Packet Scheduling Algorithms in LTE Systems

A Thesis

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by

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Certificate Of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged with the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

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ABSTRACT

There has been a huge increase in demand towards improving the Quality of Service (QoS) of wireless services. Long Term Evolution (LTE) is a development of the Third-Generation Partnership Project (3GPP) with the aim to meet the needs of International Telecommunication Union (ITU). Some of its aspects are highlighted as follows: increase in data rate, scalable bandwidth, reduced latency and increase in coverage and capacity that result in better quality of service in communication.

LTE employs Orthogonal Frequency Division Multiple Access (OFDMA) to simultaneously deliver multimedia services at a high speed rate. Packet switching is used by LTE to support different media services. To meet the QoS requirements for LTE networks, packet scheduling has been employed. Packet scheduling decides when and how different packets are delivered to the receiver. It is responsible for smart user packet selection to allocate radio resources appropriately. Therefore, packet scheduling should be cleverly designed to achieve QoS that is similar to fixed line services. eNodeB is a node in LTE network which is responsible for radio resource management that involves packet scheduling.

There are two main categories of application in multimedia services: RT (Real Time) and NRT (None Real Time) services. RT services are either delay sensitive (e.g. voice over IP), loss sensitive (e.g. Buffered Video) or both (delay &loss sensitive) for example video conferencing. Best effort users are an example of NRT services that do not have exact requisites and have been allocated to spare resources.

Reaching higher throughput has sometimes resulted in unfair allocation to users who are located far from the base station or users who suffer from bad channel conditions. Therefore, a sufficient trade-off between throughput and fairness is essential. The scarce bandwidth, fading radio channels and the QoS requirement of the users, makes resource allocation a demanding issue. Different scheduling approaches have been suggested for different service demands described briefly throughout the thesis.

Initially, a comprehensive literature review of existing work on the packet scheduling topic has been accomplished in this thesis to realize the characteristics of packet scheduling and the resource allocation for the wireless network. Many packet scheduling algorithms developed to provide satisfactory QoS for multimedia services in downlink LTE systems. Several algorithms considered in this thesis include time and frequency domain algorithms and their way of approach has been investigated.

The next objective of this thesis is to improve the performance of packet scheduling in LTE downlink systems. A new packet scheduling algorithm has been introduced in this thesis. A study on VoLTE (Voice over LTE), video streaming and best effort traffic under three different scheduling algorithms has been conducted. Heterogeneous traffic based on precise modelling of packets has been used in the simulation. The main resource allocation and assignment technique used in this work namely Dynamic Subcarrier Allocation scheme is shown to provide a solution to solve the cross layer optimisation problem. It depends on Channel Quality Information (CQI) and has been broadly investigated for single carrier and multicarrier wireless networks. The problem is based on the maximisation of average utility functions. Different scheduling algorithms in this method consider to be utility functions. The throughput, fairness and Packet Loss Ratio have been considered as the requirements for examining the performance of algorithms. Simulation results show that the proposed algorithm significantly increases the performance of streaming and best effort users in terms of PLR and throughput. Fairness has also been improved with less computational complexity compared to previous algorithms that have been introduced in this thesis.

RELATED PUBLICATION

[1] Heidari, R., Afroz, F., Subramanian, R. Cong, S. Sandrasegaran, K. Kong, X 'Packet Scheduling Study for Heterogeneous Traffic in Downlink LTE 3GPP LTE System', *International Journal of Wireless & Mobile Networks (IJWMN)*, 2015, 7(5), pp. 91–106.

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List of Acronyms

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
ACK	Acknowledgement
AMC	Adaptive Modulation and Coding
AMPS	Analogue Mobile Phone System
ARQ	Automatic Repeat Request
BER	Bit Error Rate
BET	Blind Equal Throughput
BLER	Block Error Rate
BET	Blind Equal Throughput Scheduler
CC	Carrier Component
CD-EDD	Channel-Dependent Earliest Due Deadline
CDMA	Code Division Multiple Access
cdmaOne	code division multiple access One
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CQA	Channel-QoS Aware
CRC	Cyclic Redundancy Check
CRA	Capacity Driven Resource Allocation

CRI	CQI Reporting Interval
CRR	CQI Reporting Rate
CSI	Channel State Information
DFS	Delay First Scheduling
DPS	Delay Prioritized Scheduling
DRA	Dynamic Resource Allocation
DSA	Dynamic Subcarrier Allocation
DSSS	Direct Sequence Spread Spectrum
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
eNB	eNodeB: enhanced Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
EXP	Exponential Rule
FIFO	First-In-First-Out
FD	Frequency Domain
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FDPS	Frequency Domain Packet Scheduling
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FTGS	Fair Throughput Guarantees Scheduler
GBR	Guaranteed Bit Rate
GPRS	General Packet Radio Services

GSM	Global System for Mobile Communication
HARQ	Hybrid Automatic Repeat Request
HO	Hard handoff
HOL	Head-of-Line
HSDPA	High-Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSPA+	High-Speed Packet Access+
HSUPA	High-Speed Uplink Packet Access
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IR	Incremental Redundancy
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
JTACS	Japanese Total Access Communications System
JTFDS	Joint Time and Frequency Domain Scheduling
LOG-MLWDF	Log- Modified Largest Weighted Delay First
LTE	Long Term Evolution
MAC	Medium Access Control
Max-Rate	Maximum Rate
MTS	Maximum Throughput Scheduler
MCS	Modulation and Coding Scheme
MDU	Max Delay Unit

M-LWDF	Modified-Largest Weighted Delay First
MME	Mobility Management Entity
NACK	Negative Acknowledgement
NMT	Nordic Mobile Telephone
Non-GBR	Non-Guaranteed Bit Rate
NRT	None Real Time
OFDMA	Orthogonal Frequency Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OFPF	OFDMA Frame-Based Proportional Fairness
ODS	Opportunistic and Delay Sensitive
OTFS	Oriented Time Frequency Scheduling
P-GW	Packet Gateway
PAPR	Peak-to-Average Power Ratio
PDC	Personal Digital Communications
PDN	Packet Data Network
PF	Proportional Fair
PHY	Physical
PLR	Packet Loss Ratio
PRB	Physical Resource Block
PSS	Priority Set Scheduler
PFS	Proportional Fair Scheduler
QAM	Quadrature Amplitude Modulation
QAS	Queue Aware Scheduling

QCI	QoS Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAP	Resource units Allocation Priority
RB	Resource Block
RE	Resource Element
RLC	Radio Link Control
RR	Round Robin
RAA	Resource Allocation and Assignment
RRM	Radio Resource Management
RRU	Radio Resource Unit
RT	Real Time
RU	Resource Unit
SAW	Stop-and-Wait
S-GW	Serving Gateway
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SINR	Signal-to-Interference-Plus-Noise-Ratio
TACS	Total Access Communications System
TB	Transport Block
TBR	Target Bit Rate
TD	Time Domain
TDD	Time Division Duplex
TDMA	Time Division Multiple Access

TSN	Transmission Sequence Number
TTI	Transmission Time Interval
UMTS	Universal Mobile Telecommunications System
UE	User Equipment
WCDMA	Wideband Code Division Multiple Access
WIMAX	Worldwide Interoperability for Microwave Access

List of symbols

β	Constant parameter
φ	Constant parameter
ε	A small positive constant
σ	Shadow fading standard deviation
δ_i	Service-dependent PLR threshold of user *i*
$\mu_i(t)$	Priority of user *i* at scheduling interval *t*
λ	Proportion of the total RRUs allocated to real time users at TTI *t*.
$\lambda_{i,s}$	Average arrival data rate of user *i* with traffic type *s*
γ	Path loss exponent
γ	Rate of learning
ψ	Path loss
μ_{dB}	Mean of ψ_{dB}
μ_{ψ}	Mean of ψ
$\sigma_{\psi_{dB}}$	Standard deviation of ψ_{dB}
α_n	Attenuation of n^{th}path
τ_n	Delay of n^{th} path
θ_n	Phase of n^{th} path
ρ_i	Signal to Noise Ratio for user *i*
$\gamma_{i,j}(t)$	Instantaneous SINR of user *i* on RB_j at time *t*
$\xi_i(t)$	Shadow fading gain of user *i* at time *t*
v_i	The speed of user *i* at time *t*

A^n	Set of queues at time slot *n*
a_i	QoS requirement of user *i*
$B_i(t)$	Total size of all packets (in bits) in the buffer (at base station) of user *i* at scheduling interval *t*
B^n	Set of service types
$BU_i(t)$	Total size of receive packets (in bits) in the buffer (at user) of user *i* at scheduling interval *t*
$C_i[k,n]$	Feasible data rate for RB_k at time slot *n*
d_0	Reference distance for the antenna far field
$d_i(t)$	Time to live of the HOL packet of user *i* at TTI *t*
$dir_i(t)$	Direction of user *i* at time *t*
Dpc	Web browsing reading time
$DP_{l,i}(t)$	Delay of the lth packet of user *i* at time *t*
$E[r]$	Expected mean data rate *r*
$E[R_i(t)]$	Expected mean throughput of user *i* at scheduling interval *t*
$E_{i,j}(t)$	Element (in channel matrix) of user *i* on RRU j at scheduling interval *t*
Fa	Inter-arrival time between the beginnings of successive video frames
f_c	Career frequency
$h_b(t)$	Impulse response of baseband signal
ICI	Inter cell interference in watt
$I_i(t+1)$	Indicator function of the event that packets of user *i* are selected for transmission at scheduling interval *t+1*
K	Unit less constant

$loc_i(t)$	Location of user *i* at time *t*
$m(k,n)$	RB_k is assigned to user *m* at time slot *n*
$M_i(t)$	Maximum possible data rate (channel capacity) on all *RUs* for user *i* at TTI *t*.
$\bar{M}_i(t)$	Average subcarrier capacity of i_{th} user.
$mpath_{i,j}(t)$	Multi-path fading gain of user *i* on RB_j at time *t*
$n_i(t)$	Number of RRUs that is allocated to user *i* at scheduling interval *t*
N	Total number of users
N_0	Thermal noise
N_d	Number of embedded objects in a web browsing packet call
N_p	Number of packets (slices) in a video frame
$n_{RT}(t)$	Number of resource units
$n_{NRT}(t)$ interval t	Number of resource units allocated to non-real time users at time
$Nservice$	Total number of users of a service
P_a	Inter-arrival time between packets (slices) in a video frame
P_{total}	Total eNB transmit power in dB_m
PRB_{max}	Maximum available number of RBs
$PB_i(t)$	Total number of frames in playback buffer of user *i* at scheduling interval *t*
$P_{li}(t)$	Path loss of user *i* at time *t* in dB_m
$PLR_i(t)$	PLR of user *i* at scheduling interval *t*
$r_{toti}(t)$	Total data rate on all RRUs of user *i* at scheduling interval *t*

$r(t)$	The received signal
$r_i(t)$	Instantaneous data rate (across the whole bandwidth) of user *i* at scheduling interval *t*
$r_i[n]$	Data transmission rate of user *i* at time slot *n*
$r_{i,j}(t)$	Instantaneous data rate of user *i* on RRB *j* at scheduling interval *t*
$R_i(t)$	Average throughput of user *i* at scheduling interval *t*
$R_{ofpfi}(t)$	Modified average throughput of user *i* at time interval *t*
$R_{-sch_i}(t)$	Average throughput of user *i* at simulation time *t*
$RB_{allocated}$	Total number of allocated RBs of all users
RB_{max}	Maximum available number of RBs
RE_{data}	Total number of REs specified for downlink data transmission
RRU_{max}	Maximum available number of RRUs
RRU_{rem}	Remaining RRUs
$RU_{tot}(t)$	Total available RUs at TTI *t*
Service PLR	PLR of a type of service (either GBR or Non-GBR service)
S'	Remaining unused RUs.
S_E	Web browsing embedded object size
$S_i(t)$	Satisfaction degree of user *i* at scheduling interval *t*
S_M	Web browsing main object size
S_p	Video packet (slice) size
t_c	Time constant
t_{-sch_i}	Time invariable equal to 30
T	Total simulation duration

T_i Service-dependent buffer delay threshold of user *i*

T_p Web browsing parsing time

$Twait_i(t)$ Waiting time of user *i* from the last scheduled interval until now.

$TOA_{l,i}$ Time of arrival of the l_{th} packet of user *i* in the eNB buffer

U_i Utility function of user *i*

$V_i(t)$ Number of dead line packets due to violation of i^{th} user packets up to the time *t*.

$vec_i(t)$ Unit norm vector with positive real element of user *i* at scheduling interval *t*

$W_i(t)$ Delay of the HOL packet of user *i* at time interval *T*

$We_{RT}(t)$ Weight of allocation for real time users at time interval *t*

W_{ave} Average delay of HoL packets for user *i* in simulation time *T*

$W_{wait\ i}(t)$ User *i*'s waiting time duration from the previous scheduling time until current time.

χ Transmit band pass signal

x_b Baseband signal