SHORT-TERM SPECTRUM SHARING WITH ECONOMIC AWARENESS IN 5G NETWORKS

by
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ABSTRACT

The next Generation Mobile Networks 5G is expected to start rolling out by 2020, targeting at significantly faster mobile data speeds and increasingly massive machine communications. As we are entering into a whole new wireless time, where the blend of spectrum policy and technology becomes more important, the networking practices are tightly coupled with economic considerations. Therefore, a novel economic-driven spectrum policy should be designed to support all spectrum access methods with flexibility to take advantage of potentially new spectrum sharing paradigms.

In this thesis, we present the feasibility of putting economic models in the existing dynamic spectrum sharing architectures, from three aspects: spectrum sublicensing at a small scale, spectrum auction design, and licensed and unlicensed band selection. We point out the challenges under each scenario and propose solutions to address these problems.

First, for the spectrum sublicensing, we introduce the concept of the protection zone to enable multiple operators to spatially share the spectrum and ensure exclusive usage without any interference. Furthermore, the trade-off between the precision of boundary estimation and the cost of sensing networks is analysed. Second, for the spectrum auction, we study how an interference graph influences performance of the auction algorithm and guarantees fairness and truthfulness. Additionally, we further propose a negotiable auction for a more efficient spectrum allocation based on a mixed graph which offers a base station a second chance if the original request is rejected. Unlike the existing work, our proposed solution with a

faster grouping scheme performs better in a dense situation, hence it accommodates more base stations. Third, for the licensed and unlicensed band selection from the perspective of operators, we build a finite game and present performance comparisons of different strategies. Moreover, the analysis of the Nash equilibrium is provided and so are the suggestions on how to achieve high benefits for different scales of operators.

We apply our design and findings to the potential spectrum sharing architectures, i.e., Licensed Shared Access and Spectrum Sharing System. We strengthen the coupling of the sublicensing scheme with the spectrum sharing platforms by enabling each base station as an individual bidder and let them bid for a contour based sublicense, ensuring the exclusive right and interference protection. Additionally, we also analyse the unlicensed and licensed band selection from the perspective of operators and prove the equilibrium existence in the spectrum market. In conclusion, the short-term sublicensing in the secondary market has not been fully studied and put into practice yet. The thesis has given rise to an integration of spectrum technology and policy. It is believed that, in the future, the economic-aware spectrum policy design could be incorporated into communication technology to realize an innovative, efficient and flexible sharing model.

CERTIFICATE OF ORIGINAL AUTHORSHIP

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.

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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Dedicated to My Beloved Parents

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List of Symbols

Symbol	Description
M	number of spectrum blocks or sellers
P_t^m	allowed maximum transmit powers on spectrum block m
f	frequency
p_i^j	buyer i's transmit power on the spectrum block j
P_r	the signal strength at the edge of a cell
d_0	assumed to be 1-10 m indoors and 10-100 m outdoors
N	number of base stations or buyers
p_i	buyer i's payment
D_i	shape of the contour of buyer i
$v_i(x, y)$	buyer i's valuation density in the space domain
a_i	allocation result $\in \{0, 1\}$
$\mathbb{R}$	revenue of the auction
$\rho(x, y)$	density of sensors in a region
c	the cost of the sensing or sublicense of the buyer
τ	the cost of one sensor
λ	the average distance between sensors
$\|\mathbf{B}\|$	the area of a bounded region $\mathbf{B}$
d_{ij}	the distance between buyer i and buyer j
P_h	the high received power by the sensor
P_l	the low received power by the sensor

Symbol	Description
P_b	the contour boundary power
P_s	the power of the base station
d_h	the distance from the base station to the high sensor
d_l	the distance from the base station to the low sensor
d_b	the distance from the base station to the contour boundary
w	number of the whole tiles
h	number of the half tiles
μ	boundary sensitivity
$\mathbf{V}$	a set of vertices in the Euclidean space
$\mathbf{E}$	a set of edges in the Euclidean space
v	a vertex
e	an edge
$\mathcal{T}$	function of a Delaunay triangulation for set $\mathbf{V}$
b_i	buyer i's bid for a spectrum block
l_i	buyer i's location
G	the adjacency matrix of the interference graph
p_i	buyer i's payment
$\|\beta\|$	the number of channels
ω	the weight of a buyer
Ω	a group of nodes
seq	sorted vertices
$\mathbf{b}$	the bid set of a group
$\mathbf{r}$	set of requested coverage ranges
θ_i	buyer i's ratio of these ranges
γ_i	buyer i's determined range
η_i	buyer i's satisfaction

Symbol	**Description**
B	total bid of a buyer
U	buyer's utility
A_i	effective coverage
$\mathcal{M}$	allocation mechanism
$\mathbb{S}$	spatial efficiency
$\mathbb{B}$	buyer satisfaction
Ω^B	group bid
B_α	benchmark of group
s	the player's strategy
$\mathcal{K}$	the player set
u	player's utility or payoff
C^P	average spectrum resource of the buyers under PAL
C^G	average spectrum resource of the buyers under GAA
α	the spectrum of PAL
δ	the spectrum of GAA
r	profit rate
$\mathcal{B}$	total spectrum resource for PAL and GAA use
m	subscriber mass
$\hat{M}$	total subscriber mass
x	the probability of play some strategy

List of Publications

Journal publication

- **Huiyang Wang**, Diep Nguyen, Eryk Dutkiewicz, Gengfa Fang, Markus Dominik Mueck, "Negotiable Auction based on Mixed Graph: A Novel Spectrum Sharing Framework", in IEEE Transaction on Cognitive Communications and Networking, 2017. (Corresponding to Chapter 5)

Conference publications

- **Huiyang Wang**, Eryk Dutkiewicz, Diep Nguyen, Markus Dominik Mueck, "Game Theoretic Analysis of Sublicensing for PAL and GAA Bands in Spectrum Access System," in 28th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 2017. (Corresponding to Chapter 6)

- **Huiyang Wang**, Eryk Dutkiewicz, Beeshanga Abewardana Jayawickrama, Markus Dominik Mueck, "Dection of Contour Boundary for Sublicensing in Spectrum Access Systems," in 17th International Symposium on Communications and Information Technologies, ISCIT 2017. (Corresponding to Chapter 3)

- **Huiyang Wang**, Eryk Dutkiewicz, Beeshanga Abewardana Jayawickrama, Markus Dominik Mueck, "Design of Contour based Protection Zones for Sub-licensing in Spectrum Access Systems," in IEEE 82nd Vehicular Technology Conference, VTC Spring, 2017. (Corresponding to Chapter 3)

- **Huiyang Wang**, Eryk Dutkiewicz, Gengfa Fang, Markus Dominik Mueck, "A fair spectrum sharing framework based on topological sort and max weight for femtocells," in Australian Communications Theory Workshop (AusCTW), 2016. (Corresponding to Chapter 4)

- **Huiyang Wang**, Eryk Dutkiewicz, Gengfa Fang, Markus Dominik Mueck, "Framework of Joint Auction and Mixed Graph for Licensed Shared Access Systems" in 2015 IEEE International Symposium on Dynamic Spectrum Access Networks, DySPAN 2015. (Corresponding to Chapter 5)

- **Huiyang Wang**, Eryk Dutkiewicz, Gengfa Fang, Markus Dominik Mueck, "Spectrum Sharing Based on Truthful Auction in Licensed Shared Access Systems," in IEEE 82nd Vehicular Technology Conference, VTC Fall, 2015. (Corresponding to Chapter 4)

- **Huiyang Wang**, Eryk Dutkiewicz, Gengfa Fang, Markus Dominik Mueck, "An Auction Framework Based on Flexible Transmit Powers in the Licensed Shared Access Systems," in 15th International Symposium on Communications and Information Technologies, ISCIT 2015. (Corresponding to Chapter 3 and 4)

Other

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SIG White Paper on Novel Spectrum Usage Paradigms for 5G, Chapter 6, 2014 (Corresponding to Chapter 2)

- **Huiyang Wang**, DiepNguyen, Eryk Dutkiewicz, Markus Dominik Mueck. submitted as a patent disclosure: "5G: 3.5 GHz Spectrum Sharing A Short Term Online Agreement on Spectrum Sharing for the Priority Access Licensed Systems" (Corresponding to Chapter 6)

- Gengfa Fang, Markus Dominik Mueck, Eryk Dutkiewicz, **Huiyang Wang**, submitted as a patent disclosure: "Sharing Agreement based Spectrum Sharing for Priority Access Users in 3-tier SAS." (Corresponding to Chapter 2)