RESOURCE ALLOCATION WITH ECONOMIC FRAMEWORK IN HETEROGENEOUS CELLULAR NETWORKS AND HETEROGENEOUS USERS

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OCTOBER 2019

RESOURCE ALLOCATION WITH ECONOMIC FRAMEWORK IN HETEROGENEOUS CELLULAR NETWORKS AND HETEROGENEOUS USERS

by

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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the

Indian Institute of Technology Delhi

October 2019

Certificate

This is to certify that the dissertation entitled **Resource Allocation with Economic Framework in Heterogeneous Cellular Networks and Heterogeneous Users**, submitted by **Mrs. Poonam Lohan**, a Research Scholar, in the *Department of Electrical Engineering*, *Indian Institute of Technology Delhi New Delhi*, *India*, for the award of the degree of **Doctor of Philosophy**, is a record of an original research work carried out by her under our supervision and guidance. The dissertation fulfills all requirements as per the regulations of this Institute and in our opinion has reached the standard needed for submission. Neither this dissertation nor any part of it has been submitted for any degree or academic award elsewhere.

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Acknowledgements

First of all, I would like to thank my supervisor **Dr. Jun-Bae Seo** for his guidance and encouragement which I received throughout my dissertation research journey. I am thankful to him for his invaluable advice and support which made it possible for me to complete this dissertation.

I would like to express my sincere thanks to my committee members Prof. Swades De, Prof. S. Dharmaraja, and Dr. Seshan Srirangarajan for their valuable feedback during my end semester presentations. I owe special gratitude to Prof. Swades De for his valuable discussions and suggestions for improving my research work.

I would like to thank my fellow researcher Mrs. Sharda Tripathi for her continuous support during this journey.

I express my heartfelt thanks to my family members, specially my mother Mrs. Sunita Devi and my husband Mr. Vikas Chahal who have been a constant source of inspiration to me to accomplish this work. I have no words to express my feelings, just want to say sorry to my daughter Kayna Chahal for keeping her away at that time when she needed me the most.

Poonam Lohan

Abstract

Recently, to deal with the ever-increasing traffic demand, heterogeneous cellular networks (HCN), wherein macro-cells are overlaid with small-cells, have emerged as effective means to enhance network capacity. Small-cells are helpful in filling up the coverage holes and providing extra data service in hot-spots with relatively low capital expenditure (CAPEX). However, due to different cell densities and transmission power ranges in tiers, spectrum allocation, cross-tier interference management, and load balancing are critical issues in implementing HCN. For service provider (SP), network management in terms of pricing and resource allocation in different tiers has become complex. To this end, the first two parts of this dissertation aim at the resource allocation with economic framework design in randomly deployed small-cells networks and two-tier heterogeneous cellular networks.

The first part of dissertation examines a monopoly pricing scheme for randomly deployed small cells, by proposing their profit model, which takes into account the average data rate and user's blocking probability. We further consider a dynamic traffic load on small cells such that operational expenditure for downlink transmission power cost and maintenance cost can be included in the profit model. Together with user surplus, we examine downlink transmission power of maximizing profit, feasible price ranges, and monopoly price based on some system parameters, e.g., pathloss.

In the second part of dissertation optimal bandwidth partitioning problem is studied for two-tier heterogeneous cellular network with social welfare maximization (SWM) as an objective. Spectrum is orthogonally partitioned between the tiers. Deployment of cells in the two tiers (macro- and small-cell tiers) are modeled as spatial Poisson point processes with different densities, and stochastic geometry is used to analyze the users'

association probability with macro-cell or small-cell based on the maximum signal-to-interference-plus-noise ratio (SINR) association rule. In SWM, the unique optimal bandwidth fraction is analytically obtained for the two tiers. To make the users indifferent to tiers for services, two different pricing schemes are presented. To ensure feasibility of pricing schemes, limits on operational cost factor are defined. Simulations validate the analytical results. It is shown that, with orthogonal spectrum deployment, maximum SINR association performs better than the flexible cell association scheme. The effects of different system parameters on the association probabilities and optimal bandwidth fraction are also addressed.

In the era of 5G with the goal of low-latency communication, Internet of Things (IoT), and multi-service communication networks, users have different types of resource demands, namely for real-time (delay-constrained) and elastic (delay-tolerant) traffic. Due to heterogeneous service demands, where users have different quality of service (QoS) requirement, optimal resource allocation to maintain the fairness while taking care of users satisfaction level is a challenging problem. To address this issue, the third part of this dissertation presents the resource allocation algorithm such that the utility-proportional fairness among heterogeneous users can be maximized.

The last part solves two optimization problems which aim at utility-proportional fairness maximization by optimizing power and bandwidth allocation among heterogeneous users having real-time and elastic traffic. Noting that both problems are non-convex, local optimal solutions in terms of bandwidth and power are found by alternating optimization algorithm. Numerical results validate the analysis, represent schedulability and average utility of real-time traffic user with respect to available resources, and compare utility fairness performance of both schemes.

सार

हाल ही में, बढ़ती यातायात मांग, विषम सेलुलर नेटवर्क से निपटने के लिए (एचसीएन), जिसमें मैक्रो-कोशिकाएं छोटी कोशिकाओं के साथ ओवरलैड होती हैं, प्रभावी रूप में उभरी हैं नेटवर्क क्षमता बढ़ाने का मतलब है। छोटी कोशिकाएँ कवरेज भरने में सहायक होती हैं छेद और अपेक्षाकृत कम पूंजी व्यय के साथ हॉट-स्पॉट में अतिरिक्त डेटा सेवा प्रदान करना (कैपेक्स)। हालांकि, विभिन्न सेल घनत्व और ट्रांसमिशन पावर रेंज के कारण स्तरों में, स्पेक्ट्रम आवंटन, क्रॉस-टीयर हस्तक्षेप प्रबंधन, और लोड संतुलन हैं एचसीएन को लागू करने में महत्वपूर्ण मुद्दे। सेवा प्रदाता (एसपी) के लिए, नेटवर्क प्रबंधन में विभिन्न स्तरों में मूल्य निर्धारण और संसाधन आवंटन की शर्तें जटिल हो गई हैं। इसके लिए अंत में, इस शोध प्रबंध के पहले दो भागों का लक्ष्य आर्थिक आवंटन है बेतरतीब ढंग से तैनात छोटे सेल नेटवर्क और दो स्तरीय विषम में रूपरेखा डिजाइन सेलुलर नेटवर्क। शोध प्रबंध के पहले भाग में बेतरतीब ढंग से तैनात के लिए एक एकाधिकार मूल्य निर्धारण योजना की जांच की जाती है छोटे सेल, अपने लाभ मॉडल का प्रस्ताव करके, जो औसत को ध्यान में रखते हैं डेटा दर और उपयोगकर्ता की अवरुद्ध संभावना। हम आगे एक गतिशील ट्रैफ़िक लोड पर विचार करते हैं छोटे सेल जैसे कि डाउनलिंक ट्रांसमिशन पॉवर लागत के लिए परिचालन व्यय और रखरखाव लागत लाभ मॉडल में शामिल किया जा सकता है। उपयोगकर्ता अधिशेष के साथ, हम लाभ, संभाव्य मूल्य श्रेणियों और, को अधिकतम करने की डाउनलिंक संचरण शक्ति की जाँच करें कुछ सिस्टम मापदंडों के आधार पर एकाधिकार मूल्य, जैसे, पैथलॉस।

शोध प्रबंध के दूसरे भाग में इष्टतम बैंडविड्थ विभाजन समस्या का अध्ययन किया जाता है सामाजिक कल्याण अधिकतमकरण (एसडब्ल्यूएम) के साथ दो-स्तरीय विषम सेलुलर नेटवर्क के लिए उद्देश्य। स्पेक्ट्रम ऑर्थोगोननली रूप से टीयर के बीच विभाजित है। की तैनाती दो स्तरों (स्थूल और लघु-कोशिका स्तरों) में कोशिकाओं को स्थानिक पॉइसन बिंदु के रूप में पेश किया जाता है उपयोगकर्ताओं के विश्लेषण के लिए विभिन्न घनत्व और स्टोचस्टिक ज्यामिति के साथ प्रक्रियाओं का उपयोग किया जाता है मैक्रो-सेल या स्मॉल-सेल के साथ अधिकतम सिग्नल-इनडिनेशन के आधार पर एसोसिएशन की संभावना प्लस-शोर अनुपात (SINR) एसोसिएशन नियम। एसडब्ल्यूएम में, अद्‌वितीय इष्टतम बैंडविड्थ अंश दो स्तरों के लिए विश्लेषणात्मक रूप से प्राप्त किया जाता है। उपयोगकर्ताओं को उदासीन बनाने के लिए सेवाओं के लिए स्तरों के लिए, दो अलग-अलग मूल्य निर्धारण योजनाएं प्रस्तुत की जाती हैं। व्यवहार्यता सुनिश्चित करने के लिए मूल्य निर्धारण योजनाओं में, परिचालन लागत कारक की सीमाएँ परिभाषित की गई हैं। सिमुलेशन मान्य हैं विश्लेषणात्मक परिणाम। यह दिखाया गया है कि, ऑर्थोगोनल स्पेक्ट्रम तैनाती के साथ, अधिकतम SINR

एसोसिएशन लचीली सेल एसोसिएशन स्कीम से बेहतर प्रदर्शन करती है। असर एसोसिएशन की संभावनाओं और इष्टतम बैंडविड्थ पर विभिन्न सिस्टम पैरामीटर अंश को भी संबोधित किया जाता है।

कम-विलंबता संचार के लक्ष्य के साथ 5G के युग में, इंटरनेट ऑफ थिंग्स (IoT), और बहु-सेवा संचार नेटवर्क, उपयोगकर्ताओं के पास विभिन्न प्रकार की संसाधन मांगें हैं, रियल-टाइम (विलंब-विवश) और लोचदार (विलंब-सहिष्णु) ट्रैफ़िक के लिए। देय विषम सेवा माँगों के लिए, जहाँ उपयोगकर्ताओं को सेवा की विभिन्न गुणवत्ता (QoS) की आवश्यकता होती है, उपयोगकर्ताओं की देखभाल करते हुए निष्पक्षता बनाए रखने के लिए इष्टतम संसाधन आवंटन संतुष्टि का स्तर एक चुनौतीपूर्ण समस्या है। इस मुद्दे को हल करने के लिए, इसका तीसरा भाग शोध प्रबंध संसाधन आवंटन एल्गोरिदम को प्रस्तुत करता है जैसे कि उपयोगिता-आनुपातिक विषम उपयोगकर्ताओं के बीच निष्पक्षता को अधिकतम किया जा सकता है।

अंतिम भाग दो अनुकूलन समस्याओं को हल करता है जो उपयोगिता-आनुपातिक निष्पक्षता का लक्ष्य रखते हैं विषमता के बीच शक्ति और बैंडविड्थ आवंटन का अनुकूलन करके अधिकतमकरण वास्तविक समय और लोचदार यातायात वाले उपयोगकर्ता। यह देखते हुए कि दोनों समस्याएं गैर-उत्तल हैं, स्थानीय हैं बैंडविड्थ और पावर के संदर्भ में इष्टतम समाधान वैकल्पिक अनुकूलन द्वारा पाए जाते हैं कलन विधि। संख्यात्मक परिणाम विश्लेषण को मान्य करते हैं, समयबद्धता और औसत का प्रतिनिधित्व करते हैं उपलब्ध संसाधनों के संबंध में वास्तविक समय यातायात उपयोगकर्ता की उपयोगिता, और उपयोगिता की तुलना करें दोनों योजनाओं का निष्पक्षता प्रदर्शन |

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List of Symbols

Φ_s	Homogeneous Poisson point process for small-cells deployment
λ_s	Intensity of Poisson point process Φ_s
λ_s	Users' intensity
C	Number of channels
λ_a	Call rate per user
$\boldsymbol{\lambda}$	Call arrival rate
μ	Service rate
A	Coverage area of cell
$r_o, \bar{R}_o, R_{\max}$	Radius of serving cell and neighbouring cell, maximum radius of cell
$a, \tilde{a}$	Erlang load of serving cell and neighbouring cell
P_b	Blocking probability
ϕ_j	stationary state probability of j channels in use
α	Pathloss factor
$\mathcal{P}_k, P_{\max}$	Transmission (Tx) power for a channel of cell k, maximum Tx power
h_i	Channel gain due to small scale fading
θ	SNR threshold
σ^2	Power of additive noise
C_E, C_T	Maintenance and transmission power cost
M	Monetary value or cost factor

U_S, U_u	Service provider's profit and user's surplus
$\mathcal{T}$	Spectral efficiency
$\mathcal{R}, r_l, r_u$	Feasible range of price, upper bound, lower bound on price
$\mathbf{1}(x)$	Indicator function
$\delta(x)$	Impulse function
γ_k	cells' density of tier-$k \in \{m, s\}$
m, s	m stands for macro cell, s stands for small cell
P_k	Uniform transmission power spectral density of tier-k cell
ζ	Normalized bandwidth fraction allocated to macro-cells tier
U	Expected surplus of a user
$\mathcal{A}_k$	Association probability of a user with tier-k
λ_k	Users' density associated with tier-k
α_k	Path loss exponent in tier-k
θ_k	SINR threshold for tier-k
T_k	average spectral efficiency in tier-k
d_k	data rate for a user when associated to tier-k
e_k	price per unit data rate for tier-k services
S_k	service provider's profit form tier-k services
Z_k	Maximum of SINRs that the user has form tier-k cells
c	Monetary cost per unit transmission power
$\bar{P}_{c_k}$	Coverage probability due to tier-k
$\mathbb{E}$	Expectation operator
F	Cumulative distribution function
f	Probability density function
R	Cell radius

N	total number of users
N_R	Cardinality of set of real-time traffic (RT) users
N_E	Cardinality of set of elastic traffic (ET) users
$U_i(r_i)$	Utility function of user i
r_i	Rate assigned to user i
d_i	Distance between BS and user i
r_m	Minimum rate requirement for RT users
$r_{\max}$	Maximum rate requirement for ET users
a, b	Calibration parameters for sigmoidal utility
P_t	Total power budget
B	Total Bandwidth resource
P_i	Allocated power to user i
η_i	Normalized bandwidth fraction for user i

List of Abbreviations

BS	Base Station
CAPEX	Capital Expenditure
CCD	Co-Channel Deployment
CCDF	Complimentary Cumulative Distribution Function
CDF	Cumulative Distribution Function
DPS	Differential Price Scheme
EE	Energy Efficiency
HCN	Heterogeneous Cellular Networks
KKT	Karush-Kuhn-Tucker
LTE	Long Term Evolution
NUM	Network Utility Maximization
OSD	Orthogonal Spectrum Deployment
PASTA	Poisson Arrivals See Time Average
PDF	Probability Density Function
PGFL	Probability Generating Functional
PPP	Poisson Point Process

PSD	Power Spectral Density
QoS	Quality of Service
RHS	Right Hand Side
RV	Random Variable
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise Ratio
SP	Service Provider
SPS	Single Price Scheme
SWM	Social Welfare Maximization
TDD	Time Division Duplex
Tx	Transmission
UPF	Utility-Proportional Fairness