identified and resolved using the KPIs.

RELATED PUBLICATIONS

Majority of the contributions included in this thesis appear in peer reviewed journal and conference papers. They are outlined as following:

Journal Articles

[1] R. Subramanian, R. Heidari, and K. Sandrasegaran, "Interoperability and Quality Assurance for Multi-Vendor LTE Network," *International Journal of Wireless & Mobile Networks*, vol. 7, no. 5, pp. 65–76, Oct. 2015.

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[3] R. Subramanian, R. Heidari, K. Sandrasegaran, A. M. A. Dhanraj, and K. Srinivasan, "Benchmarking of Cell Throughput Using Proportional Fair Scheduler In A Single Cell Environment," *International Journal of Wireless & Mobile Networks*, vol. 7, no. 2, pp. 67–79, Apr. 2015.

[4] R. Subramanian, P. Ghosal, S. Barua, and S. C. Lam, "Survey of LTE Downlink Schedulers Algorithms in Open access simulation Tools NS-3 and LTE-SIM," *International Journal of Wireless & Mobile Networks*, vol. 7, no. 2, pp. 01–14, Apr. 2015.

[5] S. Xing, P. Ghosal, R. Subramanian, and K. Sandrasegaran, "Level Simulation For Two Tier Macro-Femto Cellular Network," *International Journal of Wireless & Mobile Networks*, vol. 6, no. 6, pp. 01–14, Dec. 2014.

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Conference Papers

[1] R. Subramanian, K. Sandrasegaran, and X. Kong, "Benchmarking of Real-Time LTE Network in Dynamic Environment," in *IEEE Asia Pacific Communication Conference (APCC)*, Indonesia: IEEE.

[2] S. C. Lam, R. Subramanian, K. Sandrasegaran, P. Ghosal, and S. Barua, "Performance of well-known frequency reuse algorithms in LTE downlink 3GPP LTE systems," in *IEEE International Conference on Signal Processing and Communication Systems*, Cairns: IEEE, 2016.

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ACRONYMS

ABS	Almost Blank Sub-frames
AC	Admission Control
AODV	Ad hoc On-demand Distance Vector
APN	Access Point Node
APN-AMBR	APN Aggregate Maximum Bit Rate
ARP	Address Resolution Protocol
ARQ	Automatic Repeat Request
BCCH	Broadcast Control Channel
BET	Blind Equal Throughput
BGCF	Breakout Gateway Control Function
BPSK	Binary Phase Shift Keying
BSC	Base Station Controller
BTS	Base Transceiver Station
BW	Bandwidth
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CC	Congestion Control
CDMA	Code Division Multiple Access
CIFQ	Channel Independent Fair Queuing
CN	Core Network
CoMP	Coordinated Multi Point
CP	Cycle Prefix
CPRI	Common Public Radio Interface
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CS	Circuit Switched
CSCF	Call Session Control Function
DCI	Downlink Control Information
DFT	Discrete Fourier Transform
DL	Downlink
DL - SCH	Downlink Shared Channel
DMRS	Demodulation Modulation Reference Signal
DVB	Digital Video Broadcasting
DwPTS	Downlink Pilot Timeslot
eICIC	Enhanced ICIC
E-MBMS	Enhanced Multimedia Broadcast Multicast Services
eNB	eNodeB
EPC	Evolved Packet Core
EPRE	Energy Per Resource Element

EPS	Evolved Packet Core
eRAB	enhanced Radio Access Bearer
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
EVDO	Evolution Data Only/Optimized
ExPF	Exponential Proportional Fair
FDD	Frequency Division Duplex
FIFO	First In First Out
FTP	File Transfer Protocol
GBR	Guaranteed Bit Rate
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GP	Guard Period.
GPRS	General Radio Packet Service
HARQ	Hybrid Automatic Repeat Request
HDR	High Data Rates
HetNet	Heterogeneous Network
HOC	Handover Control
HOL	Head Of Line
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTTP	Hyper Text Transfer Protocol
ICC	Interference Coordination and Control
ICI	Inter Cell Interference
ICIC	Inter Cell Interference Cancellation
I-CSCF	Interrogating Call Session Control Function
IFFT	Inverse Fast Fourier Transform
IM-MGW	IP Multimedia Gateway
IMS	IP Multimedia Sub-system
ISI	Inter Symbol Interference
KPI	Key Performance Indicator
LC	Load Control
LTE	Long Term Evolution
LWDF	Largest Weighted Delay First
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Services
MBR	Maximum Bit Rate
MCS	Modulation and Coding Scheme
MGCF	Media Gateway Controller Function
MIB	Master Information Block

MIMO	Multiple Input Multiple Output
MLWDF	Modified Largest Weighted Delay First
MME	Mobility Management Entity
MT	Maximum Throughput
MTU	Message Transfer Unit
MU-MIMO	Multi User MIMO
NS-3	Network Simulator -3
OFDMA	Orthogonal Frequency Division Multiple Access
OLSR	Optimized Link State Routing Protocol
OPEX	Operational Expenditure
PBCH	Physical Broadcast Channel
PC	Power Control
PCFICH	Physical Control Format Indicator Channel
PCI	Physical Cell ID
PCRF	Policy Control and charging Rules Function
P-CSCF	Proxy Call Session Control Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDSCH	Physical Downlink Shared Channel
PF	Proportional Fair
PGW	PDN Gateway
PHICH	Physical Hybrid ARQ Indicator Channel
PHY	Physical layer
PLR	Packet Loss Ratio
PS	Packet Switched
PSS	Priority Set Scheduler
PVI	Pre-emption Vulnerability Indicator
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Random Access Channel
RAN	Radio Access Network
RB	Resource Blocks
RBG	Resource Block Group
RLC	Radio Link Control
RNC	Radio Network Controller
RR	Round Robin
RRC	Radio Resource Control
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality

RSSI	Reference Signal Strength Indicator
SBFA	Server Based Fairness Approach
SC-FDMA	Single Carrier Frequency Division Multiple Access
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SINR	Signal to Interference Noise Ratio
SLF	Subscriber Location Function
SMS	Short Message Service
SNR	Signal to Noise Ratio
SRS	Sounding Reference Signal
TBFQ	Token Bank Fair Queue Scheduler
TDD	Time Division Duplex
TEMS	Test Mobile System
TPC	Transmission Power Control
TTA	Throughout To Average
TTI	Transmission Time Interval
TxD	Transmit Diversity
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink Link
UL - SCH	Uplink Link Shared Channel
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over IP
VoLTE	Voice over LTE
WCDMA	Wideband Code Division Multiple Access
WFQ	Weighted Fair Queuing
WFS	Work Flow Scheduling
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

s_m	OFDM symbol
N	Narrowband modulated subcarriers
PL	Pathloss
SH	Shadowing
PN	Penetration loss
i, j	Users
t	Subframe index
k	Resource blocks
$M_{i,k}(t)$	Modulation coding scheme
B	Transport block in bits for resource blocks
$R_i(k,t)$	Achievable rate
τ	TTI duration
$T_j(t)$	Past throughput
α	Time constant
$\widehat{T_j}(t)$	Actual throughput
$\widehat{M_j}(t)$	Modulation coding scheme index
t_i	Packet arrival rate (byte/sec)
r_i	Token generation rate (byte/sec)
p_i	Token pool size (byte)
E_i	Number of token borrowed from or given
p_k^1(t)	Priority metric
$\frac{B}{N}$	FD-BET
R_i^{fb}	Full achievable bandwidth of a UE
T_{fdtbfq}^I	Total TBFQ throughput

T_{pss}^{I}	Total PSS throughput
nbs	Number of bits per symbol
nss	Number of symbols per slot
nts	Represents the number of slots per TTI
nsr	Represents the number of sub-carriers per RB
$pdiscard_i(t)$	Discarded or lost packet
$ptransmit_i(t)$	Transmitted packets
P_t	Transmitted power at BS
h_k	Channel gain
σ_s^2	Log normal distribution with zero mean and variance
S_k	Shadowing effect
m_k	Multipath fading
Z_k	SNR of user k
P_n	Denotes background noise power including thermal noise and other Gaussian interference.
ρ	Noise level of wireless environment
D	Radius of the cells
Z_k	Average SNR of user k
$R_k[n]$	Possible user rate in time slot n
t_c	Time constant