A Speed-Aware Joint Handover Approach for Clusters of D2D Devices

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***Abstract*—Device-to-device (D2D) communications provide a promising technique for the fifth-generation (5G) wireless networks. It has been considered to support intelligent vehicular communications, such as in LTE-Vehicle (LTE-V). Particularly, it is very challenging to manage simultaneous handover of a massive number of fast-moving devices on the cell edge. In this paper, we propose a joint handover approach that effectively exploits D2D multicast and D2D clusters to address the severe resource contention caused by the high density and high mobility of mobile devices. The handover decision takes into account the received signal strength (RSS) from each candidate base station (BS) and the moving speed toward each BS. The simulation results show that the proposed solution can significantly reduce the communication interruption probability and handover latency of mobile devices in high-density and high-speed scenarios.**

***Index Terms*—Device-to-device (D2D) communication, joint handover, D2D clusters, speed-awareness.**

I. Introduction

The fifth-generation (5G) wireless networks have proposed to integrate various smart devices into the cellular networks, which will substantially increase the number of connected terminals. In addition to regular user equipment (UE), more and more vehicles are equipped with built-in communications modules and sensors. It is envisioned that the number of access devices in the 5G systems will be 1000 times of that of the Long-Term Evolution (LTE) systems. In this context, mobility management, especially handover management, will become a substantial challenge that cannot be ignored. When a large number of devices on the cell edge simultaneously hand over during peak hours, the congestion over traffic and signalling channels will significantly increase the interruption probability and handover latency and result in severe degradation of quality of service (QoS).

The Third Generation Partnership Project (3GPP) and some communication enterprises have proposed LTE-Vehicle (LTE-V) to support intelligent vehicular communications. Device-to-device (D2D) communications are considered as an important feature of LTE-V [1,2]. D2D communications offer various benefits, such as high data rates, energy saving, coverage expanding, and traffic offloading [3]–[5]. However, when D2D communications are incorporated into the 5G networks, handover management becomes a challenging issue, especially in the high-mobility scenarios with vehicles.

Traditional handover decision algorithms can be divided into three categories [6], including judgement strategies based on utility functions, judgement strategies based on fuzzy logic and neural network, and multi-attribute decision strategies. Nevertheless, there is little research on handover management when D2D communications are taken into account. In [7], a D2D-aware handover scheme and a D2D-triggered handover scheme are proposed to reduce network signalling overhead and improve handover latency. However, this work does not address the signal quality of D2D pairs or different mobility conditions. In [8], Chen *et al.* proposed a D2D handover decision method, which switches between a joint handover procedure that all UEs hand over to the target base station (BS) together, and a half handover procedure that some UE remains in the source BS. Nonetheless, this method handles D2D pairs separately and thus involves unnecessarily large overhead when a group of UEs are moving in the same direction.

In this paper, we propose a speed-aware joint handover approach that leverages D2D multicast and D2D clusters to address simultaneous handover of massive UEs on cell edge. In the proposed solution, the service BS broadcasts the handover decision to the cluster head (CH), and then the cluster head reallocates new resources among the cluster members and follows the radio resource control (RRC) protocol to complete the handover process. The simulation results show that the proposed solution can effectively alleviate the pressure of broadcast signalling storm, and improve the handover QoS in terms of interruption probability and handover latency.

The rest of this paper is organized as follows. Section II introduces the system model with D2D multicast. In Section III, we propose a joint handover approach with speed-awareness for clustered D2D UEs. Simulation results are presented in Section IV. Section V concludes this work.

II. System Model of D2D Clusters with Multicast Communication

A. D2D Cluster with Multicast

In this paper, we consider a D2D multicast communication system to effectively assist with joint handover of D2D clusters. D2D multicast communication is further combined with

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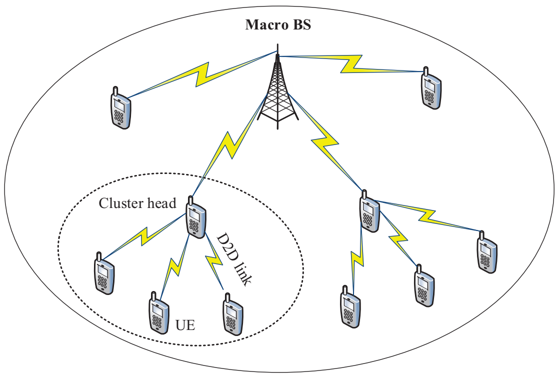

Fig. 1. D2D multicast communication scenario.

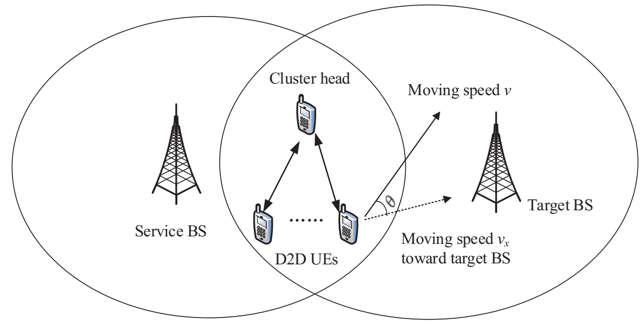

Fig. 2. Joint handover scenario with D2D cluster.

the Multimedia Broadcast and Multicast (MBMS) technology to provide MBMS services within a small range via D2D communications. Such combinations not only can supplement fundamental network capabilities and improve user experience, but also can reduce the load over BSs and relieve the pressure from high bandwidth demands.

Fig. 1 shows a scenario where the D2D multicast technology is integrated into the cellular network. Here, the neighbouring D2D UEs cluster as a D2D broadcast group that consists of one multicast sender and multiple multicast receivers. Such a D2D cluster forms a small self-organizing network under the control of a BS, which allocates orthogonal or multiplexed cellular resources in the licensed band for the cluster.

In general, the multicast sender can serve as a cluster head to facilitate communication between D2D UEs and the BS. As such, the BS can broadcast public information to all cluster heads, while each cluster head further forwards the information to the members in the cluster. On the other hand, the cluster head can relay the information collected from the D2D UEs toward the BS. This method can achieve a high performance gain because of the short distance of D2D links, and thus enhance the QoS of UEs on cell edge. Moreover, multiple D2D clusters that are spatially distant can reuse the frequency bandwidth, thereby improving spectrum utilization.

B. Joint Handover with D2D Cluster

Traditionally, the BS directly handles the handover of each individual device. When there are abundant access channels available and few handover devices, the traditional approach indeed has an advantage of low delay while reliability is guaranteed. However, in a dense network, a large number of devices may request handover simultaneously. Such a handover scenario will become more common, especially with the convergence of Internet of Things (IoT) into the 5G networks. In this case, the traditional approach may experience severe shortage of channel resources and result in service interruption.

Fig. 2 shows a two-hop joint handover process, which exploits D2D multicast shown in Fig. 1 and D2D cluster structure. Here, the cluster head can collect the related information from the D2D UEs, such as the received signal strength (RSS), and report such information to the BS. Once the BS makes a handover decision according to the reported information, it can deliver the handover information to the cluster head, which further broadcasts the handover information to the D2D-enabled devices within the cluster. Although the two-hop message delivery process may involve a longer delay, it can better cope with the high-density scenario where a large number of neighbouring devices in a cluster handover jointly.

Generally, the BS allocates a resource pool (which may be orthogonal or multiplex) to each D2D cluster. Then, the D2D UEs within a cluster obtain the spectrum resources via random-access contention or scheduling by the cluster head. The broadcast channel used by the cluster head is also allocated from the resource pool to carry the handover information. As such, the two-hop approach can alleviate the congestion of the access channels when a large number of devices request handover at the same time. Consequently, we can reduce the handover latency as well as the interruption probability of cellular users on the cell edge.

III. A Speed-Aware Joint Handover Approach with D2D Clusters

In this section, we introduce the proposed speed-aware joint handover approach. The proposed approach exploits the D2D multicast communication system and the D2D clustering structure to alleviate congestion of the signalling channel and improve handover latency. In addition, a multi-target handover decision algorithm is designed to take into account the velocity information of D2D devices with respect to each candidate BS. As a result, high-speed mobile devices can initiate early handover to reduce occurrences of service interruption.

A. Signalling Process of Joint Handover

Consider the joint handover scenario depicted in Fig. 2, where a number of devices move around the cell edge. Assume that a D2D cluster consists of K D2D UEs, represented by set $C = \{d_1, d_2, ..., d_K\}$. Fig. 3 shows the signalling process of the proposed joint handover approach. First, each member of a D2D cluster periodically reports its relevant measurement to the cluster head, which further relays the information to the service BS. According to the collected information from all devices in the cluster, the service BS performs the handover decision algorithm (to be discussed in Section III-B) and determines the target BS for each D2D UE. Depending on the

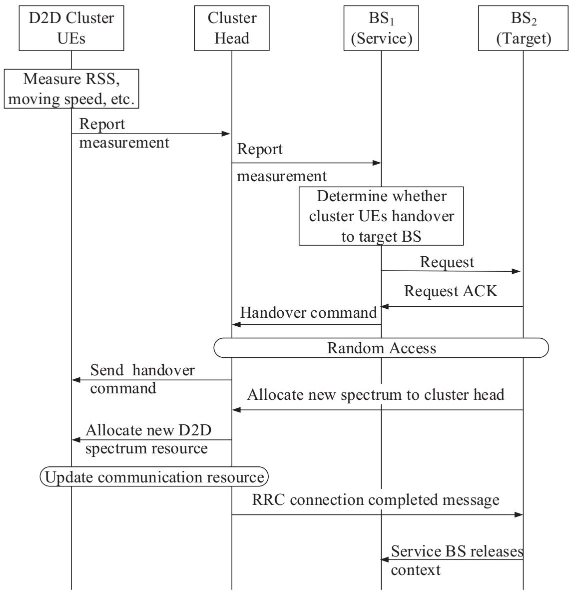

Fig. 3. Flow chart of the joint handover approach with D2D clusters.

handover decision, the devices in the D2D cluster C are splits into two subsets of devices, i.e., set $C_h = \{d_1, d_2, ..., d_{K_h}\}$ that will hand over to the target BS, and set $C_s = \{d_1, d_2, ..., d_{K_s}\}$ that will stay in the current BS.

Then, the service BS sends a handover request toward the target BS, which will allocate new spectrum resource to the D2D cluster. After that, the service BS broadcasts the handover decision (including the information of the newly allocated spectrum resource) to the cluster head. After receiving the handover information, the cluster head reallocates the new resource among the cluster members and broadcasts the information to the members. At last, the cluster head will follow the RRC protocol to complete the handover process.

B. A Speed-Aware TOPSIS Handover Decision Algorithm

In the standard LTE network, a UE should measure and report RSS to the service BS. When it is found that there exists a neighbouring BS whose measured RSS is better than that of the service BS by a certain *offset*, termed *Event A3*, a handover to this neighbouring BS can be triggered. Nonetheless, with the development of LTE-V and 5G networks, smart devices (including vehicle-mounted systems, vehicle sensors, and passengers on vehicles) will be able to inject traffic into the cellular network. Therefore, the moving speed will be another important reference factor for the device handover decision in the high-speed scenario.

Assume that a UE is under the coverage of M neighbouring BSs, including the service BS, BS_1, and the alternative BSs, $\{BS_2, BS_3, ..., BS_M\}$. The set of all neighbouring BSs is denoted by $B = \{BS_1, BS_2, ..., BS_M\}$. In the handover decision algorithm, we consider the following two main factors:

1) The RSS measured by the UE for each BS, where an offset is added to the RSS value of the serving BS; and
2) The moving speed of the UE toward each BS, denoted by $v_x = v{\cdot}\cos(\theta)$, where v is the UE's current moving speed and θ is the angle between the UE's moving direction and the direction of the BS.

In this work, we propose a speed-aware handover decision algorithm based on the technique for order preference by similarity to ideal solution (TOPSIS) [9]. TOPSIS offers an effective technique to solve multi-attribute decision problems. TOPSIS first identifies the attributes that affect the performance of the decision, and then finds out an ideal solution (also known as the best alternative) and a non-ideal solution (also known as the worst alternative) based on these attributes. Each alternative for the decision is assessed by its Euclidean distances to the ideal solution and the non-ideal solution. Last, all alternatives are ranked by its similarity to the ideal solution, and the top alternative with the shortest distance from the ideal solution (also the farthest distance from the non-ideal solution) is selected for the decision. As TOPSIS does not involve iterations, it is subject to a low complexity and easy to implement.

Alg. 1 shows the details of the proposed speed-aware handover algorithm based on TOPSIS. Here, we consider the above two attributes of each device, i.e., RSS and moving speed, for each candidate BS. Accordingly, we have an $M \times N$ evaluation matrix $\{x_{ij}\}$, where x_{ij} denotes the jth attribute of the ith BS. Then, the decision matrix is normalized as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{M} x_{ij}^2}}. \tag{1}$$

The normalized decision matrix $\{r_{ij}\}$ is further weighted by

$$u_{ij} = w_j r_{ij} \tag{2}$$

where w_j is a weighting value of the jth attribute. This weighting value can be manually set and adapted repeatedly during the simulation to improve the performance.

Next, we need to determine the best solution and the worst solution, respectively. In this paper, the considered attributes include the RSS and moving speeds of all devices in the cluster toward each BS. Therefore, the best solution (denoted by A^+) has the maximum RSS and the maximum moving speed, while the worst solution (denoted by A^-) has the minimum RSS and the minimum moving speed, given by

$$A^+ = \{u_1^+, u_2^+, ..., u_N^+\} \tag{3}$$

$$A^- = \{u_1^-, u_2^-, ..., u_N^-\} \tag{4}$$

where

$$u_j^+ = \left\{ \max_{\forall i \in B | j \in J^+} u_{ij}, \min_{\forall i \in B | j \in J^-} u_{ij} \right\} \tag{5}$$

$$u_j^- = \left\{ \max_{\forall i \in B | j \in J^-} u_{ij}, \min_{\forall i \in B | j \in J^+} u_{ij} \right\}. \tag{6}$$

Here, u_j^+ represents the best choice with respect to the jth attribute, u_j^- represents the worst choice for the jth attribute, J^+ is the set of attributes that bring positive benefits, and J^- is the set of attributes that involve negative impact such as cost and expense. Clearly, a good alternative prefers a larger value for attributes in J^+ and a smaller value for attributes in J^-.

Algorithm 1: The speed-aware handover approach based on TOPSIS.

Input: D2D cluster C, set of neighbouring BSs B
Output: Set of handover UEs C_h and target BS

Choose device $d_k \in C$ as cluster head
begin Cluster head collects information from UEs in C
    Each UE in C measures RSS and SINR, and reports them to cluster head
    Cluster head forwards UEs' reports to service BS
begin Base station makes handover decisions
    Find best solution A^+ and worst solution A^- based on UEs' reports
    for *each BS* $i \in B$ **do**
        Compute its approximate degree to best solution according to (9)
    Determine target BS for UEs in C based on TOPSIS
    Split cluster C into set C_h and set C_s according to handover decision
    Request new spectrum from the target BS for handover UEs in C_h
Return C_h and target BS

Once the best solution and the worst solution are identified, each possible alternative (i.e., the ith target BS) for the decision is assessed by calculating its Euclidean distances to the best solution and the worst solution, respectively, given by

$$D_i^+ = \sqrt{\textstyle\sum_{j=1}^{N}(u_{ij} - u_j^+)^2} \tag{7}$$

$$D_i^- = \sqrt{\textstyle\sum_{j=1}^{N}(u_{ij} - u_j^-)^2}. \tag{8}$$

Then, we compute the approximate degree of the ith target BS to the best solution, given by

$$S_i^+ = \frac{D_i^-}{D_i^- + D_i^+}, \qquad 0 \leq S_i^+ \leq 1 \tag{9}$$

where $S_i^+ = 1$ if and only if the ith BS is the best solution, while $S_i^+ = 0$ if and only if the ith BS is the worst solution. Finally, all candidate BSs are ordered according to the relevant approximate degrees to the best solution and the BS with the highest approximate degree is selected.

IV. Simulation Results

In this section, we evaluate the performance of the speed-aware joint handover approach with D2D clusters in a cellular network of high device density on the edge.

A. Simulation Parameters

Fig. 4 shows the simulation scenario, where there are seven BSs and 200 D2D devices within a square area of 1600m×1600m. The large red dots in Fig. 4 represent the macro BSs, while the magenta dots represent the mobile devices. As seen, these devices are distributed densely and moving in a similar manner to pass through the cell edges twice. In the simulations, we consider different device moving speeds, including 50 km/h, 100 km/h, 150 km/h, and 200 km/h. More detailed simulation parameters are given in Table I. The channel modelling refers to the path loss model proposed by 3GPP for LTE D2D [10], which mainly concerns large-scale fading. In addition, we assume that the D2D communication link is interrupted when the SINR is less than -6 dB.

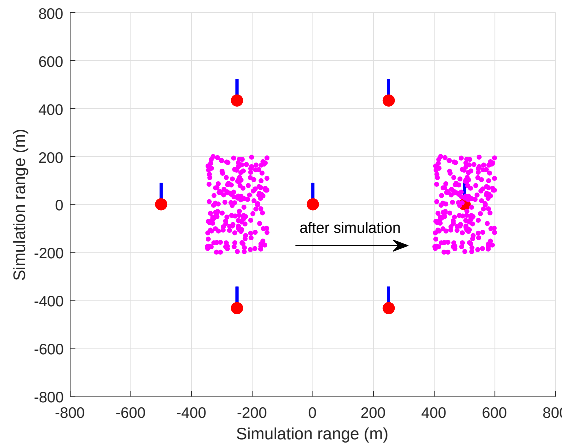

Fig. 4. System simulation scenario

In the simulations, we compare the proposed speed-aware joint handover algorithm with the standard Event A3 handover algorithm. In the proposed algorithm, the best solution is characterized by an RSS, $u_1^+ = 40$ dB, and a device moving speed toward the BS, $u_2^+ = 300$ km/h. Correspondingly, the worst solution is defined by $u_1^- = -40$ dB and $u_2^- = -300$ km/h. We consider two performance metrics, including the interruption probability and the handover latency. The handover latency is the time duration between the beginning of the handover and the completion of the handover from the moment that the handover decision criteria are met. The delay with signalling exchange depends on the cellular system protocols, which is beyond the scope of optimizing the handover decision strategies. Hence, we mainly focus on the delay caused by the limitation of broadcast channels at the BSs.

TABLE I
Simulation Parameters

Parameter	Value
Number of mobile devices	200
Maximum distance of device clusters	50 m
Distance between base stations	500 m
Number of random access channels	10
Handover decision interval	500 ms
Carrier frequency	2.4 GHz
Path loss model	$128.1 + (37.6 \cdot \log_{10} d)$
SINR threshold for link interruption	-6 dB
RSS offset for serving BS	3 dB

B. Simulation Results and Discussions

Fig. 5 shows the communication interruption probability with different handover algorithms. Here, we consider two

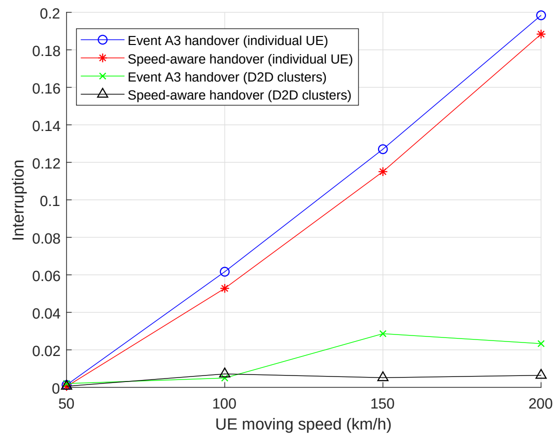

Fig. 5. Interruption probability with different handover algorithms.

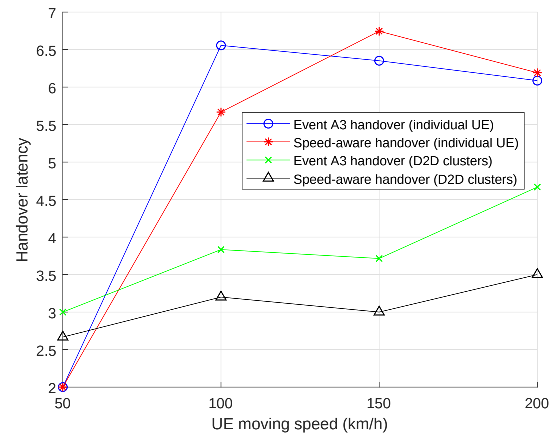

Fig. 6. Average handover latency with different handover algorithms.

different cases, with individual devices or with D2D clusters, for the proposed speed-aware handover algorithm and the Event A3 handover algorithm, which result in four different algorithms. As seen in Fig. 5, if each device is handled individually and a large number of devices hand over at the same time, these devices may not be able to complete handover in time due to the limited capacity of the broadcast channel, thus resulting in communication interruption. In addition, it is observed that the interruption probability with individual device handover is even higher when the devices are moving faster. In contrast, when D2D clusters are considered, both the speed-aware algorithm and the Event A3 algorithm achieve significantly lower interruption probability for the devices.

On the other hand, we can see that the speed-aware algorithm exhibits similar performance as the Event A3 algorithm in the low-speed scenarios (e.g., at 50 km/h and 100 km/h). Nonetheless, the interruption probability of the Event A3 algorithm increases in the high-speed scenarios (e.g., 150 km/h and 200 km/h), whereas the speed-aware algorithm maintains consistently low interruption probability for various mobility levels. This is because the speed-aware algorithm incorporates the device moving speed in the handover decision. When a device moves to a target BS at a higher speed, it is more likely to hand over to the target BS in advance.

Fig. 6 shows the average handover latency of devices with different handover algorithms. As seen, the joint handover algorithm based on D2D clusters significantly reduces the handover latency. In the cluster-based handover algorithm, the BS allocates communication resources for D2D clusters, and different D2D clusters can reuse these resources when the interference is acceptable. The cluster head uses the allocated resources to transmit service data and signalling (such as handover commands) within the cluster to assist with handover. As such, the congestion of the random access channels in the handover process is alleviated. Nonetheless, when the D2D cluster transmits the handover commands, it also involves a transmission delay, which is much smaller than the access delay in the competition for the random access channels.

V. Conclusion and Future Work

In this paper, we consider a D2D multicast communication system and propose a speed-aware joint handover approach. Aiming at challenging scenarios with high device density and high mobility, the proposed handover approach effectively exploits D2D clusters and speed-awareness to derive the handover decision. Based on the TOPSIS technique, the handover decision takes into account the RSS of each target BS and the moving speed toward each BS. We build a system-level simulation platform to evaluate the performance of the proposed solution. The simulation results show that the proposed approach can significantly reduce the communication interruption probability and handover latency of mobile devices in high-density and high-speed scenarios.

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