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High Throughput Opportunistic Cooperative Device-to-Device Communications

Masku Naveen Kumar & Golla Saidulu
[1]Assistant Professor, Dept of CSE, SCIENT Institute of Technology
[2]Assistant Professor, Dept of CSE, CMR College of Engineering And Technology

Abstract:*In this paper, we endorse an opportunistic cooperation approach for D2D transmission with the aid of exploiting the cachingcapability on the users to govern the interference amongst D2Dhyperlinks. We recall overlay inband D2D, divide the D2D usersinto clusters, and assign specific frequency bands to cooperativeand non-cooperative D2D hyperlinks. To provide the excessive possibilityfor cooperative transmission, we introduce a caching policy. Tomaximize the network throughput, we collectively optimize the clusterlength and bandwidth allocation, in which the closed-shape expressionof the bandwidth allocation element is received.*

Keywords-Caching, D2D, Cooperative transmission, Interference, High Throughput

I. INTRODUCTION

During the past decade, the volume of mobile data traffic has increased at a rapidpace and quantitative studies predict that the exponential growth will continue inthe future as illustrated in Figure 1.1. The growth is mainly due to emerging popular multimedia applications that are supported by new types of devices such assmartphones and tablets. Moreover, multiple devices may be used bythe same user to connect to the Internet through the existing cellular infrastructure, which contributes to increased data traffic. Consequently, the totalmobile data traffic generated is predicted to have a 1000-fold increase by the year 2020. This is extremely demanding in terms of network resources and linkcapacity.

Besides the issue of large data volume in the upcoming decade, user experienceis also an important challenge. Current networks may offer good quality-of-service(QoS) in isolated areas, but they cannot meet the extreme capacity demands onfuture wireless systems in areas where they have to handle situations where usersare located in close proximity to one another, such as shopping malls, festivals, stadiums, and even office buildings. Users want to be connected anytime,anywhere. Increasing capacity and connectivity will translate into higher energyconsumption and costs, which in turn are not economical or sustainable from operational perspective.During the years, mobile broadband technologies have evolved. Long-term evolution (LTE) and LTE-Advanced systems, which have embodied the fourth generation(4G) networks, have reached a certain level of maturity. Now, we are on the vergeof a transition into a state of fully connected society where high capacity is needed,but incremental changes in the current systems and technologies are not enough tomake this transitionfundamental changes are needed to handle futurenon-homogeneous networks as well as new trends in user behavior and applicationssuch as high quality video streaming and augmented reality.

Therefore, discussions of a new standard have taken place in academia andindustry in order to envision the needs and requirements of, and possible use cases 5G is not yet clear, but it needs to take into account a wider rang of use cases andcharacteristics. Therefore, stringent key performance indicators (KPIs) and tightrequirements have been proposed in order to handle higher mobile data volumes,reduce latency, and increase the number of connected devices, while at the sametime increasing energy efficiency (EE) and reducing costs.5G networks are supposed to support the existing and evolving technologiesand simultaneously integrate new solutions which have been proposed to meet the new requirements. In order to increase network capacity, oneoption is to improve the efficiency of available radio resources; another option isto increase resources such as the amount of available spectrum, the number ofantennas and the number of base stations (BSs). However, adding radio resourcesis not necessarily cost and energy

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efficient, and it may sometimes take a long timefor them to be put into practice. There are many new concepts, design criteria,and scenarios that have been proposed for 5G; some of them, if implemented, willbring fundamental changes at the architectural and node level. One example of suchproposed technologies is device-to-device (D2D) communications which will changethe nature of conventional network design.In early generations of mobile systems, the network-centric design was introduced, based on the notion of cell, uplink, and downlink communications. At thattime, the application of mobile networks was mainly for voice communication andthere was an implicit assumption that users are not in close proximity to one another. However, this assumption is not tenable anymore as the main current trendsare content (file) sharing and interest sharing (e.g., online-gaming and social networks, where users in close proximity happen to interact more). Hence, it is important to consider proximity awareness as a design parameter. To this end,one of the broad visions of 5G is its emphasis on device-centric solutions and theneed for smarter devices. D2D communication appears to be an enabling technology for this vision, which allows users in close proximity to communicate directlywith each other, bypassing the base station (BS).

II. RELATED WORK

To take the advantage of the storage capacity at smart phones, cache-enabled D2D communications have been proposed recently, which can offload the content delivery trafficand hence boost the network throughput significantly [18, 19].Since only the users in proximity communicate to each other,the distance between a user and the undesired transmitters canbe close and hence the interference in D2D networks is strong,which needs to be carefully controlled. In an early work ofstudying cache-enabled D2D communications, the D2D usersare divided into clusters. Then, the intra-cluster interferenceamong D2D links is managed by using time division multipleaccess (TDMA), while the inter-cluster interference betweenD2D links is simply treated as noise [18]. In [19], only theD2D link from one of the four adjacent clusters is allowedto be active at the same time-frequency resource block, inorder to avoid strong inter-cluster interference among adjacentclusters. In [20], interference alignment was employed tomitigate the interference among D2D links, but only threeD2D links were coordinated within each cluster, and the interference among clusters was again treated as noise. In [21–23],cooperative relay techniques were proposed to mitigate theinterference between cellular and D2D links, which howevercan not manage the interference among the D2D links.

III. PROPOSED WORK

Consider a cellular network, where M single-antenna usersare uniformly located in a square hotspot within a macro cell,where the area is with the side length of Dc as shown in Fig. 1.Each user is willing to store N files in its local cache and canact as a helper to share files. When a helper conveys a filein local cache via the D2D link to a DR requesting the file, thehelper becomes a DT. The BS is aware of the cached files at each user and coordinates the D2D communications We consider a static content catalog including Nf filesthat the users may request. To simplify the analysis, eachthe file is assumed with the same size as in [15–19]. Althoughin practice the files are with unequal sizes, each file can bedivided into chunks of equal size [16], so the same analysis canstill be applied. The Nf files are indexed in a descending orderof popularity, e.g., the 1st file is the most popular file.

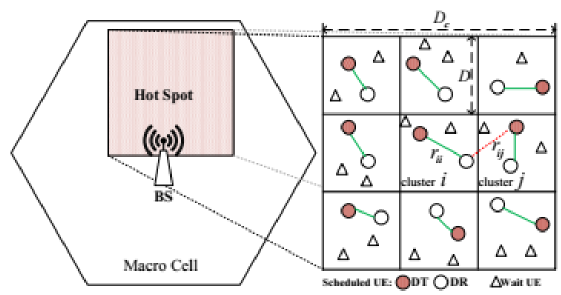

Fig. 1. Cluster division model, "UE" means user equipment.

B. Communication Protocol

D2D links can be established among users in proximity owing to the limited transmit power at each user equipment (UE)and the possible strong interference among UEs. A widelyused communication protocol for D2D communications is thattwo UEs can communicate if their distance is smaller than agiven distance [18, 29]. To control the strong interference andmake the analysis tractable, the square hotspot area is dividedinto B smaller square areas called clusters as in [19], where theside length of each cluster is D = Dc=pB. For mathematicalsimplicity, we assume that the number of users per cluster isK = M=B and each user is assumed to transmit with thesame power P as in [19].For the non-cooperative users, only those within the samethe cluster can establish D2D links in order to control interference.For the cooperative users, the users in different clusters areallowed to establish D2D links to avoid interference andexploit multiplexing gain by joint transmission.

Opportunistic cooperation strategy:

In this segment, we first introduce a caching policy to provide high opportunity for cache-enabled cooperative D2Dtransmission. Then, we propose an opportunistic cooperativetransmission policy. Finally, we optimize two key parametersin the strategy to maximize the network throughput.

A. Caching Policy

To maximize the probability that a user can fetch filesthrough D2D links, the users within a cluster should cachedifferent files. To maximize the probability of cooperativetransmission among DTs in different clusters, the files cachedat the users of each cluster should be the same. This suggeststhat the caching policy needs to balance the diversity of contentwith the redundancy of the replicas of popular contents.

B. Opportunistic Cooperative Transmission Policy

According to whether a user can find the requested file inthe hotspot area, we can classify the users into two types.

D2D users: If the file requested by a user is cached atany UE in the cluster it belongs to (and hence also cachedin UEs in other clusters according to the above-mentionedcaching policy), then the user can directly obtain the filewith D2D communication, either without or with cooperation.Such a user is referred to as a D2D user. Besides, if the filerequested by a user is in its local cache, it can retrieve thefile immediately with zero delay, but we ignore this case foranalysis simplicity as in [19].

Cellular users: If the file requested by a user is not cachedin the UEs within the hotspot area, the user fetches the filefrom the BS and becomes a regular cellular user. The numberof cellular users is denoted as N^b.

For easy understanding, we introduce the strategy with thehelp of an example.

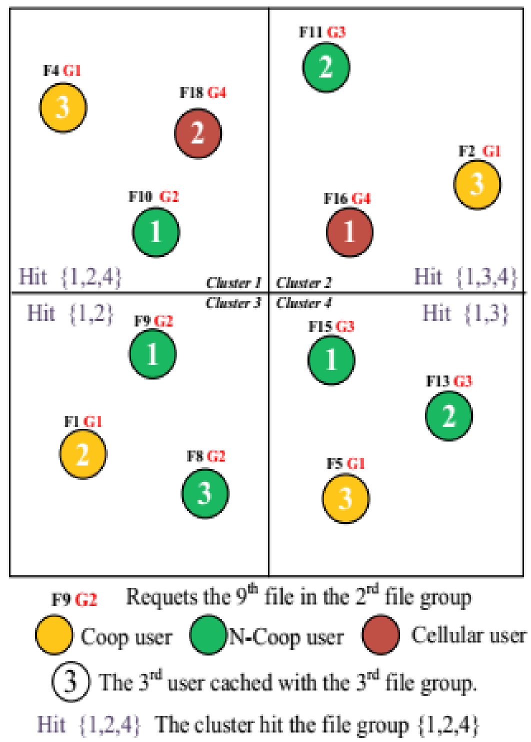

Fig. 2. Illustration of the opportunistic cooperaton strategy. Catalog sizeNf = 20, B = 4 clusters in the hotspot, K = 3 users in each cluster andeach user caches N = 5 files.

1) Cooperative D2D Users: If there exists at least one userin a cluster requesting the files in G_k, then we say that thecluster hits the kth file group. In Fig. 2, the users in the firstcluster respectively request the files in G_1, G_2 and G_4, andhence the first cluster hits the {1; 2; 4}th file groups.

If every cluster hits the same file group G_k, the k^{th} user ineach cluster who caches the file group Gk can act as a DT,and all DTs in these clusters cooperatively transmit files tothe DRs requesting the files in G_k. Those DRs are referredto as cooperative D2D users (Coop users for short), whosenumber is denoted as N^c.

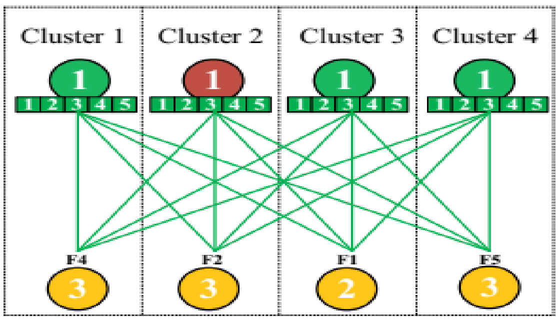

Fig. 3. Illustration for cooperative transmission from multiple DTs to DRs.

In Fig. 2, every cluster hits the 1st file group. Hence, the 1st users in all the four clusters who cache the files in G1 can actas DTs to cooperatively transmit files with indices {4; 2; 1; 5} respectively to the 3rd user in cluster 1, the 3rd user in cluster2, the 2nd user in cluster 3, and the 3rd user in cluster 4, asshown in Fig. 3

C. Optimization of Cluster Size and Bandwidth AllocationIn this subsection, we jointly optimize the bandwidth allocation factor η and cluster size K to maximize the averagenetwork throughput under a constraint that the average userdata rate is larger than a given value, μ (Mbps). Because weassume overlay D2D communications, only D2D users areconsidered in the network throughput.

IV. CONCLUSION

In this paper, we proposed an opportunistic cooperationstrategy for cache-enabled D2D communications. We at the same timeoptimized the cluster size and the bandwidth allotted to Coopand N-Coop customers to maximise the community throughput withminimum consumer information price constraint.

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BIODATA

Masku Naveen Kumar working as Assistant Professor, Dept of CSE, in SCIENT Institute of Technology with Experience of 2 years.

Golla Saidulu working as Assistant Professor, Dept of CSE, in CMR College of Engineering And Technology with Experience of 3.6 years.