SVC Video Caching and Delivery for Ultra-Dense Networks in Beyond 5G

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Abstract

Bandwidth hungry video streaming has been a challenge in wireless networks. The proliferation of high-end user equipment (UE) have enabled the user to demand high quality of videos through wireless communication. The fifth generation of the cellular system (5G) has already been deployed and researchers are working on the sixth generation of the wireless system (6G). However, bandwidth improvement in the network system alone may not be able to cope with the users' demand-base for the higher quality of the video. Therefore, application-specific adaptation is also important. In this paper, we proposed proactively caching H.264/SVC encoded layered video in the aerial vehicle and delivering it to the requesting users. In the proposed mechanism, layers of the video, potentially to be requested by the users, are proactively cache in Unmanned Air Vehicle Small-cell Base Station (UAV-SBS). UAV-SBS delivers a layer of the segment to the user on request. The proposed optimization problem is combinatorial in nature and is NP-hard. We propose a heuristic algorithm to solve the problem. Our performance evaluation reveals the significance of the proposed mechanism.

1. Introduction

The proliferation of high specification User Equipment (UE), demand for high quality video has become a basic commodity of life [1]. 5G cellular system has already appeared on the horizon of cellular communication and the research community is actively working on 6G wireless system. However, development on the network capacity domain alone may not be enough without taking the application-specific properties in account.

Caching, resource allocation, and quality adaption for the video contents have been studied well for future networks [2]-[6]. However, to the best of our knowledge, caching and delivery of H.264/SVC encoded layered video, also termed as Scalable Video Coding (SVC), has not been studied in ultra-dense wireless systems with mobile base stations such as Unmanned Air Vehicle Small-cell Base Station (UAV-SBS). In this paper, we propose proactively caching SVC video content in UAV-SBS and delivering it to the requesting UE. In our proposed mechanism, the Macro Base Station (MBS) proactively cache layers of the video content that are potentially to be requested by the UE in the UAV-SBS cache and position them closer to the requesting UE so that the requesting UE get higher rate in getting the contents. The proposed optimization problem is combinatorial in nature and is NP hard. In order to solve the formulated problem, we propose a heuristic algorithm. Our performance evaluation reveals the significance of the proposed mechanism.

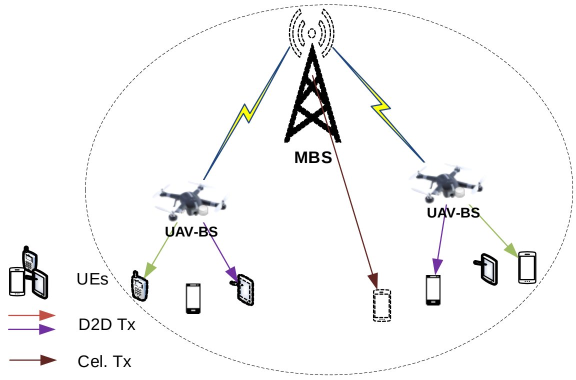

Figure 1: *System Architecture*

2. System Architecture

Our proposed network architecture is a future cellular system consisted of an MBS and $M=\{1,2,3,\cdots,M\}$ mobile UAV-SBSs. There are total $N=\{1,2,3,\cdots,N\}$ User Equipment (UE) in the system. There are $V=\{1,2,3,\cdots,V\}$ videos each of which consisted of $L=\{1,2,3,\cdots,L\}$ layers. The UAV-SBSs are equipped with cache and deployed nearer to the video requesting UE as shown in figure 1. The UAV-SBSs can cache the videos and provide it to UE if they request those videos. The video contents are H.264/SVC encoded contents consisted of the mandatory base-layer and multiple enhancement layers. The base-layer is independently decodable unit with the lowest quality of the video. Enhancement layers are used to improve the video quality in special, temporal, and SNR domains. The addition of each enhancement layer improves the video quality and hence the user Quality-of-Experience (QoE).

In our system, UE follow [2] for quality adaptation. In the beginning, when UE needs a video segment, It sends a request for the base layer of the first segment of the content to the MBS. The MBS searches the requested content in the cache of all the UAV-SBSs, if found in the cache of any UAV-SBSs, MBS estimates the achievable data-rate between the UE and the UAV-SBSs with the help of the distance between them. The communication scenario is given in figure 2. For the quality adaption, UE follow the mechanism presented in [2].

3. Communication Model

We assume that any two UAV-SBSs are apart from each other such that they do not interfere with each other's transmission and maintain a line-on-sight with the MBS. The communication between MBS and UAV-SBS on millimeter waves with very high data-rate.

All the UE connected with the same UAV-SBS are assigned orthogonal frequencies, therefore, their transmissions do not interfere with each other. Signal-to-Interference-Noise-Ratio (SINR), of the UE_n connected with $UAV\text{-}SBS_m$ represented by ($\gamma_{m,n}$), is calculated as follow:

$$\gamma_{m,n} = \frac{P_m h_{m,n} d_{m,n}^{-\alpha}}{\sigma^2}, \qquad (1)$$

where σ^2 is the Gaussian noise. The transmission rate Shannon capacity) of the UE, represented by $r_{m,n}$, is calculated as follow:

$$r_{m,n} = W \log_2 (1 + \gamma_{m,n}), \qquad (2)$$

where, W is the channel bandwidth.

The binary variable $x_{m,n}$ represents the caching status of the requested content which can be defined as follow:

$$x_{m,n} = \begin{cases} 1, & \text{if content requested by n is cached at } m \\ 0, & \text{otherwise.} \end{cases}$$

Another binary variable y_{mn} represents the association of the user with the UAV-SBS.

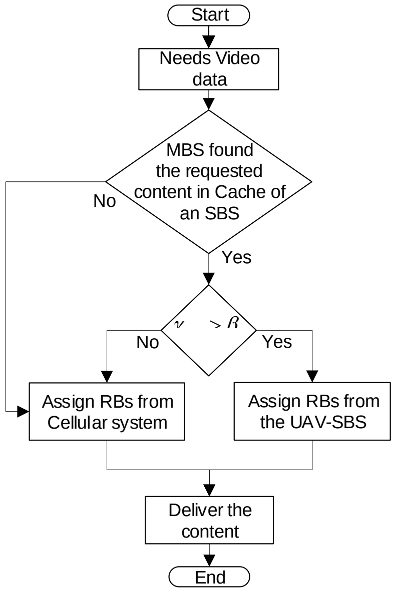

Figure 2: *Communication Scenario*

4. Problem Formulation

Our utility function is as follow:

$$U_m(x,y) = \sum_{n \in N} \sum_{m \in M} x_{m,n} R_{m,n} + \sum_{v \in V} y_{v,m}. \qquad (3)$$

In this paper, our focus is on the proactive caching of video contents in UAV-SBSs and delivery of it to the UEs. Therefore, we consider, UE get a constant rate from the cellular transmission.

In such a scenario, the users' QoE is improved by improving the UAV-SBSs transmissions.

The optimization problem is designed as follow:

$$\max_{x,y} \sum_{s \in S} \sum_{m \in M} U_m(x,y) \qquad (4)$$

subject to:

$$\sum_{v \in V} y_{v,m} \le c_m, \quad \forall n \in N, \qquad (5)$$

$$\sum_{n \in N} x_{m,n} \le 1, \quad \forall m \in M, \qquad (6)$$

$$x_{m,n},\ y_{v,m} \in \{0,1\}, \quad \forall m,n,v. \qquad (7)$$

Where constraint in eq (5) represents that content in UAV-SBS can not be more than the cache capacity. The constraint in eq (6) is to ensure that UE is associated with only one UAV-SBS.

The maximization problem in eq (4) is a maxed-integer optimization problem and combinatorial [8]. Obtaining an optimal solution via exhaustive search may not be computationally possible for the large-scale network. We present a heuristic solution for the problem in the next section.

5. Proposed Solution

At the start, MBS fixes location for the UAV-SBS. Then we perform the user association with UAV-SBS through distancebased K-mean clustering [7]. The UE is associated with UAV-SBS only if the achievable data-rate is more than the threshold β. The proposed mechanism is present in detail in algorithm 1. The UE that remain unassociated with any UAV-SBS are served directly by MBS.

For the caching, we assume that the user requests the segments of the video in sequential order. When the UE requests the base layer of the segment of the video, MBS starts proactively caching all the layers of the entire video in the cache of the UAV-SBS.

Algorithm 1: *Proposed Solution*

```
FOR m=1 to M
    FOR n=1 to M
        - IF ( r_{m,n} ≥ β ) THEN
            IF (UE already associated to another UAV-SBS) THEN
              IF ( r_{m,n} > r_{m',n} ) THEN
                - Associate UE with the UAV-SBS
              ENDIF
            ENDIF
        - ELSE
            - Associate UE with the UAV-SBS
        - ENDIF
    EndFOR
EndFOR
EXIT
```

6. Performance Evaluation:

In this section, we present a scenario-based performance evaluation for our proposed mechanism. We consider a cellular network environment in which there is an MBS 2 UAV-SBS. UEs are placed in the shape of grid with equal distance between them in a cell of 400x400 meters. MBS is located at (10,0), UAV-SBS1 at (5,15) and UAV-SBS1 at (15,15). Coverage range of each UAV-SBS is 5 meter on all the directions. UE achieves equal rate from MBS and both the SBSs directly proportional to distance between them. Initially, all the UEs are associated with the MBS. Association is updated after the deployment of UAV-SBSs. UE follow [2] for the quality adaptation. We assume the system is always have sufficient network resources for all the UEs in the system. Figure 3 shows the mean quality of video received by the UEs in the network for the case of network with SBSs and without SBSs for different number of UEs.

7. Conclusion and Future Work

In this paper, we presented layered video streaming in the ultra-dense cellular network. The MBS proactively caches the contents that are highly likely to be requested by the UE in the cache of UAV-SBS. The UE is associated with the UAV-SBS that provides the highest data-rate to the UE. In the future, we aim to make a mathematical model for our proposed mechanism and simulate it with realistic parameters and a large scale network.

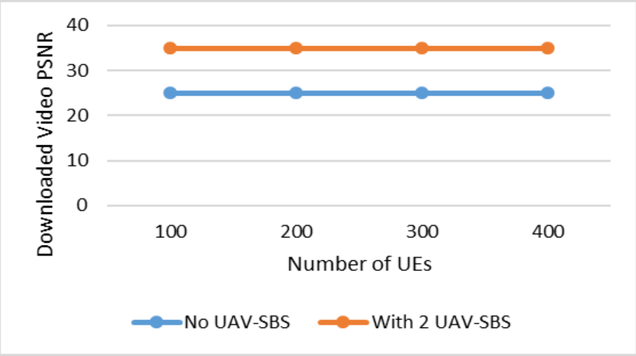

Figure 3: *Scenario-based evaluation*

8. Acknowledgement

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9. References

[1] cisco VNI index (last access May 9, 2020) <www.cisco.com>

[2] Saeed Ullah, et al. "Quality Adaptation and Resource Allocation for Scalable Video in D2D Communication Networks." IEEE Access 8 (2020): 48060-48073.

[3] Kyi Thar, et al., "Online Caching and Cooperative Forwarding in Information Centric Networking," IEEE Access, Vol.6, pp.59679 - 59694, October 2018

[4] Anselme Ndikumana, et al., "DeepAuC: Joint deep learning and auction for congestion-aware caching in Named Data Networking," PLOS ONE, Vol.14, No. 8, pp.1-26, Aug. 2019.

[5] Saeed Ullah, et al. "Delivering Scalable Video Streaming in ICN Enabled Long Term Evolution Networks" 18th Asia-Pacific Network Operations and Management Symposium (APNOMS 2016), Japan

[6] S.M. Ahsan Kazmi, et al., "Infotainment Enabled Smart Cars: A Joint Communication, Caching and Computation Approach," IEEE TVT. 2019

[7] Dabbura, Imad. "K-means Clustering: Algorithm, Applications, Evaluation Methods, and Drawbacks." https://towardsdatascience.com/k-means-clustering-algorithm-applications-evaluation-methods-and-drawbacks-aa03e644b48a. 2018.

[8] S. Boyd and L. Vandenberghe, Convex Optimization. Cambridge, U.K.: Cambridge Univ. Press, 2004