Smart Contract-based Resource Purchasing for Seamless Media Streaming at the Mobile Edge

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Abstract

Multimedia streaming for the mobile users in the existing network architecture is facilitated by the enabling technologies such as content caching networks (CCNs) and proactive caching mechanisms at the network edge. However, the intermittent disruptions caused during media streaming due to the contention amongst increasing multimedia nodes to withhold scarce network resources is yet a challenge to overcome in a UAV-assisted wireless network. Moreover, the mobility of such nodes causes additional burden to the edge resource provider (ERP), such as in UAV-assisted cellular networks, for guaranteeing the quality of experience (QoE) in multimedia streaming. To address this issue, we propose a novel smart contract-based resource purchasing mechanism at the network edge for seamless media streaming services. In particular, we propose a proactive network resource leasing strategy for the next-generation cellular architecture, with cloud radio access networks (CRANs) assisted by hovering UAVs to serve the mobile users. The UAVs form a mining network, and the implemented proof-of-stake consensus algorithm enables the execution of specific smart contracts that, in particular contains information related with the leased resource at the network edge and the requested time window from the users. This way it will guarantee to provide necessary access rights to the mobile users for seamless on-demand resource availability for next generation applications.

Keywords – *CRANs, edge networks, resource management, smart contracts, caching, multimedia.*

I. Introduction

The next-generation of cellular architecture integrates the interaction of intelligent mobile devices (IMDs) with central cloud processor, known as cloud radio access networks (CRANs) [1], while considering their quality-of-experience (QoE) in contents streaming. The appearance of multi-access edge computing (MEC) paradigm is unleashing integral scopes of caching, computation, and control for the sensitive applications at the network edge. Furthermore, cache-enabled UAVs are complementing the stringent requirements of the mobile users to have the access of multimedia content at lower latency and higher throughput in the existing network topology. In [2], the authors discussed about the application scenario and significance of such methodologies in the upcoming 5G networks. The proposed mechanism highlights the role of caching contents at the peak hours to facilitate the users with impromptu service upon request, and further alleviating the backhaul traffic by doing so. In this regard, MEC-enabled UAVs, due to their flying abilities, are working as an integral element to improve the availability of network resources for the remote mobile users. Authors in [3] discussed about the user's behavior prediction model and corresponding proactive caching mechanism at the UAV in the optimal location. In this work, the authors considered the mobility of mobile users under the limited available network information.

The rise of IMDs and internet of things (IoT) networks expects state-of-the-art solution approach to deal with spectrum scarcity and the mobility of users. Further, it is deemed to be self-organizing and have fully decentralized access control schemes to use network resources at the edge. For instance, in a 5G network topology, various scheduling schemes need to be implemented to guarantee the QoE and quality-of-service (QoS) requirements for disparate services such as low-latency and ultra-reliable communications [4], [5], [7]. In reference to managing decentralized access control approach and self-organizing networks, one important attribute to consider for cache-enabled UAV networks is proactive resource leasing ability for seamless multimedia streaming. For this, recent works have considered the use of permissionless blockchain technology, and specifically, for various decentralized applications, namely *DApps* [6]. The use of smart contracts to perform data trading under a self-organized data management platform is gaining popularity. However, the issue related with user's mobility when accessing the edge resource for multimedia services is not discussed so far. In this regard, the challenge exacerbates when a user served by the hovering cache-enabled UAV is in motion, say for instance, an autonomous car.

To address this issue, we at first introduce a smart contract-based resource purchasing mechanism to lease the edge resources in a proactive manner for the mobile users. Specifically, we consider a smart contract market (SCM) to which the edge resource providers (ERPs) will interact and reserve edge resources for their users. Then, the ERP can benefit their users with defined service level agreements (SLAs) to execute the smart contracts for the resource credentials. Here, the smart contracts are deployed at the UAV node, which acts as the virtual miner to reach a consensus for the reserved resources to facilitate uninterrupted services to the mobile users in the network. In particular, a lightweight proof-of-stake (PoS) is adopted to reach the consensus [8].

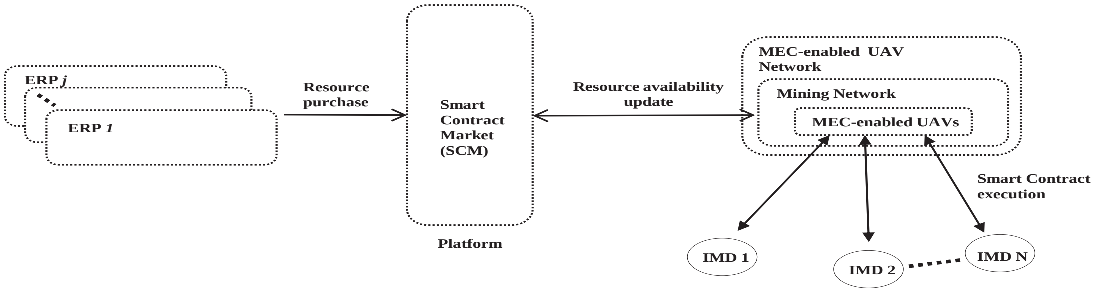

Fig. 1: System Model

The rest of this paper is organized as follows. Section II discusses about the system model and Section III explains about the problem formulation. We present the numerical results in Section IV. Finally, Section V concludes the paper with future work.

II. System Model

We illustrate the system model with the schematics of interaction scenario for our proposed mechanism in Fig. 1. The coordination between cache-enable UAVs (interchangeably, *MEC-enabled UAVs* in this manuscript) is managed by a relay station using radio links. Note that the neighboring UAVs can communicate with each other directly as well. However, the connection range is limited, and therefore, the role of a relay station exists. The moving IMDs can be associated to the hovering UAVs via a wireless link for their request fulfillment. The edge resources at the UAVs are managed by ERPs, which in fact provides smart contract privileges to the IMDs. In the following, we define the elements involved in our proposed mechanism.

A. Smart Contract

Smart contract is an executable code of complex logic in a program common process. It represents the contract-based agreement that is self-executing digital contract in a secure environment such as blockchain networks. The UAVs will execute such contracts to ensure some level of guaranteed edge resources, for some instance of time duration to the requesting IMDs.

B. Smart Contract Market (SCM)

Smart Contract Market (SCM) is a contract pool with multiple smart contract provider, who compete to sell their plans for the requester(s), who are in fact ERPs. Together, they create a flexible framework, namely SCM, where the ERP can apply for resource leasing for the edge resources. The IMDs can then interact with ERPs to have access rights for resources in the edge network in a secure manner, without compromising for stringent latency requirements to on-demand next generation services such as high video streaming, and Augmented/Virtual reality.

In other words, SCM acts as a proxy mining pool of virtual miners who sell smart contracts of different configuration in order to facilitate for distributed resource allocation at edge networks to the IMDs, that eventually ensures quality-of-experience to the users. The mechanism of proxy mining pool, or the competition to sell appropriate smart contracts to the ERPs is out of scope in this work.

C. Proof-of-Stake Mechanism

Seamless access privileges for the requester, i.e., IMDs without burden of mining the smart contracts as per their requirements is facilitated by Proof-of-Stake (PoS) consensus mechanism amongst UAVs. The UAVs will deploy the smart contracts in the mining network. In particular, Proof-of-Stake (PoS) consensus algorithm is utilized for establishing smart contract-enabled resource purchasing catalogs that will improve user's quality of experience (QoE) for having seamless media streaming services. Considerably, the limitation of resource constrained IMDs to directly interact with the blockchain networks inspired us to choose the execution of smart contracts by the UAVs.

Each UAVs are registered as a trusted entity by the central authority in the beginning. After the authentication phase, the miner (UAVs) will deposit their stake under public supervision. The deposited stake is usually in terms of available edge resources to serve. Each miner can then act as a blockchain manager who verifies and broadcasts new blocks based upon the smart contract execution. With this lightweight consensus mechansim, the IMDs can get benefits of guaranteed edge resource for enjoying multimedia streaming services even when they are moving. The prior resource settlement will enhance their overall user experience, and by consuming on-demand computing resources for the next generation applications (such as Augmented Reality, Virtual Reality) via smart contract execution enables each participating UAV nodes manage their resources efficiently.

III. Problem Formulation

Consider a set of MEC enabled UAV-Base Station (M-UBS) $\mathcal{M}$ and IMDs users $\mathcal{S}$. The amount of edge resources guaranteed by the consensus process of the blockchain infrastructure for the time T is $f_{s,M}$. We denote the association of the users to the M-BS by $y = (y_{sm} : s \in \mathcal{S}, m \in \mathcal{M})$, where $y_{sm} = \{0, 1\}$. Consider r_{sm} is defined as transmission rate for user s from the base station m after considering path loss,

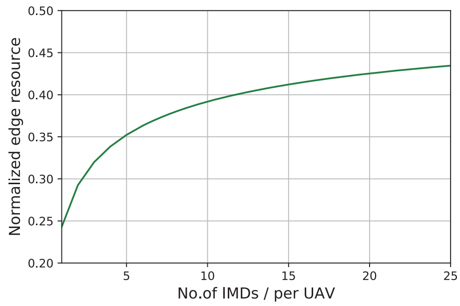

Fig. 2: Impact of the increase in the number of IMDs per UAV on normalized edge resource trading point.

and corresponding interference [1]- kept fixed for simplifying the model. Then, the quality of service (QoS) in terms of allocate rate to the user s is defined as

$$R_{sm} \equiv \sum\nolimits_{m \in \mathcal{M}} f_{s,M} y_{sm} r_{sm}. \tag{1}$$

The ERPs prepares smart contract for the mobile users based upon their QoS/QoE requirements for the seamless execution of next generation applications, such as multimedia streaming with AR/VR and extended-Reality (XR) facilities, during mobility. In the following, we present an overview to a formulation that optimizes overall network utility while considering the quality requirements at the user's end under our proposal.

$$\begin{aligned} \max_{y_{sm}, r_{sm}} \quad & \mathcal{U}(\sum\nolimits_{s \in \mathcal{S}} R_{sm}) \\ \text{s.t.} \quad & g_s(T(r_{sm})) \leq \delta_s, \forall s \in \mathcal{S} \\ & \sum_{\forall m \in \mathcal{M}} y_{sm} = 1, \forall s \in \mathcal{S} \\ & y_{sm} = \{0, 1\}. \end{aligned} \tag{2}$$

Here, $\mathcal{U}(\sum_{s \in \mathcal{S}} R_{sm})$ characterizes the overall network utility due to consensus mechanism and followed by user's association rule. The function $g_s(T(r_{sm}))$ defined in terms of association time (resource lease period) and transmission rate generalizes the quality requirement for the users with an individual bound $\delta_s, \forall \mathcal{S}$.

IV. Numerical Results

We simulate the proposed methodology with a log sum-rate utility model. The combinatorial constraint of association variables can be relaxed to solve the problem in polynomial time. In Fig. 2, we show the impact of the increase in the number of IMDs per UAV on normalized edge resource trading point to maximize the overall utility of the network. Basically, we observe the resource trading point at each UAV to update to the SCM as their stake for the consensus process. We observe that, with the increase in the number of IMDs, the UAV will improve/increase its resource trading options. This is intuitive, as the number of requests will allow them to sell more. However, the rate decreases with the number of IMDs. This saturation is due to the UAV's limitation to lease and withhold more of its resources just for improving the QoEs of the users.

[1]We consider users' mobility, and the transmission rate mentioned here considers compensation during handovers as well.

V. Conclusion

In this work, we proposed a smart contract-based resource purchasing mechanism to facilitate next-generation applications at the edge. With the deployment of lightweight PoS consensus algorithms, we proactively lease the required amount of resources at the network edge, which in return will enable seamless multimedia streaming services to the mobile devices. We adopted a CRAN architecture with cache-enable UAVs to realize the presented next-generation network paradigm. Further, we presented a network utility maximization problem to address this issue of guaranteeing QoE to the moving users. Numerical results show the normalized edge resource trading strategy of the UAVs at the network edge with the increase in the number of requests from the IMDs to do smart contract execution.

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