CORE
Metadata, citation and similar papers at core.ac.uk
Provided by Northumbria Research Link

Northumbria Research Link

Citation: Yang, Jiachen, Xiao, Shuai, Jiang, Bin, Song, Houbing, Khan, Suleman and Ul Islam, Saif (2019) Cache-enabled Unmanned Aerial Vehicles for Cooperative Cognitive Radio Networks. IEEE Wireless Communications. ISSN 1536-1284 (In Press)

Published by: IEEE

URL:

This version was downloaded from Northumbria Research Link: http://nrl.northumbria.ac.uk/41378/

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: http://nrl.northumbria.ac.uk/policies.html

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)

Northumbria University NEWCASTLE

CUSTOMER SERVICE EXCELLENCE CSE UniversityLibrary

Cache-Enabled Unmanned Aerial Vehicles for Cooperative Cognitive Radio Networks

Jiachen Yang, *Member, IEEE,*, Shuai Xiao, Bin Jiang, Houbing Song, *Senior Member, IEEE*, Suleman Khan, Saif ul Islam,

***Abstract*—Cooperative cognitive radio network is a new method to alleviate the spectrum scarcity problem. The proactive content caching and unmanned aerial vehicles (UAVs) relaying techniques are deployed in a cognitive radio network (CRN), to enable the achievable rates for primary and secondary systems. Even though these two emerging technologies are grateful to solve the problem of spectrum scarcity, there are still open issues to influence the system performance and the utilization of spectrum. In this article, we provide an overview of the cooperation technique, including their theoretical schemes and the advanced performance in radio networks. Then, this paper proposes a cache-enabled UAV cooperation scheme in CRN, which enhances the CRN's transmission capability and reduces the redundant traffic load of CRN. The experimental results show that the cache-enabled UAV scheme significantly improves the achievable rates for both systems in cooperative cognitive radio network (CCRN). In addition, we present the future work related to content caching, deployment of UAV and CCRN to support radio networks.**

I. Introduction

As the rapid growth of Internet of Things (IoT), data traffic will increase unprecedentedly [1]. The existing literature shows that mobile video traffic will occupy 72 percentage of the total traffic [2], which requires more spectrum to meet the data traffic requirement. To deal with the spectrum scarcity problem of wireless communication, cognitive radio (CR) technique has been developed [3]. In cognitive radio network (CRN), there are mainly three schemes for secondary users (SUs) to share the spectrum resources [4]. In one scheme, interleave refers that some SUs can opportunistically access on an idle channel supported by the primary users (PUs). Another scheme called underlay in which the SUs can transmit simultaneously with the PUs as long as there is no interference to PUs' transmission. Overlay allows the SU to provide special services in exchange for the opportunity to obtain the PU licensed bandwidth.

Motivated by feasible schemes, CRN has been systematically studied by researchers in the past few years [5]. However, these researches were based on the assumption of non-cooperative networking between the primary and secondary users. To further improve the efficiency of CRN, cooperative cognitive radio network (CCRN) is considered. In CCRN, the secondary base station (SBS) helps relay the data for the PUs and in return it gains access of the primary spectrum to serve the SUs, which can achieve a mutual benefits for both systems. This is particularly useful for the primary system when the quality of experience (QOE) can not be achieved by PUs. CRN has used full-duplex, zero forcing beam-forming, game theory techniques for both cooperation system [3]. However, the limited capacity of wireless backhaul link will offset the benefits of these cooperation methods. Another popular method to improve the efficiency of CRN by reducing the backhaul overhead is to store some popular contents at close base stations which contributes to lower backhaul utilization and decrease the transmission delay for multiple users [6]. Thus, this article considers content caching as a key technology and proposes a mobile relay caching in

This work was partially supported by National Natural Science Foundation of China (No. 61871283), Foundation of Pre-Research on Equipment of China (NO.61403120103) and Major Civil-Military Integration Project in Tianjin, China (NO.18ZXJMTG00170) *(Corresponding author: Shuai Xiao.)*

J. Yang, S. Xiao and B. Jiang are with the School of Electrical and Information Engineering, Tianjin University, China (e-mail:{yangjiachen, xs611, jiangbin}@tju.edu.cn).

H. Song is with the Department of Electrical, Computer, Software, and Systems Engineering, Embry-Riddle Aeronautical University, Daytona Beach, USA (e-mail: h.song@ieee.org).

Suleman Khan, Department of Computer and Information Sciences, Northumbria University, Newcastle, UK (e-mail: Suleman.khan@Northumbria.ac.uk).

Saif ul Islam, Department of Computer Science, KICSIT, Institute of Space Technology, Islamabad, Pakistan (e-mail: saiflu2004@gmail.com, saif@kicsit.edu.pk).

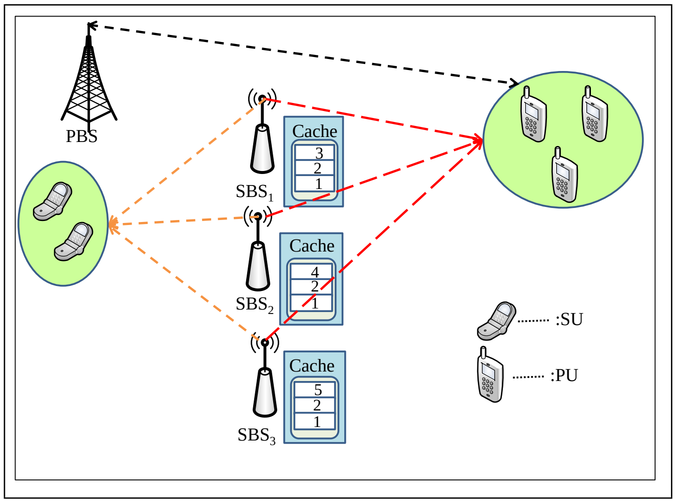

Figure 1. A typical architecture of content caching in SBS for a CCRN, red dotted lines represent the SBSs cache files to serve SUs by exchanging the access of the primary spectrum.

cognitive radio network to expand the capacity and performance. The proposed approach would support heterogeneous networks. The existing research work on cache-enabled cooperation in CRN didn't address the limitations with floating caching, which has become an important implementation of content caching, to enhance the performance [7].

Unmanned aerial vehicles (UAVs) is regarded as moving basestations to store the popular files, changing coverage according to users' requirement, tracking the users state and efficiently transmit files [8]. Due to their flexibility and mobility, UAV-assisted wireless communications have been employed in many practical applications, such as smart cities [8], surveillance and IOT communications [9]. Inspired by this, UAVs-assisted CCRN is emerging. However, more comprehensive investigation on cache-enabled UAV in CCRN is still an open issue. There are some state-of-the-art methods. [10] proposed an edge computing empowered radio access network based on free space optical(FSO) communication, which can realize rapid event response and flexible deployment by mount fronthaul and backhaul links on UAVs. A novel conceptor-based echo state networks (ESNs) algorithm was proposed to predict the optimal user-UAV association, optimal locations of UAVs as well as the content to cache at UAVs[11].

In this article, a cache-enabled UAV basestation to improve cooperation in CRN is presented to solve the spectrum scarcity problems brought by the increasing traffic. Comepared with the method mentioned above, which realized the optimal location of UAVs, our work enables cooperation between the primary and secondary networks in CRN and achieves adaptive coverage. This paper presents current researches in this field including CCRN, caching scheme and UAV placement, and the requirements of cache-enabled UAV in CCRN, and proposes a new architecture for CRN. We propose a cache-enabled UAV cooperation approach in CRN, which improves the achievable data rates for primary and secondary systems. We also presents challenges when we combine the CRN based on the cache-enabled with floating basestation.

II. Proactive Caching for Cognitive Radio Networks

With the advances of software defined radio (S-DR) and wireless sensor networks (WSN), cognitive radio technology is becoming mature. Cognitive radio can sense the PU's idle spectrum for SUs to serve its own requests in cognitive radio networks (CRNs) [5]. To further improve the spectrum efficiency in CRN, we take CCRN into consideration, where secondary users help PU's transmission, in return, the primary user will free the occupied channels, thus improving transmission opportunity to its own. Cooperative cognitive radio networks (CCRN-s) expand the CRNs' capabilities and performance, which support spectrum requirements for system. The optimization of backhaul transmission is an important issue in CCRNs. The traditional CCRN achieve the benefits only from information cooperation or both information and energy cooperation [3] but ignore the optimization of backhaul transmission. Although the dedicated energy beamforming remedies the low efficiency of wireless power transfer, the out-of-band energy harvest (EH) phases lead to low cooperation efficiency in CCRN. In [12], the authors propose an original CCRN assisted by full-duplex (FD) energy access point. In this context, the use of proactive caching within the radio access network is utilized to reduce the backhaul overheads and improve the performance of CCRN. One of the next generation CRN technologies will be enabled by the proactive caching of secondary system [7].

As shown in Fig.1, the SBSs cache a set of files which assist in the relay of the content of the PUs and in the exchange of the access to the primary spectrum to serve the SUs. In this way, the performance of both systems could be improved significantly. For content caching, whether it is a wired or a wireless communication network, content caching mainly consists of two parts: caching placement and caching delivery. We need to allocate the storage space of cache and calculate the optimal relay location of UAV, the same time we should reduce the communication time between UAV and the user or the base station to efficiently perform cache delivery. In CCRN, content items can be cached at locations of the CRN. Within Radio Access Network (RAN), SBS, SU devices and access points can be improved with additional caching capacity. However, CCRN also has some limitations. Content caching may load the operation of the base station. The flexibility of the base station is poor, and the service scope is limited. It is difficult to meet the requirements of the dynamic scenario in real time. The development of UAVs has brought new direction to solve these problems.

III. Applications of UAVs in Cognitive Radio Networks

UAVs have been proposed to operate as a part of the wireless networks to meet some of the requirements and enable multiple applications, such as urban management, agriculture, geology, meteorology, electricity, emergency rescue and disaster relief, video shooting and so on because of their mobility and flexibility [13]. Recently it has been applied to the IOT and smart city applications. As discussed earlier, there is high potential for UAVs to solve the spectrum problems existing in CCRN. In CCRN, new cooperation could be enabled by using automated UAVs to not only help improve achievable data rates of primary and secondary systems, but also enhance the spectrum utilization efficiency of networks. Before being able to use UAVs in CCRN, there are still some serious challenges to address, including limited energy, converge, signal transmission range and poor processing ability. In consideration of technology evolutions, the above restrictions have been solved by several ways, though some ways can be applied directly to UANs and some can't. By solving these challenges, UAVs can fully utilize the advantages in CCRN, which will minimize the pressure of base station, provide users with convenient and fast information transmission and meet the growing environmental needs. In the following sections, we only list and represent a few applications of UAVs in CCRN.

A. Flying Relay

In CCRN, when the PUs are located in the edge of the PBS, the requests may not be responded, due to the poor quality of the edge transport channel, at the same time the PUs will occupy the licensed bandwidth which leads that the SUs have no chance to access the licensed bandwidth for its own information, resulting in the reduced overall throughput of CRN and the degraded performance for both systems. In particular, when both PUs and SUs have an emergency situation which urgently need successful information transmission to the destinations, if the CRN is paralyzed, it will result in a great loss for both systems.

In this context, due to the reduced cost and size[4], UAVs might be a good complementary solution with their fast deployment to help the network edge PUs, which can satisfy the requirements of the transmission rates within a short time. In CCRN, as shown in Fig.2(a), an automated UAV equipping in the transmission system as a flying relay can quickly receive the requested content from PBS to the PU, which is required to have some intelligent route planning algorithms to select the optimal path and the best relay location. The UAV plays a role of decode-and-forward relay for mitigating the effects of connection between the PBS and the PU, the location of which is important to improve the primary network connectivity, accessibility and throughput. When the UAV reaches the optimal location, it can be used to establish a real-time communication channel, the PBS can connect with UAV and UAV also links to the PU, the PU can successfully receive the requested files from PBS. Therefore, there are more opportunities for SUs to utilize the released bandwidth of the PU, which increase the achievable rate, the probability successful transmission and other performance for the secondary network. Flying relay can also be used to both of the PUs and SUs, which aim to communicate to the closet PBS via a multiple RAN through the same UAV relay. For the problem of drained power, we consider the way to use the built-in battery and external solar panels to supply power together because of the flexibility of UAV relays. In addition, the power management unit (PMU) is installed in the UAV

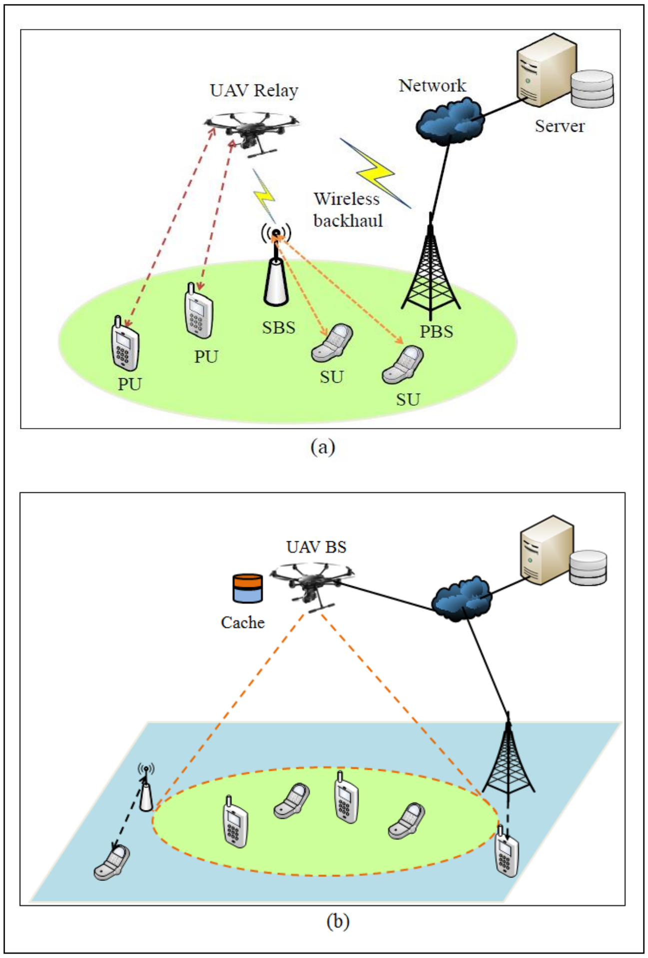

Figure 2. UAV applications in CRN: a) a UAV is used to relay the primary and secondary information from PBS and SBS to PUs and SUs, respectively; b) a UAV is used as a floating base station to directly serve the PUs and SUs.

to control the power consumption threshold, to reduce the power consumption under the premise of ensuring the transmission performance of UAN relays, and the built-in battery and solar energy can be used to effectively distribute the power to different components of the system.

B. Flying Base Stations

The latest techniques are used to enable higher capacity and spectrum efficiency in CCRN. In recent years, EH and game theory technologies have proposed to increase cooperation opportunities for both systems [12]. As time goes by, the static cooperation approaches based on the management of bandwidth and energy resources become less efficient as the primary and secondary users dramatically increase. This motivated the adoption of mobile basestations that can fly at different locations to efficiently serve the covered users.

Indeed, with the fast deployment, UAVs have received increasing attention in the past decade, which can be used to provide better wireless coverage and supplement the ground static base station to provide higher data rates for the users. The UAVs can provide relay transmission for the primary and secondary users of the edge and improve the radio transmission utilization. We use the tethered UAVs as the flying base stations, which can be powered by the ground generator and can be hovered in a certain area in the air for a long time, and set the content cache to fit the actual needs of the edge users, which can reduce the working pressure of the ground base stations. Therefore, utilization of UAV basestations (UAV-BSs) in CCRN has emerged as a prospective method to temporarily improve the capacity or coverage and improve the spectrum efficiency in airborne networks. In CCRN, UAV-BSs can help a CRN of PBSs and SBSs provide high data rate and even in an unexpected emergency situations happening such as adverse weather, transmission problems and earthquakes, etc [14]. A cellular network is provided by a flying basestation in CCRN is shown in Fig.2(b), where the basestation is mounted on a flying UAV in the air, and the mobile terminals for primary and secondary user are distributed on the ground. The UAV-BS can support primary and secondary users where there is no coverage provided by the poor networks. SBSs can help PBSs send the PUs' data to UAV-BSs, and the signaling content includes the user address, channel, and content encryption information. Meanwhile, SBSs can obtain occupied channels transmission permission in PBSs to serve SUs, and SBSs can send SUs' data to UAV-BSs, the signaling content including the user address, the PBSs channel and the encrypted information.

IV. USE OF CACHING FOR UAVS IN COGNITIVE RADIO NETWORKS

Caches for UAVs have emerged in areas of ultra-dense users such as residential areas and stadiums. It is remarkable that the achievable rates of CCRN system served by cache-enabled UAVs have not been investigated before. Hence, in this section, we study the CCRN system for primary and secondary users supported by UAVs serving as a basestation.

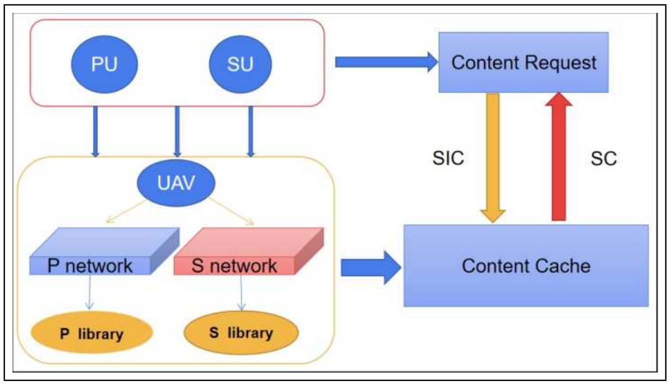

Figure 3. The system architecture, including communication ways of UAVs and PUs and SUs , content caching model and service model

A. Proactive Content Caching for UAVs

Content caching technology aims to solve the problem of reducing transmission performance caused by repeated requests for video files. In order to solve this problem, it is usually possible to improve the achieveable data rates of the primary and secondary systems by prefetching popular content during off-peak periods and serving in the peak periods. We envision content cache deployments in CCRN that consists of not only ground cache-enabled SBSs, but also flying popular contents that are stored at UAVs. Such flying cache-enabled UAVs will bring the achievable rates of optimally caching contents and dynamically placing them. In order for UAVs to be utilized for longer time in CCRN, the optimal caching contents required by primary and secondary users will be critical. However, users' needs will continue to be enriched. Due to the limitation of data storage size, user throughput will soon reach a peak. Considering the continuous updating of cached content, relying on big data storage technology, several UAVs in a region are built as a distributed storage system, each UAV is a child node of the system, so the data storage capacity will be increased several times. And the content caching for UAVs will be efficient.

B. UAV Location Deployment and Coverage Optimization

In recent years, deployment of UAVs for terrestrial heterogeneous networks (HetNets) scenarios has been investigated. To improve the system throughput, the location deployment of UAVs is also developed from initial 2D deployment to the 3D deployment. At present, 3D placement of UAVs is regarded as an important problem to devise UAVs enabled HetNets. In [13], the authors study the 3D placement to satisfy the high data rate. They show that a UAV decreases its height to serve users in a dense area, when in a low density area, the altitude is reasonable increasing to serve more users. On the other hand, 3D placement of UAVs in CCRN has not been considered to the best of our knowledge. In this context, though 3D placement of UAVs may cause some negative impact such as increased energy consumption, noise pollution and so on, we still investigate the 3D deployment of UAVs in CCRN, because we believe that these negative effects are neglected compared to the benefits. In addition, considering the limited wireless backhaul between UAVs and the core network UAVs placement, we employ content caching approach in the design and implementation of UAVs enabled CCRN in networks.

C. Experimental Framework

Based on the above analysis of the content caching and location for UAVs, we briefly introduce a preliminary framework for deployment optimization of UAVs in CCRN like Fig.3 shows. Considering the object of service are mobile terminals, we think the non-orthogonal multiple-access (NOMA) which will be the key technology of 5G, is exploited to serve all PUs [3]. When sending data to PUs, UAVs communicate with all users through superposition coding (SC) technology. UAVs receive data through successive interference cancelation (SIC) technology, which can step by step analysis of all user information by filtering signal power. And NOMA can access a large amount of users with high edge throughput and strong anti-interference ability, which can reduce the conflict between UAV and user transmission. In addition, we consider a CRN with cache-enabled UAV which contains a primary network and a secondary network, as depicted in Fig.2(b). The primary network includes a PBS and N_p PUs, and the secondary network contains N_s SUs. The sets of $N_p \triangleq \{1, 2, 3 \cdots N_p\}$ and $N_s \triangleq \{1, 2, 3 \cdots N_s\}$ denote PUs and SUs respectively. The secondary network can use the idle spectrum belong to the primary.

The Contents Caching Models: We consider

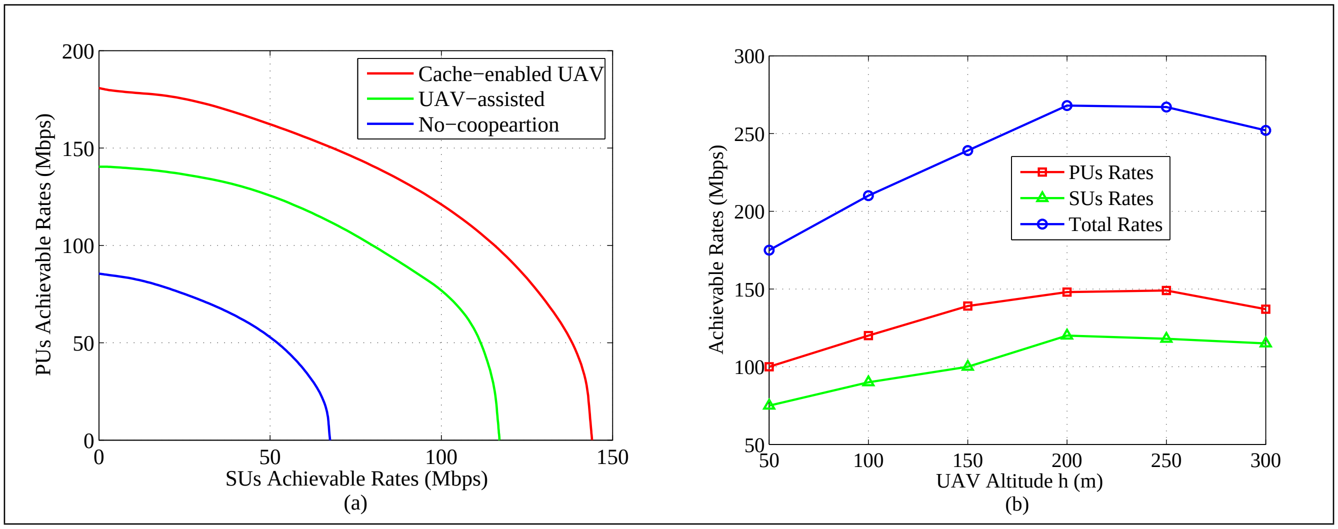

Figure 4. Simulation results: a) SUs and PUs achievable rates with different assistant schemes; b) PUs and SUs achievable rates versus the UAV altitude.

two different content libraries for the system of primary and secondary. The file libraries $F_p \triangleq \{1, 2, 3 \cdots F_p\}$ and $F_s \triangleq \{1, 2, 3 \cdots F_s\}$ are the primary and secondary contents respectively. The UAV has a limited cache capacity C. We assume that the UAV use C_o capacity to cache the primary files to serve primary requests, the remaining capacity $(C - C_o)$ is employed to cache some secondary files to serve the secondary users. We also assume that the popularity of the PU the SU are decreasing with the file number, i.e., $f_1^p \geq f_2^p \geq \cdots f_{F^p}^p$ and $f_1^s \geq f_2^s \geq \cdots f_{F^s}^s$, with $\sum_{i=1}^{F_p} f_i = 1$ and $\sum_{j=1}^{F_s} f_j = 1$. The content popularity is Zipf distributed, which is γ_p and γ_s for the content of PU and SU respectively.

Service Models: The primary requests can be responsed by the UAVs or the PBS. When the cache-enabled UAVs pre-fetches partial most popular contents required by the PUs, the data can be directly transmitted through the UAVs. When the files are not cached in the UAVs, the PUs obtain the caching content from the PBS. We assume that the distances between the PBS and the PUs are far away, so the downlink channels are poor to serve the PUs. Similarly, secondary requests can be satisfied by the UAV or the SBS. However, the SU's requests only obtained by the SBS and the UAV. For the SUs, the popular contents requested can be also directly served by the UAV. The UAV is used to serve the requests for the cached content of primary and secondary users, and the PBS, the SBS and the UAV have the fixed transmit power.Thereby, the cache allocation C_o is important.

Problem Formulation: Cache-enabled UAV can increase the achievable rates of the secondary network while satisfying the target rates of PU. More formally, under the given deployment constraint bandwidth B and the constraint of the location of UAV $x_{min} \leq x \leq x_{max}$, $y_{min} \leq y \leq y_{max}$ and $h_{min} \leq h \leq h_{max}$, we can define the optimization problem for joint caching and UAV location placement according to the target rates of PU R_{th} , the probability of the PU f_i^s and SU f_i^p requesting i-th file and the achievable rates for the j-th SU $R_j^{\rm s}$ and PU $R_j^{\rm p}$ provided by the UAV. Given this optimization problem, there are various algorithms to jointly find the optimal caching allocation and UAV locations, such as genetic algorithms, branch-and-bound method and particle swarm optimization (PSO) approach. In [15], PSO as a very basic global search algorithm has been studied on the deployment of UAV, which can achieve the effect of searching for the minimum value. Apart from this, PSO can be easily implemented while ensuring well quality and there are no many parameters to adjust. Therefore we plan to design data collation module in UAV to collect data, distribute popular content and non-popular content, and calculate the appropriate cache space. Considering the joint optimization of the cache allocation and UAV location deployment, relying on big data and cloud computing technology, we will build a big data

TABLE I
SIMULATION PARAMETERS

Simulation Parameters	Values	
Wireless transmission bandwidth	20MHz	
Transmit power of SBS	23dBm	
Transmit power of PBS	37dBm	
Transmit power of UAV	30dBm	
Cache capacity of UAV	100	
Considered region	1km × 1km	
Contents caching library	Primary system	Secondary system
	300	200
Content popularity	0.8	1.2
Number of single-antenna users	300	100
Capacity backhaul	80Mbps	
Maximum height of UAV	300m	

distributed computing platform in the cloud and upload the collected user location information to the cloud, meanwhile we use the PSO algorithm in real time through the cloud computing technology to calculate the optimal UAV location to maximize network utility.

V. Simulation Results

The proactive content caching and the location optimization of UAV were simulated by MATLAB, and the experimental results illustrate the performance of the proposed scheme are shown in Fig.4. The parameters in the experiment are listed in table I. Fig.4(a) shows the transmission rate regions of the primary and secondary systems for different assistant strategies. UAVs act as a relay between the primary system and the secondary system, and there is always a dedicated channel to communicate with the related system. And when the secondary network uses the same channels as the primary network, SBSs will transmit using the same power as the primary network. The results show that cache-enabled UAV cooperation schemes can obtain larger rate regions compared with the no-cooperation and only UAV-assisted schemes. This is because compared with UAV-assisted scheme limited by the backhaul links, cache-enabled UAV can directly deliver the cached contents without the influence of wireless backhaul.

Fig.4(b) shows the impact of the UAV altitudes on both primary and secondary rates. We show that when the altitude is 200m or 250m, PUs and SUs rates are maximum, as both the served coverage and the number of the served users are increased. However, beyond the optimal height of primary and secondary system, PUs and SUs achievable rates start to decrease because the distance between UAV and PUs (or SUs) increases which leads to the loss of path increasing and service performance decreasing.

VI. Challenges

There are some challenges related to content caching and deployment of UAVs in CCRN, as identified below.

Content Popularity Prediction: In the past few years, it has been reported that the popularity of files follows a Zipf model. In general, the popularity distribution changes over time instead of a constant. At the same time, the content popularity prediction affects the performance of proactive caching due to the limited cache capacity. The implementation of content caching in prediction popularity is part of our next steps for future work. With the development of cloud computing and machine learning, it is more feasible to achieve the prediction of content popularity. One feasible way is that ground caching techniques apply high-capacity storage devices with high-efficiency computing power to UAVs in CCRN. Another is the CCRN can learn massive users' information including content request and location to predict the popularity through deep learning algorithms.

Dynamic Scenarios: At present, the study is limited to static scenarios with regard to primary and secondary users and file popularity. Mobile phone is the research object of this paper. Considering the actual problem, the location of the object will be uncontrollable, and the dynamic program of the optimal service location of UAVs is an inevitable research work. The work of this paper is a preliminary exploration of UAVs as relay base stations, but dynamic Scenarios is an important part of UAV CCRN to ensure efficient processing and communication in marginal areas or emergencies. The results show that the direction is feasible. The future work will definitely use the technology of big data and cloud computing to maximize the network utility in the position of UAVs.

VII. Conclusion

We study a cache-enabled UAV scheme for C-CRN to solve the problem of spectrum scarcity and support the networking requirement challenges. We study the applications, location placement optimization for the use of UAV in CCRN. The simulation results indicate that cache-enabled UAV can improve the achievable rates of PUs and SUs, UAVs improves the transmission efficiency and access speed between the base station, PUs and SUs. For users, the increase in access speed represents an increase in the overall system capacity. The performance gain is from saving licensed bandwidth to serve the SUs due to the cache-enabled UAV directly transmitting cached contents for PU. We also shows the potential work to advance CCRN for networks.A promising future direction is to study the scenario in which the dynamic situation also need to be considered for the UAV.

References

[1] D. Wu *et al.*, "Collaborative Caching and Matching for D2D Content Sharing," *IEEE Trans. Wireless Commun.* vol. 25, no. 3, June. 2018, pp. 43–49.

[2] J. Yang, H. Xu *et al.*, "Exploiting Secondary Caching for Cooperative Cognitive Radio Networks," *IEEE Commun. Letters.* vol. 23, no. 1, Jan. 2019, pp. 124–127.

[3] F.Zhou *et al.*, "State of the Art, Taxonomy, and Open Issues on Cognitive Radio Networks with NOMA," *IEEE Trans. Wireless Commun.* vol. 25, no. 2, Apr. 2018, pp. 100–108.

[4] Y.Zeng *et al.*, "Cellular-Connected UAV: Potential, Challenges, and Promising Technologies," *IEEE Trans. Wireless Commun.* vol. 26, no. 1, Apr. 2019, pp. 120–127.

[5] J. Yang, C.Ma *et al.*, "Cache-enabled in cooperative cognitive radio networks for transmission performance," *Tsinghua Science and Technology*, vol. 25, no. 1, Feb.2020, pp. 1–11.

[6] B. Jiang, J.Yang *et al.*, "Multimedia Data Throughput Maximization in Internet-of-Things System Based on Optimization of Cache-Enabled UAV,", *IEEE Internet of Things Journal* vol. 6, no. 2, Apr. 2019, pp. 3525–3532.

[7] J. Zhao *et al*, "Delay-Constrained Caching in Cognitive Radio Networks", *Proc. IEEE INFOCOM, Toronto, Canada,* July 2014, pp. 2094–102.

[8] G. E. Athanasiadou *et al.*, "LTE Ground-to-Air Field Measurements in the Context of Flying Relays," *IEEE Trans. Wireless Commun.*, vol. 26, no. 1, Feb 2019, pp. 12–17.

[9] M. Mozaffari *et al.*, "Mobile internet of things: Can UAVs provide an energy-efficient mobile architecture?," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2016.

[10] Y. Dong *et al.*, "An edge computing empowered radio access network with UAV-mounted FSO fronthaul and backhaul: Key challenges and approaches," IEEE Wireless Commun, vol. 25, no. 3, pp. 154–160, June 2018

[11] M. Chen *et al.*, "Caching in the Sky: Proactive Deployment of Cache-Enabled Unmanned Aerial Vehicles for Optimized Quality-of-Experience, IEEE JSAC, vol. 35, no. 5, pp. 1046C61, May 2017

[12] R. Zhang *et al*, "Full-duplex cooperative cognitive radio networks with wireless energy harvesting", *IEEE ICC, Paris, France,* July 2017, pp. 1–6.

[13] E. Kalantari *et al*, "Backhaul-aware robust 3D drone placement in 5G+ wireless networks", *IEEE ICC Workshops, Paris, France,* July 2017, pp. 109–14.

[14] Y. Li *et al.*, "UAV-Assisted Dynamic Coverage in a Heterogeneous Cellular System", *IEEE Network,* vol. 31, no. 4, July 2017, pp. 56–61.

[15] H. Shakhatreh *et al*, "Efficient 3D placement of a UAV using particle swarm optimization," *ICIS,* Irbid, Jordan, May 2017.

Jiachen Yang [M'15] (yangjiachen@tju.edu.cn) received the M.S. and Ph.D. degrees in communication and information engineering from Tianjin University, Tianjin, China, in 2005 and 2009, respectively. He is currently a professor at Tianjin University. His research interests include image quality evaluation, wireless content caching, stereo vision research, pattern recognition and virtual reality.

Shuai Xiao (xs611@tju.edu.cn) is currently pursuing the Ph.D. degree at the School of Electrical and Information Engineering, Tianjin University, Tianjin, China. His research interests are in wireless content caching and UAV networks.

Bin Jiang (jiangbin@tju.edu.cn) received the B.S. and M.S. degree in communication and information engineering from Tianjin University, Tianjin, China, in 2013 and 2016. He is currently pursuing the Ph.D. degree at the School of Electrical and Information Engineering, Tianjin University, Tianjin, China. He is also a visiting sholar in Department of Electrical, Computer, Software, and Systems Engineering, Embry-Riddle Aeronautical University, Daytona Beach, FL, US. His research interests lie in perceptual image processing, including UAV networks, image quality assessment, stereo vision research and virtual reality.

Houbing Song [M'12–SM'14] (h.song@ieee.org) received the Ph.D. degree in electrical engineering from the University of Virginia, Charlottesville, VA, in August 2012. In August 2017, he joined the Department of Electrical, Computer, Software, and Systems Engineering, Embry-Riddle Aeronautical University, Daytona Beach, FL, where he is currently an Assistant Professor and the Director of the Security and Optimization for Networked Globe Laboratory (SONG Lab, www.SONGLab.us). He serves as an Associate Technical Editor for IEEE Communications Magazine.

Suleman Khan (suleman.khan@monash.edu) received the Ph.D. degree (Hons.) from the Faculty of Computer Science and Information Technology, University of Malaya, Malaysia, in 2017. He is a Faculty Member with the Department of Computer and Information Sciences, Northumbria University, Newcastle, UK. He has published more than 45 high-impact research articles in reputed international journals, including the IEEE Communications Surveys and Tutorials, ACM Computing Surveys, the IEEE Transactions on Intelligent Transportation Systems. He has published in the 2018 Local Computer Networks Conference. His research areas include, but are not limited to, network forensics, software-defined networks, the Internet of Things, cloud computing, and vehicular communications.

Saif ul Islam (saiflu2004@gmail.com, saif@kicsit.edu.pk) received his Ph.D. in Computer Science at the University Toulouse III Paul Sabatier, France in 2015. He is Assistant Professor at the Department of Computer Science, KICSIT, Institute of Space Technology, Islamabad, Pakistan. Previously, he served as Assistant Professor for three years at the COMSATS University, Islamabad, Pakistan. He has been part of the European Union-funded research projects during his Ph.D. He was a focal person of a research team at COMSATS working in O2 project in collaboration with CERN Switzerland. His research interests include resource and energy management in large-scale distributed systems (Edge/Fog, Cloud, Content Distribution Network (CDN)) and the Internet of Things (IoT)