Layered Video Communication in ICN Enabled Cellular Network with D2D Communication

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***Abstract*—Modern day's User Equipments (UEs) are equipped with rich resources which encourage them to be used for more sophisticated applications. On the other hand, with these equipments in hand, users demand for high-quality video on the move is increasing day-by-day. Moreover, Information/Content Centric Networking (ICN/CCN) has changed the network dynamics by getting the desired contents regardless of the location. Unused memory in UEs can be used to cache the contents and provide it to the other nearby users on demand. In this paper, we propose to provide the requested video to users from other users cache, using D2D link, if it is present there. Our objective is to reduce the download delay for the users' requested video. We formulate the problem as a matching game in which the resources are assigned to the users in the uplink period. The UEs select the content node for D2D communication and the suitable channel. We have evaluated the proposed mechanism by implementing it in Matlab and have compared it with greedy approach and no D2D communication scheme. The experimental results show the effectiveness of our proposed mechanism.**

***Index Terms*—ICN/CCN, Video Streaming, D2D communication, Resource allocation, Scalability.**

I. Introduction

Explosive growth of smart wireless devices like smart phones and tablets have increased demand for bandwidth intensive applications like video streaming. The Cisco Visual Index reports that Internet traffic will grow 3-fold from 2015 to 2020, 79% of which will be video traffic, while mobile traffic will grow 3 times faster than the fixed IP traffic [1]. To meet this increasing demand, current cellular networks are proceeding towards fifth generation (5G). The 5G will be consisted of higher carrier frequencies, massive MIMO techniques, and dense heterogeneous deployments. Meanwhile, mobile devices are rapidly becoming powerful in computation and communication capabilities. This tremendous hardware improvement has brought many possibilities to use User Equipments (UEs) for networking functionalities. More specifically, Device-to-Device (D2D) communication is envisioned to assist in enhancing users' Quality of Experience (QoE). Moreover, Information/Content Centric Networking (ICN/CCN), the future Internet architecture, has shifted the center of gravity from network core to the periphery [2]. In CCN, networking nodes cache the passing data chunk in its cache memory and provide it to the similar request from its cache in the following request for the same data chunk [3], [4]. Mobile devices i.e., smart-phones/tablets etc., can use a part of its storage memory (which is usually under utilized) for caching the content [5].

On the other hand, H.264/SVC encoding achieves scalability by trans-coding video in a single file consisted of mandatory base layer and multiple enhancement layers. The users are provided as many layers as they need from this single file according to network condition and device capabilities. Different layers of the H.264/SVC encoded video are strongly interdependent. A layer can only be used if all the lower layers are present.

D2D communication (which is usually taking place in short range) enhances the spectrum efficiency by reusing the frequencies. In D2D communication, the UEs communicate directly without routing its traffic through the Base Station (BS). However, if D2D communication is carried on the cellular frequencies, i.e., both the CUs and D2D pairs are using the same frequency band for their communication, then it bring multiple users in the same collision and interference domain. Interference management has been a critical challenge in the cellular domain[6]. D2D communication has brought promising advantages [7], [8]. However, it also posed new challenges [9], [10].

In this paper we have proposed resource allocation to the Cellular Users (CU) and D2D users for layered video in a cellular network who are competing for getting the resources. Our objective is to minimize the delay for getting the requested video. D2D communication takes place in the uplink transmission period. The D2D communication is carried on the cellular frequencies i.e., both the CUs and D2D users are communicating in the same frequency band.

Our contribution in this paper can be summarized as follow:

- We formulate the problem of resource allocation to the cellular users and D2D users as a matching game in which all the users are competing for getting the cellular resources for their communications.
- Solving the problem of resource allocation to cellular users and D2D pair in the uplink period is a mixed linear programming NP hard. We propose a distributed algorithm to solve this problem.
- We have intensively simulated our proposed mechanism in Matlab and have compared it with other existing solutions. Our simulation results show that our proposal outperforms greedy approach and no D2D communication scenario under the same experimental circumstances.

The rest of this paper is organized as follows. In section II some background of CCN and SVS have been covered, while section III covers some of the related work. Section IV describes the system architecture. Our proposed mechanism is presented V. Section VII covers the performance analysis of the proposed scheme. Finally, we have concluded the paper in section VIII.

II. Background

In this section we discuss some basic background of layered video streaming and CCN in order to make the paper self oriented.

A. Content Centric Networking (CCN)

The current TCP/IP based Internet, introduced in 1980's, is a location specific in which two end hosts communicates. In this current Internet, the networking nodes are dumb and perform only forwarding the incoming packets to the destination. To take advantage of of the resource enriched networking nodes, Jacobson et. al, [2] has introduced new Internet architecture called CCN. In CCN, there are two types of packets, namely Interest and Data. Interest packets are generated by the users/consumers for their desired contents. In a reply, they get Data packets.

Interest packet is carrying name of the Data which are hierarchically structured like URIs or the path of file system like x/y/z.mpg etc. These hierarchal names are used to direct the Interest towards the content provider [2]. Caching, one of the premium attribute of the a CCN node, enables CCN node to provide the desired content from its local content store if it is present there. In this way, traffic in the network is reduced significantly [3]. CCN is consisted of three data structures mainly, i.e., Content Store (CS), Pending Interest Table (PIT) and Forward Information Base (FIB). The received Interest is first searched in CS to find the requested contents, if the requested content is found, the corresponding Data packet is generated and is sent back on the reverse path. Otherwise, PIT is checked to avoid duplicate Interest forwarding. In case of finding entry in PIT, the Interest arriving face is added in the PIT entry. The corresponding Data is duplicated of all the Interests incoming paths. In case of not finding any entry in the PIT, the node searches FIB for forwarding the Interest towards the potential Data source.

Data delivery is rather simple. On Data arrival, CCN node forwards it to all the faces in PIT and also cache a copy of it in CS according to its caching policy. If there is no entry for the arriving Data in PIT, it is considered as redundant or outdated Data and is discarded. Interested readers are directed to [2] for further details of CCN.

B. Layered Scalable Video Streaming

The H.264/SVC encodes video into multiple layers. In the encoded stream, there is a mandatory base layer and a number of optional enhancement layers [11]. BL is an independent unit, that can decode the video with the lowest quality. The ELs are used to enhance the spatial, temporal quality or overall quality of the video. Users demand the BL and ELs of the required video according the network condition or according to their device specification. In H.264/SVC, video layers are strongly interdependent. BL is mandatory for decoding any video. EL1 can only be used if the corresponding BL is already present. Similarly, EL2 can only be used if BL and EL1 are already present and so on. H.264/SVC encoded videos are envisioned to be beneficial in CCN [12].

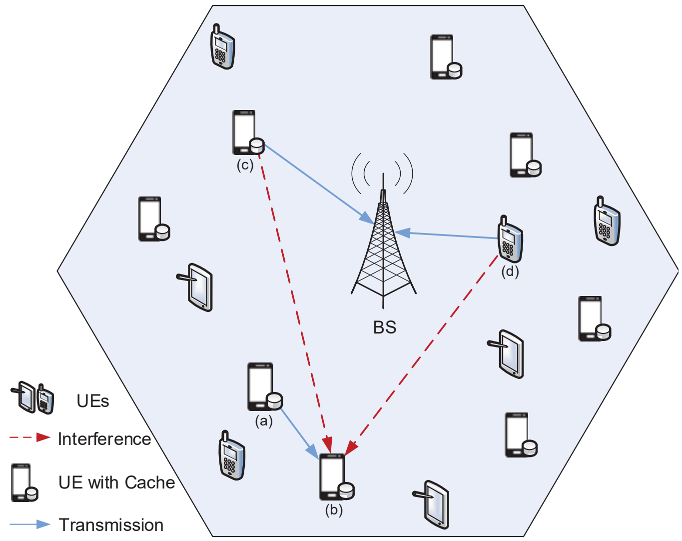

Fig. 1. System diagram

III. Related Work

In this section, we are presenting research work that has been done in the field of resource and cache management in cellular network and D2D communication specially for video streaming. Cooperative D2D multi-cast has received attention of the research community to a great extent in the recent years. A comprehensive survey on D2D communication can be found in [7].

In [13], presented a concise review of video delivery with base station assisted D2D wireless networks and caching. Their approach is in the form of a tutorial. Their model is showing a sharp characterization of the throughout-outage trade-off in the asymptotic regime of dense networks. The superiority of D2D caching network approach is shown via this trade-off as compared to the conventional schemes.

In [3], we have proposed caching layered video in an autonomous system. Here, we have shown that caching the lower layer nearer to the users improve user QoE by delivering video quickly. We also consider the popularity of the video in taking caching decision. In [14] the authors proposed a novel and social network-aware approach for user association in D2D underlaid small cell base stations. the problem is formulated as a matching game with externalites. Their goal is to maximize the social welfare for each cluster of small-cell base-stations. They have introduced a dynamic clustering approach in which they have clustered base stations on the basis of their distance and load similarities. Their simulation results show significance of the proposed mechanism as compared to maximum RSSI.

IV. System Architecture

Our proposed mechanism can be implemented in a typical cellular network like shown in Fig. 1. There are N user equipments in the system. Let $\mathcal{N} = \{1, 2, 3, ...N\}$ are the UEs that put request for the layered video and $\mathcal{M} = \{1, 2, 3, ...M\}$ are the UEs that have the requested content in their cache. To get data content from nodes in $\mathcal{M}$, a set of $\mathcal{K} = \{1, 2, ..., K\}$ subchannels are used to transmit data from node m and node n. We assume that each subchannel is only contained only single resource block as in single carrier frequency division multiple access (SC-FDMA) technology in LTE system [15]. The D2D communication will only be possible if the requesting user n and the UE having the requested data i.e., m belongs to the same cluster. The UEs put requests for the layered video. The BS searches the requested contents within the cluster the requesting UE belonging to, if the requested content is found in the UE's cache then BS goes for the resource allocation phase otherwise BS arranges the requested content from its own cache or from download it from the content provider's server. The communication scenario is discussed in detail in section IV-A.

The D2D pair communication takes place in the uplink period. The D2D pairs and cellular UEs use same frequency band, so D2D receiver getting interference due to CU's transmission as shown by an example in Fig. 1. UE a transmits to b and in the meanwhile c and d are transmitting to the BS. Transmission of c and d causes interference on D2D receiver b. Derivation of the Interference is discussed in V-A

A. Communication Scenario

In our proposed system, the UEs generate Interest for a chunk of video. We assume that the users request one segment of the video in one Interest (segment is a small portion of the video that ranging from 2 to 10 sec. of playback time). BS searches for all the layers of the video in cache of all the devices in the requesting UEs cluster and sends the information of different layers available with UEs in the cluster to the requesting UE. The requesting UE then schedule the chunk requesting with the aim of maximizing the video quality. UE will download the layers of the desired segment from the D2D if it is available and the remaining layers from the BS/server, if it can get the resources from the system. UE, whose higher layers of the desired video are available with another UE (which it can get via D2D communication), get higher priority of getting the BS resources in order to download the lower layers of the desired video from the BS. Communication scenario is presented in Fig. 2 in detail.

V. Proposed Mechanism of Layered Video Delivery with D2D Communication

In this section we present our proposed mechanism of delivering H.264/SVC encoded layered video in detail.

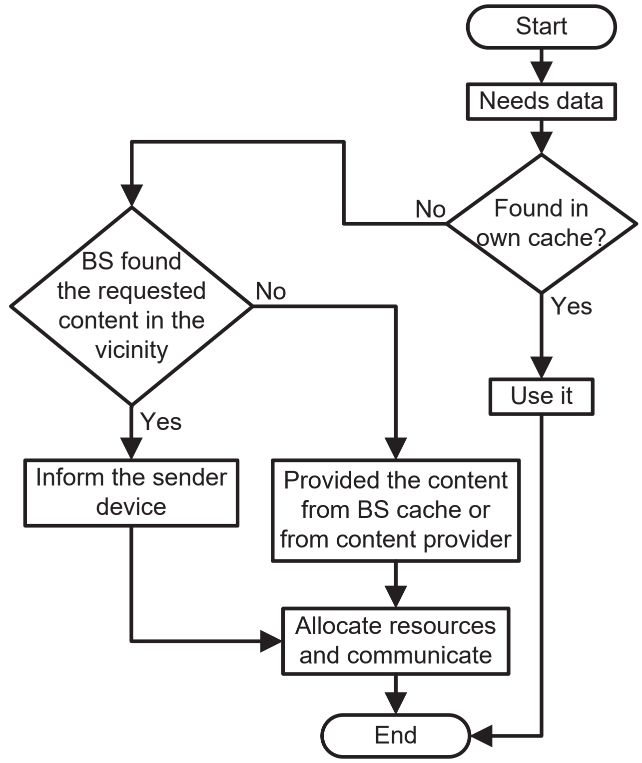

Fig. 2. Video delivery for D2D and BS

A. Interference and Rate

In our model, the D2D transmission and the cellular UEs are operated on orthogonal frequencies i.e., D2D pairs and cellular UEs are assigned different portion of the spectrum [reference]. Therefore, they are not interfering each other. D2D receiver gets interference from other D2D transmission. Each D2D transmitter uses different power for different RB. D2D pair determines the feasible power level for available RB to avoid interface at the macrocell base station. For RB allocation we use binary variable x_{mn}^k:

$$x_{mn}^k = \begin{cases} 1, & \text{If D2D pair in group } g \text{ is assigned RB } k, \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

D2D transmission rate of a UE is calculated according to the following equation:

$$R_{nm}^k(\mathbf{X}, \mathbf{P}) = W^k \log \left(1 + \frac{h_{nm}^k P_{nm}^k}{\sum\limits_{\substack{n' \neq n, \\ m' \neq m}} x_{n'm'}^k h_{n'm}^k P_{n'm'}^k + \sigma^2} \right), \tag{2}$$

where h_{nm}^k is the gain of D2D pair, P_{nm}^k is the transmit power of D2D transmitting UE, and σ^2 is the noise power. Total transmission rate of the system on channels k is calculated according to the following formula.

$$R_n(\mathbf{X},\mathbf{P}) = \sum_{m,k} W^k x_{nm}^k R_{nm}^k(\mathbf{X},\mathbf{P}). \quad (3)$$

B. Delay Analysis

The delay due to queue for content request in such a situation that the requested content of two different users is with the same node. Given a requested layer l of video i from node m having a length of $b_{i,l}^m$ bits, the average delay transmit for content m can be computed based on M/D/1 queuing model as follows [16]

$$D_n(\mathbf{X},\mathbf{P}) = \frac{b_{i,l}^m}{2R_n(m,k)\left(R_n(m,k) - b_{i,l}^m\right)}, \quad (4)$$

where $b_{i,l}^m$ is the arrival rate (bit/s) to the queue; R_m is considered as the service rate in the M/D/1 queuing model is determined by (4). Here, we assume that there is no packet loss between content and requesting nodes.

C. Problem Formulation

From the above analysis, our problem formulation of the joint D2D pair establishment and resource allocation is formulated as follows:

$\mathbf{OPT\text{-}1}$:

$$\text{minimize}_x \quad \sum_{n\in\mathcal{N}} D_n, \quad (5)$$

subject to:

$$R_m(\mathbf{X},\mathbf{P}) \geq R_{m,\min}, \quad (6)$$

$$P_{nm}^k \in P_n = \{0,\ P_{n,\max}\};\ \forall m,n,k, \quad (7)$$

$$x_{nm}^k = \{0,1\},\quad \forall m,n,k, \quad (8)$$

$$\sum_{k\in\mathcal{K}} x_{mn}^k \leq 1,\ \forall m,n, \quad (9)$$

$$x_{mn} = \{0,1\},\quad \forall m,n, \quad (10)$$

$$\sum_{n\in\mathcal{N}} x_{mn} \leq 1,\quad \forall m, \quad (11)$$

$$\sum_{m\in\mathcal{M}} x_{mn} \leq 1,\quad \forall n. \quad (12)$$

In this optimization, our goal is to minimizing total delay for getting the requested contents in the ICN network, which is represented by objective function (6). In the OPT-2, constraint in equation (6) is to ensure that the rate of D2D pair must be greater than the $R_{m,\min}$ threshold. Constraint in equation (7) is that the transmit power of the D2D transmitter must be in the range of 0 and maximum transmit power $P_{m,\max}$. Equation (9) represents that each D2D pair will be assigned at most one channel. Constraints in equation (11) and (12) are to ensure that at a time at most one D2D transmitter is transmitting to at most one receiver.

The above optimization problem is a mixed linear programming NP hard because of the binary constraints. In order to solve it, we propose a distributed matching game based approach in next sections.

VI. Matching Game-based Solution

In this section, we first formulate the $\mathbf{OPT\text{-}1}$ as a matching game. Then, we propose a distributed algorithm to find a stable solution for the formulated game.

1) Definition of Matching Game for Joint Resource Allocation and Cache Allocation for D2D in ICN: The problem $\mathbf{OPT\text{-}1}$ is formulated as a matching game, which is defined by a tuple $(\mathcal{N},\mathcal{X},\succ_{\mathcal{N}},\succ_{\mathcal{X}})$. Here, $\succ_{\mathcal{N}}=\{\succ_n\}_{n\in\mathcal{N}}$ and $\succ_{\mathcal{X}}=\{\succ_x\}_{x\in\mathcal{X}}$ denote the preference relations of the requested UEs and available network resources, respectively. Here, each network resource allocating to requesting UEs are determined by pair (m,k), where $\forall m\in\mathcal{M},\forall k\in\mathcal{K}$.

We define the problem as a one-to-one matching game, as follows:

***Definition** 1:* Given two disjoint finite sets $\mathcal{N}$ and $\mathcal{X}$, a matching game for subchannel allocation is defined as a function μ_x: $\mathcal{N}\mapsto\mathcal{X}$ such that:
1, $n=\mu(x)\leftrightarrow x=\mu_(n)$, $\forall n\in\mathcal{N}, x\in\mathcal{X}$;
2, $|\mu(x)|\leq 1$ and $|\mu(n)|\leq 1$, $n\in\mathcal{N}, x\in\mathcal{X}$.

The conditions $|\mu(r)|\leq 1$ and $|\mu(n)|\leq 1$ in Definition 1 correspond to the constraints (12)-(14), respectively. In the matching μ, we define $\phi^n(r)$ and $\phi^r(n)$ as the preference relations of utility values of requesting UEs in evaluating network resources for D2D in the ICN and the utility value of requesting UE n in network resource r for UE n, respectively. After that, we define the utility function of both UEs.

Utility function of the requesting UE. After each requesting UE is allocated with a network resource r, the requesting UE obtains the corresponding utility as:

$$\phi^n(x) = D_n^x, \quad (13)$$

where UE n estimates its utility on each network resource r based on the estimated delay sensitive achieved on subchannel k from content node m. By using the utility function in (13), requesting UEs have to bid to occupy each subchannel that minimize their utility function.

Utility function of the ICN provide for each network resources. In response to the requests from the UEs for occupying certain subchannels, the ICN provide wishes to minimize a utility function on each subchannel, which is proposed as follows:

$$\phi^x(n) = \arg\min \sum_{n\in\mathcal{N}_x} D_n^x, \quad (14)$$

where $\mathcal{N}_x$ is a set of requesting node on network resource x. In our proposed matching game, each network resource x prefers to assign its pair (m,k) to the requesting UE that minimize the delay to download content m.

For the proposed one-to-one matching game, our goal is to find a stable matching. A matching μ is said to be stable if it is not blocked by individual requesting UE n and network resource x or any pair.

A. Distributed Algorithm

Algorithm 1 is a distributed algorithm which solves the $\mathbf{OPT\text{-}1}$. In this algorithm, each requesting UE constructs its

Algorithm 1 Resource Allocation to cellular and D2D users

1: **Initialize:** N_x^{req}, $N_x^{accepted}$, $N_x^{rejected}$
2: **Stage I:** *Discovery and utility computation*
3: UE sends request to BS to get content.
4: BS searches the requested content in VC and find M
5: BS broadcasts its sub-channels and M to requesting UEs
6: Requesting UEs compute its utility values and build based on (3)
7: **Stage II:** *Matching operation to find stable matching*
8: Each UE n sends a request for network resource $x\ (m, k)$ to BS, $x = \arg\min(D_n(x))$
9: *Base station do:*
10: Updates set of requested UEs N_x^{req}
11: Computes utility values and build $\succ_x$ based on (6).
12: Update accepted list following (6):
13: **if** n satisfy (6) **then**
14: $\quad N_x^{accepted} \leftarrow = \arg\min(D_n(x))$ using the Hungarian matching algorithm
15: **else**
16: $\quad N_x^{accepted} \leftarrow n$
17: **end if**
18: BS informs $N_x^{rejected}$. This $N_x^{rejected}$ will be considered in the next uplink transmission period.
19: Go back to step 2
20: Outputs: α^* and Stable matching μ^* [6]

own preference relation based on (13). In the swap matching phase, each requesting UE sends a bid request $b_{n \to x}(t) = 1$ to access the network resource x that has the lowest utility value. At the BS side, the BS collects all bidding requests and constructs a preference list on each subchannel. Based on the preference relation of the subchannels, the BS assigns network resources to requesting UEs which bring the lowest utility value. The requesting UE removes the network resource x which is rejected by BS in its preference. The process of acceptance or rejection of applicants is performed in a manner similar to the conventional deferred acceptance algorithms [17]. Thus, the Algorithm 1 converges to the stable matching μ^*.

VII. Performance Evaluation

In this section, we are going to present the experimental evaluation of our proposed scheme to show its effectiveness. We have compared our proposed scheme with the greedy approach and no D2D communication. In the greedy approach the node always select the best channel for its transmission. In no D2D approach all the users requests are fulfilled by the BS either from its local content store or from the content provider's server. We consider an indoor environment for our experiments where N =5. Some parameters used in the experiments are as follows: M = 10 unless stated otherwise; $P_{nm}^{\max}$ = 20 dBm; σ^2=-105 dBm; Bk =180 kHz; K = 10 sub-channels unless stated otherwise. In all the experiments, we have assumed the channel gain to be iid Rayleigh random

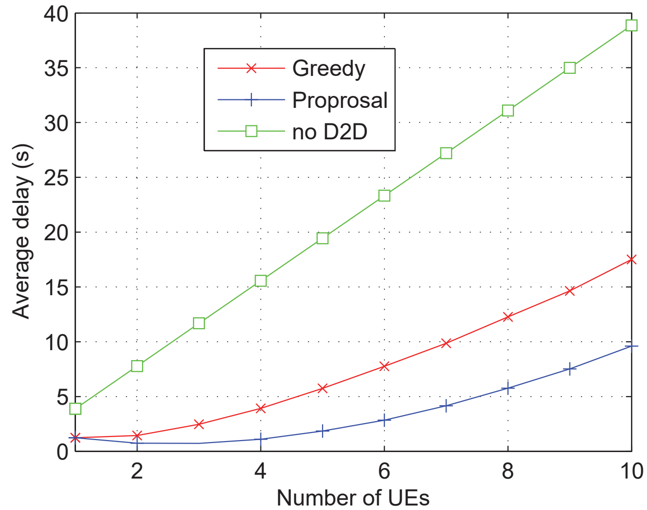

Fig. 3. Download delay for different number of UEs

variables with mean value h(d) = h0(d/15)-4 where h0 is a reference channel gain at a distance of 15 meters.

A. Effect of Node Density

First of all, we have fixed the RBs as 10 and changed the number of UEs in the network to see the download delay. Fig. 3 is showing the delay performance of all the compared schemes for increasing the UEs from 1 to 10. The performance gape between the greedy approach and our proposed scheme is increasing as the node density is increasing. The reason for this the interference caused by more number of UEs. No D2D case always have the highest delay because the content fetched from the service provider by the BS in all the cases.

B. Effect of Cellular Resources

Fig. 4 is showing the download delay performance of the proposed scheme for different cellular resources. Here, we have fixed number of UEs as 10 and have changed Resource Blocks (RBs) from 1 to 10. In the Figure, we see that the delay performance gape between the proposed mechanism and the greedy approach is increasing. In the greedy approach, the UEs always selects the resources that are best suited which causes disturbance to other transmissions in the vicinity. No D2D case again is having the highest delay because all the requested contents are downloaded from the service provider's server via BS.

C. Effect of Content Nodes

In this section, we are discussing the download delay performance for different number of content nodes. From the term "content nodes" we mean those UEs that have the requested videos of other nodes in its cache. In Fig. 5, we see that the delay performance of our proposed scheme and the greedy approach is increasing with the increasing number of content nodes. No D2D again is not effected by the varying number of content nodes as it always get the content from the server via the BS.

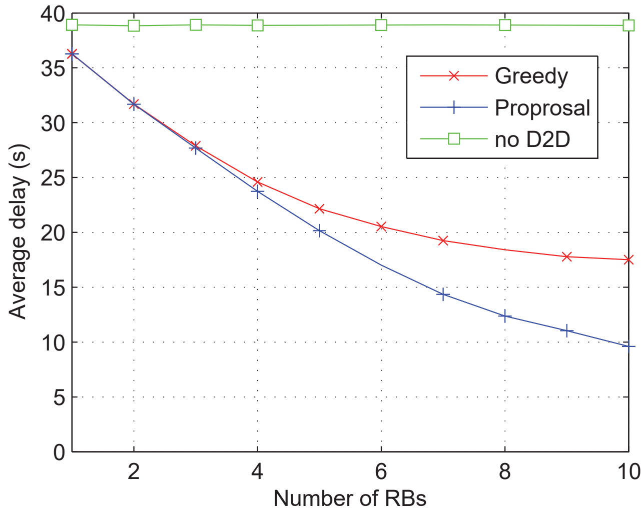

Fig. 4. Download delay for different number of RBs

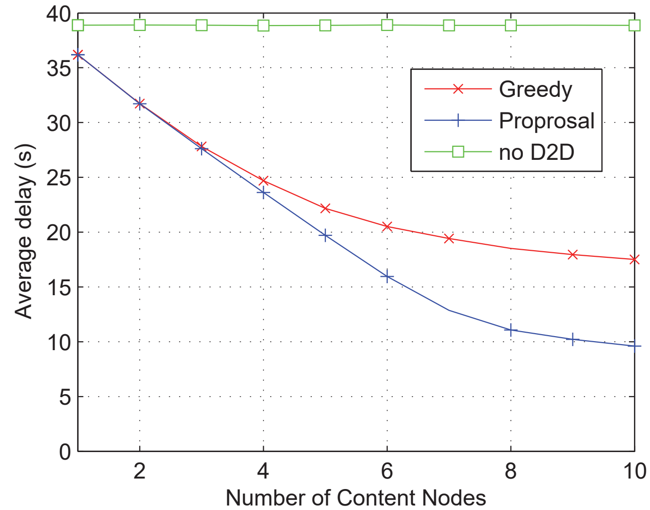

Fig. 5. Download delay for different number of content nodes

VIII. Conclusion

In this paper, we presented resource allocation to the CU and D2D pair in the uplink transmission period. All the devices in the system operate on CCN i.e., they put Interest for required content and get Data chunk as a result. UEs with memory can provide other users requested content, if it is present, via D2D link. Allocating k sub channels to a set of $\mathcal{M}$ users is a mixed linear programming NP hard problem and it is not possible to solve it for a substantial set of UEs. We proposed matching game based approach to solve the resource allocation problem. Objective of the resource allocation is to reduce the download delay of the requesting UEs. We evaluate the proposed mechanism in by implementing it in Matlab and comparing it with the greedy and no D2D approaches. Our experimental results show the effectiveness of our proposed mechanism. In the future, we aim to extend this work by focusing more on the video layer dynamics and characteristics of CCN like caching and forwarding.

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