Faculty of Electronics and Computer Engineering

MODELLING OF A NEW FULLY HYBRID SPECTRUM SHARING APPROACH FOR FIFTH GENERATION CELLULAR OPERATORS

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Doctor of Philosophy

2020

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

Faculty of Electronics and Computer Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this thesis entitled "Modelling of a New Fully Hybrid Spectrum Sharing Approach for Fifth Generation Cellular Operators" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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Date	:	…………………………………………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : …………………….………………….

Supervisor Name : Associate Professor Dr. Azmi Bin Awang Md Isa

Date : ………………...………..…………..

DEDICATION

Dedicated to Allah S.W.T. Almighty and Rasulullah S.A.W. Thanks also

To my father

For earning an honest living for us and for supporting and encouraging me to believe in myself

To my mother

A strong and gentle soul who taught me to trust in Allah, believes in hard work and thought so much could be done with less

To my brothers and sisters

To my wife and my kids

The reason for what I have become today

Thanks for your great support and continuous care

ABSTRACT

Spectrum sharing approach (SSA) has been emerged as a cost-efficient solution for the enhancement of spectrum utilization to meet the stringent requirements of 5G systems. However, practical issues concerning the implementation of such an approach are rarely addressed such as mutual inter- or intra-operator interference, millimeter wave user association (mUA) suboptimality, the associated infrastructure cost for deploying more mmWave cells, and fairness. Therefore, in this thesis, a new fully hybrid spectrum sharing (FHSS) approach consisting of an efficient mmWave cell–carrier distribution strategy and a new hybrid and adaptive QoE-based mUA algorithm (HAQ-mUA) were proposed with consideration to the interference dilemma. More precisely, the mmWave cell–carrier distribution strategy was implemented by setting up a tolerable distance among the mmWave cells (mCells) that operate at the same band (28 or 73 GHz) which are adopted in this work. The fully hybrid allocation of the spectrum is ensured by considering three spectrum access strategies (licensed, semi-shared, and fully-shared access) in an integrated and hybrid manner. Whereas, the new HAQ-mUA was presented to assign a typical user to the serving mCell, which offers the highest achievable data rate. The proposed FHSS based on the HAQ-mUA algorithm was compared with recent works and with both the FHSS approach based on the most conventional max-SINR mUA algorithm and the baseline scenario (utilizing licensed spectrum access). Numerical results demonstrate the superiority of the proposed FHSS based on the HAQ-mUA algorithm over the baselines approaches (licensed spectrum access strategy and FHSS based on max-SINR mUA algorithm) and the other relevant studies. In terms of system coverage performance, the proposed approach achieves (0%) outage probability with SINR value (>2 dB) of the cell edge users. Whereas, it is observed that the achievable data rate of all the users exceeds 100 Mbps, with an average data rate of more than (1.8X) over the benchmarks. Furthermore, it also proves its effectiveness in distributing the load across the network, where 20.5%–32%, 10.5%–20%, and 59.5%–65% of the users associate with mCells that support the three spectrum access strategies, respectively, reducing the number of mCell to half (16 mCells), thus saving half of the cost of the network infrastructure, and achieving a higher degree of fairness (F_{index} =0.9608) among the participating operators. This approach may serve as an incentive and encourage operators to share the spectrum with others.

PEMODELAN SATU PENDEKATAN BAHARU PERKONGSIAN SPEKTRUM HIBRID PENUH UNTUK PENGENDALI SELULAR GENERASI KELIMA

ABSTRAK

Pendekatan perkongsian spektrum (SSA) telah muncul sebagai penyelesaian kos efektif bagi peningkatan penggunaan spektrum untuk memenuhi keperluan ketat sistem 5G. Walau bagaimanapun, isu-isu praktikal mengenai pelaksanaan pendekatan sedemikian jarang ditangani seperti campur tangan inter-atau intra-operator, suboptimality persatuan pengguna mmWave (mUA), kos infrastruktur yang berkaitan untuk menggerakkan lebih banyak sel-sel mmWave, dan keadilan. Oleh itu, dalam tesis ini, pendekatan perkongsian spektrum hibrida penuh (FHSS) baru yang terdiri daripada strategi pengedaran pembawa sel mmWave yang cekap dan algoritma mUA berasaskan QoE hibrid dan adaptif yang baru dicadangkan dengan pertimbangan terhadap dilema gangguan . Lebih tepat lagi, strategi pengedaran pembawa sel mmWave telah dilaksanakan dengan menubuhkan jarak yang boleh diterima di kalangan sel-sel mmWave (mCells) yang beroperasi pada band yang sama (28 atau 73 GHz) yang diguna pakai dalam kerja ini. Peruntukan spektrum hibrida sepenuhnya dipastikan dengan mempertimbangkan tiga strategi akses spektrum (akses berlesen, separa kongsi, dan akses penuh) dalam cara bersepadu dan hibrida. Sedangkan, HAQ-mUA baru dibentangkan untuk memberi pengguna biasa kepada mCell yang melayani, yang menawarkan kadar data tertinggi yang boleh dicapai. FHSS yang dicadangkan berdasarkan algoritma HAQ-mUA dibandingkan dengan kerja-kerja terkini dan dengan kedua-dua pendekatan FHSS berdasarkan algoritma max-SINR mUA yang paling konvensional dan senario asas (menggunakan akses spektrum berlesen). Keputusan berangka menunjukkan keunggulan FHSS yang dicadangkan berdasarkan algoritma HAQ-mUA melalui pendekatan asas (strategi akses spektrum berlesen dan FHSS berdasarkan algoritma max-SINR mUA) dan kajian lain yang berkaitan. Dari segi prestasi liputan sistem, pendekatan yang dicadangkan mencapai (0%) kebarangkalian gangguan dengan nilai SINR (> 2 dB) pengguna tepi sel. Sedangkan diamati bahwa tingkat data yang dapat dicapai semua pengguna melebihi 100 Mbps, dengan data rata-rata lebih dari (1.8X) di atas tanda aras. Tambahan pula, ia juga membuktikan keberkesanannya dalam mengagihkan beban di seluruh rangkaian, di mana 20.5% -32%, 10.5% -20%, dan 59.5% -65% pengguna mengaitkan dengan mCells yang menyokong tiga strategi akses spektrum, masing-masing, mengurangkan jumlah mCell kepada setengah (16 mCells), dengan itu menjimatkan separuh daripada kos infrastruktur rangkaian, dan mencapai tahap keadilan yang lebih tinggi (F_{index}=0.9608) di kalangan pengendali yang mengambil bahagian. Pendekatan ini boleh menjadi insentif dan menggalakkan pengendali untuk berkongsi spektrum dengan orang lain.

ACKNOWLEDGEMENTS

First and for most, all praises are due to Allah, the Almighty, the Most Gracious and the Most Merciful, on Whom ultimately, we depend for sustenance, guidance, and blessing. Secondly, I would like to express my deepest gratitude and uncountable appreciation to my supervisor Associate Professor Dr. Azmi Bin Awang Md Isa for his continuous support, stimulating suggestions, inspirational encouragement and constructive criticism from the initial to the final level of my research. My gratitude and appreciation are also extended to my co-supervisor Professor Dr. Zahriladha Bin Zakaria and my M.Sc. supervisor, Professor Dr. Mahamod Ismail who gave me valuable support and help, thanks from the heart to them. I wish also to extend my warmest thanks to all UTeM staff, Faculty of Electronics and Computer Engineering for their support during my study and research in the university and I would like to acknowledge the Universiti Teknikal Malaysia Melaka (UTeM), UTeM Zamalah Scheme for the scholarships and the research grants. May Allah show mercy to my father, Lafta, who left this world before he could see this moment that he had always hoped to. I would like to convey my gratitude and appreciation to my brothers, and sisters for their always accessible support. My mother's enormous love and prayers have definitely helped me towards the successful completion of this thesis. Last but not least, I am indebted to all my friends, and colleagues who have directly or implicitly contributed to this thesis. Thank you all, thank you very much.

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1G	-	First Generation
2D	-	Two Dimension
2G	-	Second-Generation
3G	-	Third-Generation
3GPP	-	Third Generation Partnership Project
4G	-	Fourth-Generation
5G	-	Fifth-Generation
5GPPP	-	5G Infrastructure Public Private Partnership
AMPS	-	Advance Mobile Phone Service
AP	-	Access Point
AR	-	Augmented Reality
BDMA	-	Beam Division Multiple Access
BH	-	Backhaul
BPS	-	Best Path Selection
BRS	-	Best Relay Selection

BS	-	Base Station
BSS	-	Business Support Systems
CA	-	Carrier Aggregation
CAPEX	-	Capital Expenditure
CBSsA	-	Closest BSs Association
CC	-	Coordination Context
CDMA	-	Code Division Multiple Access
CEPT	-	European Conference of Postal and Telecommunication Administrations
CLOSA	-	Closest LOS Association
CMOS	-	Complementary Metal-Oxide-Semiconductor
CN	-	Core Network
CP	-	Control Plane
CSMF	-	Communication Service Management Function
D2D	-	Device-To-Device
DL	-	Downlink
DUDe	-	Decoupled Uplink and Downlink
eMBB	-	Enhanced Mobile Broadband
ETSI	-	European Telecommunications Standards Institute

EU	-	European Union
FBMC	-	Filter Bank Multi Carrier
FCC	-	Federal Communications Commission
FCD	-	Fixed Combined Density
FDMA	-	Frequency Division Multiple Access
FHSS	-	Fully Hybrid Spectrum Sharing
FID	-	Fixed Individual Densities
F-SA	-	Fully-Shared Access
GHz	-	Giga Hertz
GSM	-	Global System for Mobile Communications
HAQ-mUA	-	Hybrid and Adaptive QoE-based mmWave user Association
HD	-	High-Definition
HetNets	-	Heterogeneous Networks
HR	-	Handover Rate
ICT	-	Information and Communications Technology
IIoT	-	Industrial Internet of Things
IMT-2020	-	International Mobile Telecommunications-2020
IMT-Advanced	-	International Mobile Telecommunications-Advanced
INFs	-	Intra-Slice Network Function

IoTs	-	Internet of Things
IP	-	Internet Protocol
IR	-	Infrared
ISC	-	Intra-Slice Controller
ISD	-	Inter-Site-Distance
ISPs	-	Internet Service Providers
JC	-	Joint Coordination
KPIs	-	Key Performance Indicators
LB	-	Load Balancing
LL	-	Link-Level
LMDS	-	Local Multipoint Distribution Service
LOS	-	Line-of-Sight
LSA	-	Licensed Spectrum Access
LTE-Advanced	-	Long Term Evolution-Advanced
M&O	-	Management and Orchestration
MAC	-	Medium Access Layer
Max-BRP	-	Maximum-Biased Received Powers
Max-RSS	-	Maximum-Received Signal Strength
max-SINR	-	Maximum Signal-to-Interference-Plus-Noise-Ratio

MC	-	Multi-Connectivity
MCDM	-	Multi-Criteria Decision Making
mCell	-	mmWave Cell
MD-MIMO	-	Massive and Distributed-Multiple Input Multiple Output
MDP	-	Markov Decision Processes
MEC	-	Multi-Access Edge Computing
MEITS	-	Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society
MHN	-	Mobile Hotspot Network
MIIT	-	Ministry of Industry and Information Technology
mMIMO	-	Massive Multiple-Input and Multiple-Output
mmWave	-	Millimeter Wave
MNOs	-	Mobile Network Operators
MOST	-	Ministry of Science and Technology
mUA	-	mmWave User Association
Multi-ImCOs	-	Multi-Independent mmWave Cellular Operators
multi-RATs	-	Multi-Radio Access Technologies
MWC	-	Mobile World Congress
NC	-	Network Coding

NDRC	-	National Development and Reform Commission
NFs	-	Network Functions
NFV	-	Network Function Virtualization
NFVI	-	Network Function Virtualization Infrastructure
NLOS	-	Non-Line-of-Sight
NOMA	-	Non-Orthogonal Multiple Access
NSA	-	Non-Standalone
NSI	-	Network Slice Instance
NSMF	-	Network Slice Management Function
NSPs	-	Network Service Providers
NSSI	-	Network Slice Subnet Instance
NTT DoCoMo	-	Nippon Telegraph and Telephone Do Communications Over the Mobile Network
NYU WIRELESS	-	New York University Wireless
OFDMA	-	Orthogonal Frequency-Division Multiple Access
OPEX	-	Operating Expenditure
OSS/BSS	-	Operations Support System/Business Support System
PHY	-	Physical Layer
PL	-	Path-Loss