Base-Station Assisted Socially-Aware Reactive Caching in ICN-enabled D2D Communication Network

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Abstract

Caching the highly popular content at the most appropriate location has been a hot issue in Information Centric Networks (ICN) in the recent years. The content popularity drastically changes with the location and the nature of the users in the vicinity. Social relationship of the users and the Device-to-Device (D2D) communication have put new dynamics on the horizon of content caching. In this paper, we have proposed caching the content in User Equipments (UEs) based on social following of the nearby devices under the guidance of Base Station (BS) in ICN based D2D communication network. In the proposed caching decision mechanism, BS provides a scalable recommendation to the UE, with the requested data chunk, for reactively caching the content on the basis of near-by users' social following. The UE evaluates the significance of the recommended content in light of the already cached content and takes a cache decision. The UE then provide the content to other nearby UE's through Device-to-Device (D2D) communication link in reply to their request in the near future. The proposed mechanism increases cache hit and hence results in lower download delay.

1. Introduction

Continuous improvement in the smartphones and tablets market is causing to increase the mobile Internet traffic manifold. According to Cisco, from 2017 to 2019, mobile data-traffic will have annual growth of 46% and will grow 7-fold [1]. Video traffic will dominate the mobile data traffic. Fifth generation (5G) has already emerged on the horizon of wireless communication, which has not only closed the door for further improvement in the frequency domain but also has implemented the MIMO. New techniques are needed to be developed to meet the increasing demand of mobile users. A portion of smart phones/tablets storage (which is in the range of several 10s of GBs) can be used to cache the content and provide it to the other users via D2D link [2],[3]. Caching and communication in ICN, a future Internet architecture, has been studied in the literature [4]-[8] intensively. In this paper, we are presenting a semi-distributed mechanism for the content caching according to the social connectivity of the users in a D2D communication network. According to our proposed mechanism, the BS evaluates and mark the importance of every Data packet according to the social connectivity of the users in the communication range of the requesting user. The data requesting user, on arrival of the requested data, evaluates the significance of the data and cache the content if it is more significant than the replacing Data chunk. In case the Data is provided to the requesting UE from the cache of another UE then the importance of the Data is calculated according to the social connectivity of the non-overlapping users of both the requesting and provider UEs. In our performance evaluation, we have shown that the proposed mechanism increases the cache hit which results in the lower download for the requested content to the UEs.

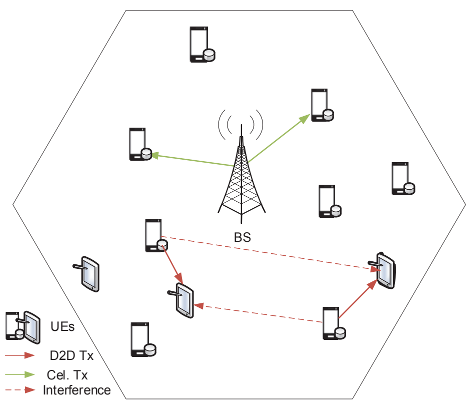

Figure 1: System Diagram

2. System Design

We are considering a typical cellular network as shown in figure 1, there is a Base-Station (BS) and N UEs. The UEs reserve a portion of their storage for caching the content. D2D communication uses orthogonal frequencies for communication, therefore, there is no interference between the cellular users and the D2D users. However, D2D receiver gets interference from all other D2D transmission using the same frequency. We are giving high priority to the D2D communication i.e., a user will get the data from another nearby UE via D2D communication. If the requested data is not present in the nearby UEs' cache or there is no network resources available for getting the requested content then the requested data is provided via BS. Since the wireless transmission weakens with increase in the distance due to relay fading. Therefore, in our mechanism, we are also considering the channel to be Relay fading. To cope with the worst case scenario, we are considering the fully loaded network model i.e., all the UEs either requesting the data or providing the data via D2D link to other UEs.

3. Preliminaries

Signal-to-Interference and Noise Ratio (SINR), represented by ($\Gamma_{i,j}$), for D2D pair user i and user j is calculated as follow:

$$\Gamma_{i,j} = \frac{P_i h_{i,j} d_{i,j}^{-\alpha}}{\sum_{i' \neq i, i \in N} P_{i'} h_{i',j} d_{i',j}^{-\alpha} + n_0^2}, \quad (1)$$

where $\sum_{i' \neq i, i \in N} P_{i'} h_{i',j} d_{i',j}^{-\alpha}$ is the total interference from all other D2D transmission on the same channel, P_i is the transmit power of the transmitting UE i, $h_{i,j}$ is the channel gain between the D2D pair i and j, $d_{i,j}^{-\alpha}$ is the path-loss between the D2D pair. Here $d_{i,j}$ is the distance between the UEs and α is the exponent of path-loss. n_0^2 is the Gaussian noise. The transmission rate, $r_{i,j}$, between D2D pair i and j is calculated as follow:

$$r_{i,j} = W \log_2 (1 + \Gamma_{i,j}), \quad (2)$$

where, W is the channel bandwidth. The user content request is governed by Zipf distribution. The user request c^{th} content from total of {1,2, ⋯, C} contents with the following probability.

$$P_j^c = \frac{1/c_j^{\omega}}{\sum_{m=1}^{C} 1/m_j^{\omega}} \quad (3)$$

Where ω is the Zipf distribution skewness parameter. Higher value of ω means a few files are very popular and are requested more frequently, while the others are requested very rarely. Lower value of ω means all the files are requested with even probability. Typically ω is taken in the range of 0.5 to 2.

4. Proposed mechanism

Our main objective is to reduce the download delay for the user requested content. In ICN user generates Interest packet for a small chunk of content. Typically one data packet is delivered for each Interest. In one time slot, a user can get the data either from BS via cellular transmission or from another user via D2D transmission. Delay for downloading l^{th} chunk of a content is calculated as follow:

$$U_{j,c_l} = \left\{ \begin{array}{ll} \min\{\frac{s_{c_l}}{r_{i,j}}\}, & \exists \Gamma > \gamma, \\ \frac{s_{c_l}}{r_{j,0}}, & otherwise \end{array} \right\}, \quad (4)$$

where s_{c_l} is the length of the segment. For the average download delay eq (4) can be re-write as:

$$U = CH \times \frac{S}{\bar{R}_{D2D}} + (1 - CH) \times \frac{S}{\bar{R}_0}, \quad (5)$$

where CH is the cache hit in another UE cache in the vicinity, $\bar{R}_{D2D}$ and $\bar{R}_0$ are average rate for D2D and cellular transmission respectively. Since the D2D communication provides the content very quickly, there is no backhaul delay involved, therefore, higher CH means lower delay. We propose caching scheme, presented in algorithm 1, that increases the CH and thus results in lower download delay. Each UE constructs a list of it's neighboring UEs, $\mathbf{X}(J)$, on the basis of its transmission range as follow:

$$\mathbf{X}(J) = \left\{ \begin{array}{ll} 1, & \exists \Gamma > \gamma, \forall j \in J \\ 0, & otherwise \end{array} \right\}, \quad (6)$$

where γ is a threshold for the PSNR. All the UEs share it's $\mathbf{X}(J)$ with the BS. We assume that the BS also has social connectivity information of all the users, which can be realized in the real world as the YouTube channel subscription, Twitter followings, and Facebook friends/followings etc. When BS passes data packet to a requesting UE, it calculates importance of the data packet based on source of the content and UEs in the neighborhood of the requesting UEs:

$$c_{imp} = \frac{1}{J} \sum_{j=1}^{J} y_c(j), \quad (7)$$

Where $y_c(j)$ is a binary variable which is 1 if user j is having social connection with the content provider for the content c and 0 otherwise. The data requesting UE, on reception of the requested Data, calculates the significance of the Data by comparing it with the Least Frequently Used (LFU) Data chunk in it's cache as follow:

$$c_{sig} = c_{imp} - LFU(c_{imp}). \quad (8)$$

Positive value of c_{sig} means the new Data is more significant than the LFU Data chunk in the cache and vice versa.

5. Performance Evaluation:

In this section, we present a scenario-based performance evaluation for our proposed caching mechanism. We consider a typical cellular network environment in which there is a BS and UEs. UEs can communicate via D2D link whenever possible. Fig. 2 shows delay for a given user who is downloading a file/video of 100 MB. The Average rate that a user get via D2D is 5MBps while the average rate from BS is 2MBps (including the delay cause by the (backhaul).

Algorithm 1: *BS-Assisted Caching Mechanism*

BS, On reception of Interest packet

BS first searches the requested content in the nearby users' cache.

IF ($CH = 1$ & $x(j) = 1$) **THEN**

—BS calculates c_{imp} using eq(7) for the non-overlapping neighbors and passes it to i

—UE i appends this c_{imp} with the data packet

—UE i transmits the Data to UE j after getting the network resources for D2D communication

—UE j calculates the significance using eq(8)

IF ($c_{sig} \geq 0$) **THEN**

—Cache the content

ELSE

—Consume the content and do not cache it.

EndIF

ELSE

—BS Downloads the content from the service provider via backhaul link

—BS calculates importance of the Data using eq(7)

—BS appends the importance with the Data and transmit it to requesting UE

—Requesting UE calculates significance of the Data using eq(8)

IF ($c_{sig} \geq 0$) **THEN**

—Cache the content

ELSE

—Consume the content and do not cache it.

EndIF

EndIF

In the figure, we see that as the cache hit probability (HitRate) increases the total delay for downloading the file is decreasing. In case of no D2D, all the files/videos are downloaded from the content provider's server via BS.

6. Conclusion and Future Work

In this paper, we presented semi-distributed cache decision mechanism in which BS calculates the importance of the Data packet and passes this information to the receiving UE. The receiving UE calculates the significance of the newly came Data by comparing it with the LFU Data chunk in its cache, and cache the new Data chunk accordingly. In the future, we aim to derive expressions for the social connectivity of the UEs and the transmission probabilities and the cache hit probabilities and verify our formulation through intensive simulation of the complete system.

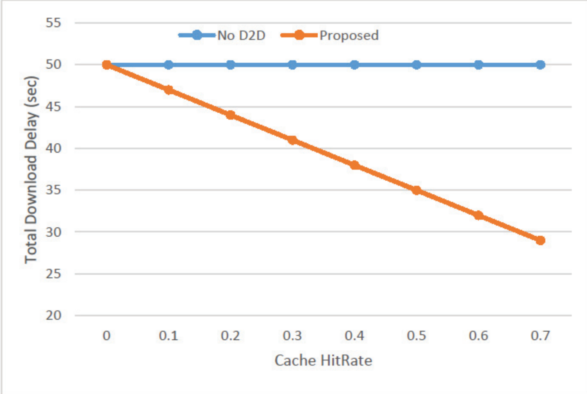

Figure 2: *Download delay performance with different cache hit rate.*

7. Acknowledgement

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