Collaborative Radio Access of Heterogeneous Cloud Radio Access Networks and Edge Computing Networks

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***Abstract*—Although the technical merits of the heterogeneous cloud radio access networks (H-CRAN) architecture have been well demonstrated in terms of data rate enhancement and ubiquitous wireless service provisioning, solely relying on the H-CRAN may not be sufficient to further support full automation and everything-to-everything (X2X) connection for the next generation wireless applications. Recently, the edge computing network (EdgeNet) architecture exploiting socially-aware information and edge/fog computing technology has emerged to promisingly enhance the front-haul throughput and end-to-end latency performance. However, the EdgeNet architecture suffers from lacking of prosperous resource coordination. Although the spirits of the H-CRAN and EdgeNet appear opposite with each other, this two networking technologies actually complement each other in engineering practice. In this paper, we analytically derive the sufficient conditions for the optimum collaborative radio access. Our results thus suggest a harmonization between the H-CRAN adopting a scheduling based radio access and the EdgeNet applying a random access.**

I. Introduction

Mobile/cellular networks have been deployed for several decades to provide seamless and reliable streaming (voice/video) services for an increasing number of mobile users. From GSM/GPRS, UMTS, to LTE/LTE-A, the transmission data rates has been enhanced a million-fold. Relying on the heterogeneous network (HetNet) deployment [1]–[5] involving macrocells, small cells (femtocells, picocells), and/or relay nodes, ubiquitously supporting basic multimedia and Internet browsing applications has been tractable. As a result, it seems a satisfaction to primitive human-to-human (H2H) communication applications using existing network architectures/technologies. However, to substantially facilitate human daily activities, only providing basic voice/video and Internet access services is largely insufficient. On the contrary, achieving "full automation" and "everything-to-everything (X2X) connection" has been regarded as two urgent and ultimate targets for the next evolution not only in industry, but also in economics, social communities/activities, transportations, agriculture, and energy allocation [6]. "Full automation" implies a significant enhancement of human sensory and processing capabilities, which embraces unmanned or remotely controlled vehicles/robots/offices/factories/stores, augmented/virtual/kinetic reality, and immersive sensory experiences. On the other hand, X2X connection implies that diverse entities including human and machines are able to form new types of communities in addition to H2H, such as social networks of human-to-machine (H2M) and machine-to-machine (M2M) [7]–[12]. The applications include intelligent transportation systems [13], volunteer information networks [14], Internet of Things (IoT) [15]–[17], smart buildings/cities/grids [18]–[20], and mobile social networks, to name but a few.

To support these various applications, boosting the transmission data rates is only one of the diverse requirements to provide a part of services. In addition, the performance in terms of end-to-end transmission latency [6], energy efficiency, reliability, scalability, cost efficiency as well as stability shall be fundamentally enhanced. For example, ultra-low-latency and reliable data exchanges are particularly required by unmanned or remotely controlled vehicles/robots, augmented/virtual/kinetic reality, immersive sensory experiences, and intelligent transportation systems. On the contrary, as a tremendous number of sensors may be involved in Internet of Things (IoT) and smart buildings/cities/grids, scalability, cost efficiency, and energy efficiency are under the primitive concern. Unfortunately, the state-of-the-art network architectures of UMTS/LTE/LTE-A solely designed to optimize the data rates may face an unprecedented challenge to meet all kinds of requirements for above two targets. This obstacle consequently drives the development of new network architectures. Recently, two promising architectures are of particular interests not only in analytical research but also in engineering practice: heterogeneous cloud radio access networks (H-CRAN) and the edge computing network (EdgeNet).

The concept of H-CRAN originates from the hierarchical network architecture of UMTS, in which each radio network controller (RNC) coordinates a number of NodeBs [21]. In UMTS, radio resource management (RRM) is conducted by each RNC, while NodeBs only perform physical signal transmissions/receptions. Although RRM is subsequently implemented to be performed by an eNB in LTE/LTE-A/EPC, this concept opens the designs of integrating the radio resource optimization in individual eNBs into a joint optimization. Coordinated multi-point (CoMP) transmissions/receptions are thus a practical paradigm of joint resource scheduling/optimization among multiple eNBs [22]–[25]. In [26], I *et al* proposed novel evolution of CoMP to separate the radio resource optimization and front-end/baseband signal processing, in which the resource optimization is efficiently executed via the cloud

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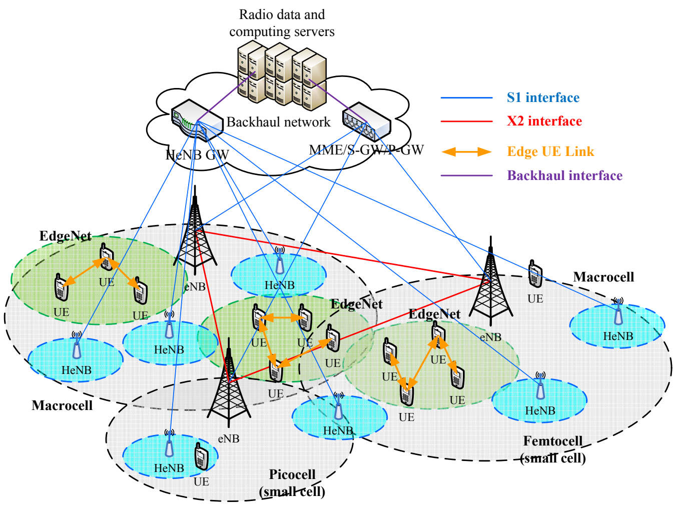

Fig. 1. The EdgeNets coexisting with the H-CRAN

computing technology. Based on this design, the baseband unit (BBU) and the radio head do not have to be collocated within an eNB. Instead, a number of BBUs and remote radio heads (RRHs) can be separated from an eNB to be massively deployed. Through the fiber-optic cables to connect an eNB and BBUs/RRHs, coverage of eNBs is therefore ubiquitously extended. This architecture is the well-known CRAN [27]–[30]. Subsequently, Peng *et al* [31] and Lei *et al* [32] are pioneers to reveal the concept of H-CRAN. Through the provided wired/wireless interfaces (i.e., S1, X2, and Un), not only BBUs/RRHs but also multiple Home eNBs (HeNBs), relay nodes, and eNBs are able to exchange information for joint resource scheduling/allocation [6], as shown in Fig. 1.

Fully exploiting the technical merits of the HetNet to densely deploy different kinds of cells with different coverage, potential coverage holes can be effectively eliminated to adapt to all kinds of environment through the H-CRAN. Furthermore, via cloud computing, a universal resource scheduling/allocation optimization can be achieved to reject potential (inter-cell or intra-cell) interference. Therefore, under the H-CRAN, the mobile users are able to enjoy promoted wireless experiences and boosted quality-of-service (QoS) to satisfy various requirements. However, to deliver enhanced user experiences, the cost behind the H-CRAN could be tremendous. First, it is projected that the number of heterogeneous devices (e.g., user equipments, sensors, vehicles, robots, etc.) is dramatically increasing in the following decades. The complexity of the resource optimization in the H-CRAN may be a growing and inevitable issue, even with the facilitation of the cloud computing technology. Second, along with the growing number of heterogeneous devices, the traffic amounts could increase more than a thousand-fold. Under the H-CRAN, all the traffic amounts rely on infrastructures to be exchanged among edge entities (such as human, sensors, machines, servers). Such a star-like topology centered with the cloud for traffic flows may eventually be a mega-burden on both front-haul and back-haul links. In the H-CRAN, three facts are generally ignored. (i) Traffic may be exchanged socially/locally. It is assumed that each packet from each edge entity may be delivered to any other edge entity in the world under the H-CRAN. However, this assumption may not be generally true, as more and more social applications only require data exchanges in close physical proximity. (ii) Each edge entity may exchange information with edge entities within its social network more frequently than other edge entities. Such a social network can be a set of webs, servers, human, or machines. (iii) Downlink traffic to different edge entities or uplink traffic from different edge entities may be with strong correlations. For example, a large number of users may enjoy the same sport game streaming program simultaneously, and therefore the downlink traffic to these users is correlated. A group of densely deployed sensors measuring a common physical quantity may obtain a similar result, and thus the uplink data to the cloud may also be correlated. As a result, the technical merits of the H-CRAN also bring those engineering challenges to limit the performance of the H-CRAN. This predicament thus motivates us to revisit the EdgeNet.

The EdgeNet is also known as the fog computing network (FogNet), whose concept emerges from the fog/edge computing technology [33]. In contrast to the cloud computing, the edge computing facilitates processing/computing capabilities at edge entities, by which not all information for performance optimization should be delivered to the cloud. Instead, only the tasks (and corresponding information for optimization) those cannot be well processed by edge entities are handled by the cloud. The fog computing therefore may significantly alleviate the computing burdens in the cloud computing to achieve the scalability. Aryafar *et al* are the pioneers to apply the concept of the fog computing to form a new type of network architecture known as the EdgeNet [34]. Under the EdgeNet, each edge entity having social messages to be exchanged among other edge entities does not rely on traffic relay via the cloud, while edge entities in close physical proximity are able to locally share messages. This design leads to the concept of socially-aware traffic managements to significantly decrease the traffic amounts to be supported by the cloud. Recently, radio access technologies (RATs) such as device-to-device (D2D) communications [35]–[40] or using small cells as smart data/traffic routing gateways are successful practices of the EdgeNet. Subsequently, Peng *et al* bring the development of the EdgeNet to the next stage by taking the correlation among traffic to/from different edge entities into considerations [41]. When a group of edge entities have highly correlated traffic to be delivered to the cloud, each entity does not have to upload traffic individually. Instead, the common part of traffic is delivered once by a single edge entity. On the other hand, when the cloud has highly correlated traffic to be forward to multiple edge entities, the cloud does not forward traffic individually to each edge entity. Instead, the cloud only selects one edge entity to forward traffic, then the selected edge entity autonomously shares traffic with other edge entities. Consequently, traffic amounts supported by both the fronthaul and backhaul links are largely alleviated.

Although the EdgeNet provides considerable technical virtues to potentially tackle the issues of complexity, scalability, and heavy traffic burdens in the H-CRAN, new challenges are also created. Although traffic can be socially shared among edge entities, there is no guarantee that all edge entities needing this traffic are able to successfully receive this traffic. Therefore, reliability for data delivery lies in the primary concern. The reason of this concern comes from the lack of well resource coordination among edge entities in the EdgeNet. Unlike the H-CRAN in which the resource scheduling/allocation optimization is the key feature to well reject/mitigate interference, a random access scheme may be a baseline access scheme in the EdgeNet. Consequently, interference among edge entities may drastically impact the performance of the EdgeNet.

Although the design spirits of the H-CRAN and the EdgeNet appear to be opposite to each other, different technical merits in the H-CRAN and in the EdgeNet may lead to a complementary harmonization. This observation consequently motivates us to investigate sufficient conditions to adequately integrate the H-CRAN and the EdgeNet. In [42], the preliminary concept of the harmonization between the H-CRAN and the FogNet is revealed. As a research extension of [42], in this paper, we particularly emphasize on the sufficient conditions from the perspective of radio access. Our analytical results reveal that a H-CRAN architecture with well radio resource scheduling/allocation is preferred under a splendid channel condition, while an EdgeNet architecture with uncoordinated random access should be adopted under a poor channel condition, to lead to an optimized system throughput.

II. System Architecture

In this paper, the data exchanges issue for edge user equipments (UEs) is considered, and we particularly emphasize on the uplink radio access. If a H-CRAN architecture is adopted to support the data exchanges among edge UEs, then each UEs connect to an eNB (which can be a Macrocell eNB or a small cell eNB) and an eNB relay the signals/data to a destination edge UE (may or may not via the core network). In this case, a scheduling based radio access is applied to allocate disjoint radio resources to each edge UE for uplink transmissions. As a result, there is no interference among edge UEs.

On the other hand, if multiple edge UEs forming EdgeNets to directly exchange data with each other in close proximity using the D2D technology, as shown in Fig. 1, then the H-CRAN may allocate a pool of radio resources to these EdgeNets. The technical benefit of allocating a pool of radio resources will be elaborated later. However, due to the lack of well resource coordination in EdgeNets, a random access scheme may be applied to each edge UEs to access a pool of resources autonomously. In this case, interference may occur if multiple edge UEs transmit data on the same radio resource.

Although it appears that a scheduling based radio access could result in a better throughout than that of a random access scheme, we find that this benefit may not always exist. This issue is comprehensively studied in the following section.

III. Collaboration of H-CRAN and Edge Networking

To be backward compatible to LTE-Advanced system, the radio resources are allocated/accessed in the unit of a resource block (RB). When the H-CRAN architecture is adopted and the existing scheduling based radio access is used, if an edge UE requests one RB to upload data, then the H-CRAN may allocate exact one RB to this edge UE.

Definition 1. *For a edge UE requesting one RB to upload data, the throughput of the edge UE is defined as the probability that this edge UE is able to utilize at least one RB without suffering interference and a deep fading channel condition.*

Before scheduling/allocating an RB to an edge UE, the channel estimation/prediction may be applied to all available RBs for the H-CRAN, and an RB predicted to be with acceptable channel condition can be allocated to an edge UE. However, even performing channel estimation/prediction on each RB, there is no guarantee that an edge UE can always enjoy an excellent channel condition on the allocated RB. In practice, an edge UE may still suffer from a poor channel condition on the allocated RB. As a resource scheduling/allocation algorithm may virtualize the occupation of physical RBs, the probability of a deep fading channel occurrence at each RB (that is, communications on this RB are unavailable) can be regarded as independently and identically distributed (i.i.d.) p due to potential randomization of physical RBs. If an edge UE requests one RB form the H-CRAN and the H-CRAN allocate exactly one RB to this edge UE, then the throughput of this edge UE is $1-p$, which completely depends on channel condition of the RB.

To enhance the throughput of an edge UE, a promising scheme is to exploit frequency/spatial diversity. Consider that there are in total K RBs available in the frequency domain to be shared by N edge UEs. If an edge UE needs one RB but the H-CRAN allocate $1 \leq k \leq K$ RBs to this edge UE, then this edge UE is able to successfully transmit data if these k RBs do not simultaneously suffer from a deep fading channel condition. As a result, the throughput of the edge UE is $1-p^k$, which is enhanced as compared with that using a scheduling based radio access. However, in this case, the utilization of each RB may be severely degraded.

Definition 2. *The utilization of each RB is defined by*

$$\rho \equiv \mathbb{E}[K']/k, \tag{1}$$

where K' is number of RBs utilized by edge UEs without interference and a deep fading channel condition, $\mathbb{E}[K']$ is the expected value of K', and k is the number of allocated RBs.

If the H-CRAN allocate one RB to an edge UE requesting one RB, then the utilization of this RB is $1-p$. However, if the H-CRAN allocate two RBs to an edge UE requesting one RB, then the utilization of each of these two RBs is $\frac{1-p^2}{2}$, which could be lower than $1-p$. To further enhance the utilization of each RB, denote $\mathcal{K}$ as a set of RBs allocated to the ith edge UE and denote $\|\mathcal{K}\| = M$ as the cardinality of $\mathcal{K}$ (where $M \leq K$). By observing the fact that different edge UEs may suffer from different levels of fading conditions at the same RB, the H-CRAN thus may allocate these RBs $\mathcal{K}$ to other edge UEs. In this case, $\mathcal{K}$ form a *resource pool* shared by multiple edge UEs. This scheme suggests multiple edge UEs to form EdgeNets to share a pool of RBs.

In this case, if each edge UE utilizes a different RB, then these RBs $\mathcal{K}$ can be fully utilized to enhance the utilization of each RB. However, if some of edge UEs unfortunately select the same RB, then collisions occur (intra-system interference) and the utilization degrades. We therefore should derive the conditions with those the utilization of each RB is maximized.

IV. Optimization of Collaborative Radio Access

Given a resource pool $\mathcal{K}$ composed of M RBs indexed by $m = 1, \ldots, M$ to be shared by N edge UEs indexed by $i = 1 \ldots, N$, let

$$\mathbf{I}_{m,i} = \begin{cases} 1, i\text{th edge UE selects the } m\text{th RB}, \\ 0, \text{ otherwise}, \end{cases} \tag{2}$$

be an indication function. The utilization of each RB can be obtained by the following theorem.

Theorem 1. *The utilization of each RB is*

$$\rho = N\Big(\frac{1-p^M}{M}\Big)\Big(1 - \frac{1-p^M}{M}\Big)^{N-1}. \tag{3}$$

Proof: Since the probability that the ith edge UE has one RB without suffering deep fading channel condition to transmit data is given by

$$\Pr\Big\{\sum_{m=1}^{M}\mathbf{I}_{m,i} = 1\Big\} = 1 - p^M, \tag{4}$$

while the probability that the ith edge UE has no RB to transmit data is given by

$$\Pr\Big\{\sum_{m=1}^{M}\mathbf{I}_{m,i} = 0\Big\} = p^M, \tag{5}$$

we obtain the expected value of $\sum_{m=1}^{M}\mathbf{I}_{m,i}$ as

$$\mathbb{E}\Big[\sum_{m=1}^{M}\mathbf{I}_{m,i}\Big] = \sum_{m=1}^{M}\mathbb{E}[\mathbf{I}_{m,i}] = M\mathbb{E}[\mathbf{I}_{m,i}] = 1 - p^M. \tag{6}$$

Thus, we have

$$\mathbb{E}[\mathbf{I}_{m,i}] = \Pr\{\mathbf{I}_{m,i} = 1\} = \frac{1-p^M}{M}. \tag{7}$$

For each edge UE, the probability that the mth RB is selected and no collision occurs at this RB is given by

$$\Pr\Big\{\sum_{i=1}^{N}\mathbf{I}_{m,i} = 1\Big\} = N\Big(\frac{1-p^M}{M}\Big)\Big(1 - \frac{1-p^M}{M}\Big)^{N-1}, \tag{8}$$

which is the utilization of the mth RB. Since the deep fading channel occurrence at each RB is i.i.d., the utilization of each RB among M is therefore given by (3). ■

Since the H-CRAN need to optimize the performance even though a part of RBs suffer a deep fading condition, it is quite necessary to derive the optimum operating condition of EdgeNets as a pool of RBs are shared by EdgeNets.

Proposition 1. *Given a resource pool composed of M RBs, the optimum number of edge UEs forming EdgeNets to share these RBs can be obtained by*

$$N^* = \arg\max_{N}\Big\{N\Big(\frac{1-p^M}{M}\Big)\Big(1 - \frac{1-p^M}{M}\Big)^{N-1}\Big\}. \tag{9}$$

Theorem 2. *The optimum number of edge UEs forming EdgeNets to share M RBs is*

$$N^* = \begin{cases} \frac{M}{1-p^M}, \text{ if } \frac{M}{1-p^M} \text{ is an integer }, \\ \lfloor\frac{M}{1-p^M}\rfloor, \text{ otherwise,} \end{cases} \tag{10}$$

where $\lfloor x \rfloor$ is the floor function of x.

Proof: Since ρ is a function of N, we denote $\rho = f(N)$. The optimum N^* should satisfy two conditions. First,

$$\begin{aligned} &f(N^*) - f(N^*-1) \\ &\quad = N^*\Big(\frac{1-p^M}{M}\Big)\Big(1 - \frac{1-p^M}{M}\Big)^{N^*-1} \\ &\quad - (N^*-1)\Big(\frac{1-p^M}{M}\Big)\Big(1 - \frac{1-p^M}{M}\Big)^{N^*-2} \\ &\quad = \Big[1 - N^*\frac{1-p^M}{M}\Big]\frac{1-p^M}{M}\Big(1 - \frac{1-p^M}{M}\Big)^{N^*-2} \\ &\quad \geq 0, \end{aligned} \tag{11}$$

we therefore obtain

$$\Big[1 - N^*\frac{1-p^M}{M}\Big] \geq 0 \Leftrightarrow N^* \leq \frac{M}{1-p^M} \Rightarrow N^* \leq \Big\lfloor\frac{M}{1-p^M}\Big\rfloor \tag{12}$$

for $N^* \in \mathbb{Z}^+$. Second,

$$\begin{aligned} &f(N^*) - f(N^*+1) \\ &\quad = N^*\Big(\frac{1-p^M}{M}\Big)\Big(1 - \frac{1-p^M}{M}\Big)^{N^*-1} \\ &\quad - (N^*+1)\Big(\frac{1-p^M}{M}\Big)\Big(1 - \frac{1-p^M}{M}\Big)^{N^*} \\ &\quad = \Big[(N^*+1)\frac{1-p^M}{M} - 1\Big]\frac{1-p^M}{M}\Big(1 - \frac{1-p^M}{M}\Big)^{N^*-1} \\ &\quad \geq 0, \end{aligned} \tag{13}$$

then we have

$$\begin{aligned} \Big[(N^*+1)\frac{1-p^M}{M} - 1\Big] \geq 0 \Leftrightarrow N^* \geq \frac{1 - \frac{1-p^M}{M}}{\frac{1-p^M}{M}} \\ \Rightarrow N^* \geq \Big\lceil\frac{M}{1-p^M}\Big\rceil - 1, \end{aligned} \tag{14}$$

where $\lceil x \rceil$ is the ceiling function of x. Since

$$\Big\lfloor\frac{M}{1-p^M}\Big\rfloor \geq N^* \geq \Big\lceil\frac{M}{1-p^M}\Big\rceil - 1, \tag{15}$$

(10) can thus be obtained. ■

Theorem 2 reveals a significant insight that multiple edge UEs forming EdgeNets to share a resource pool are able to enhance the utilization of each RB. This performance enhancement is boosted by "*statistical multiplexing*" from multiple edge UEs' channel accesses.

Corollary 1. *For a pool of RBs shared by multiple edge UEs forming EdgeNets, each RB may enjoy a higher utilization as compared with that of a scheduling based radio access using* *the H-CRAN architecture.*

Proof: Theorem 2 reveals that, for $M = 1$,

$$N^* = \left\lceil \frac{1}{1-p} \right\rceil \geq 1. \quad (16)$$

In other words, if a resource pool only contains one RB, to maximize the utilization of the RB, this resource batch may be shared by more than one edge UE. (10) further reveals that, for a resource pool composed of M RBs,

$$N^* = \left\lceil \frac{M}{1-p^M} \right\rceil \geq M, \quad (17)$$

which suggests that more than M edge UEs can be introduced to share M RBs. ∎

In the following theorems, we further provide the optimum utilization of each RB when a pool of M RBs are shared by N^* edge UEs.

Theorem 3. *The optimum utilization of each RB when M RBs are shared by N^* edge UEs forming EdgeNets is given by*

$$\rho^* = \begin{cases} \left(1 - \frac{1-p^M}{M}\right)^{\frac{M}{1-p^M}-1}, & \text{if } \frac{M}{1-p^M} \text{ is an integer}, \\ \lfloor \frac{M}{1-p^M} \rfloor \left(\frac{1-p^M}{M}\right)\left(1 - \frac{1-p^M}{M}\right)^{\lfloor \frac{M}{1-p^M} \rfloor - 1}, & \text{otherwise.} \end{cases} \quad (18)$$

Proof: (18) is obtained by substituting (10) into (3). ∎

Corollary 1 suggests that a pool of M RBs shared by $N^* \geq M$ edge UEs may enhance the utilization of each RB. In the following theorem, the condition of this performance enhancement is provided.

Theorem 4. *A pool of M RBs shared by N^* edge UEs provides a higher utilization of each RB than that of a scheduling based radio access using the H-CRAN architecture if*

$$p \geq 1 - \left(1 - \frac{1}{M}\right)^{M-1}. \quad (19)$$

Proof: If the H-CRAN is adopted, then each RB is allocated to only one edge UE. In this case, the utilization of each RB is $(1-p)$. On the other hand, if these M RBs are randomly accessed by N^* edge UEs, the optimum utilization can be obtained by (18), which provides better performance if

$$\left\lfloor \frac{M}{1-p^M} \right\rfloor \left(\frac{1-p^M}{M}\right)\left(1 - \frac{1-p^M}{M}\right)^{\lfloor \frac{M}{1-p^M} \rfloor - 1} \geq (1-p) \quad (20)$$

Since

$$\left\lfloor \frac{M}{1-p^M} \right\rfloor \left(\frac{1-p^M}{M}\right)\left(1 - \frac{1-p^M}{M}\right)^{\lfloor \frac{M}{1-p^M} \rfloor - 1} \approx \left(1 - \frac{1-p^M}{M}\right)^{\frac{M}{1-p^M}-1}, \quad (21)$$

we can rewrite (20) as

$$\left(1 - \frac{1-p^M}{M}\right)^{\frac{M}{1-p^M}-1} \geq (1-p)$$
$$\Rightarrow p \geq 1 - \left(1 - \frac{1-p^M}{M}\right)^{\frac{M}{1-p^M}-1} \approx 1 - \left(1 - \frac{1}{M}\right)^{M-1}. \quad (22)$$

We therefore obtain (19). ∎

Based on (19), the optimum collaborative radio access is obtained by the following proposition.

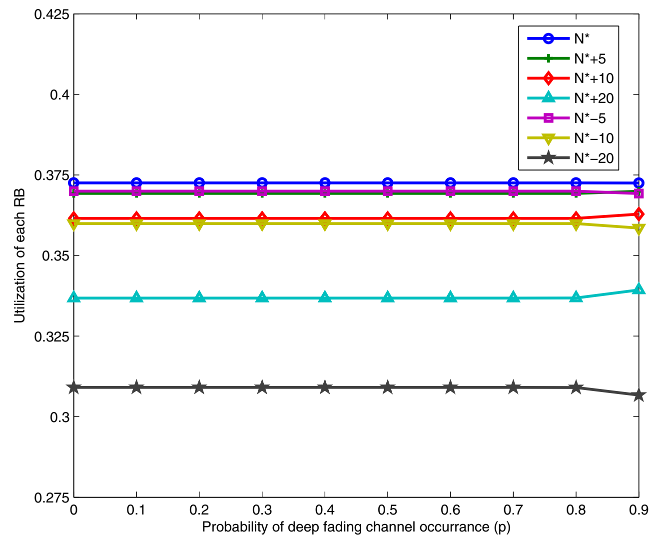

Fig. 2. Utilization of each RB under different numbers of edge UEs forming EdgeNets to share a pool of 40 RBs.

Proposition 2. *A H-CRAN architecture should be adopted if $p < 1 - (1 - \frac{1}{M})^{M-1}$; otherwise, EdgeNets can be formed by N^* edge UEs to share a pool of RBs.*

Remark 1. *Proposition 2 suggests the condition of direct traffic to H-CRAN or EdgeNets, which is critical to design entire network management functions in such collaborative radio access.*

V. Simulation Evaluation

To justify our design, we conduct the simulations through the Matlab LTE environment, and a 20 MHz bandwidth is considered (i.e., 50 RBs in the frequency domain). 160 edge UEs are randomly and uniformly deployed over a $4000m^2$ area. Transmission power of an edge UE is designated to 20dBm.

In Theorem 1, the analytical result of the utilization of each RB when a pool of resource batches are shared by N edge UEs forming EdgeNets is provided. Theorem 2 further demonstrates the optimum N^*. To verify these results, in Fig. 2, the utilization of each RB under different numbers of edge UEs sharing the pool is shown. We can observe from Fig. 2 that any number of edge UEs N deviates from the derived N^* leads to the performance degradation. This result thus justify Theorem 1 and Theorem 2.

In Corollary 1, we further prove that a pool of M RBs can be potentially shared by $N^* \geq M$ edge UEs forming EdgeNets. To justify this result, in Fig. 3, N^* for different number RBs in the pool is demonstrated. We can observe from Fig. 3 indeed $N^* \geq M$, which supports Corollary 1.

Finally, in Proposition 2, we derive the sufficient condition for the optimum collaborative radio access between the H-CRAN and EdgeNets. Fig. 4 thus demonstrates this condition

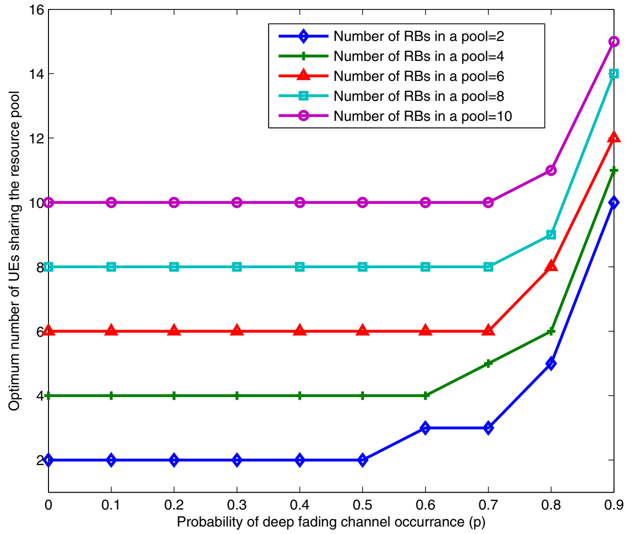

Fig. 3. Optimum number of edge UEs forming EdgeNets to share different number RBs in the pool.

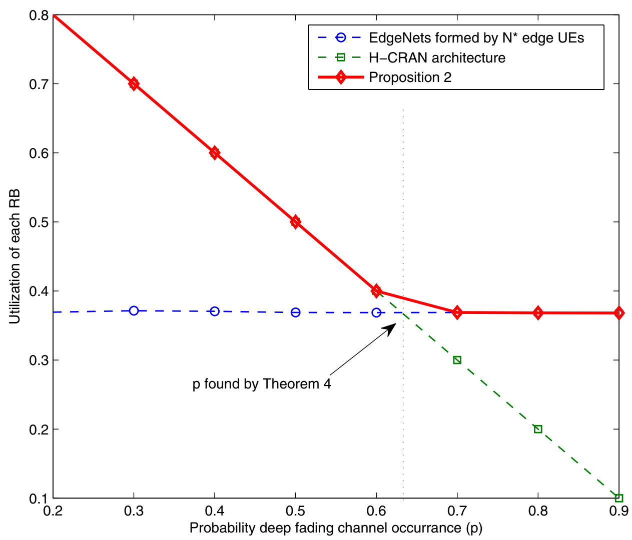

Fig. 4. Sufficient condition for the optimum coexistence of the H-CRAN and EdgeNets.

at $p = 1 - (1 - \frac{1}{M})^{M-1} \approx 0.63$, which confirms the results in Theorem 5 and Proposition 2.

VI. Conclusion

In this paper, we analytically derive the optimum collaborative radio access for the H-CRAN architecture and the EdgeNet architecture. If the probability of deep fading channel occurrence does not exceed $p = 1 - (1 - \frac{1}{M})^{M-1} \approx 0.63$, then the H-CRNA architecture should be adopted, by which each edge UE relies on the H-CRAN to exchange data with other edge UEs. Otherwise, the EdgeNet architecture should be adopted, by which edge UEs form EdgeNets to randomly access a resource pool. Our results thus pave essential foundations for the urgent needs of the 5G radio access and network architecture design.

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