RGC Ref.:N-HKUST605/13 NSFC Ref. : *(please insert ref. above)*

The Research Grants Council of Hong Kong
NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Delay-Aware Large-Scale Radio Resource Management: Theory and Algorithm Design for Cloud Radio Access Networks
云无线接入网络基于延迟感应的无线资源管理理论与算法设计

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Vincent LAU (劉堅能)	Prof. Mugen PENG (彭木根)
Post	Chair Professor	Professor
Unit / Department / Institution	ECE / HKUST	School of ICE, BUPT
Contact Information		
Co-investigator(s) *(with title and institution)*		

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted*)
Project Start date	01/01/2014		
Project Completion date	31/12/2017		
Duration *(in month)*	36		
Deadline for Submission of Completion Report	31/12/2018		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Performance Analysis and Optimization Modeling for C-RAN based on the Channel States and Queue States
2. Development of Low Complexity, Self-Organizing Dynamic RRM for C-RAN
3. Application of the Delay-Aware RRM to future Wireless Systems

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____

_____

1.
2.
3. ....

6. Research Outcome

Major findings and research outcome

(maximum 1 page; please make reference to Part C where necessary)

In this project, we have established a generic stochastic optimization framework that can embrace the queue dynamics and the physical layer dynamics. The optimization approach provides a systematic framework for the design of algorithms as well as the benchmarking of performance. Based on this optimization framework, the PIs have developed efficient and effective algorithms for the radio resource optimization in C-RAN network, which is a very important new network architecture for 5G wireless systems. We have considered various configurations from single antenna system, interference coordination to the clustering and massive MIMO optimization in C-RAN systems. Application specific algorithms were developed and simulation performance revealed significant performance gains compared with the state-of-the-art approaches. The established optimization framework also provides important guideline for designing more complex radio resource optimization algorithm.

The two teams in HKUST and BUPT have engaged in regular teleconference and discussion to brainstorm and explore specific problems for collaboration during the period. For instance, Prof. Peng has been invited to visit HKUST and we had fruitful discussions out of the meetings.

Overall, we have produced 8 papers in top IEEE journals and 2 papers in IEEE top conference. In addition, we have co-edit a special issue of “Heterogeneous Cloud Radio Access Network” on IEEE Wireless Communications Magazine as well as a special issue on “Cloud Computing based Radio Access Networks” in China Communications.

The following summarizes the research outcomes with respect to the three objectives.

[Objective 1] Journal Paper #2, #5 and Conference Paper #1 concerns about delay-aware stochastic modeling involving both queue and channel dynamics. Through consideration of these joint state dynamics as elaborated in objective 1, we have developed a stochastic modeling and optimization framework for the problems.

[Objective 2] Journal Paper #1, #3, #4, #6 and Conference Paper #2 concerns about the development of dynamic and self-learning algorithm for specific RRM problems (such as user centric clustering, fronthaul loading compression in C-RAN, interference mitigation and coordination as well as user association in C-RAN). The performance of the proposed algorithms achieved significant gains compared with state-of-the-art solutions.

[Objective 3] Journal Paper #2, #5 and Conference Paper #1 applied the optimization and modeling framework to design delay-aware RRM for future wireless systems. We obtained low complexity and close-to-optimal solutions with superb delay performance.

Potential for further development of the research and the proposed course of action *(maximum half a page)*

Potential areas for further development include design of parallel computable algorithms that can match the parallel computing cluster architecture in C-RAN. The centralization of C-RAN system provides challenges and opportunities for better radio resource management. On one hand, centralization opens up the possibility of massive cooperation among the radio units in the system and this results in significant performance improvement in controlling interference. On the other hand, centralization means the scale of the radio resource optimization problem will be significantly increased. As such, scalable and parallel algorithms will be needed to have a scalable run time for real-time control of radio resource in C-RAN.

7. The Layman's Summary

(describe <u>in layman's language</u> the nature, significance and value of the research project, in no more than 200 words)

In this project, we have designed efficient algorithms for radio resource optimization in Cloud Radio Access Network, which is an important new architecture for future 5G wireless systems. The radio resource management plays a key role in fully unleashing the potential of C-RAN in interference management and control. Due to the scale and the inherit complexity, current practice of radio resource management in C-RAN is mostly based on heuristics. In this project, we propose a systematic framework based on stochastic optimization, which can provide important guideline on the design of efficient and effective algorithms for radio resource control. We apply the framework to practical systems and have achieved significant performance gains over existing state-of-the-art solutions.

<u>Part C: Research Output</u>

8. Peer-reviewed journal publication(s) arising <u>directly</u> from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s)	Title and Journal/ Book	Submitted to RGC	Attached to this report	Acknowledged the support of this Joint Research Scheme	Accessible from the institutional repository
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*	***(bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	*(with the volume, pages and other necessary publishing details specified)*	*(indicate the year ending of the relevant progress report)*	*(Yes or No)*	*(Yes or No)*	*(Yes or No)*

2017				**J.C. Liu***, **A. Liu**, **V. Lau**	Compressive Interference Mitigation and Data Recovery in Cloud Radio Access Networks with Limited Fronthaul, IEEE Transactions on Signal Processing, vol. 65, no. 6, March **2017**	31 Dec 2017	Yes	Yes	Yes
2017				**W. Wang, V.Lau, M.Peng**	Delay-Aware Uplink Fronthaul Allocation in Cloud Radio Access Networks, IEEE Transactions in Wireless Communications, vol. 16, no. 7, pp 4275—4287, July 2017.	31 Dec 2017	Yes	Yes	Yes
2017				**A. Liu, V. Lau**	Joint BS-user Association, Power Allocation and User Side Interference Cancellation in Cell-free Heterogeneous Networks, **IEEE Transactions on Signal Processing**, vol. 65, no. 2, pp 335-345, Jan **2017**.	31 Dec 2017	Yes	Yes	Yes
2018				**A Liu, V. Lau**	Two-Timescale User-Centric RRH Clustering and Precoding Optimization for Cloud RAN via Local Stochastic Cutting Plane, IEEE Transactions on Signal Processing, vol. 66, no. 1, pp 64-76, Jan 2018.	31 Dec 2017	Yes	Yes	Yes
2015				***W. Wang, F. Zhang, V. LAU**	"Dynamic Power Control for Delay-Aware Device-to-Device Communications", IEEE Journals of Selected Areas on Communications (JSAC), Vol. 33, no. 1, pp 14-27, Jan 2015	31-Dec-2015	No	Yes	Yes
2015				***X. Rao, V. LAU**	"Distributed Fronthaul Compression and Joint Signal Recovery in Cloud-RAN", IEEE Transactions on Signal Processing, Vol. 63, Issue 4, pp 1056—1065, Jan 2015	31-Dec-2015	No	Yes	Yes

2015				***Peng, Mugen**、Quek, Tony Q. S.、Ding, Zhiguo、**Lau, Vincent**、Poor, H. Vincent	"Heterogeneous cloud radio access networks", IEEE Wireless Communications, 22(3), pp 12-13, 2015	31-Dec-2015	No	No (This is an editorial of a special issue)	No
2015				***Mugen Peng**, Chonggang Wang, **V. Lau**, H. V. Poor.	"Fronthaul-constrained cloud r adio access networks: insights and challenges" IEEE Wireless Communications Magazine, vol.22, no.2, pp 152-160	31-Dec-2015	No	Yes	Yes

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
Dec 2015/ San Diego	Queue-Aware Joint Remote Radio Head Activation and Beamforming for Green Cloud Radio Access Networks	IEEE Globecom	31-Dec-2015	No	Yes	Yes
Dec 2016	Joint Interference Mitigation and Data Recovery in C-RAN with Distributed Fronthaul Compression	IEEE International Conference on Communication Systems (ICCS)	31 Dec 2017	Yes	Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Jiachang LIU	PhD	Sept 2013	July 2019
X. RAO	Ph.D.	Sept 2010	Aug 2015

F. Zhang	Ph.D.	Sept 2010	Dec 2015

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

The conference paper was in the finalist of the best paper award in IEEE Globecom 2015.