AN INVESTIGATION INTO THE IMPROVEMENT IN WCDMA SYSTEM PERFORMANCE USING MULTIUSER DETECTION AND INTERFERENCE CANCELLATION

by

Themba M.A. Ngwenya

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SUMMARY

WCDMA is typically characterised as a system capable of providing mobile users with data rates up to 2 Mb/s and beyond. It has been termed an ultra high-speed, ultra high-capacity radio technology that will be able to carry a new range of fast, colourful media, such as colour graphics, video, animations, digital audio, Internet and e-mail that consumers will be able to access over their mobiles devices.

This current study has researched on the various existing Multiuser detection (MUD) processes or proposals conducted by various research institutions around the world. It has identified the advantages that the past work offers, and it is these advantages that form the basis of the current research into the improvement techniques. The proposed Partial Parallel Pipelined Multiuser Detector (PPPMUD or P^3MUD) has come about from two main flavours or directions of research. The first one seeks to promote the Soft Parallel Interference Cancellation technique as an effective bias mitigation technique. This bias occurring in the second stage decision statistics, exhibits a very harmful effect on system Bit Error Rate, (BER), particularly for large system loads. This current study goes further by carefully analysing the Soft Cancellation Factor, SCF behaviour to eventually derive and determine the optimum SCF value which exhibits positive characteristics when varied with the increasing system load (number of users). This optimum SCF value is called the universal SCF or SCF_{UNV}, as it is theoretically supposed to perform favourably under various system loads. A favourable or acceptable performance would be characterised by low observed or measured BER during the system processing stages. A further enhancement to the operational performance of the SCF_{UNV} algorithm is the SCF_{UNV} Compensator, which is basically a compensation mechanism created by modelling the behaviour of the SCF values, and adjusts the SCF_{UNV} depending on the system load, (number of simultaneous users). Thus, the SCF_{UNV} is adaptively adjusted in order to perform acceptably under all load conditions.

The second direction of research, as regards improvements in MUD techniques, involves the conventional Bit-Streaming, Pipelined Multiuser Detector. This came about due to the computational complexity as well as matrix inversions which affected earlier asynchronous multiuser detection techniques. This detector has a pipelined architecture which avoids multishot (block-based) detection and instead, processes the bits in a streaming fashion. The architecture consists of a matched filter followed by three stages of parallel interference cancellation, (PIC).

This present study extends that research by outlining the advantages of incorporating the soft parallel interference cancellation technique, by way of the universal soft cancellation factor, (SCF_{UNV}), into the conventional pipelined multiuser detector architecture to form the P^3MUD architecture, which includes the compensator. The contributions of the proposed P^3MUD system is that the observed BER output simulations are promising, with an observed overall decrease in the error rate for the P^3MUD process, as compared to the conventional pipelined detection method. This decrease signifies an improvement offered by the proposed P^3MUD algorithm. Further observed analysis indicates the possibility of decreasing the number of parallel interference cancellation stages from three to at least two, after the matched filter detection stage, without an observable change in system BER. Hence, the proposal of the two-stage P^3MUD.

Keywords: Wide-band Code Division Multiple Access, Multiuser Detection, Pipelined Multiuser Detector, Partial Parallel Pipelined Multiuser Detector $\left(P^3MUD\right)$, Soft Parallel Interference, Soft Cancellation Factor, Universal Soft Cancellation Factor, Parallel Interference Cancellation

OPSOMMING

Wyeband CDMA (WCDMA) word tipes gekenmerk as ‘n stelsel wat in staat is om mobiele gebruikers van datatempos tot soveel as 2 Mb/s en meer te bedien. Dit word gevolglik bestempel as ‘n ultra-hoëspoed ultra-hoë kapasiteit radiotegnologie wat in staat sal wees om ‘n nuwe verskeidenheid vinnige, kleurvolle media te dra, soos byvoorbeeld kleurgrafika, video, animasies, syfer-oudio, Internet and e-pos, waartoe verbruikers in staat sal wees om via hulle draagbare handstelle toegang te hê.

Hierdie studie het die bestudering van ‘n verskeidenheid bestaande multi-gebruiker-deteksie (MGD) -prosesse en -voorstelle, wat deur verskillende navorsingsinstellings dwarsoor die wêreld onderneem is, ten doel gehad. Die voordele wat die genoemde navorsingsprojekte inhou, is identifiseer en as basis gebruik vir die huidige soektog na verbeterde MGD-tegnieke. Die voorgestelde parsieel- (of gedeeltelike) parallelle pyplyngeoriënteerde (of sekwensiële) multigebruiker detektor (PPPMGD, oftewel ‘Partial Parallel Pipelined Multiuser Detector – ‘PPPMUD’ of ‘P^3MUD’) het uit hoofsaaklik twee hoofnavorsingsrigtings onstaan:

Die eerste navorsingsbenadering poog om ‘n sagte parallelle steuringskansellasiemetode as ‘n baie effektiewe oplossing tot die statistiese wanafsetprobleem (‘bias mitigation technique’) te bevorder. Hierdie wanafset wat in die beslissingsstatistieke van die tweede stadium van die MGD ontstaan, toon ‘n baie skadelike effek op die stelselbisfourwaarskynlikheid (BFW of ‘bit error rate’ - BER), en in besonder in die geval van stelsels met ‘n groot gebruikersbelading. Hierdie studie is verder gevoer deur ‘n in-diepte ondersoek van die sogenaamde sagte kansellasie-faktor - (SKF, oftewel ‘soft cancellation factor - SCF’) gedrag te loods, waaruit uiteindelik die optimum SKF-waarde bepaal is, wat positiewe stelselkenmerke openbaar wanneer dit as ‘n funksie van die toenemende stelselbelading (d.i, die aantal gebruikers) verstel word. Hierdie optimum SKF-waarde word die universele SKF, of $SKF_{UNV,}$ genoem, aangesien dit teoreties gunstig behoort te vaar onder ‘n substansiële bereik van stelselbeladings. ‘n Gunstige of aanvaarbare stelselwerkverrigting word gekenmerk deur ‘n lae waargenome (gemete) stelselbisfoutwaarskynlikheid (BER) na MGD-prosessering. ‘n Verdere verbetering tot die operasionele werkverrigting van die SKF_{UNV}–algoritme is die sogenaamde SKF-kompensator, wat basies ‘n kompensasiemeganisme is wat uit die modellering van die SKF-waardes ontwikkel is, en die SKF_{UNV}–waardes as ‘n funksie van die

stelselbelading (aantal gelyktydige stelselgebruikers) verstel. SKF_{UNV} word aanpasbaar verstel ten einde onder alle lastoestande aanvaarbaar te funksioneer.

Die tweede navorsingsbenadering wat daarop gemik is om die MGD-proses te verbeter, behels die konvensionele bitstroom, pyplyngebaseerde multigebruiker-detektor (BPMGD. Hierdie BPMGD-konfigurasie is ontwikkel om die berekeningskompleksiteit en die aantal matriksinversies wat vroëere asinkrone MGD-tegnieke gekniehalter het, die hoof te bied. Die detektor het ‘n pyplynargitektuur wat blokgebaseerde multistapdeteksie vermy, en die bisstroom op ‘n sekwensiële wyse prosesseer. Die argitektuur bestaan uit ‘n aangepaste filter, gevolg deur drie stadia van parallelle steuringskansellasie (PSK, oftewel ‘parallel interference canellation – PIC’).

Hierdie studie brei vorige navorsing op die voordele van die insluiting van ‘n sagte parallelle steuringskanselleringstegniek uit, deur die inkorporering van die universele sagte kansellasiefaktor, SKF_{UNV} (met inbegrip van die SKF-kompensator), by die konvensionele pyplyngebaseerde MGD, om die sogenaamde P^3MGD (‘P^3MUD’)-argitektuur te vorm. Die bydrae van die voorgestelde P^3MUD-stelsel is dat dit die waargenome stelsel-BER merkbaar verbeter, met ‘n waargenome algehele afname in BER vir die P^3MUD-proses, in vergelyking met die konvensionele pyplyn-gebaseerde MGD-metode. Hierdie waarnemings dui op ‘n aansienlike verbetering in stelselwerkverrigting deur die P^3MUD-metode te gebruik. ‘n Verdere bydrae van hierdie ondersoek is die bevinding dat die algehele prosesseringsintensiteit aansienlik verminder kan word deur die aantal parallelle kansellasiestadia na die aangepaste-filter deteksieproses van drie na slegs twee te verminder, sonder enige merkbare verandering in stelsel-BER. Gevolglik is die voorstel van ‘n twee-stadium P^3MUD ‘n verdere bydrae wat deur hierdie navorsingsprojek tot ‘n verbeterde en vereenvoudigde MGD gemaak word.

Sleutelwoorde: Wyeband Kode-Divisie Multi-Toegang (WKDMT, oftewel ‘Wideband Code Division Multiple Access - WCDMA’), Multigebruiker-deteksie (MGD), Pyplyn-gabaseerde MGD (‘Pipelined Multiuser Detector – PMUD’), Parsiële Parallelle Multigebruiker-Detektor (P^3MGD oftewel, ‘P^3MUD’), Sagte Parallelle Steurseinkansellering, Sagte Kansellasie-Faktor (SKF), Universele Sagte Kansellasie-Faktor (SKF_{UNV}), Parallelle SteuringsKansellering (PSK, oftewel, “Parallel Interference Cancellation – PIC’).

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LIST OF ABBREVIATIONS

AMPS	Advanced Mobile Phone Service
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CDMA2000	CDMA Third Generation Networks Standard
DS-CDMA	Direct Sequence CDMA
DPDCH	Dedicated Physical Data Channel
DPDCCH	Dedicated Physical Control Channel
DSP	Digital Signal Processing
EDGE	Enhanced Data for Global Evolution
ETSI TS	European Telecommunication Standard Institute Technical Specifications
ETACS	European Total Access Cellular System
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FIR	Finite Impulse Response filter
FPGA	Field Programmable Gate Array
GSM	Groupe Speciale Mobile Standard
GPRS	GSM Packet Radio System
GUI	Graphical User Interface

HCS	Hierarchical Cell Structures
HIC	Hybrid Interference Cancellation
HPSK	Hybrid Phase Shift Keying
HSCSD	High Speed Circuit Switched Data
IC	Interference Cancellation
ITU	International Telecommunications Union
IP	Internet Protocol Standard
IMT-2000	3G Universal Name
IS-95	Wireless Telecommunications Standard(cdmaOne)
IS-136	Wireless Telecommunications Standard(US- TDMA)
ISO	International Standards Organization
Kb/s	Kilo-bits per second
MAI	Multiple Access Interference
Mb/s	Mega-bits per second
MUD	Multiuser Detection
Mcps	Mega-cycles per second
MMSE	Minimum Mean Square Error Detector
NTT	Nippon Telephone & Telegraph
OVSF	Orthogonal Variable Spreading Factor codes
OSI	Open System Interconnection
PDC	Pacific Digital Cellular Standard
PIC	Parallel Interference Cancellation

P^3MUD	Partial Parallel Pipelined Multiuser Detector
PN	Pseudo Noise code
QPSK	Quadrature Phase Shift Keying
SCF	Soft Cancellation Factor
SCF_{UNV}	Universal Soft Cancellation Factor
SNR	Signal-to-Noise Ratio
SIC	Serial Interference Cancellation
TDMA	Time Division Multiple Access
TDD	Time Division Duplex
TFI	Transport Format Indicator
TPC	Transmit Power Control
3G	Third Generation Cellular Systems
3GPP-TS	3G Project Partnership Technical Specifications
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code Division Multiple Access

LIST OF SYMBOLS

ξ_κ	Soft Cancellation Factor , SCF.
P_b	Probability of Bit Error
W_n^N	A walsh function
b_i	i^{th} data signal
$b(t)$	data signal
$P_T(t)$	unit rectangular pulse
$a(t)$	PN code waveform
N	System processing gain
$s(t)$	Transmitted signal
$r(t)$	Received signal
Z_i	Decision statistic or metric
τ	Delay parameter
w_i	FIR filter weights
K	Number of users in system; $k = 1,2,\ldots K$
T	bit duration
$\Re$	real part operator
ϕ_k	received phase
η	noise due to AWGN
P_k	baseband power of the k^{th} user
θ_k	carrier phase
N_w	Observation symbols for standard differential detection
$y^{(0)}$	Initial soft decision outputs
$\hat{d}^{(0)}$	Initial hard decision outputs
$y_i^{(l)}$	Soft decision after each stage of multistage detector
$\hat{d}_i^{(l)}$	Hard decision after each stage of multistage detector
M	Number of RAKE fingers