Smart Mobility Management for D2D Communications in 5G Networks

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***Abstract*—Direct device-to-device (D2D) communications is regarded as a promising technology to provide low-power, high-data rate and low-latency services between end-users in the future 5G networks. However, it may not always be feasible to provide low-latency reliable communication between end-users due to the nature of mobility. For instance, the latency could be increased when several controlling nodes have to exchange D2D related information among each other. Moreover, the introduced signaling overhead due to D2D operation need to be minimized. Therefore, in this paper, we propose several mobility management solutions with their technical challenges and expected gains under the assumptions of 5G small cell networks.**

Keywords*— *D2D, 5G, Mobility, Small cells, Context-aware handover, Self-organization

I. Introduction

The more the world becomes connected, the more the wireless devices appear in our proximity. Due to the rapid increase in the number of connected devices and traffic volumes, the fifth generation (5G) networks are expected to be much more dynamic and densely deployed than today's networks [1] as depicted in Figure 1. In addition to the current cellular services, wireless devices in the future are expected to be constantly interacting with each other as well as with their environment (e.g., data communications from wireless sensors to device or vice versa). Besides the human-centric device-to-device (D2D) communications, one very important use case for D2D is vehicle-to-vehicle (V2V) communications [2] where the mobility plays a very important role.

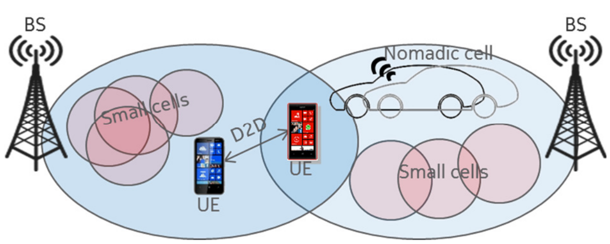

Fig. 1. 5G communications scenario where small cells, nomadic cells and D2D are expected to be essential technical enablers for capacity extension and traffic offloading in the future networking.

D2D communications has already been of the attention of wireless communications community for many years [3]. Most recently more and more people believe that D2D communications will be a corner stone in the future 5G networks. For instance, the third generation partnership project (3GPP) agreed that device-to-device (D2D) discovery and communication will become one of the new features to be studied during 3GPP Rel-12 and Rel-13 timeframes under the LTE Proximity Services (ProSe) study item [4]. In 3GPP, two new types of ProSe communication scenarios are defined [5]: (1) direct data path where two devices are exchanging packet data without involvement of any network element in the data plane; and (2) locally-routed data path where D2D user equipment (UE) exchanges the data locally by relaying through the controlling node without the involvement of core network elements. However, due to the short-time frame, the outcome of 3GPP work on D2D will be reduced at least in Rel-12 time frame. In the current standardization there has not been much emphasis on the commercial use cases which are mainly considered for the future 5G scenarios [2].

To satisfy the needs of 2020 wireless communications society, 5G communication system has to be significantly more efficient and scalable in terms of energy, cost and spectral efficiency [6]. Efficiency and scalability will be vital in order to reach the specified targets, i.e., 1000 times higher mobile data volume per area, 10 to 100 times higher number of connected devices and 5 times reduced end-to-end latency as discussed in EU FP7 METIS project [6]. In addition, next generation networks have to support a significant diversity of use cases, such as the different requirements of services in mobility management. These requirements also apply to D2D communications ranging from device discovery to interference management. In this paper we focus on the need of reduced control signaling and improved end-to-end (E2E) latency in network-assisted D2D communications by presenting two smart mobility management solutions as the support for ultra-reliable communications (e.g., V2V communications) and low-latency services in future ultra-dense networks is a requirement to be realized by beyond-2020 (5G) communication systems.

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II. SMART MOBILITY MANAGEMENT FOR D2D COMMUNICATIONS

In our solutions we assume that the D2D resource usage and coordination are under the network's control. This is due to the fact that in-band D2D operation, as an underlay for cellular communications, requires the network's control on D2D radio resources in order to provide optimized resource utilization, minimized interference among D2D links and from D2D links to cellular link, as well as more robust mobility.

Enabling very low latency data communications between end-users is one of the distinctive advantages expected from D2D communications. However, when several base stations (BSs), which are connected to each other via a non-ideal backhaul, are involved in the D2D radio resource control, the quality of service requirement in terms of latency may not be satisfied due to large backhaul delay. Furthermore, the additional control overhead is expected due to the exchange of necessary information between controlling nodes as depicted in Figure 2. Therefore, we propose two smart mobility management solutions that can be used to minimize the negative impacts (e.g., larger latency and additional signaling overhead) of multi-site radio resource control on D2D communications by controlling the D2D control handover and cell selection during the mobility of D2D UEs (DUEs):

- *D2D-aware handover solution,*
- *D2D-triggered handover solution.*

Here, it should be noted that D2D control handover and regular cellular handover could be executed separately, such as in dual connectivity [7].

A. D2D-Aware Handover Solution

D2D-aware handover solution is introduced to minimize the E2E latency in D2D communications and reduce the network signaling overhead in case of DUE mobility.

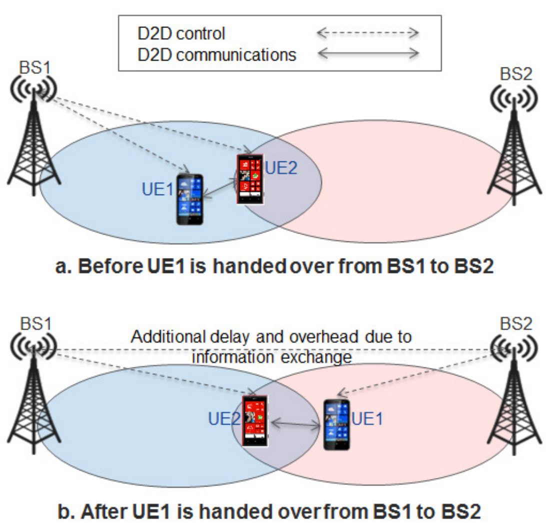


Fig. 2. D2D control and communications before and after a regular cellular handover execution.

As shown in Figure 3a, a D2D pair is initially controlled by the same BS. Figure 3b depicts that one of the DUEs, UE1, may move toward BS2 when fulfilling the regular cellular handover condition, such as event A3 [8] in which the received signal strength of neighbor cell becomes an offset better than primary cell, i.e., $RSRP_{target} - RSRP_{source} > offset$. However, to reduce the latency and signaling overhead, it is beneficial to keep the D2D pair controlled by the same BS. Otherwise, when the DUEs are under the control of different BSs, there can be potential performance degradation, for instance, due to possible asynchronous BSs. Using the regular handover condition for each DUE independently does not guarantee this. Therefore, we propose D2D-aware handover solution which enables BS1 to postpone the handover of at least the D2D control (or both D2D control and cellular connectivity) to BS2 unless the signal quality of BS1 becomes worse than a predefined D2D control condition which is defined as the minimal requirement in terms of link quality to maintain the D2D control. D2D control condition can be set according to, for example, signal-to-interference-plus-noise-ratio (SINR) threshold (e.g., -6 dB in our performance evaluations). However, when the signal quality of BS2 is able to fulfill the D2D control condition for both UE1 and UE2, a joint handover to BS2, which provides the best SINR among all the candidate target cells, is enabled by D2D-aware handover solution as shown in Figure 3c.

B. D2D-Triggered Handover Solution

With D2D-triggered handover solution, we propose to cluster the members of a D2D group within a minimum number of cells or BSs in order to reduce the network signaling overhead caused by the inter-BS information exchange, such as

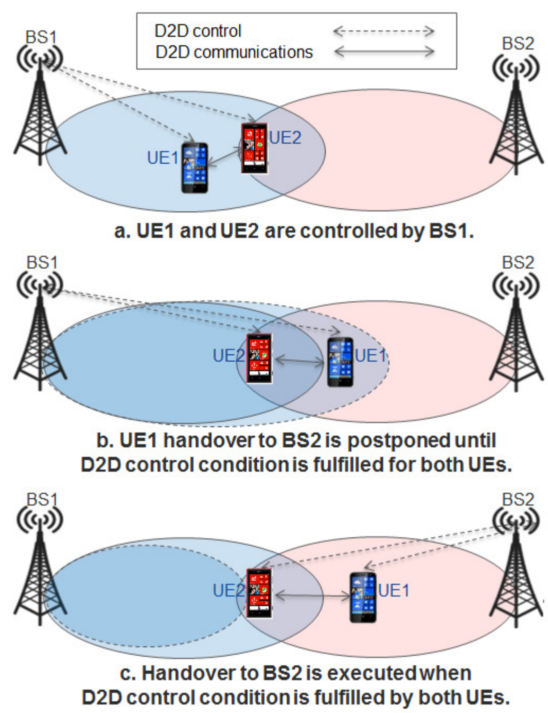


Fig. 3. D2D control and communications during the DUE mobility between different sites.

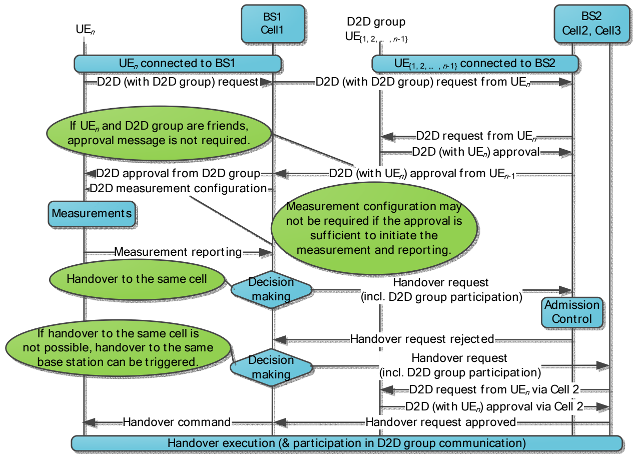


Fig. 4. A signaling flow-chart depicts how D2D-triggered handover solution selects the target cell for handing over D2D control of a new member to participate in D2D group communications.

related to D2D radio resource usage. The solution targets the scenarios where D2D groups are dynamically formed by more than two DUEs. The solution can be applied when DUEs taking part in a D2D group are varying in time, for instance, due to the mobility.

Figure 4 illustrates a signaling flow-chart that depicts how D2D-triggered handover solution selects the target cell for handing over the D2D control of a new DUE (UE$_n$) to join D2D group communications. D2D-triggered handover solution first checks whether UE$_n$ can be controlled by the same cell (BS2-Cell1) or the BS (BS2) that controls the majority of the members in the respective D2D group. In this example, the same cell cannot be selected to hand over the D2D control of UE$_n$, however, the second best target cell (BS2-Cell2), which is under the same BS with the best target cell, can be selected to minimize the control overhead. The reasons why the same cell cannot be selected are expected to be the admission control or the D2D control condition.

III. SIMULATION SCENARIO AND ASSUMPTIONS

Simulation scenario assumes the ultra-dense deployment of 5G networks, i.e., up to 10 times more densely deployed than today's networks [6]. In the network layout, there are 60 randomly positioned small cells under the coverage of a three-sector macro BS. Under each macro sector, small cells are randomly and uniformly located with the minimum distance of 40 m among each other as depicted in Figure 5. Macro and small cell layers are allocated with different carrier frequencies.

In the simulation scenario it is assumed that there are 8 terminals per small cell on average. Initially, some UEs are randomly and uniformly dropped throughout the macro geographical area. Next, other UEs are dropped randomly and uniformly within the radius of 10 or 50 m from the initially dropped UEs. D2D groups are created with two and four UEs in each other's proximity. The mobility is modeled such that a group of DUEs moves straight to the same direction, which is randomly chosen, with 3 km/h velocity. The UE direction is modified at the layout border.

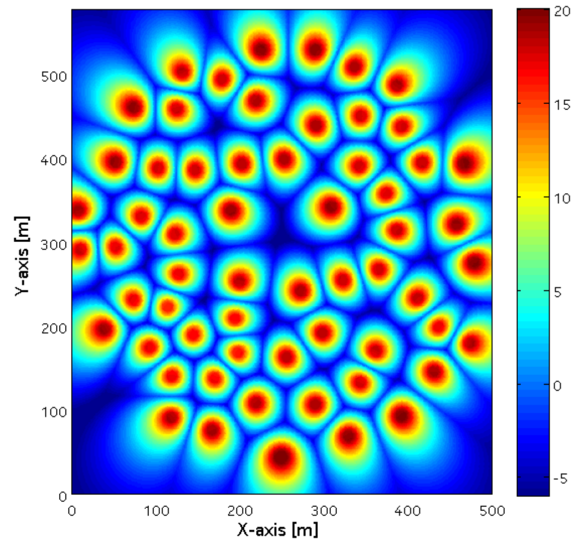


Fig. 5. Small cell-only coverage in terms of SINR [dB] (when shadow fading is neglected).

The main simulation assumptions follow the simulation guidelines recommended by 3GPP [9, 10] and Table 1.

TABLE I. MAIN SIMULATION ASSUMPTIONS

Simulation time	10 drops with 1000 s each
Network layout	3 macro cells, 60 small cells
Number of UEs	960 (8 per small cell)
UE velocity	3 km/h
Carrier frequency	2 GHz
Downlink tx power	Macro BS: 46 dBm, Small BS: 30 dBm
BS antenna height	Macro BS: 25 m, Small BS: 10 m
UE antenna height	1.5 m
Pathloss model	ITU Urban Macro NLOS and Micro NLOS
Fading model {Macro BS, Small BS}	Shadow fading deviation: {6, 4} dB Correlation distance: {40, 10} m
A3 margin & TTT [8]	3 dB & 100 ms
D2D control thr.	-6 dB (SINR)

IV. SIMULATION RESULTS

The smart handover solutions proposed in this paper aim at maximizing the single small cell control on D2D communications so that DUEs can effectively be offloaded to the small cell layer; E2E latency can be kept minimal; and the network signaling overhead is reduced. Inter-frequency deployment, where macro and small layers are allocated with non-overlapping parts of the radio spectrum, is of our interest in this paper. In such a scenario if D2D control is given to a macro cell, benefits of the small cell offloading may not be maximized due to the lack of control of the macro layer on small cell resources. Furthermore, not only in the inter-frequency deployments of macro and small cells but also in the intra-frequency deployments, D2D control by the macro layer

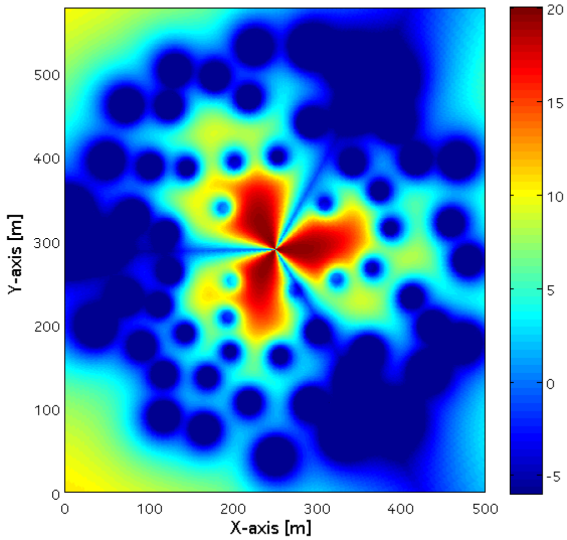


Fig. 6. Macro-only coverage in terms of SINR [dB] under the co-channel interference from the small cell layer (when shadow fading is neglected).

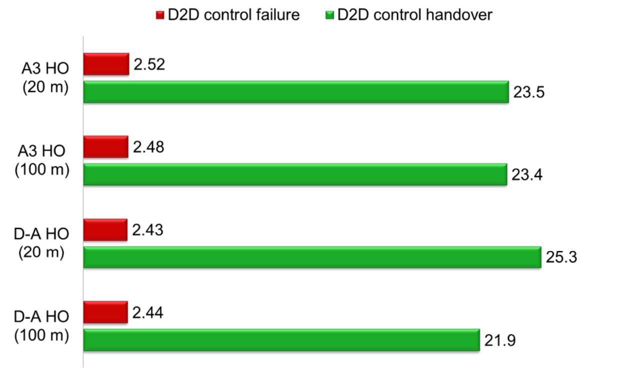
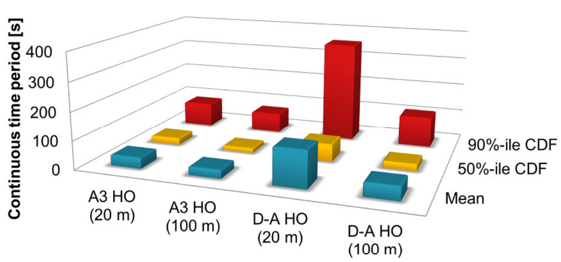
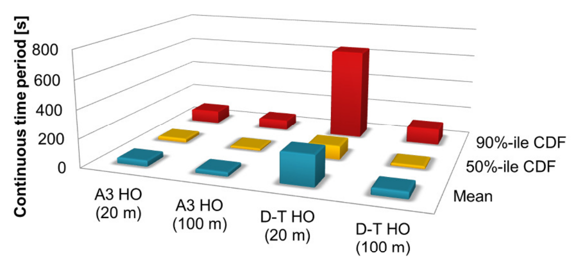


Fig. 8. Mobility robustness in terms of D2D control handover and failure indicators. Number of events is given per UE per simulation drop (1000 s). A3 HO and D-A HO denote A3 event-triggered handover and D2D-aware handover, respectively.



	A3 HO (20 m)	A3 HO (100 m)	D-A HO (20 m)	D-A HO (100 m)
Mean	38.2	29.5	128.1	47.9
50%-ile CDF	23.8	16.1	61.7	24
90%-ile CDF	86.7	72.1	356.3	109.8

Fig. 7. Statistics (mean, 50%-ile CDF, 90%-ile CDF) of the continuous D2D pair service time operated under the same small cell. A3 HO and D-A HO denote A3 event-triggered handover and D2D-aware handover, respectively.



	A3 HO (20 m)	A3 HO (100 m)	D-T HO (20 m)	D-T HO (100 m)
Mean	41.4	28.8	212.6	46.8
50%-ile CDF	27.3	14.6	95.8	18.1
90%-ile CDF	94.4	72.8	644	114.7

Fig. 9. Statistics (mean, 50%-ile CDF, 90%-ile CDF) of the continuous D2D group service time when the majority of DUEs are under the control of the same small cell. Each D2D group consists of 4 DUEs. A3 HO and D-T HO denote A3 event-triggered handover and D2D-triggered handover respectively.

may not be optimal. As depicted in Figure 6, seamless D2D control by a macro cell cannot be guaranteed due to the strong co-channel interference of ultra-dense deployment of small cells.

As shown in Figure 7, D2D-aware handover (D-A HO) improves the mean continuous time period of the D2D pair control under the same small cell by 235% and 62% for the maximal D2D pair distances of 20 m and 100 m, respectively.

Besides the optimization of the continuous time period of the D2D pair control under the same small cell, D2D-aware handover solution is able to keep the mobility robust because it does not cause a notable change in either the number of (potential) D2D control failures, i.e., *SINR < D2D control thr.*; or the number of D2D control handovers as given in Figure 8.

Figure 9, where a D2D group comprises 4 DUEs, illustrates that D2D-triggered handover (D-T HO) enables the majority of the DUEs to be kept under a single small cell for longer mean continuous time period by 414% and 63% for the maximal D2D link distances of 20 m and 100 m, respectively. Here, the main advantage of the solution is expected to be the reduction in the network signaling overhead, whereas D2D-aware handover solution aims at minimizing the E2E latency primarily.

V. CONCLUSIONS

As shown by the simulation results, the proposed smart mobility solutions can reduce the network signaling overhead and improve the D2D E2E latency by maximizing the time period when the DUEs are under the control of the same small cell.

With these system level improvements, we are thus able to support more reliable communications, for instance, for V2V communications and low-latency services in future ultra-dense networks, as required to be realized for beyond-2020 (5G) communication systems.

Future work may consider different mobility scenarios in cellular radio networks, for example, vehicular communications.

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