A Cluster Head Assisted UE Switching Solution for Device-to-Device Communications

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Abstract. Device-to-Device (D2D) cluster communication underlaying cellular networks has been proposed as a means of increasing the resource utilization, and improving the spectral efficiency. However, when D2D links cannot satisfy the connection requirements, in order to keep the connection, D2D communication has to switch back to cellular communication. Consider that the previous switching methods mainly concentrated on the network centralized controlled D2D communications, so we propose a novel switching solution aided by a cluster head for (semi-) distributed controlled D2D communications. We propose the switched D2D user itself search and access the target base station. The cluster head determines transmission mode based on the channel state information after switching. The numerical simulation demonstrates the hybrid mode outperforms the D2D mode in some conditions.

Keywords: Device-to-Device/D2D, cluster head, switching, hybrid mode, semi-distributed controlled.

1 Introduction

With the development of broadband networks, wireless data traffic is expected to continue strong growth in the near future. Mobile devices are dramatic increasing in the access to the limited frequency bands in the recent years while the limited available bands are more and more strained. It requires more efficient new solutions for use of existing spectrum resources. Device-to-Device (D2D) [1-7] communication technology is expected to become a promising resolution, which has been introduced to the conventional cellular communications. As an underlay of an LTE Advanced network, D2D enables new service opportunities, reduces the overhead for short range time intensive services and increase power and spectrum efficiency, which is becoming a beneficial complement of the IMT-Advanced system.

D2D communication [3], as the name implies, denotes a group of devices (e.g., UEs (User Equipments)) that are close and communicate with each other. As an

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underlay cellular networks, D2D has two distinct links: D2D links and cellular links. D2D users exchange information with each other via D2D links directly, rather than via cellular wireless networks relaying within a D2D cluster (including D2D pair). When a D2D UE connects to the base station (evolved NodeB, eNB), it uses cellular links. D2D communication has two operating types. One is a network (e.g., eNB) centralized controlled D2D communications [1-2], i.e. eNB controls and manages D2D cluster communications, every D2D UE interacts control signalling with eNB respectively. Another is a cluster head (CH) semi-distributed controlled D2D cluster communications, i.e. the CH is responsible for managing and maintaining intra-cluster control signalling and data transmission, besides, it also interacts necessary control signaling such as synchronization, access, resource allocation and (re-)allocation with eNB via cellular links. eNB only has context information of the CH while it possibly has no information of other cluster members. These cluster UEs connect with the CH via D2D links and they are possibly without connection to the eNB. CH managed the cluster UEs.

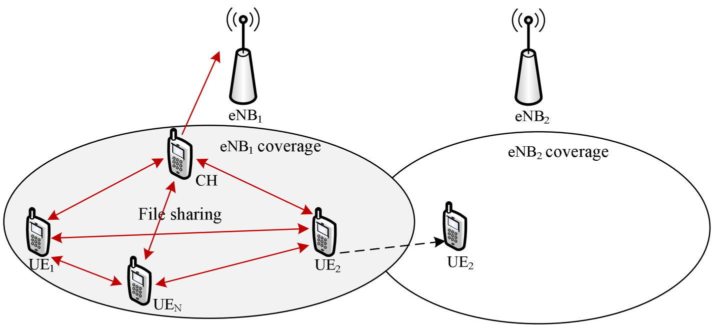

Fig. 1. D2D cluster communication and UE movement scenario

D2D cluster dynamically changes as user mobility within varying and unstable channel conditions, which might lead to the D2D link quality sharply deteriorate, even it could not meet connection requirements. As a result, D2D cluster might need to update, re-establishment. Under such condition, if D2D UEs were communicating with each other directly, in order to guarantee service continuity, D2D UEs might try to switch to the cellular networks to continue the communication. Since the introduction of D2D communication mode, there exist two communication modes for UEs: D2D mode and cellular mode. Therefore, the selection of communication mode should not only consider the link quality between UEs but also the link quality between eNB and UEs. To obtain the more efficient communications at any time, switching between D2D and cellular is inevitable.

For eNB centralized controlled D2D communications, eNB receive measurement reports from UEs periodically, eNB handles D2D link and cellular link conditions. Once D2D link quality is less than some limit value, the eNB determines D2D UEs switch back to cellular communications, vice verse. But for a CH semi-distributed controlled D2D communication, if eNB is lack of UE context, switching aided by eNB is not applicable. In this paper, we propose a D2D cluster UE switching to cellular wireless communications solution for CH semi-distributed controlled D2D cluster communications, and it can reduce routing latency and save radio resources.

This paper is organized as follows. Section 2 reviews related works and problem description. Section 3 presents the switching solution and implementation. The Section 4 presents numerical simulation and results.

2 Related Works and Solved Problem

In the existing literature, most research focuses on eNB centralized controlled D2D communications. [1-2] presented the concept of D2D communication as an underlay to a cellular network. In this system, eNB controls and manages D2D cluster (pair) UEs. If D2D links cannot provide good service quality, eNB is responsible for UEs switching to cellular communication mode from D2D mode. But in a CH semi-distributed controlled D2D cluster communication, for a certain amount of the cluster members, since those common cluster UEs have no dedicated channels to connect with eNB, taking Fig. 1 as an example, intra-eNB (CH and UE_2 is in the same eNB coverage) switching between D2D mode and cellular mode is hard to implement. It becomes much harder to implement inter-eNB switching when UE_2 moves to the other eNB. Even if communication mode switching can be processed, it would cost significant signalling overhead and time delay, and further degrade systems capacity and throughput.

Conventional cellular networks support UEs mobility and roaming. When users move from one cell to another one, in order to achieve call continuation during boundary crossings, handover is a key step. [8] discussed the handover initiation techniques and the handoff decision protocols, which decrease forced termination probability while not increasing call blocking probability significantly, when users transferring an active call from one cell to another. In cellular networks, the source eNB determines the target eNB for a UE who intends to make handover in cellular wireless networks [9]. Due to the limited range, D2D radio should be designed for rather stationary links. Nevertheless, it should also offer limited mobility support. In a cellular centralized controlled D2D communications, a handover from a D2D connection to a cellular connection is initiated when the cellular connection achieves higher throughput than the D2D or if one of the policies for D2D connections is violated. Obviously, eNB-based handover decision can be also applicable to a network centralized controlled D2D communications. In eNB centralized controlled D2D pair communications, once D2D link quality no longer satisfies communication requirements, eNB can make decision require D2D UEs in D2D mode switch to cellular mode. Assuming a pair of D2D UEs are located in the same eNB coverage area, and control signalling can be interacted between every D2D UE and eNB. The straightforward phases are as follows: Once D2D link quality is below some pre-ordered threshold value, D2D UEs can send request to eNB for switching to cellular mode respectively; After receiving the switching request, eNB allocates radio resources for cellular communication to UEs; if the cellular link quality is above some pre-ordered radio link threshold value in cellular mode, both UEs can switch back to cellular mode. This solution will be applicable for a group of UEs formed a D2D cluster communication as well, but it would be no doubt cost significantly radio resource and signalling. Worse still, the solution is hard to implement a cluster UE switches seamlessly to cellular mode. For the CH semi-distributed controlled D2D communications, due to lack of a centralized controller node, we have to search a new switching solution to mitigate data loss.

Within a D2D cluster as illustrated in Fig. 1, a group of UEs directly exchange information (e.g., file sharing) with each other via D2D links, without eNB relaying. All D2D UEs are in the coverage of eNB_1. The data source is elected as the CH of the cluster, which is responsible for managing and maintaining the operation within the cluster and keeping connection with eNB_1. Actually, any of UEs within the cluster can serve as a CH. Here just for convenient expression. In this case, if a D2D user UE_2 leaves from the cluster and UE_2 wishes to keep the existing service, even in an extreme case, UE_2 maybe leave from eNB_1 to eNB_2, how to keep communication connection? A straight-forward solution is the UE switches to cellular communication. It is also useful for a CH semi-distributed controlled D2D cluster communications. However, due to eNB is lack of UE context, D2D UE(s) switching to cellular communication mode has a bigger challenge to reduce resources consumption and time delay as much as possible and still provide existing service QoS to the communicating UEs. In this paper, our contribution has two points: on the one hand, if a D2D UE has to switch back to conventional cellular mode for communication, the D2D UE selects the identifier (ID) of the target eNB by itself for switching to the conventional cellular mode from D2D mode; on the other hand, the CH will use a new hybrid mode to transmit the data in case the leaving UE and current D2D users want to receive the same data information. The hybrid mode includes two cases based on the MCS (Modulation Coding Scheme) information: one is CH broadcasts data packets to D2D cluster and the target eNB (or CH itself eNB, then forward to the target eNB); the other is CH multicasts packets within the cluster in a dedicated resource while CH unicasts to the target eNB (or CH itself eNB, then forward to the target eNB) in another dedicated resource.

3 Protocol Implementation

We assume that D2D communication utilizes the eNB uplink resource orthogonally. As illustrated in Fig. 2, at the beginning, a data source CH multicasts files to a D2D cluster, CH can listen all of the cluster members. Afterwards, UE_2 gradually moves far away from CH. Once the D2D link quality between UE_2 and CH cannot satisfy the connection conditions, in this case, UE_2 still want to receive the present file, UE_2 will have to switch to the conventional cellular communication mode. The switching procedure includes the switching preparation phase, the switching execution phase, the data transfer phase.

In the switching preparation phase, UE_2 first initiates a cell search and a random access procedure. If eNB ID of the D2D UE_2 who intends to access is the same as eNB ID of the D2D CH as illustrated in Fig. 2(a), then UE_2 will access to eNB_1 and establish RRC connection with eNB_1. Otherwise, if UE_2 transfers to eNB_2 (Fig. 2(b)), in this case, the D2D UE_2 will intend to access to eNB_2 and establish RRC connection with eNB_2, which is different from eNB (eNB_1) of the D2D CH.

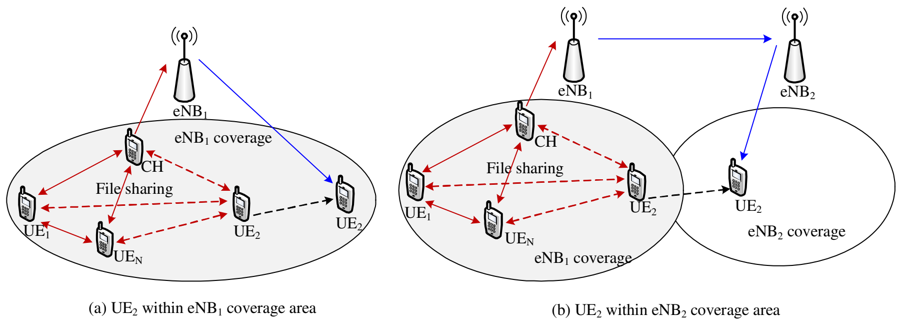

Fig. 2. Implementation process

In the switching execution phase, UE_2 sends a switching request to the CH via D2D link for keeping the existing service. The request includes the UE_2 accessed eNB ID. Note that it's different from handover procedure of the conventional cellular wireless network. In the cellular network, the source eNB finds and determines the target eNB for its UE, and the source eNB assists the UE to access the target eNB. Here the UE itself searches and accesses to the target eNB and informs the target eNB ID to the CH. Then the CH (not the source eNB) sends the switching request of UE_2 together with UE_2 accessed eNB ID to eNB_1 (the eNB ID of the CH) via the cellular links. Once eNB_1 receives the request message from CH, eNB_1 will know to which eNB UE_2 has accessed. If UE_2 accessed eNB ID is the same as eNB_1, the procedure will turn to the data transfer phase. Otherwise, if UE_2 accessed eNB ID is the eNB_2, the two cellular eNBs will have to exchange the switching request and confirmed message for UE_2. After CH receives the switching command via the cellular links, CH sends a switching confirmation message to UE_2 via D2D links, as a result, UE_2 receives the rest of packets via cellular links. UE_2 disconnects D2D links.

In the data transfer phase, CH adopts a hybrid communication mode. In hybrid mode of communication, D2D mode and cellular mode communicate simultaneously. That is, CH transmits packets to UE_2 via cellular links, while CH transmits packets to the rest of the D2D members via D2D links. In detailed implementations, CH compares the MCS between CH and eNB_1 with MCS between D2D links to determine the resource assignment. It has two cases.

(1) $MCS_{CH\text{-}eNB1}$ is (approximately) equal to MCS_{D2D}: In this case, CH uses a dedicated resource to broadcast the data packets to both the D2D cluster (the rest of D2D member UEs) and eNB_1, which saves the radio resources. It notes that if CH and UE_2 is not in the same eNB, eNB_1 would have to forward the packets to the target eNB (e.g., it is eNB_2 in Fig. 2(b)), until the data packets are sent to UE_2 via cellular links at last.

(2) Great difference to compare $MCS_{CH\text{-}eNB1}$ with MCS_{D2D}: In this case, CH selects a parallel communication operation using two dedicated resources, i.e., multicasting data packets via D2D links and unicasting via cellular links. The two communication modes are independently exist at the CH. On the one hand, CH determines the MCS based on the the D2D link quality between CH and the rest of D2D users and multicasts data packets within a cluster; on the other hand; on the other hand, CH determines the MCS based on the the cellular link quality between CH and its eNB itself (eNB_1) and unicasts data packets. Since D2D link transmission efficiency is much better than cellular links typically. Under this assumption, applying this parallel communication operation could enable D2D UEs to meet the original service requirements; besides, it can guarantee reliable cellular communications by unicasting via cellular links. Note that if CH and the leaving user (UE_2) is not in the same eNB, eNB_1 has to forward data packets to the target eNB, until UE_2 receives the packets via cellular links.

Fig. 3 illustrates a state transition model for D2D UEs between a CH semi-distributed controlled D2D communication mode and conventional eNB centralized controlled cellular communication mode. At the beginning, all UEs stay in D2D mode (The CH still connects with eNB). When D2D links of a cluster member UE within a cluster can't satisfy direct communication requirement as the position of the D2D UE and communication environment changes, in order to accomplish some communication service, the D2D UE will have to switch to cellular mode from D2D mode. In this case, the UE keeps the previous D2D link to maintain D2D communication, while the UE establishes a cellular link. If the UE can satisfy the cellular communication requirement, the UE will leave the D2D connection state and enter cellular connection state. At this time, the CH communicates with the UE via cellular links, while CH communicates with the rest of cluster members via D2D links. That is, for the original cluster, it enters hybrid state.

On the contrary, if at the beginning, UEs are in cellular communication mode. When a cellular UE multicasts data through eNB relaying, if the data source UE and one of receiver UEs satisfy the requirement for D2D communication and UEs have D2D communication capability, eNB shall instruct the UEs to switch from cellular mode to D2D mode. In this case, eNB designates the source UE to serve as a cluster head which still keeps connection with eNB, meanwhile, the source UE and the receiver UE try to establish D2D links. When a D2D link is already established between the two UEs successfully, both UEs respectively enter D2D communication state. However, if the D2D link quality between the source UE and the rest of receiver UEs cannot satisfy the requirement, they would continue to communicate through cellular links, that is, the network enters hybrid communication mode. But when all the rest of receiver UEs can enter D2D communication state, this network enters D2D mode.

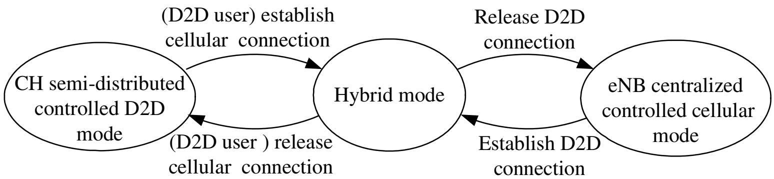

Fig. 3. Cluster member state transition and mode switching

4 Numerical Simulation and Results

In this section, we analyze the cost of time-frequency resource in D2D mode and hybrid mode respectively. As shown in Fig. 1, for simplified calculation, only one user UE_2 moves far away from D2D, other users are static. In D2D mode, we assume the communication radius of the D2D is large enough, even if the user moves far away from D2D, the communication is still via D2D links. In hybrid mode, we assume the moving user UE_2 is still in the coverage of eNB_1, besides, only UE_2 communicates with CH via cellular links, other D2D members communicate with CH via D2D links. D2D and cellular communication use orthogonal resource, assuming frequency resource is the same in D2D multicast and cellular uplink/downlink unicast. The channel model considers only path loss. We do not consider shadowing or fast fading. In this case, we compare D2D mode and hybrid mode in the single-cell. Shannon's capacity formula is used to calculate the sum cost of time-frequency resources of unit-bit. In D2D mode,

$$Sum_{D2D} = \frac{1}{B_{D2D} \cdot R_{D2D}} = \frac{1}{B \log_2 (1 + SNR_{D2D})} \tag{1}$$

Wherein, B_{D2D} denotes the transmission bandwidth of D2D mode, e.g, one physical resource block (PRB). For convenience, we assume that the bandwidth of both D2D mode and cellular mode are B. R_{D2D} is the D2D multicast transmission rate on each PRB (including the leaving UE_2), and SNR_{D2D} is the signal to noise radio of the D2D links.

In the hybrid mode, in order to make the updated D2D keep transmitting data, the networks still allocate the same frequency resource (B). In this case, the sum cost of time-frequency resources of unit-bit is

$$\begin{aligned} Sum_{hybrid} &= \frac{1}{B_{rD2D} \cdot R_{rD2D}} + \frac{1}{B_{UL} \cdot R_{UL}} + \frac{1}{B_{DL} \cdot R_{DL}} \\ &= \frac{1}{B \log_2 (1 + SNR_{rD2D})} + \frac{1}{B \log_2 (1 + SNR_{UL})} + \frac{1}{B \log_2 (1 + SNR_{DL})} \end{aligned} \tag{2}$$

Wherein, R_{rD2D} is the transmission rate of the rest D2D members (excluding UE_2), which forms a updated D2D, compared to the original D2D. RUL and R_{DL} are the cellular uplink/downlink transmission rate on each PRB respectively. SNR_{rD2D} denotes the SNR among the rest D2D links, and SNR_{UL} and SNR_{DL} are cellular uplink and downlink SNR.If we do not consider interference, assuming the channel model considers only path loss, when the transmission power and thermal noise is fixed, larger distance, lower SNR, and larger resource cost.

From (1) and (2), we perform the numerical simulations. Table I summarizes a list of simulation parameters and their default values. The simulation tool is developed in MatlabTM. In the first scenario, we keep fixed the distance between CH and eNB (e.g., 23m, 73m and 140m) and the positions of the cluster users excluding the moving UE_2. As shown in Fig. 4, when UE_2 moves far away from the CH, the distance attenuation increases, the sum resource cost of the time-frequency of D2D mode increases as well. For hybrid mode, if the distance between CH and eNB was fixed, UE_2 mobility has a tiny influence for the cost of the cellular uplink/downlink and the rest of D2D members, the resource cost increases slowly. Obviously, at the beginning, the performance of the D2D mode is better, however, as the distance between CH and UE_2 increases, the performance of the hybrid mode will outperform the D2D mode. So the crossing point can be as 'switching point', it represents the best switching location found in each case, considering D2D modes and hybrid modes. We can conclude that if the hybrid mode is chosen in some occasions, it will be a gain in the system capacity.

Table 1. Simulation parameters and values

Parameters	Values
Carrier frequency	2 GHz
Max eNB Tx power	46 dBm
UE Tx Power	10 dBm
Tx bandwidth	1 PRB
Distance attenuation	128.1+37.6lg(*d*), with *d* in km
UE noise figure	9 dB
UE thermal noise density	-174 dBm/Hz

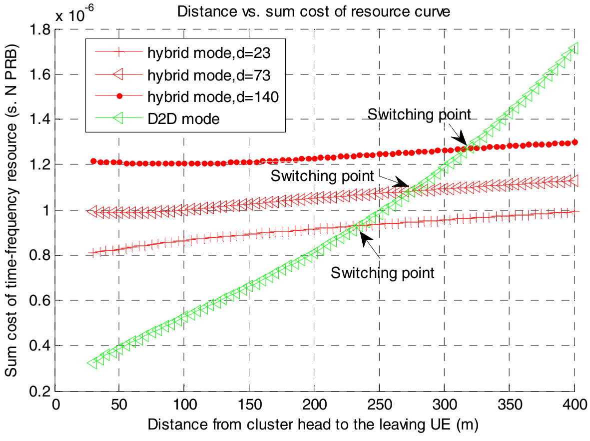

Fig. 4. Sum cost of time-frequency resource in the first scenario

In the second scenario, we keep fixed the communication radius of D2D and eNB varies its position. Fig. 5 illustrates the resource cost of the hybrid mode increases with the distance and the cost of D2D mode in some special D2D coverage distances. Due to in hybrid mode, some packets are transmitted via eNB relaying, so when the distance between CH and eNB increases, the gain of the hybrid mode degrades. But as expected, the hybrid mode has better performance than D2D mode when we consider the short distance between CH and eNB. Actually, when the D2D coverage is 250m, and the cellular communication distance is below 60m, the resource cost of the hybrid mode is lower than those required in the D2D mode. Once the distance between CH and eNB is beyond 60m, the sum resource cost of the hybrid mode will be larger. In this case, the crossing point can become a switching threshold value. If the coverage distance of D2D mode and cellular mode increase, the switching threshold value will increase as well.

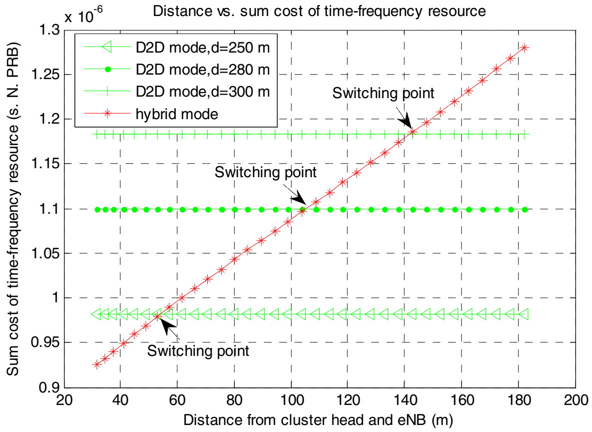

Fig. 5. Sum cost of time-frequency resource in the second scenario

In short, the simulations illustrate that the D2D communication and cellular communication should not be applied all the time, but only in some favorable conditions. Therefore, switching between D2D communication and cellular communication is inevitable. It notes that D2D is a short-range communication technology. Only when UE is close to each other, D2D communication may allow for extreme high bit rates, low delays and low power consumption. So when a part of D2D users have to switch to cellular communication from D2D communication, the proposed hybrid communication mode adopts the hybrid communication mode, that is, the integration of D2D communication and cellular communication to improve the system efficiency significantly.

5 Conclusion

In this paper, we investigated a switching solution between cellular communications and D2D communications. It can speed up routing lookup process and reduce time delay, especially for inter-eNB switching to cellular links from D2D links, compared with cellular handover. As in the cellular handover, in order to lookup the target eNB, the source eNB has to resort to Mobility Management Entity (MME), and its latency is much longer. While in the proposal, the D2D CH reports the target eNB ID to the source eNB, then the source eNB knows who is the target eNB in advance. This process is without need to relocation procedure signalling and MME routing lookup, and it reduces latency.

The proposal also improves spectrum efficiency. From the simulations, the hybrid communication mode can save radio resources and improve spectrum efficiency while without degrading D2D transmission rate.

In this paper, either centralized or semi-distributed D2D communication utilizes licensed spectrum resources. Consider the unlicensed bands are used inefficiently and D2D communications technology can increase power and spectrum efficiency, in the near future, we would study D2D utilization on unlicensed bands.

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