Traffic offloading based on content sharing in D2D for Smart Grid

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ABSTRACT

The Edge-Device architecture is an excellent companion of mobile communication systems, to alleviate load of IoT (internet of things) and to bring user improved experience. We consider a content sharing network (CSN) where smart devices functioned as contributory offloading-devices (CODs) can perform content sharing on demand via Edge-Device links in order to offload the cellular traffic. In this paper we study the problem of maximizing traffic offloading via content sharing among smart devices, by applying a contribution-based incentive mechanism, and by selectively caching popular contents locally. Specifically, the incentive mechanism formulated as a utility maximization problem can converge to Nash equilibrium while selective caching scheme formulated as a 0-1 Knapsack problem can improve performance of CSN. Our simulation results identify the important characteristics of proposed policies in the CSN.

CCS CONCEPTS

• **Networks**; • **Network protocols**; • **Network layer protocols**; • **Routing protocols**;

KEYWORDS

content sharing network, incentive mechanism, caching policy

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1 INTRODUCTION

With the application of the Internet of Things in the smart grid, the bandwidth-hungry data services have a critical impact on network traffic in serving multimedia content to end-users with high availability and performance. It tends that a small portion of popular contents, especially associated with the common interests, incurs the enormous amount of traffic that would take up a major portion of the overall traffic, as social network service allows them to be shared dynamically and steadily among the public [1, 2]. In this situation, a concept of content sharing network (CSN) has been introduced as an offloading system. The users who are living in the proximity tend to consume the same contents more than others and then form a CSN naturally. The main advantage of communication among devices in the CSN is spatial reuse gained by enabling multiple direct links between two nearby devices at the same time. If a neighboring device happens to have the available content cached locally, it can be shared without incurring the overhead of using cellular bandwidth. As a result, the communication among devices is accounted as one of the most promising approaches to offload cellular traffic and provide data services with high performance. Existing works on communication among devices have discussed how to perform a pair of devices communication including establishing Device-to-Device (D2D) links effectively and steadily in terms of D2D device discovery, resource allocation and interference avoidance [3–6]. However, in the current commercial system, content sharing via D2D communication links would be rarely activated owing to the following major challenges. First, the inherent selfishness of devices has presented a daunting challenge conducting content sharing because of the limited battery and the uplink bandwidth. In other words, the assumption that the devices are willing to help may not hold for civilian circumstance where the devices are autonomous and self-interested in the sense that they aim to maximize their welfare and minimize their contributions. Second, the local storage of devices who agree to provide others with desired content is limited, thus it is unpractical to cache all desired contents to satisfy requests from nearby devices. The decision on whether or not a piece of content should be cached needs to be made in a decentralized fashion, such that cached contents can best meet local demand.

In this paper we particularly concentrate on designing a set of incentive mechanism to promote communications among devices and a caching scheme applying at mobile devices. The goal of maximizing the traffic offloading through content sharing networks is based on the availability of tens and even hundreds of GByte of largely under-utilized storage space in smart devices for smart gird.

2 SYSTEM MODEL AND PROBLEM STATEMENT

The CSN comes into effect in offloading the traffic when devices choose content sharing to assist neighbors in acquiring a piece of desired content, referred to herein as a *message*. However, devices as the Ends are involuntary to conduct content sharing due to the inherently selfish nature. Furthermore, we wish devices to cache messages selectively to meet local demand, taking advantage of its limited storage capacity. Our objective is to facilitate content sharing utilizing effective incentive mechanism and to maximize traffic offloading with comprehensive caching policy.

2.1 System Model

For simplicity, we consider a content sharing network formed by n devices $D = D_1, D_2, \ldots, D_n$. We assume that the n devices are independently and uniformly distributed in the network. Each pair of their can communication directly and share the spectrum with normal data transmission to the sink nods. A central base station (BS) is responsible to relay requests from each device to the Internet and controls the coexistence of D2D communications and cellular communications in terms of resource allocation and interference avoidance. The techniques for distributed resource allocation and link scheduling are already mature that D2D links have ignorable affect over cellular links [7]. Nevertheless, it is still possible that two concurrent links at a single device will conflict with each other. Fortunately, a research work by Zhou *et al* in [8] designed a reliable transceiver to enable full duplex using a directional antenna in wireless communication. Based on this work, we can suppose that each device can transmit and receive messages simultaneously with the limitation that the transmitting and receiving procedure are both dedicated to another end host respectively. It follows that at most one outgoing link from the device and one incoming link to the device can exist.

Let $\mathbf{M} = \mathrm{M}_1, \mathrm{M}_2, \ldots, \mathrm{M}_m$ denote the set of m messages, one of which is potentially desired by devices at arbitrary times. Each message is cached and transmitted in its entirety, and may not be split. Note that the D2D communication-enabled CODs with content-caching capability is allowed to store the messages that are obtained upon its own requests and some requests from neighbors, and provide these messages to any proper nearby device via a direct link upon the request. It follows that the idle devices with extra capacity can actively cache the potentially desired messages and later share to others by D2D communication on their own initiative. We stipulate those devices with a distance of no more than R can communicate with each other. As a result, for a device D_i, we denote the set of its neighboring devices as $N_i = \{D_j \in D : 0 < \| D_j - D_i \| \leq R\}$ where R is the maximum communication distance. In addition, we assume that the devices adopt the signaling mechanism from [9] to communicate with their neighboring devices.

To fully motivate mobile users to participate in D2D content sharing, the base station pays rewards to senders and receivers based on their contribution to offloading [10]. For a receiving device, it first inquires its neighbors whether they have the desired message. If some idle neighbors have the message, the receiver can select one of them as its sender. Otherwise, the request is resent to the base station. For a sending device, if it happens to have the same message cached locally and agrees to share the message, the message can be retrieved without incurring the cost of using cellular bandwidth. Effective algorithm exists in D2D communication to select communication partners [11]. After matching process, the D2D users become CODs and they can be rewarded for offloading the cellular traffic slightly.

2.2 Problem Description

In the content sharing network, each device can act both as a message sender and receiver. Firstly, devices acting as message senders in the CSN are involuntary to cache messages and perform D2D content sharing since such caching and sharing will consume their local storage, energy, and uplink bandwidth. Consequently, an incentive mechanism is requisite for content sharing to proceed in practice. Secondly, for a potential contributory offloading-device, it needs to decide whether to cache the message that is completely received. Specifically, the device should consider the order of cached messages in order to benefit as many nearby devices as possible. Our problem is to find a set of effective incentive and caching strategies for D2D users to meet our objective of maximizing cellular traffic offloading.

2.2.1 Incentive Mechanism. Being inherently selfish, devices may not be willing to cache and share messages due to the storage capacities and battery lives of them are limited. To thoroughly encourage the idle device to cache the desired messages initiatively and participate in D2D content sharing, we suppose that the base station pays corresponding rewards to D2D users (CODs) based on their contribution for offloading the system. We propose that the base station prearranges bonus bandwidth to reward CODs who perform D2D content sharing no matter they are senders or receivers. It is thus necessary for the CODs to assess whether it deserves making contribution. This observation inspires us to formulate such an incentive mechanism as a utility maximization problem, with bandwidth reward as the local decision variable.

For a more formal treatment of the incentive mechanism, the bandwidth reward variable x_i is introduced here, which represents bonus bandwidth offered to D_i. The total bonus bandwidth which is set aside for incentive is $\boldsymbol{W}$. The problem to allocate bonus bandwidth justly can be formulated as a utility maximization problem, with the objective being the sum of user utilities:

$$\max^{\circ} \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{U_i}\left(\mathrm{x_i}\right)$$
$$\text{s.t.} \sum\nolimits_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{x_i} = \mathrm{W} \tag{1}$$

The problem (1) often arises in networked systems, where each user D_i is associated with an utility $U_i(x_i)$ by using x_i units of some resource. The utility function represents the satisfaction after the D_i gained its bandwidth reward here. Traditional utility maximization problems generally aim to maximize uncoupled utilities and can be solved by distributed solutions [11]. Our objective is to make resource allocation decision $\boldsymbol{x}$ such that the social welfare is maximized.

2.2.2 *Message Caching.* The devices are encouraged to cache desired contents with the assistance of incentive mechanism. However, the D2D communication-enabled CODs with caching capability differ from conventional caching servers in the network in many ways such as limited communication coverage and storage. As a result of these characteristics, the main challenge is how cellular traffic can be maximally offloaded by using the limited storage capability to the greatest extent to satisfy requests for content, and to share messages between neighboring devices.

As devices request different messages over cellular networks which can vary widely in both the size and popularity. It is not feasible to cache all messages subject to the limited storage capacities. The decision on whether a message should be cached needs to be made in a decentralized fashion, such that the cached massages are likely to meet the local demand and maximize the cellular traffic offloading. From a commercial point of view, we formulate message caching problem as a value-based optimization problem which fits the need to design our caching policies such that, (1) the value of message is an indicator reflecting the neighborhood demand; (2) the value should be positively related to the local energy consumed or the cellular traffic incurred when transmitting the message; (3) the CODs who cache more valuable messages should receive more bonus bandwidth.

Let v_{ij} indicate the value of M_j for D_i, which is positively related to the local resources consumed or the cellular traffic incurred when transmitting M_j from the base station to D_i. We define a set of 0-1 variables h_{ij}, where $h_{ij} = 1$ when the message M_j is chosen to be cached by the device D_i, otherwise $h_{ij} = 0$. Denote the cache capacity of D_i as C_i and the size of M_j as $|M_j|$. The value-based optimization problem to maximize the aggregated value of cached messages in system can be defined as:

$$\max \quad \sum_i \sum_j h_{ij} v_{ij} \tag{2}$$

$$\text{s.t.} \quad \sum\nolimits_j h_{ij} \left|M_j\right| \le C_i, \quad \forall 1 \le i \le n.$$

$$h_{ij} \in \{0, 1\} \tag{3}$$

The constrains (3) holds for every single device, requiring the total cached messages never exceed a device's local capacity. Our objective is to find a selection matrix $\boldsymbol{H}_{n\times m}$ to decide which message should be cached.

3 FAIRNESS-AWARE INCENTIVE MECHANISM

In this section, we regard each D2D user as a contributory offloading-device, and all the CODs and the base station compose a local community. We formulate such a content sharing community as a trading network, where CODs are buyers, and the BS is a unique seller. The following two observations motivate such a formulation. First, since sharing is resource-consuming, devices are unwilling to share messages for free; they need to get paid in return. Second, it is the responsibility of the base station to stimulate D2D content sharing since all users have already paid the cellular operators for mobile data services. As mentioned above, the payoff for the COD is the additional bandwidth which is offered by the base station. The COD chooses to conduct a transaction only if the incentive payoff is satisfactory. Thus, we convert content sharing problem into a utility maximization problem. Our goal is to present an incentive mechanism involving bandwidth reservation to maximize user utility with fairness guarantee.

3.1 Problem Formulation

To motivate content sharing among devices, the base station rewards contributory offloading-devices with supernumerary bandwidth which is proportional to their contributions in a successful D2D communication. Hence, we introduce a variable c_i, which represents the contribution of D_i during a round. We impose the restriction that no bandwidth will be given if a mobile device makes no contribution, i.e., the contribution vector $\boldsymbol{c} = (c_1, c_2, \ldots, c_n) > 0$. The basic framework of the incentive mechanism is shown in Figure 1.

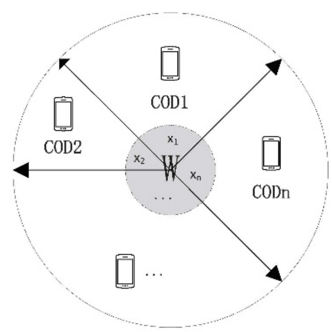


Figure 1: The framework of the incentive mechanism

We assume each utility function is: (1) twice continuously differentiable (2) monotonically increasing in each x_i and (3) a strictly concave function. As a result, problem (1) turns into a convex optimization problem which has been widely used in the analysis of multiuser communication systems. [12] In our paper, we select the following utility function for the user device which is consistent with the above properties:

$$U_i\left(x_i\right) = c_i \log\left(1 + x_i\right) \qquad i = 1, 2, \ldots, n.$$

Thus, problem (1) turns into:

$$\max \quad \sum_{i=1}^{n} c_i \log\left(1 + x_i\right) \tag{4}$$

$$\text{s.t.} \quad \sum_{i=1}^{n} x_i = W.$$

3.2 Bandwidth Allocation Algorithm

We consider a bandwidth allocation strategy. If there is $x_i < 0$, the base station will reward nothing to corresponding mobile device and reallocate bandwidth resource taking no account of it. Therefore, the value of c_i should not be too deviated from the average contribution, subject to the condition that unique solution $x_i^* \ge 0$. On the other hand, the device deserves more bandwidth reward for making more contribution to system, which is equivalent to more excellent service experience. Through the above analysis, we present our bonus bandwidth allocation strategy in Algorithm 1

Algorithm 1 Bonus Bandwidth Allocation

1: The Base Station collects c_i from D_i, $D_i \in D$;
2: **while** $c_i > 0$ **do**
3: **for** all device $D_i \in D$ **do**
4: Allocate corresponding bonus bandwidth as $x_i = \frac{c_i}{\sum_{k=1}^{n} c_k}(W+n) - 1$
5: **if** $x_i < 0$ **then**
6: $D \Leftarrow D \backslash D_i$
7: $x_i = 0$
8: **end if**
9: **end for**
10: Repeat Step 3 until all $x_i \geq 0$
11: **end while**

Apparently, the bonus bandwidth allocation algorithm can guarantee all $x_i \geq 0$. In fact, the devices whose contributions are far less than average are treated as general users during current round, blundering away the bonus bandwidth.

4 CACHING MESSAGE SELECTIVELY

Inspired by the incentive mechanism, the contributory offloading-devices are willing to cache messages and participate in D2D communication to satisfy the demands of their neighborhood. To get more bandwidth reward from the BS and maximize the cellular traffic offloading, the device would have to cache all the messages and share to others upon its or neighbors' requests. However, the storage capacities are limited, and the CODs need to consider whether a message should be cached. Given multiple alternative messages, a device should make decision on selecting a subset of desired messages to be cached in its local storage.

4.1 Problem Formulation

Since the local storage is limited, it is not feasible to cache all messages. The decision on whether a message should be cached needs to be made in a decentralized fashion, such that cached messages are most likely to be requested by neighboring devices in the future. As we have mentioned above, we formulate message caching problem as a value-based optimization problem in which how to estimate the value of each message makes sense. The value should indicate the demand of the neighborhood and the incurred cellular traffic when the message is transmitted from the BS. Thus, the value of message M_j is $P_{ij}|M_j|$, where P_{ij} is the probability that one of D_i's neighbors requests for M_j. We refresh the value-based optimization problem as follows:

$$\max_{h_{ij} \in \{0,1\}} \quad \sum_i \sum_j h_{ij} P_{ij} \left|M_j\right| \tag{5}$$
$$\text{s.t.} \quad \sum_j h_{ij} \left|M_j\right| \leq C_i, \quad \forall 1 \leq i \leq n.$$

The problem above is NP-hard, even if the value of each message is priori knowledge. However, given the dynamic user demands and various kinds of messages, it's irrational to fix the value of messages for different users. The problem above is thorny even if the value of each message is the prior knowledge. Actually, the value of a message cannot be known beforehand due to the time-dependent and place-dependent nature. To tackle this problem, we need to estimate the value of each message. A device itself firstly estimates the value of a message and then assess the benefit of caching it. Thus, as the foregoing process of D2D communication, we should estimate the potential value of each message to the neighboring devices, and predict the amount of benefit of caching a message. Subsequently, the devices need to make decision on which message deserves to be cached.

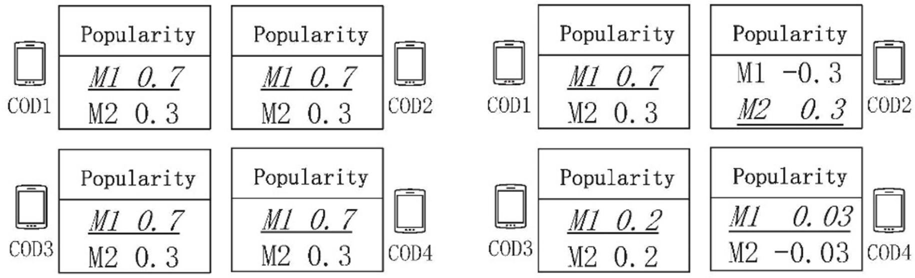
Intuitively, popular contents are requested more frequently than the others. To be consistent with proposed incentive mechanism, the popular contents should have a higher priority to be cached by CCDs that locates closer to devices. Meanwhile, the more valuable message has the higher probability that is requested by local users in the future. As a result, the value of content depends on its popularity and caching contents by its value can increase the hit probability. As a matter of course, it is essential to predicate the popularity of a message over the local neighborhood which is related to the number of requested times according to Zipf's law. [13] Historical statistics can act as a good reference for trends in following requests when we consider the behavior of mobile devices only for a short period of time.

To summarize, by exchanging the interest for messages among neighboring devices periodically, the value of message is calculated in a decentralized manner. It effectively reflects the demand and supply level of messages in the real-time world and has influence on which to cache among multiple messages. It is no exaggeration that the value of message is the key foundation of the caching polices. When the popular message can be cached closer to the required mobile users, the users can directly fetch the content from the storage of CCDs without requiring it from the base station.

4.2 Collaborative Caching

Information exchange can help devices to identify popular messages in time and promote the CODs to cache the most popular messages that are likely to be requested by nearby devices. However, user online activity shows the locality effect where people who are near to each other may have similar preference of accessing the same content [13]. For example, a burst of hot news might be extremely popular and trigger a series of local requests. Most CODs would like to catch the breaking news causing access peak and repeated caching. On the other hand, CODs often ignore the lower-value message due to the profitable nature, which results in incompleteness of information. The following example exposes the drawbacks of an independent caching policy.

Consider Fig. 2, a local content sharing network is populated by four CODs with unit cache storage capacity and the popularities of the messages M_1 and M_2 with unit size are 0.7 and 0.3, respectively. Initially, the caches of the four devices are all empty. In Fig. 2a, the four CODs sort the values of messages and make their own decisions independently. As a result, they all choose to cache M_1, thus the local message availability is missing. Once a device desires M_2, none of the local devices can satisfy this request. The cause for this phenomenon is the mismatch between the demand for a message



(a) Independent caching

(b) Collaborative caching

Figure 2: The motivation for collaboration caching

and the proportion of local storage occupied by this message. Using all caches to store M_1 is extravagant to meet future demands, which demonstrates the low efficiency of independent caching. For M_2, the probability to ask for it is as high as 30%, whereas the storage used to cache it is zero. The gap between demand and supply decreases local message availability and storage effective utilization.

To tackle this problem, we enable devices to gather information about the caches of the neighborhood and select the message with the maximum gap between its popularity and caching proportion. In Fig. 2b, when device COD_1 starts to gather information, the caches of the other three devices are still empty. It finds out the cache proportions of the two messages are zero, which means that the difference between the popularity and the cache proportion is 0.7 for M_1 and 0.3 for M_2. COD_1 selects M_1 to cache, meanwhile, COD_2 begins to gather information: COD_1 has cached M_1, and the caches of COD_3 and COD_4 are empty. Then the cache proportion of M_1 becomes 1. Suppose that within a short time period, the popularities of the messages remain unchanged. The gaps of M_1 and M_2 becomes -0.3 and 0.3. COD_2 decides to cache M_2 accordingly. Later when COD_3 tries to cache a message, it will discover that the cache proportions of the two messages are both 0.5 and it will cache M_1. Similarly, COD_4 finds the gaps of M_1 and M_2 are 0.03 and -0.03, thus it chooses M_1 to cache. After this caching cycle, the overall cache proportions of M_1 and M_2 are 0.75 and 0.25, which matches the distribution of local popularity much better.

Each time a device COD_i makes a caching decision, it will generate a broadcast message to all of its neighbors, querying about the messages currently cached in their storage. Once the caching information is collected, the device is able to calculate the proportion of storage used to cache each message M_j, denoted as S_{ij}. Therefore, the gap between the local popularity and caching proportion, denoted as G_{ij}, can be calculated as $P_{ij} - S_{ij}$. We revise the value of M_j as $G_{ij}|M_j|$, which is positively related to the benefit COD_i will get if it caches M_j locally.

5 SIMULATION RESULTS

In this section, we evaluate the performance of our content sharing network composed by 1000 devices who are uniformly randomly distributed in a 500m×500m area for smart gird. There is no mobility of any user during the simulation period. The local capacities of CODs are fixed to be 100 if no definite specification is made.

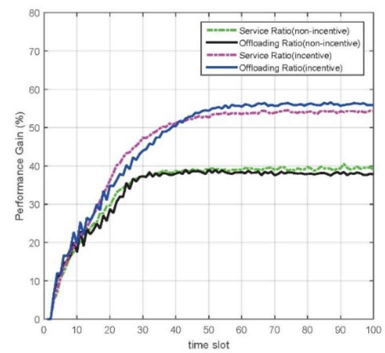
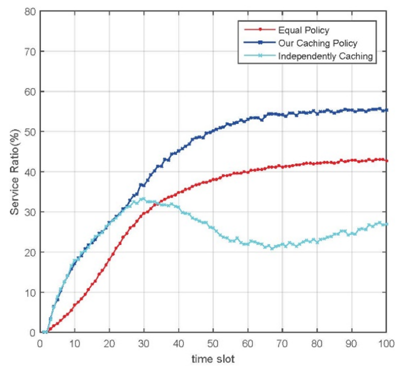


Figure 3: System performance with an average message size of 10, a standard deviation of 1, and a storage capacity of 100

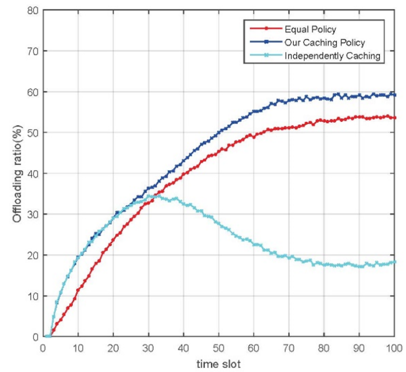
Each device sends a request with probability 0.5 in each time slot independently. It is commonly assumed that the popularity of messages follows Zipf-like distribution and the size follows the normal distribution, respectively. First, we present the overall performance of the CSN by examining the service ratio and the offloading ratio. The service ratio is the percentage of neighbors whose requests are serviced, and the offloading ratio is the percentage of the cellular traffic offloaded through D2D communication within the simulation period.

5.1 Overall Performance

Fig. 3 gives a first glance of the system performance over 100 time slots with or without applying the incentive mechanism. Since the caches of all devices are empty initially, the service ratio and offloading ratio both equal zero at first. All requests are responded to by the base station and it's unfeasible to conduct D2D communication for content sharing. Gradually, devices start to retrieve messages. After 10 time slots the incentive mechanism comes into effect making devices start to cache the valuable messages in order to help others and get bandwidth reward. After about 40 time slots, the system performance of the group with encouragement stabilizes around 60%. In contrast, the other group without encouragement is less than 40%. From the results, the inductive solution succeeds in encouraging devices to be CODs and maximizing offloading



(a) Service ratios under three caching policies



(b) Offloading ratios under three caching policies

Figure 4: System Performance under three caching policies

of cellular network. Furthermore, we can see that the difference between the service radio and the offloading ratio is fairly small, which demonstrates the efficacy of our caching policy.

5.2 Comparison of Different Caching Policies

We conduct a series of experiments to compare the system performance of three different caching algorithms in Fig. 4. As a benchmark, devices in the first group cache with equal probability making no distinction among various messages. In the second group, we enable devices cache messages independently neglecting the gap between the popularity of message and proportion of local storage for this message. The last group applies our caching policy, which integrates the cache information of neighbors into individual caching decision. As we can see from the results, our scheme outperforms the other method obviously. Furthermore, our solution is more effective and stable: compared with the equal policy, our policy relatively improves the service ratio and offloading ration by 15% and 8%; after 30 time slots, the performance of independent caching policy degrades while ours increases significantly, improving the service ratio and offloading ratio by 30% and 40%$, respectively. The result demonstrates the strong capability of our caching policy in alleviating the cellular traffic through D2D communication.

6 CONCLUSION

In this paper, we have studied the content sharing network leveraging D2D communication with the objective of maximizing cellular traffic offloading. Firstly, we put forward a contribution-based analysis on inspire devices to be CODs and establishing D2D links for content sharing. The proposed incentive mechanism contains a bonus bandwidth allocation scheme which can coverage to a Nash equilibrium. Secondly we enable devices collaboratively cache more valuable messages, and convert the caching problem into a 0-1 Knapsack problem. We select dynamic programming with the list to decide whether to cache. The results from both theoretical analyses and simulations demonstrate that our scheme can promote D2D communication and offload cellular traffic effectively.

REFERENCES

[1] Cisco, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016C2021 White Paper,” Technical Report, March. 2017.
[2] H. J. Kang, K. Y. Park, K. Cho, and C. G. Kang ,“ Mobile caching policies for device-to-device content delivery networking,” in IEEE IN-FOCOM Workshop on Dynamic Social Networks, Toronto, ON, Canada, pp.299-304, April 2014.
[3] G. Fodor, E. Dahlman, G. Mildh, S. Parkvall, N. Reider, G. Mikls, and Z. Turnyi, “Design aspects of network assisted device-to-device commu-nications,” IEEE Commun. Mag., vol.50, no.3, pp.170-177, March 2012.
[4] C. H. Yu, K. Doppler, C. B. Ribeiro, and O. Tirkkonen, “Resource sharing optimization for device-to-device communication underlaying cellular networks,” IEEE Trans. on Wireless Commun., vol.10, no.8, pp.2752-2763, June 2011.
[5] J. Liu, J. Dai, N. Kato, and N. Ansari, “Optimizing uplink resource allocation for D2D overlaying cellular networks with power control,” in 2016 IEEE Global Communications Conference , pp.1-6, Dec. 2016.
[6] Q. Li, and D. Xu, “Power allocation for eErgodic capacity and outage probability tradeoff in cognitive radio networks,”IEICE Trans. Commun., vol.E198-B, no.10, pp.1988-1995, Oct. 2015.
[7] X. Wu, S. Tavildar, S. Shakkottai, T. Richardson, J. Li, R. Laroia, and A. Jovicic, “FlashLinQ: a synchronous distributed scheduler for peer-to-peer ad hoc networks,” IEEE Trans. on Networking, vol.21, no.4, pp.1215-1228, June 2013.
[8] J. T. Choi, M. Jain, K. Srinivasan, P. Levis, and S. Katti, “Achieving single channel, full duplex wireless communication,” in Proc. ACM MobiCom, Chicago, USA, pp.1-12, Sept. 2010.
[9] B. S. C. Choi, and M. Gerla, “Wireless interrupt: inter-device signaling in next generation wireless networks,” in 2010 IEEE Conf. on Computer Communications Workshops, San Diego, USA, pp.1-5, March 2010.
[10] J. Jiang, S. Zhang, B. Li, and B. Li, “Maximized cellular traffic Offload-ing via device-to-device content sharing,” IEEE Journal on Selected Areas in Commu., vol.34, no.1, pp.82-91, July 2016.
[11] D. Niu, and B. Li, “An asynchronous fixed-point algorithm for resource sharing with coubled objectives,” IEEE Trans. on Networking, vol.24, no.5, pp.2593-2606, Oct. 2016.
[12] G. Scutari, D. P. Polomar, F. Facchinei, and J-s. Pang”onvex opti-mization, game theory, and variational inequality theory,” IEEE Signal Processing Mag., vol.27, no.3, pp.35-49, April 2010.
[13] M. Ji, G. Caire, A. F. Molish, “Optimal throughput-outage trade-off in wireless one-hop caching networks,” in 2013 IEEE International Symposium on Inf. Theory, Istanbul, Turkey, pp.1461-1465, July 2013.