LTE-A Access, Core, and Protocol Architecture for D2D Communication

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1 Introduction to D2D Communications

The term device-to-device (D2D) communications refers to direct short-range communications between terminals of a mobile network, without the intermediate transmission to a base station (BS). Differing from conventional approaches, such as Bluetooth and WiFi-Direct, D2D communications utilize licensed spectrum with quality of service (QoS) guarantees, while no manual network detection-selection is required. Compared to the very appealing cognitive radio communications, where secondary transmissions are allowed in parallel with cellular (primary) transmissions, D2D communications are established by cellular (primary) users, reaping the benefits of being synchronized and controlled by the BS.

The introduction of D2D communications in cellular networks is expected to be beneficial from a variety of perspectives, shifting the current cellular communications to a more flexible and dynamic state. The short distance between D2D transmitter and receiver provides better link conditions and, thus, more efficient connection with lower energy consumption. From the network's perspective, the use of spectrum and processing resources is reduced, since the intermediate transmissions to the BS are avoided. Moreover, the coexistence of cellular and D2D transmissions in shared spectrum bands can lead to higher spectrum utilization, offloading at the same time the cellular network. From the operators' point

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of view, new business models, probably with a new charging policy, may be designed, without the need for purchasing additional spectrum.

In the standardization field, although direct communications are already offered by local area networks in unlicensed ISM bands (e.g., WiFi-Direct), D2D communications are absent from most cellular systems. For the Long Term Evolution (LTE) system [1], the first standardization efforts have recently begun in Release 12, in which D2D communications are mainly examined under the perspective of providing new commercial or public safety proximity services (ProSe) [2]. In parallel, academia copes with a series of challenges toward enabling D2D communications (referred to as ProSe communications) in licensed spectrum.

The remainder of this chapter is organized as follows. First, we provide a comprehensive literature review on coexistence issues between D2D cellular communications. Next, we focus on D2D communication aspects currently examined by 3GPP for integrating D2D communications in future LTE networks. Finally, we propose a scheme for enabling D2D communications in LTE-A networks by enhancing standardized functionalities at the access network.

2 State of the Art on D2D Communications

In the literature, the coexistence of D2D and cellular communications is defined under two basic spectrum sharing approaches: (i) the spectrum underlay, where D2D transmissions reuse spectrum portions utilized by cellular transmitters and (ii) the spectrum overlay, where temporary empty spectrum portions are used. A comparison of the two approaches can be found in [3] and [4], in terms of transmission capacity and throughput, respectively. The key challenge in both cases is the mitigation of the generated interferences. To this end, a widely accepted choice is the exploitation of the uplink (UL) cellular period, where the only cellular interference victim is the immobile BS [5–7], shifting the major interference problem to the protection of the D2D receivers. However, the protection of the D2D receivers is quite challenging, since in both underlay and overlay approaches the interferences caused by neighboring transmissions (either cellular or D2D) are far from negligible. This is an important concern, considering that the current trend is to reduce the cell size for achieving higher spatial network capacity. This trend poses the need for more research on controlling the inter-cell interference perceived by D2D receivers in multicellular networks.

In the literature, the interference problem is mainly dealt with interference-aware Resource Allocation (RA) and Power Control (PC) schemes, e.g., [8–11]. The BS selects appropriate spectrum resources and power levels for the D2D transmitters, taking into account information about the interferences among D2D and cellular nodes. An important issue here is how the BS acquires the interference information. To this end, different mechanisms that inform the BS about the channel conditions between the D2D nodes have been introduced, exploiting mainly periodic measurements guided by the BS, e.g., [9, 12, 13]. However, gathering of the interference information consumes network resources, while reliability highly correlates with the network traffic and topology changes. Additionally, even if accurate information is available at the BS, the D2D RA and PC problems are complex and hard to optimize. Consequently, the design of solutions that reduce the need for interference information at the BS is an open challenge.

Other approaches in the literature deal with the functional enhancements required to cellular networks in order to enable D2D communications. Different scenarios and challenges in an LTE network are presented in [14, 15]. Especially in [15], a detailed classification of D2D communication aspects in LTE networks is presented, and an abstract description of the signaling needed for D2D resource allocations and data transmission is described. A major problem considered is the peer discovery, i.e., the problem of finding whether the D2D peers are close enough to directly communicate. The two basic peer discovery approaches are the centralized and the distributed. The distributed approach is considered more flexible and scalable, since it operates under local-level requirements and the complexity is shifted to the end-users. However, in modern cellular systems, such as LTE, this approach can lead to uncontrolled use of the licensed band, imposing the design of centrally controlled peer discovery schemes. A promising peer discovery solution has also been proposed by Qualcomm under the term FlashLinQ in [16]. In addition to peer discovery, this scheme includes: (i) timing and frequency synchronization derived from cellular spectrum, (ii) link management, and (iii) channel-aware distributed power, data rate, and link scheduling.

Focusing on the LTE system, the integration of D2D communications is thoroughly examined in [17, 18], where the D2D connections are mainly used for network performance optimization based on the idea of switching between the cellular and the D2D communication modes. This idea has also motivated a number of other papers in the literature, e.g., [19–21]. The strong point of this approach is that the cellular communications take advantage of the D2D benefits, while the changes in the transmission mode are totally transparent to the end-user. By contrast, the requirement of avoiding interruption during switching from one mode to the other needs more investigation. Another promising approach, described in [22], proposes to enhance the LTE network entities in order to offer extra D2D communications on allocated or empty spectrum portions, independently of the cellular transmissions. The main advantage of this approach is that the network can handle both the types of communication separately, making D2D connections transparent to the core network. In both the approaches, the use of licensed spectrum by the D2D transmitters calls for designing operator-controlled D2D schemes, and shifts the research interest to more centralized solutions.

Parallel to the research effort from academia, 3GPP has recently begun working on integrating D2D communications in LTE Release 12. The main aspects considered by 3GPP are provided in the following section.

3 D2D Communication Aspects in LTE-A Network

3.1 Background in LTE-A Network

The main cellular system that is expected to adopt the D2D communications is the LTE system. The architecture of an LTE system (and the current release LTE-Advanced—LTE-A) is divided into two basic subsystems: the Evolved—Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC) (Fig. 1). This architecture has been adopted on the Internet avoiding the hierarchical structures and providing increased scalability and efficiency. On the one hand, the EPC subsystem is a flat all-IP system designed to support high packet data rates and low latency in serving flows. On the other hand the E-UTRAN is the access network of the LTE system. The main entities of E-UTRAN are the base stations—referred to as eNBs (evolved NodeBs) for the macro-cells and HeNBs (Home-eNBs) for the femto-cells, and the cellular terminals—referred to as UEs (User Equipments).

The communication between eNBs and UEs is organized in frames of 10 ms, while each frame is divided into 10 subframes of 1 ms. Referring to transmissions from and to eNBs, there are two basic categories of subframes; the downlink (DL) and the uplink (UL), respectively. In the frequency domain, each subframe utilizes scalable bandwidth up to 20 MHz (and up to 100 MHz through the carrier aggregation mechanism) divided into subcarriers of 15 KHz spacing. Subcarriers are organized into resource blocks RBs of 180 KHz each, i.e., 12 subcarriers define an RB, the minimum allocation unit in the network.

The introduction of the D2D communications must be done in respect to this architecture, while the need for physical layer backward compatibility imposes the D2D-enabled UEs to utilize for their direct transmissions the current structure of the spectrum resources.

3.2 D2D Communication Scenarios

Currently, a lot of effort is being made by 3GPP Internet introducing the D2D communications in the next amendments of the LTE system. For a better study of the problem 3GPP has adopted the following terminologies [2]:

ProSe direct communication: a communication between two or more UEs in proximity that are ProSe-enabled, by means of user plane transmission using E-UTRA technology via a path not traversing any network node.

ProSe-enabled UE: a UE that supports ProSe requirements and associated procedures. Unless explicitly stated otherwise, a ProSe-enabled UE refers both to a non-public safety UE and a public safety UE.

ProSe-enabled Public Safety UE: a ProSe-enabled UE that also supports ProSe procedures and capabilities specific to Public Safety.

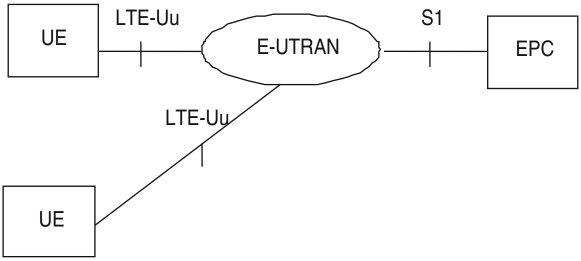

Fig. 1 LTE-A architecture

ProSe-enabled non-public safety UE: a UE that supports ProSe procedures and but not capabilities specific to public safety.

ProSe direct discovery: a procedure employed by a ProSe-enabled UE to discover other ProSe-enabled UEs in its vicinity by using only the capabilities of the two UEs with rel.12 E-UTRA technology.

EPC-level ProSe discovery: a process by which the EPC determines the proximity of two ProSe-enabled UEs and informs them of their proximity.

Based on this terminology two direct communication modes are proposed: (i) the network independent and (ii) the network authorized mode. The first mode of operation does not require any network assistance to authorize the connection and communication is performed by using only functionality and information available locally to the UE(s). This mode is applicable:

- only to preauthorized ProSe-enabled Public Safety UEs,
- regardless of whether the UEs are served by E-UTRAN or not, and
- to both one-to-one and one-to-many direct communication.

The second mode of operation for ProSe direct communication always requires network assistance by the EPC to authorize the connection. This mode of operation applies:

- to ProSe one-to-one direct communication,
- when both UEs are “served by E-UTRAN,” and
- for Public Safety UEs it may apply when only one UE is served by E-UTRAN.

For these communication modes and considering the registered public land mobile network (PLMN), the direct communication path and coverage status (in coverage or out of coverage), a number of different possible communication scenarios are defined as shown in Table 1, while a comprehensive illustration of these scenarios is provided in Fig. 2. However, these scenarios do not cover all the possible scenarios for direct communication, and 3GPP in working on adding more scenarios especially for the case of group communication.

Table 1 D2D communication scenarios in LTE networks

Scenario	In/out coverage		Serving PLMN/cell
	UE-A	UE-B	
A	Out	Out	No serving PLMN/cell
B	In	Out	No serving PLMN/cell for UE-B
C	In	In	Same PLMN/cell
D	In	In	Same PLMN—different cell
E	In	In	Different PLMN/cell both UEs are in both cells' coverage
F	In	In	Different PLMN/cell UE-A is in both cells' coverage UE-B is in serving cell's coverage
G	In	In	Different PLMN/cell both UEs are in their own serving cells' coverage)

3.3 D2D Reference Architecture

For supporting the scenarios defined above enhancements are required to the LTE architecture. Figure 3 depicts this architecture and aims to fulfill the following requirements posed by 3GPP.

- Enable the operator to control the ProSe discovery feature in its network and authorize the functionality required for the ProSe discovery functions for each UE.
- Enable the ProSe communication or ProSe-assisted WLAN Direct communication and seamless service continuity when switching user traffic between an infrastructure paths and a ProSe communication path of the ProSe-enabled UEs.
- Enable HPLMN operator to authorize ProSe-enabled UE to use ProSe communication separately for the HPLMN and for roaming in VPLMNs.
- Enable an authorized third party ProSe application to interact with 3GPP network in order to utilize the ProSe services offered by the network.
- Be able to control ProSe communication between ProSe-enabled UEs when the UEs are served by a same eNB or different eNBs.
- Accommodate the ProSe-related security functions related to privacy, support for regulatory functions including Lawful Interception, and authentication upon ProSe discovery and ProSe communication.
- Enable the operator to authorize and authenticate the third-party applications before making use of the ProSe feature.
- Accommodate for charging by the operators (HPLMN or VPLMN) for utilization of the ProSe functionality.

As depicted in Fig. 3, additional to the entities of the conventional LTE architecture, a number of new entities are required as shown in Fig. 1. These entities are as follows:

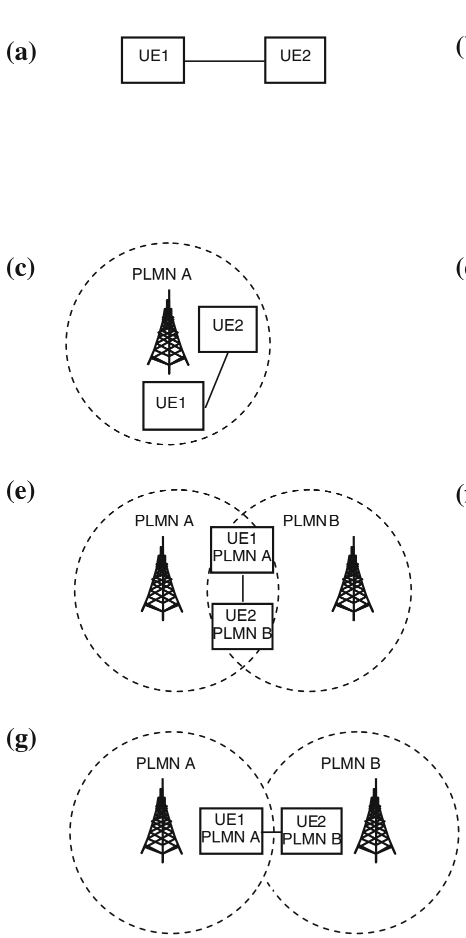

Fig. 2 3GPP direct communication scenarios [2]

Application servers (ProSe App Server) incorporates the ProSe capability for building the application functionality, e.g., in the Public Safety cases they can be specific agencies (PSAP) or in the commercial cases social media. These applications are defined outside the 3GPP architecture but there may be reference points toward 3GPP entities. The Application server can communicate toward an application in the UE.

Applications in the UE (ProSe UEs App) use the ProSe capability for building the application functionality. An example may be for communication between members of Public Safety groups or for social media application that requests to find buddies in proximity.

ProSe Function in the network (as part of EPS) defined by 3GPP has a reference point toward the ProSe App Server, the EPC, and the UE. The functionality

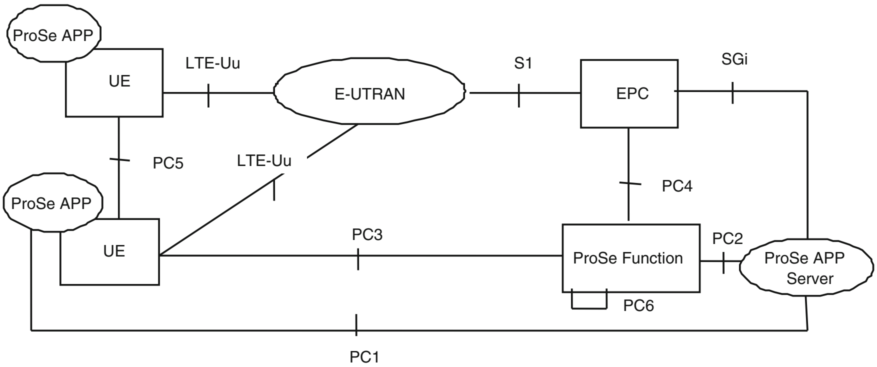

Fig. 3 D2D-enhanced LTE architecture [2]

may include but is not restricted to: interworking via a reference point toward the third-party applications, authorization and configuration of the UE for discovery and direct communication, enable the functionality of the EPC-level ProSe discovery, and provide functionality for charging (via or outside of EPC, e.g., offline charging).

Note that for the interconnection of the new entities and the connection with the conventional LTE entities, seven new interfaces/reference points are defined as PC1, PC2, PC3, PC4, PC5, PC6, and SGi (Fig. 3).

4 Proposed D2D Scheme

4.1 System Model

We adopt a ProSe communication scenario where both ProSe-Enabled UEs are connected to the same PLMN/cell. The eNB operates as a D2D controller, and as such, it is responsible for the following: (i) the D2D RA and PC and (ii) the peer discovery and tuning for the D2D peers. Potentially, the capability for D2D transmission is provided to all UEs of the network; however, hereinafter, to simplify our description, the UEs that implement our D2D scheme will be referred to as eUEs (enhanced UEs).

Similar to UEs, eUEs request resources for D2D communications from the eNB. For each one of the D2D requests, eNB launches a peer discovery procedure, while only the valid D2D pairs (with successful peer discovery procedure) are considered in the D2D RA and PC procedures. Differing from the conventional RA procedure, in the D2D RA one the eNB informs both D2D transmitter and receiver about the allocation grant, tuning them to the allocated resources. However, this tuning requires the eNB to know the identity of the D2D receiver. Conventionally, identities, such as the destination IP addresses, or destination IMSI/S-TMSI identities (International-/Subscriber-Temporary Mobile Subscriber Identity), or other upper explicit level identities (e.g., SIP addresses), are not available locally at the eNB and thus, cannot be used without the involvement of the core network. Thus, the introduction of a new identity for each eUE is required. As explained later, this new identity is generated by each eUE during its initial access to the network, and any transmitting eUE device has the ability to produce the D2D identity of its target eUE. When an eUE wants to establish a D2D connection, the D2D identity of the target eUE is included in the D2D resource request. The serving eNB, having a one-to-one mapping between standardized and D2D identities, uses the former identities in order to inform both D2D transmitter and receiver about the resource allocation.

The adopted D2D model can be summarized as follows:

- Each eUE produces its D2D identity and transmits it to the eNB during its first access to the network.
- eUEs make D2D spectrum requests using the standard spectrum request procedure, including, however, the D2D identity of the target D2D receiver.
- The eNB launches a peer discovery procedure for the requested D2D pair.
- The eNB allocates cellular resources to valid D2D pairs and informs both D2D peers, tuning them indirectly at the same spectrum portion. The D2D RA combined with a PC scheme guarantees the interference-free conditions between cellular and D2D system.
- The eUE transmitter sends its data using the spectrum region that has been allocated by the eNB, while the eUE receiver tunes to the same spectrum region to receive the transmitted data.
- The eUE receiver acknowledges the reception (or not) of the data through the eNB following the conventional-standardized procedure.

The proposed system model requires enhanced functionality only at the access network, i.e., at the standard UEs (upgrading them to eUEs), and at the eNBs.

4.2 Proposed Enhancements in Access Network

4.2.1 D2D Identity Production and Notification at the *eNB*

In standardized–cellular communications, the eNB uses the Cell Radio Network Temporary Identifier (C-RNTI) to uniquely identify UEs. A unique C-RNTI is assigned by the eNB to a UE during the initial random access procedure and is used for identifying the Radio Resource Control (RRC) connection and for scheduling purposes. Practically, the coding/decoding of the physical downlink control channel (PDCCH) intended for a specific UE is based on this UE's C-RNTI [1]. In more detail, each UE initiates a contention-based access to the network by transmitting a preamble sequence on the physical random access channel (PRACH) (Fig. 4). As a result, it is supplied with a temporary random C-RNTI by the eNB via the random access response message. Assuming that contention resolution due to potential preamble collisions is not required or is already resolved, this temporary C-RNTI will be promoted to normal C-RNTI, to be used for unique identification inside the cell, for as long as this UE stays in connected mode. The random access procedure is successfully completed upon the reception and acknowledgment of the RRC Connection Setup message by the UE.

In D2D communications, as resulted by the description of the proposed system model in Sect. 2, an additional D2D identity is required at the eNB for the D2D transmission. Hereafter, this identity will be referred to as *D2D-ID*. The eUE register to the network like any standard UE following the procedure described above, including, however, its D2D-ID in the RRC Connection Request message, transmitted via the physical UL shared channel (PUSCH). This is the same message where the initial UE identity (International-/Temporary Mobile Subscriber Identity—IMSI/S-TMSI) is included. The D2D-ID is introduced as a new information element in the RRC connection request message (Fig. 4) [23]. In line with the 3GPP description of the RRC connection request, we define the D2D-ID as an optional (OP) information element, in the sense that its presence or absence is significant and modifies the behavior of the receiver. Nevertheless, whether the information is present or not does not lead to an error diagnosis [23].

The D2D-ID is produced by the eUE, using a transformation of the Mobile Subscriber Identification Number (MSIN), the 10-digit number that uniquely and globally identifies a mobile phone. All eUEs use the same algorithm/technique for the D2D-ID production; thus, provided that the MSIN of the target eUE is known at the eUE transmitter (in its contact list), the target's D2D-ID can be faultlessly produced. Note that in the general/simplest approach the D2D-ID could be the MSIN. However, the adoption of this new D2D-ID, instead of directly using the MSIN, is based on privacy, security, and optimization reasons. The transformation algorithm can guarantee the concealment of the MSIN and also the production of D2D-IDs from valid-MSIN, preventing users to use any 10-digit number when trying to establish a D2D connection. The selection of an efficient algorithm for the MSIN transformation is out of the scope of this paper. However, any conventional hashing algorithm is applicable.

4.2.2 D2D Connection Request

Let eUE_1 want to establish a D2D connection to eUE_2. Assume that both eUEs have already submitted their D2D-IDs using the D2D-ID information element in their RRC connection request message, as explained above. Normally, when a UE has data to transmit, the Buffer Status Report (BSR) procedure is initiated [23]. According to this procedure, a Regular BSR informs the serving eNB via the PUSCH about the amount of data pending for transmission in its UL buffers. Note that, if no BSR is already allocated (i.e., no other transmissions are already

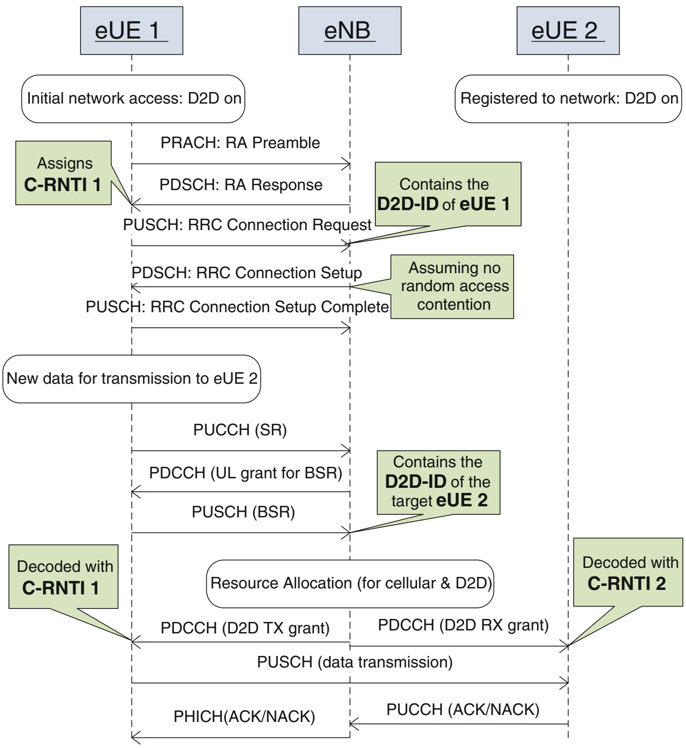

Fig. 4 D2D enhancements in standard LTE signaling

initiated), a single-bit Scheduling Request (SR) on the physical UL control channel (PUCCH) precedes the BSR request [23].

In addition to the standard information that any UE includes in the BSR request, the eUE_1 produces the D2D-ID of the target UE (eUE_2) and adds it to the request (Fig. 4). An unused 16-bit long MAC Control Element inside the BSR request is used for that purpose, differentiating a D2D request from a cellular one. This element utilizes space currently reserved for future use and it is indexed in the MAC Protocol Data Unit (PDU) sub-header by the Logical Channel ID (LCID) value equal to 11,000. The new element is called *D2D Receiver ID* and is appended to the existing LCID values, such as the common control channel (CCCH), the C-RNTI, and the Padding [23]. The MAC PDU structure that includes D2D requests is shown in Fig. 5. In this figure, the extra MAC sub-header for D2D request is depicted as the last sub-header of the MAC header.

The eNB keeps a one-to-one mapping between C-RNTIs and D2D-IDs, created during the initial network access of each eUE, as previously explained. Consequently, upon the reception of a request, eNB locates the C-RNTIs of the requesting and the destination eUE in this mapping table using the respective

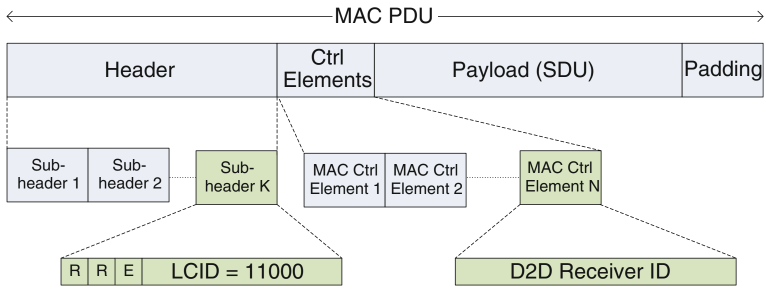

Fig. 5 Enhanced MAC PDU

D2D-IDs. Following that, it uses the corresponding C-RNTIs to encode the allocation messages (allocation grant) for the eUE transmitter and receiver.

4.2.3 D2D Resource Allocation and Power Control

The selection of the D2D RA and PC is a key factor for guaranteeing fair, reliable, and interference-free spectrum sharing between cellular and D2D communications, as well as among D2D communications. The secondary resource allocation scheme can be independent of the cellular/primary one. However, as shown in [13], the primary resource allocation algorithm includes important information that can be used for the design of an interference-aware secondary allocator. In the general case, eNB can use any RA and PC scheme that guarantees interference-free conditions among all the concurrent transmissions.

Differing from the standardized procedure, the D2D allocation grant is also transmitted to the target eUEs (D2D receivers) to inform them about the appropriate spectrum region in which they will receive the D2D data. Potentially, this choice increases the loading on downing control channels; however, no changes in the eNB signaling are needed. Note that in Fig. 4, we refer to the resource allocation to the D2D receiver as D2D RX grant to differentiate it from the D2D TX grant of the D2D transmitter, even though both refer to the same physical resources.

The very first D2D RA to a D2D request is used for device discovery purposes. The eNB allocates an empty RB to the D2D request as if the request was by a cellular UE. This RB is used by the D2D transmitter to send a pilot signal toward checking if it can reach the D2D receiver. Since the RB is more than adequate for a pilot signal, the D2D transmitter adds data to fill in the resources of the RB, utilizing in that way the extra spectrum space in case the D2D receiver is reached. Note that the appropriate power for the pilot signal transmission is fixed and depends on the range of the D2D connections that the eNB allows inside its cell. After a successful peer discovery, the D2D receiver acknowledges the reception of the pilot signal to eNB. For the subsequent allocations of the same request, the eNB can utilize primarily allocated or empty resources referring to the spectrum underlay and overlay approach, respectively.

For the D2D transmissions the ACK/NACK messages are transmitted as in the case of standardized–cellular transmissions. According to the standardized procedures, an ACK/NACK message is transmitted by the receiver to eNB through the PUCCH in order to acknowledge (or not) whether the data have been successfully received. Then, eNB forwards this message through the Physical Hybrid ARQ Indicator Channel (PHICH) [23] to inform the transmitter.

4.3 Evaluation Results

To evaluate the proposed scheme, we made changes to the system level simulator proposed in [24] in order to support D2D communications. The basic parameters of the simulation are shown in Table 2.

4.3.1 D2D Spatial Spectrum Reuse

In Fig. 6, we examine the maximum number of D2D devices that can transmit concurrently with a UE transmitter located at a distance of half the cell radius from the eNB. The UE, through the power control procedure, transmits with the minimum power that guarantees a target SINR threshold at the eNB. D2D transmitters use fixed power that equals to -19 dBm, a power level that can guarantee an acceptable SINR level at a small distance (up to 50 m). As it was expected the more the D2D transmitters the more the SINR degradation at the eNB. However, an interesting result extracted by Fig. 6, is that for D2D users located at a distance more than $\sim$35 % of the cell radius from the eNB, the SINR distortion is negligible and practically independent of the number of D2D transmitters. This result validates that the D2D connectivity is a suitable candidate for improving the spatial spectrum utilization, especially at areas closer to cell edges. From the opposite perspective, the protection of the D2D connections from the UE and the other D2D transmissions is also very important. In this direction, a comprehensive result is given in Fig. 7.

In Fig. 7, we calculate the percentage of the cell area where potential D2D receivers are instantaneously not interfered by the cellular UE's transmission. This percentage is actually a measure of the maximum spatial spectrum reuse ratio. As shown in this figure, the dependency of the spectrum reusability on the distance of the cellular UE from the eNB is higher as the target SINR at the eNB increases. The higher the required quality for a cellular communication, the higher the required SINR at the eNB, and, thus, the higher the transmit power of the UE, something that will inevitably reduce the allowed D2D reuse. Moreover, since the UE transmitter uses an omnidirectional antenna, its signal best covers the cell area when it is located at a distance of approximately half the radius from the eNB,

Table 2 Basic simulation parameters

Parameter	Value
Region of interest (ROI)	Cell sector
Cell radius	320 m
(e) UE distribution	Uniform
Carrier frequency	2 GHz
Bandwidth	10 MHz
Pathloss model	3GPP TS 36.942
Max cellular UE Tx power	200 mW (23 dBm)
Fixed D2D UE (eUE) Tx power	0.0125 mW (−19 dBm)
eNB noise figure	5 dB
eNB thermal noise density	−174 dBm/Hz
Accepted block error rate (BLER)	<10 %

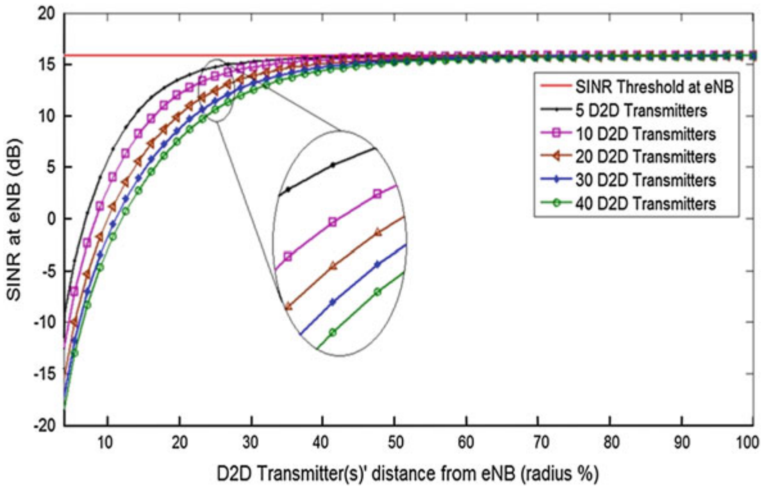

Fig. 6 SINR at eNB for different number and locations of D2D transmitters

suppressing the possibility for parallel noninterfering D2D transmissions, which justifies the concave shape of the curves. In the case of multiple D2D transmitters reusing the same resources, this ratio is expected to decrease, because neighboring D2D transmissions will cause interference to each other. Generally, during each UL cellular transmission, around 40–100 % of the cell area seems to be available for extra D2D transmissions.

4.3.2 Performance Degradation due to Device Discovery Procedure

In Fig. 8, we monitor the system's performance in terms of throughput for 500 subframes in two cases: (i) the conventional one, with no device discovery (solid

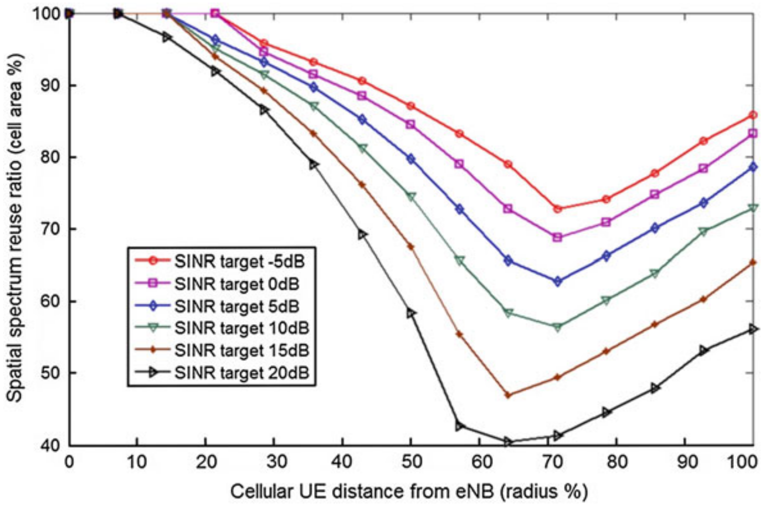

Fig. 7 Spatial spectrum reuse ratio in a cell for different UE locations

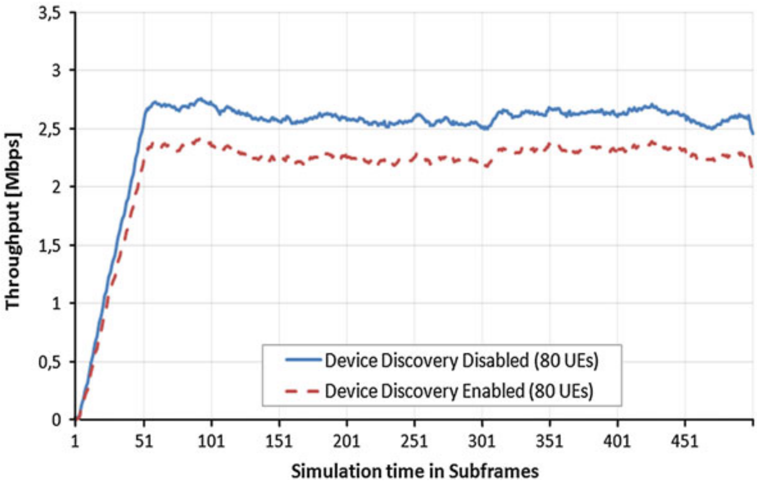

Fig. 8 Burdening of cellular communication's throughput due to discovery transmissions

line), and (ii) the case that 20 % of the UEs in a target cell launch a device discovery scheme (dashed line). We assume that a single RB is allocated for each expression code transmission, while the throughput is calculated in a frame per frame basis (every 10 subframes). The result depicted in Fig. 8 shows a reasonable decrease in the achievable throughput of about 13 %. However, in this result, the gain on better spectrum utilization offered by the direct communications is not included.

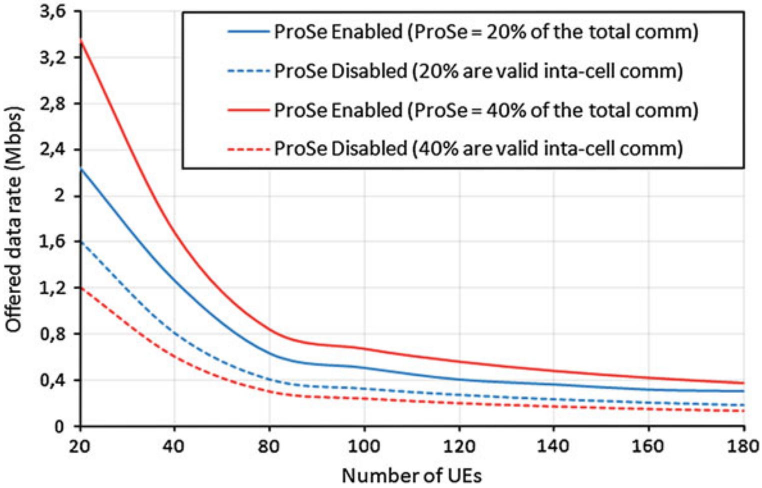

Fig. 9 Offered data rates with enabled and disabled direct communications

4.3.3 Traffic Offloading due to Direct Transmissions

After a successful device discovery procedure, intra-cell communications, i.e., cellular communications between UEs served by the same eNB, can switch to direct mode. This results to better spectrum utilization due to the proximity gain, and consequently, higher total data rates are offered to the system. Figure 9 depicts the mean data rate offered to conventional transmissions with (solid line) and without (dashed line) the ability of switching the valid intra-cell communications to direct ones. Two different scenarios are assumed. In the first scenario, the intra-cell communication requests are 20 % of the total requests (blue curves), while in the second one, they are increased to 40 % (red curves). As shown in Fig. 9, in the second scenario, the extra mean data rate offered to an inter-cell communication is higher than that in the first one, due to the increased number of transmissions served in direct mode. Also, for both scenarios, the offered gain in data rates is quite large (up to 50 %) and decreases for an increased number of UEs. This decrease is because the spectrum resources are limited, and as the number of UEs increases, the available spectrum utilization for every UE is reduced.

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