

# On Delay Minimization of Layered Video Streaming in ICN Enabled Cellular Networks with D2D Communication

Saeed Ullah, Tuan LeAnh, and Choong Seon Hong\*

Dept. of Computer Science and Engineering, Kyung Hee University, Rep. of Korea

Email: {saeed, latuan, cshong}@khu.ac.kr

## Abstract

High-end Users Equipment (UEs) demanding high-quality video on the move and this demand is increasing day-by-day. Although, fourth generation cellular network has achieved spectral efficiency of a high level. However, bandwidth is not sufficient for meeting video-on-demand requests. Device-to-Device (D2D) communication is envisioned to achieve more spectral efficiency by frequency re-use. On the other hand, Information-Centric Networking (ICN) is introduced to fully utilize the enhanced features of modern networking nodes to meet the users' demand in a smart way. In this paper, we propose a novel scheme based on matching theory for D2D link establishment in order to reduce the download delay for the H.264/SVC encoded layered video in ICN enabled cellular network. Python based simulation results show the significance of our proposed mechanism.

## 1. Introduction

Users demand for video content is increasing very rapidly. According to cisco, video traffic will grow 3-fold from 2015 to 2020 [1]. Meanwhile, mobile video traffic will grow 11-fold [1].

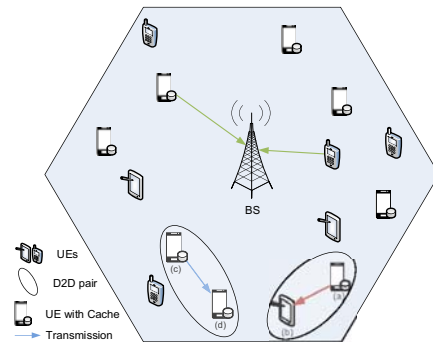
LTE-Advance uses MIMO-OFDM with very efficient codes, thus further improvement in spectral efficiency will be very limited.

A solution for increasing the spectral efficiency is to decrease the transmit power of BS so that the frequency is reused. However, this solution is not cost effective as this will need a huge infrastructural development cost. Device-to-device (D2D) communication is envisioned to increase the spectrum reuse without any investment in infrastructural development.

To take full advantage of advanced networking devices, Van Jacobson et al. has introduced a new architecture for future Internet, which is called Content Centric Networking (CCN) [2]. CCN changes the Internet structure from "where" to "what" [8] i.e., making it information specific rather than location specific.

Video streaming, on the other hand, is always been a challenging issue to deal with in wireless networks because of its dynamic nature and large size. H.264/SVC encodes video in a Base-Layer (BL) and multiple Enhancement-Layers (ELs) [7]. BL is mandatory for decoding a video. ELS are used to improve the special and temporal quality of the video [4], [5].

In this paper, we propose a novel scheme based on matching theory for getting to deal the D2D link establishment. The aim of our proposed mechanism is to achieve minimum delay for downloading the requested contents.



**Figure 1:** System architecture for the proposed scheme

We have simulated our proposed solution in Python to show the significance of our proposed solution.

## 2. System Architecture and Assumptions

System architecture for our proposed mechanism is shown in Fig. 1. In our proposed system, all the devices in the system are CCN enabled i.e., they generate Interest packet for the required data and get it in the form of Data packets. Some of the UEs are equipped with cache memory and serves the requesting UEs by providing data from its cache via D2D link. D2D communication takes place in the Transmission (Tx) period using cellular frequencies. All the Tx take place on orthogonal frequencies so there is no interference among them. Channels for the D2D communication are reserved by the BS, which are assumed to be flat fading model.

BS maintain a Content Store (CS) like table that we call Virtual Cache (VC). VC contains all the contents cached in UEs' cache. The requested segment with the desired layer of the videos is

first searched in VC by the BS to see the D2D communication possibility. Let suppose  $M$  represent the set of UEs that possess  $v_{ij}^l$  i.e., the requested segment  $j$  of video  $i$  with layer  $l$ , in its cache. The BS will inform the requesting UE about  $M$ , the requesting UE will follow the matching theory to get the desired content from one of the UE in  $M$ .

### 3. Problem Statement

In our model, for channel allocation and D2D establishment, we use the binary variable

$$\alpha_{mn}^{v_{ij}^l} = \begin{cases} 1, & \text{If } n \text{ receives content } v_{ij}^l \text{ from } m, \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

D2D  $(n,m)$  pair's Tx rate to get the content  $v_{ij}^l$  is determined according to the following equation:

$$R_{nm}^{v_{ij}^l, k} = W \log \left( 1 + \frac{g_{nm}^k P_{nm}^k}{\sigma^2} \right) \quad (2)$$

Where,  $g_{nm}^k$  is the gain of D2D pair,  $P_{nm}^k$  is the transmit power of D2D transmitting UE and  $\sigma^2$  is the noise power.

Hence, the data rate of the D2D receiver  $n$  to get the requested content of size  $b_n$  is calculated as:

$$R_n(\alpha) = \sum_m \alpha_{mn}^{v_{ij}^l, k} R_{nm}^{v_{ij}^l, k} \quad (3)$$

From (1), (2), and (3), our delay minimization problem can be formulated as follow:

*OPT-1*:

$$\min_{\alpha} \sum_{n \in N} \frac{b_n}{R_n(\alpha)} \quad (4)$$

*Subject to*:

$$R_n(\alpha) \geq R_{n, \min} \quad (5)$$

$$\alpha_{mn}^{v_{ij}^l, k} \in \{0, 1\}, \quad \forall n, m, v_{ij}^l \quad (6)$$

$$\sum_{n \in N} \alpha_{mn}^{v_{ij}^l, k} \leq 1, \quad \forall m \quad (7)$$

$$\sum_{m \in M} \alpha_{mn}^{v_{ij}^l, k} \leq 1, \quad \forall n \quad (8)$$

Problem *OPT-1* is an integer linear programming and finding the solution for a practical size network is NP-Hard [3]. We aim that the problem in *OPT-1* can be solved in a distributed manner with low complexity and distributed manner. In order to solve *OPT-1*, we use matching theory in the following section.

---

**Algorithm 1:** Resource allocation and D2D link establishment based on matching theory

---

Initialize:  $N_m^{req}, N_m^{accepted}, N_m^{rejected}$

*Stage I: Discovery and utility computation*

- 1) UE sent request to BS to get content.
- 2) BS searches the requested content in VC and find  $M$
- 3) BS broadcasts its sub-channels and  $M$  to requesting UEs
- 4) Requesting UEs compute its utility values and build  $\succ_n$  based on (3)

*Stage II: Matching operation to find stable matching  $\mu^*$*

- 5) Each UE  $n$  sends a request for  $m$  to BS,  $m = \text{argmax}(\succ_n)$
- 6) Base station do:
  - a. Updates set of requested UEs  $N_m^{req}$ .
  - b. Computes utility values and build  $\succ_m$  based on (6).
  - c. Update accepted list following (6):
  - d. If  $n$  satisfy (6) then,

$$N_m^{accepted} \leftarrow n = \text{arg min}(U_m(n))$$

$$\text{Else } N_m^{rejected} \leftarrow n$$

BS informs  $N_m^{rejected}$ . This  $N_m^{rejected}$  will be considered in the next uplink transmission period.

Go back to step 2

**Outputs:**  $\alpha^*$  and Stable matching  $\mu^*$  [6]

---

### 4. Proposed solution

Based on matching game theory [6], we transform variable  $z$  by using one-to-one matching between two sets  $N$  and  $Z$  which satisfy constraints in *OPT-1*. For this problem, the matching game problem is defined as follows:

**Definition 1:** A matching-based user association problem  $(\mu)$  is defined by the tuple as a function. The sought solutions is a  $(N, M, \succ_n, \succ_m, q_n = 1, q_m = 1)$  matching function of matching game which provides the final allocation between requesting users and entities in the set  $Z$  based on preference functions  $\succ_n$  &  $\succ_m$ .

Let  $U_n$  &  $U_m$  denote the utility functions of players, i.e., requesting user  $n$  and content node  $m$ , respectively.

Each UE prefers to associate to the best content node, i.e., with minimum delay. The utility function is as follows:

$$U_n(\alpha) = \frac{b_n}{R_n(\alpha)} \quad (9)$$

At the BS side, given the set of requested UEs' proposal, the BS decides to associate the  $m$  to the requesting UE  $n$  if it satisfies the following condition:

$$U_m(n) = \min_{n \in N_m} \left( \frac{b_n}{R_n(\alpha)} \right) \quad (10)$$

(5), (6), (7), (8)

Where  $N_m$  is set of proposals from requesting UEs to entity  $m$  in set  $M$ . From (5) and (6), by using these preference list, the requested UE wants to be matched to the best  $m$  with minimum delay. At the BS side, BS prefers to assign  $m$  to the best requested UE with lowest transmission delay. Clearly, we can reduce total transmission delay after each rejection/acceptance operation of the matching game. Algorithm 1 is presenting our proposal in detail.

### 5. Evaluation

To evaluate the performance of our proposal, we simulated it in Python. We consider an indoor environment where  $N = 5$ . Some parameters are as follows:  $M = 10$ ;  $P_{mm} = 20$  dBm;  $P_{mm}^{\max} = 105$  dBm;  $B_k = 180$  kHz;  $K = 10$  sub-channels. The channel gain is assumed to be iid Rayleigh rv with mean value  $h(d) = h_0(d/15)^{-4}$ ,  $h_0$  is a reference channel gain at a distance 15m.

We compare three schemes composed of the global optimum solution; greedy approach and the proposed scheme. In order to estimate our proposal in phase I, we increase the number of requesting UEs (1 to 10) and compare with others schemes. In Fig. 2, we can see that our proposed mechanism always performs better than the greedy approach. Obviously, the global optimum solution is better than our proposed mechanism. However, solving the global optimum solution for a denser network within the time frame is not possible and secondly, the UEs required to pass too many messages for getting the global optimum solution.

### 6. Conclusion and Future Work

In this paper, we presented to minimize the download delay for layered video content in ICN enabled cellular networks with D2D communication. The resource allocation problem, formulated in the paper, is NP-hard. We used matching game to solve the

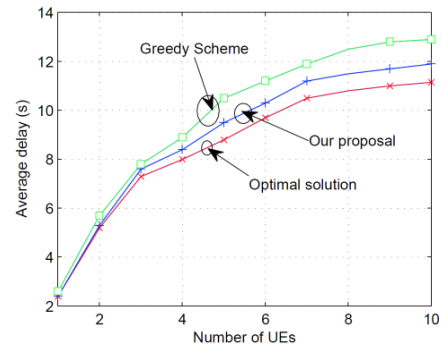


Figure 2: Video download delay analysis

problem. Our proposed solution minimizes the download delay. In future, we aim to perform more simulation with complex scenarios to show the effectiveness of our proposed solution in a more concrete manner.

### 7. Acknowledgement

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) (No. 2013-0-00409, Research and Development of 5G Mobile Communications Technologies using CCN-based Multi-dimensional Scalability)

\*Dr. CS Hong is the corresponding author

### 8. References

- [1] Cisco VNI forecast., <<http://www.cisco.com>>
- [2] Van Jacobson, et al., "Networking Named Content", CoNext, Rome, Italy, 2009.
- [3] S. Boyd, and L. Vandenberghe "Convex Optimization", Cambridge University Press, 2004.
- [4] Ullah, Saeed, Kyi Thar, and Choong Seon Hong. "Management of scalable video streaming in information centric networking." *Multimedia Tools and Applications* (2016): 1-28.
- [5] Ullah, Saeed, et al. "Delivering Scalable Video Streaming in ICN Enabled Long Term Evolution Networks." *Network Operations and Management Symposium (APNOMS), 18th Asia-Pacific*. IEEE, 2016.
- [6] Gu, Y., Saad, W., Bennis, M., Debbah, M., & Han, Z. "Matching Theory for Future Wireless Networks", *Fundamentals and Applications*. (2014)
- [7] Schwarz et al. "Overview of the scalable video coding extension of the H. 264/AVC standard." *IEEE Tran. on Cir. & Sys. for VT '07*
- [8] Thar, Kyi, Saeed Ullah, and Choong Seon Hong. "Consistent hashing based cooperative caching and forwarding in content centric network." *16th Asia-Pacific Network Operations and Management Symposium (APNOMS)*, IEEE, 2014.