

Sidelink-Assisted Handover for Cellular Networks

Konstantinos Manolakis, Wen Xu

Huawei Technologies, German Research Center, 80992 Munich, Germany

Email: {konstantinos.manolakis; wen.dr.xu}@huawei.com

Abstract—Direct device-to-device (D2D) communication is considered as a key technology and enabler for a multitude of new services in future fifth generation (5G) networks. Especially safety and emergency applications will require fast and reliable handover, seamless D2D connectivity and proper radio access to the cellular network. This paper proposes a novel handover scheme, which takes advantage of the D2D sidelink in order to assist the handover procedure, provide connectivity and maintain synchronization among multiple radio links. The scheme is in particular beneficial for cases including users with partial cellular coverage, for which standard handover is not possible, provides connectivity to out-of-coverage users and further assists them in accessing again the cellular network. In a network-controlled implementation the proposed scheme can be used for flexible handover, allowing multi-link coexistence and avoiding large delays of inter-cellular D2D. Sequence diagrams and procedure flow charts are provided for selected scenarios.

I. INTRODUCTION

It is widely accepted that fifth generation (5G) networks will have to satisfy high demands of data rate, latency and reliability for a potentially high number of devices. The overall goal is to deliver 1000 times more data, serve 10 to 100 times more devices, provide reliability above 99% and reduce latency by a factor of 5, compared to existing Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) [1].

Looking at the 5G landscape, device-to-device (D2D) communication will have a prominent role. In cellular networks as shown in Fig. 1, direct D2D shall enable low-latency communication and enhance the overall spectral efficiency through frequency reuse. So-called cellular-assisted D2D, where the network assigns physical resources and provides control information to the mobile users, is seen as a promising scheme for enabling high reliability. Reaching low latency and high reliability naturally requires fast and reliable handover between base stations (BSs) and seamless connectivity. At the same time, multi-link coexistence requires time synchronization in order to avoid inter-link interference.

Traditional handover treats user equipments (UEs) independently, which may cause interference due to synchronization misalignments, especially if non-synchronized BSs are involved. Moreover, inter-cellular D2D increases latency due to information exchange between BS. More sophisticated solutions proposing joint D2D handover can be found in [2], [3]. There, sidelink can be maintained, while a simultaneous handover of several mobile users is performed. Although avoiding inter-cellular D2D, such schemes are not necessarily optimal in terms of the achievable signal-to-interference-plus-

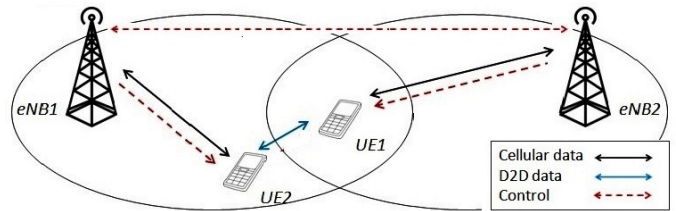


Fig. 1. Coexistence of multiple D2D and cellular links needs time synchronization. Inter-cellular D2D, where users are assigned to different base stations, causes time-consuming information exchange between base stations.

noise ratio (SINR), especially if UEs are far from each other, as not unusual in vehicle-to-vehicle (V2V) communication.

A flexible half-handover scheme allows UEs to be handed over sequentially, if one of the UEs postpones the handover [4]. The procedure includes a joint request from two UEs to the serving BS and UEs are handed over closely in time, so that measurements provided are still relevant. Switching between cellular and D2D links has been investigated in [5] for enhancing SINR close to cell edges, as a UE serves as a relay for the detached UE, however without considering synchronization and coexistence issues. Cell selection and traffic balancing for inter-cellular D2D has been investigated in [6]. These schemes assume all UEs being in cellular coverage and are not applicable in partial coverage scenarios.

This work deals with handover for scenarios in which some D2D-capable UEs are out of cellular coverage and standard handover is not applicable or recommended. A new scheme termed *sidelink-assisted handover (SAHO)* is proposed, which allows to detached UEs to remain synchronized, receive control information and data from the cellular network through the sidelink. In this way, UEs remain synchronized and indirectly connected and are thus assisted in re-attaching to the network when possible, while inter-link interference due to synchronization misalignments is avoided. In a different implementation, SAHO provides network flexibility in controlling a D2D handover and prevent from interference and latency enhancements. SAHO should not replace standard handover, but aims to cover scenarios where this is not possible e.g. due to lack of cellular coverage, or is not preferable because of being inflexible and slow in inter-cellular D2D.

The rest of this paper is organized as follows. In Section II, the scenario and problem along with synchronization and latency requirements are described. The proposed handover solutions are presented in Section III for different scenarios and setups. Conclusions are discussed in Section IV.

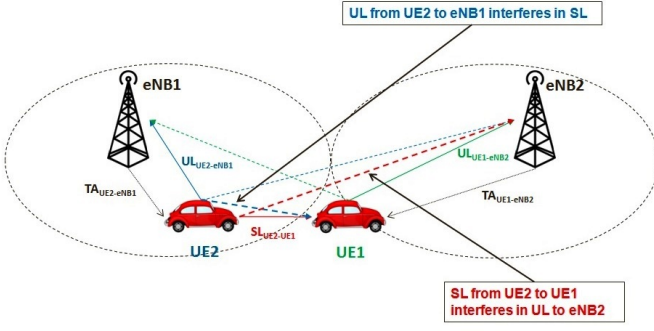


Fig. 2. Interference scenario with inter-cellular D2D/V2V and cellular links, driven by non-synchronized eNBs. Synchronization and timing information are provided by the network to UEs in the coverage area.

II. SCENARIO DESCRIPTION AND REQUIREMENTS

One of the improvements of UEs in next generation networks is to simultaneously maintain multiple sidelink connections, also of different type (unicast or broadcast), along with cellular uplink and/or downlink. For *in-band* D2D, sidelink can be allocated on adjacent frequency subbands of the same band, or even reuse the cellular frequencies, while *out-of-band* D2D uses a separated frequency band. In network-controlled D2D, control and signaling information is transmitted between evolved Node Bs (eNBs) and UEs in order to guide initial access, handover, synchronization and provide cell assignment, timing advance (TA) etc. The rest of this section discusses requirements and challenges for D2D handover in multi-cellular networks in terms of *coexistence* and *latency*.

A. Coexistence and synchronization requirements

Coexistence of multiple D2D and/or cellular transmissions in the same frequency band requires time alignment of over-the-air transmissions to avoid interference; thus time synchronization among eNBs, relays, road side units (RSUs), D2D-capable UEs and other cellular UEs is required, as analyzed in [7].

Multi-carrier waveforms such as orthogonal frequency division multiplexing (OFDM) will suffer from inter-symbol interference (ISI), if time offsets between signals -even if transmitted on different subcarriers- exceed the cyclic prefix (CP). Naturally, signals overlap over the air, but even if the individual times of arrival are detected, they cannot be perfectly separated. Time offsets further cause inter-carrier interference (ICI), as the circular convolution properties between signal and channel, thus subcarriers' orthogonality, are misaligned.

For inter-cellular D2D, synchronization needs to include multiple eNBs and the attached UEs. Fig. 2 shows an example with two UEs transmitting in sidelink and uplink. If adjacent cells are driven by non-synchronized eNBs, which is typical for cellular networks using frequency division duplex (FDD), and UEs acquire their time reference from their serving eNB via downlink synchronization signals, interference will be caused due to synchronization misalignments. This problem also occurs for synchronized eNBs, in case the assigned TA

values differ more than the CP duration. As the transmit power level is typically higher in the uplink, the D2D sidelink will probably suffer from strong interference. In case a pair or group of UEs attached to the same eNB moves towards the cell edge, e.g. vehicular users following the road infrastructure, advanced D2D handover schemes will be required in order to avoid such interference enhancement.

Out-of-band D2D uses a dedicated frequency band, therefore interference due to synchronization misalignments between the bands will not occur if a sufficiently large guard band is used. However, interference will still arise among multiple sidelink connections of the same or different UEs, therefore time synchronization is also needed.

There are situations in which a UE may need to detach from its serving eNB e.g. due to weak signal reception. Then, it can establish or maintain sidelink connections to other out-of-coverage UEs and synchronize to them, but will be not synchronized with respect to (w.r.t.) the cellular network. Acquisition and initial access must be then performed from the beginning when the UE re-enters the cellular coverage region.

B. Latency requirements

In case a UE is handed over from one eNB to another, control and signaling information need to be exchanged between the eNBs to provide synchronization, assign TA index, physical resources, procedures which naturally introduce some delay. Even after a successful handover and initial access, and apart from the aforementioned coexistence issues, it will be still difficult to meet low-latency requirements with inter-cellular D2D. Time-consuming information exchange between eNBs will result into delays and increase latency.

III. SIDELINK-ASSISTED HANDOVER (SAHO)

The SAHO procedure consists of four main phases, which are shown in Fig. 3 in a two-UE example. Here, UE1 and UE2 are initially attached to the same source eNB (S-eNB), here eNB1, and are connected via D2D. Afterwards, UE1 detaches from eNB1, but instead of a direct handover to a target eNB (T-eNB), here eNB2, it maintains the sidelink connection to UE2. During this phase, UE2 should remain attached to eNB1, so that UE1 can receive synchronization, timing advance and other required information over UE2, as well as cellular data, if a relaying function is supported by UE2 and the network. In case UE2 needs to detach from eNB1 before UE1 attaches to eNB2, the sidelink should be still maintained, and both UEs shall seek for other in-coverage UEs to connect and acquire time reference and control information from network.

In the third phase, UE1 attaches to eNB2, synchronizes and receives all needed information, while maintaining sidelink to UE2. Sidelink is maintained by re-establishing connection by using the time reference acquired from eNB2. Therefore, if UE2 is still attached to eNB1, it will have to disconnect, if the difference between its own time references and the one instructed by UE1 exceeds a certain threshold. Before detaching or if remaining connected to eNB1, UE2 informs

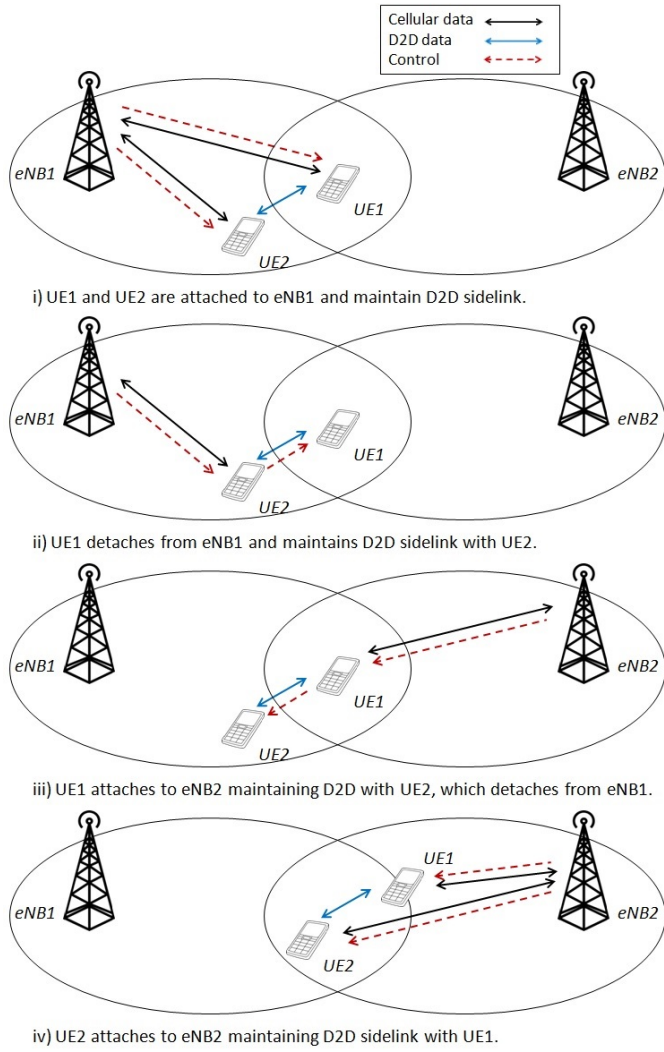


Fig. 3. Four phases of sidelink-assisted handover (SAHO) for interference-aware coexistence of in-band D2D sidelink and cellular transmissions, assistance and synchronization of UEs detached from their eNB.

eNB1 about the sidelink with UE1 and reports all required information and measurements.

During the fourth SAHO phase, UE2 attaches to eNB2 either when experiencing a sufficiently strong signal (if out of coverage before), or by following the instructions given by its serving eNB1. Summarizing, the four main phases of SAHO as shown in Fig. 3 are:

- i) UE1 and UE2 are initially attached to eNB1.
- ii) UE1 detaches from eNB1 but remains connected to UE2 via sidelink obtaining time reference and control information from eNB1. Sidelink is maintained even if UE2 detaches from eNB1.
- iii) UE1 attaches to eNB2, but maintains sidelink to UE2 by re-establishing connection using the time reference provided by eNB2. If still connected to eNB1, UE2 needs to request the sidelink and possibly detach from eNB1.
- iv) UE2 attaches to eNB2 and maintains sidelink to UE1.

In the following subsections, two scenario-dependent imple-

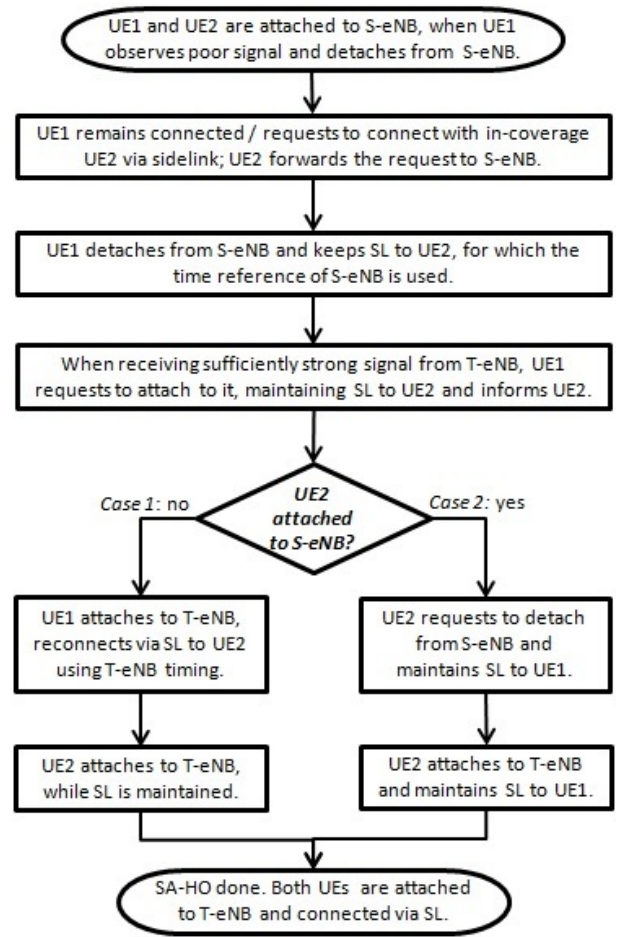


Fig. 4. Flow chart for UE-triggered SAHO, depending on whether UE2 is (still) attached to S-eNB when UE1 attempts to attach T-eNB.

mentations termed *UE-triggered* and *eNB-instructed* SAHO, are described in more detail, based on their sequence diagrams.

A. UE-triggered SAHO

The first implementation (UE-triggered SAHO) is applicable in scenarios where a UE1 needs to detach from S-eNB e.g. due to weak signal as leaving the cell coverage region. According to the flow chart shown in Fig. 4, UE1 maintains or establishes sidelink connection to UE2 (or more in-coverage UEs), which are attached to S-eNB. In this way, UE1 synchronizes to UE2, receives TA, control information and potentially cellular data. In case UE2 needs to detach from S-eNB, the sidelink to UE1 is maintained and both UEs aim to establish/maintain sidelink connections to other UEs attached to the cellular network.

As soon as UE1 approaches the coverage area of a T-eNB and attempts to attach, two different cases need to be distinguished, depending on whether UE2 is attached to S-eNB or not. In parallel to the attach request of UE1 to T-eNB, the request must be also sent by UE1 to UE2 informing it about the attach attempt. If UE2 is not attached to an eNB, it can respond to UE1, synchronize and establish sidelink. UE2 may further report measurements to UE1, which are forwarded

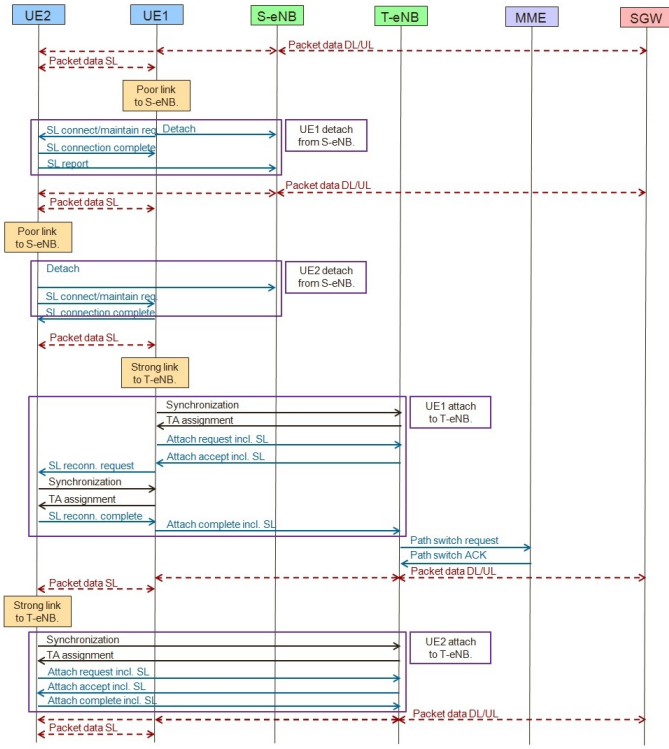


Fig. 5. UE-triggered SAHO – first case: UEs lose coverage and sequentially detach from their source eNB and maintain a sidelink connection while out of coverage, before sequentially attaching to the target eNB. Second UE is not assigned to any eNB when first UE attaches to target eNB.

together with own UE1 measurements to the T-eNB. At a later time instant, UE2 may also attach to T-eNB.

If, however, UE2 is still attached to S-eNB when receiving the sidelink request by UE1, the request must be forwarded to S-eNB, together with all required measurements and information, including the time reference instructed by UE1. Based on the provided information and requirements, the S-eNB then gives one of following *instructions* to UE2:

- Maintain sidelink to UE1, detach from S-eNB (if needed) and (later) attach to T-eNB.
- Maintain sidelink to UE1 and be directly handed over to T-eNB.
- Remain attached to S-eNB and (if needed) terminate sidelink to UE1.

If the *first instruction* is given, or if UE2 was not attached to any eNB at the moment of receiving the request from UE1, sidelink is maintained, UE2 detaches immediately or to a later time instant, according to the instructions. After having detached, UE2 maintains sidelink and may at a later time instant attach to T-eNB.

The *second instruction* requires that UE2 already observes strong enough signal from T-eNB. Here, sidelink is maintained and a direct handover of UE2 to T-eNB is instructed after negotiation and information exchange between the eNBs.

Finally, the *third instruction* is given to maintain a cellular connection, e.g. in case handover is not possible. If the time reference of UE1 differs from the one instructed by the S-eNB

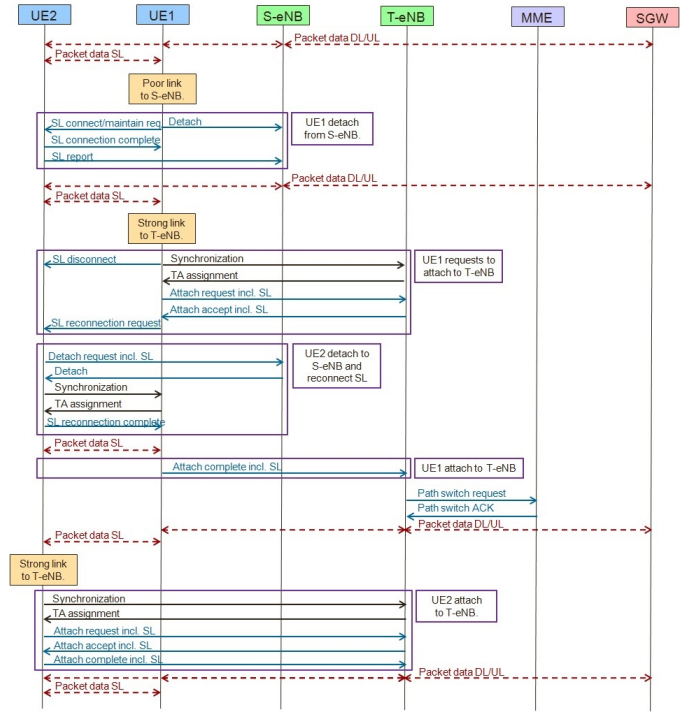


Fig. 6. UE-triggered SAHO – second case: UEs lose coverage and sequentially detach from their source eNB and maintain a sidelink connection while out of coverage, before sequentially attaching to the target eNB. Second UE is attached to source eNB when first UE attaches to target eNB.

by more than a certain threshold, the (in-band) sidelink must be interrupted to avoid interference. If synchronized eNBs assign TA to UEs, which differ less than that a certain level, coexistence of sidelink and cellular links in the same band is possible.

Independently of whether UE2 received the request from UE1 to maintain a sidelink, while being attached to S-eNB or not, the result of SAHO will be that sidelink is maintained, synchronization is provided over UE1 and finally UE2 attaches to T-eNB. However, the signaling and information exchange will be different in the two cases, as shown by sequence diagrams in Fig. 5 and Fig. 6. Here, requests and commands are shown with blue lines, data exchange with red dashed lines and synchronization procedures with black lines. Occurring events (e.g. loss of cellular coverage) are shown in yellow boxes, while procedures performed during the same logical step are shown in purple frames. mobility management entity (MME) and serving gateway (SGW) are included in the sequence diagrams, whereas it is assumed that eNBs belong to the same MME and SGW. For the general case of inter-MME or inter-SGW handover, the part referring to the SAHO procedure can be applied as shown in the diagrams.

B. eNB-instructed SAHO

According to the eNB-instructed SAHO implementation, both UEs are attached to the same S-eNB. As shown in the sequence diagram in Fig. 7, the S-eNB instructs UE1 to detach, but instead of handed over to T-eNB, it is instructed to

