Packet Scheduling under Imperfect Channel Conditions in Long Term Evolution (LTE)

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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 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.

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ABSTRACT

The growing demand for high speed wireless data services, such as Voice Over Internet Protocol (VoIP), web browsing, video streaming and gaming, with constraints on system capacity and delay requirements, poses new challenges in future mobile cellular systems. Orthogonal Frequency Division Multiple Access (OFDMA) is the preferred access technology for downlink Long Term Evolution (LTE) standardisation as a solution to the challenges. As a network based on an all-IP packet switched architecture, LTE employs packet scheduling to satisfy Quality of Service (QoS) requirements. Therefore, efficient design of packet scheduling becomes a fundamental issue. The aim of this thesis is to propose a novel packet scheduling algorithm to improve system performance for practical downlink LTE system.

This thesis first focuses on time domain packet scheduling algorithms. A number of time domain packet scheduling algorithms are studied and some well-known time domain packet scheduling algorithms are compared in downlink LTE. A packet scheduling algorithm is identified that it is able to provide a better trade-off between maximizing the system performance and guaranteeing the fairness.

Thereafter, some frequency domain packet schemes are introduced and examples of QoS aware packet scheduling algorithms employing these schemes are presented. To balance the scheduling performance and computational complexity and be tolerant to the time-varying wireless channel, a novel scheduling scheme and a packet scheduling algorithm are proposed. Simulation results show this proposed algorithm achieves an overall reasonable system performance.

Packet scheduling is further studied in a practical channel condition environment which assumes imperfect Channel Quality Information (CQI). To alleviate the performance degradation due to simultaneous multiple imperfect channel conditions, a packet scheduling algorithm based on channel prediction and the proposed scheduling scheme is developed in downlink LTE system for GBR services. It was shown in simulation results that the Kalman filter based channel predictor can effectively recover the correct

CQI from erroneous channel quality feedback, therefore, the system performance is significantly improved.

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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
APFS	Advanced Proportional Fair Scheduling
ARQ	Automatic Repeat Request
BET	Blind Equal Throughput
BLER	Block Error Rate
CBR	Constant Bit Rate
CC	Chase Combining
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CPGS	Channel Predictive Grouping Scheduling
CQI	Channel Quality Information
CRC	Cyclic Redundancy Check
DFS	Delay First Scheduling
DPS	Delay Prioritised Scheduling
DSSS	Direct Sequence Spread Spectrum
eUTRAN	evolved Universal Terrestrial Radio Access Network
eNB	enhanced Node B
EPS	Evolved Packet System
EXP	Exponential Rule
FIFO	First-In-First-Out
FD	Frequency Domain
FDD	Frequency Division Duplex

FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
GBR	Guaranteed Bit Rate
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communication
HARQ	Hybrid Automatic Repeat Request
HAS	HARQ Aware Scheduling
HATFS	HARQ Aware TD-FD Scheduling
HDR	High Data Rate
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
IR	Incremental Redundancy
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
JTFDS	Joint Time and Frequency Domain Scheduling
LOS	Load-oriented Scheduling
LS	Least Squares
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MAC	Modulation and Coding
Max-Rate	Maximum Rate
MBS	Matrix-Based Scheduling
MCS	Modulation and Coding Scheme
MLF	Maximum Laxity First
M-LWDF	Modified-Largest Weighted Delay First
MQAS	Multi-QoS Adaptive Scheduling
NACK	Negative Acknowledgement
NRT	Non real time
OFDMA	Orthogonal Frequency Division Multiple Access

OFPF	OFDMA Frame-Based Proportional Fairness
OTFS	Oriented Time-Frequency Scheduling
PF	Proportional Fair
PFS	Proportional Fair Scheduled
PGS	Parity Grouping Scheduling
PLR	Packet Loss Ratio
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QOGS	QoS-Oriented Grouping Scheduling
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAA	Resource Allocation and Assignment
RAP	RU Allocation Priority
RB	Resource Block
RE	Resource Element
RLC	Radio Link Control
RQ-DS	Robust and QoS-Drive Scheduling
RR	Round Robin
RRM	Radio Resource Management
RU	Resource Unit
RT	Real time
SAW	Stop-and-Wait
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SINR	Signal-to-Interference-plus-Noise-Ratio
TTA	Throughput-to-Average
TACS	Total Access Communications System
TB	Transport Block
TBR	Target Bit Rate
TD	Time Domain
TDD	Time Division Duplex
TDGS	Time Domain Grouping Scheduling

TSN	Transmission Sequence Number
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	Universal Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

LIST OF SYMBOLS

α	Constant parameter
β	Constant parameter
ε	A small positive constant
ε_t	Additive noise
θ_t	System noise
η	Learning rate
$\lambda(t)$	Proportion of the total RUs allocated to real time users at TTI t
σ	Shadow fading standard deviation
σ_θ^2	Noise
$\sigma_{e,\gamma}^2$	Covariance of $X_{e,r}(t)$
$\sigma_{e,v}^2$	Covariance of $X_{e,v}(t)$
$\sigma_{e,b}^2$	Covariance of $X_{e,b}(t)$
$\sigma_{\mu 0}$	Variance (mean power)
δ_i	Service-dependent PLR threshold of user i
$\mu\_ap_i(t)$	Approximated uncorrelated filtered white Gaussian noise with zero mean of process i at time t
$\mu_i(t)$	Priority of user i at scheduling interval t
μ_n	Uncorrelated filtered white Gaussian noise with zero mean of the nth sinusoid
$\mu_{RTi}(t)$	Priority for non real time users
$\rho_i(t)$	Shadow fading autocorrelation function,
$\gamma_{i,j}$	SINR of user i on PRB j
$\gamma_{i,j}(t)$	Instantaneous SINR of user i on PRB j at time t
$\theta_{i,n}$	Doppler phase of process i of the nth sinusoid
$\zeta(t)$	Frequency flat Rayleigh fading at time t
$\xi_i(t)$	Shadow fading gain of user i at time t
a	System gain
a_i	QoS requirement of user i
$a(h_m)$	Mobile antenna correction factor

aW_avg	Average of QoS requirement and delay of the HoL packet across all users
$A(t)$	State transition matrix
b	A coefficient
b_i	Gradient of $\gamma_{i,j}$
$B(t)$	Input transition matrix
$B_i(t)$	Total size of all packets (in bits) in the buffer(at base station) of user i at scheduling interval t
$c_{i,n}$	Doppler coefficient (which represents a real weighting factor) of process i of the nth sinusoid
d_0	Shadow fading correlation distance
$d_i(t)$	Time to live of the HoL packet of user i at TTI t
$dir_i(t)$	Direction of user i at time t
$\|dis_i(t)\|$	Magnitude of distance of user i from eNB at time t
$DP_{l,i}(t)$	Delay of the lth packet of user i at time t
$Dretx_i(t)$	Average retransmission delay of user i at scheduling interval t
e_t	Estimation error
$E[r]$	Expected mean data rate r
$E_{i,j}(t)$	Element (in channel matrix) of user i on RU j at scheduling interval t
$Efficiency_{i,j}(t)$	Efficiency (in bits/RE) of PRB j of user i at time t
$Exe_i(t)$	Execution time of user i at TTI t
$f_{i,n}$	Discrete Doppler frequency of process i of the nth sinusoid
f_{max}	Maximum Doppler frequency
$G(t)$	Gaussian random variable of user i at time t
h_b	Height of the eNB
$H_i(t)$	Average channel gain of RUs for user i at TTI t
$H(t)$	Observation matrix
I	Identity matrix
$I_i(t+1)$	Indicator function of the event that packets of user i are selected for transmission at scheduling interval $t+1$
ICI	Inter-cell interference

k	A variable of the summation to compute across all users
$K(t)$	Kalman gain
$lax_i(t)$	Laxity time of user i at TTI t
$loc_i(t)$	Location of user i at time t
$mpath_{i,j}(t)$	Multi-path fading gain of user i on PRB j at time t
$n_i(t)$	Number of RUs that is allocated to user i at scheduling interval t
$n_{NRT}(t)$	Number of RUs allocated to non real time users at scheduling interval t
$n_{RT}(t)$	Number of RUs allocated to real time users at scheduling interval t
N	Total number of users
N_o	Thermal noise
N_i	Number of sinusoids of process i
P_{t-1}	Estimated error
$pdiscard_i(t)$	Total size of discarded packets (in bits) of user i at time t
$pl_i(t)$	Path loss of user i at time t
$prx_i(t)$	Total size of correctly received packets (in bits) of user i at time t
$psize_i(t)$	Total size of all packets that have arrived to the eNB buffer of user i at time t
P_{total}	Total eNB transmit power
$P(t)$	Update covariance matrix
$PLR_i(t)$	PLR of user i at scheduling interval t
PRB_{max}	Maximum available number of PRBs
$Q(t)$	State noise covariance matrix
$Q_i(t)$	Buffer length of user i at TTI t
$r_i(t)$	Instantaneous data rate(across the whole bandwidth) of user i at scheduling interval t
$r_{i,j}(t)$	Instantaneous data rate of user i on RU j at scheduling interval t
$ra_i(t)$	Average data rate over a number of scheduling intervals of user i at scheduling interval t
$ravg_i(t)$	Average data rate over a number of scheduling intervals of user i at scheduling interval t

$rtot_i(t)$	Total number of bits supportable on the PRBs allocated to user *i* at TTI *t*
$R(t)$	Additive observation noise
$R_i(t)$	Average throughput of user *i* at scheduling interval *t*
$R_{ofpfi}(t)$	Modified average throughput of user *i* at TTI *t*
$R\_req_i(t)$	Average throughput required by user *i* at scheduling interval *t*
$R\_sch_i(t)$	Estimated average throughput of user *i* at TTI *t*,
$P(t\|t-1)$	Covariance matrix at time t conditioned on the estimate $X(t\|t-1)$
PRB_{rem}	Total number of remaining PRBs of all users
PRB_{HARQ}	Total number of PRBs required by all HARQ users
RE_{data}	Total number of REs specified for downlink data transmission
RU_{HARQ}	Total number of RUs required by all HARQ users
RU_{rem}	Remaining RUs
RU_{total}	Total available RUs at TTI *t*
T	Total simulation time
t_c	A time constant
T_i	Service-dependent buffer delay threshold of user *i*
$T_{waiti}(t)$	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
$u(t)$	Input vector
v_i	Change rate of SINR of user *i*
$v_i(t)$	Speed of user *i* at time *t*
$W_i(t)$	Delay of the HOL packet of user *i* at time *t*
$W_{RT}(t)$	Allocation weight given to the real time users at TTI *t*
x_t	Current state
$\hat{x}_t$	Estimation of x_t
$X(t\|t-1)$	Estimated state at time *t* based on the estimate at time *t-1*
$\tilde{X}(t)$	Estimated state at time *t*
$X_{e,b}(t)$	Measurement error of b_i
$X_{e,r}(t)$	Measurement error of $\gamma_{i,j}$
$X_{e,v}(t)$	Measurement error of v_i

y_t	Measurement of x_t
$Z_i(t)$	Sequence of observation values