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OPERATOR CONTROLLED DEVICE-TO-DEVICE COMMUNICATIONS IN LTE-ADVANCED NETWORKS

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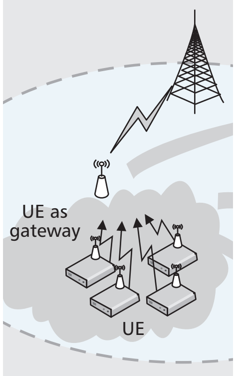

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ABSTRACT

This article studies direct communications between user equipments in the LTE-advanced cellular networks. Different from traditional device-to-device communication technologies such as Bluetooth and WiFi-direct, the operator controls the communication process to provide better user experience and make profit accordingly. The related usage cases and business models are analyzed. Some technical considerations are discussed, and a resource allocation and data transmission procedure is provided.

INTRODUCTION

Device-to-device (D2D) communications commonly refer to the technologies that enable devices to communicate directly without an infrastructure of access points or base stations, and the involvement of wireless operators. The term "device" here refers to the user who uses cell phones or other devices in Human-to-Human (H2H) communications as well as "machine" in Machine-to-Machine (M2M) communications without the involvement of human activities. The most widely known D2D technologies are Bluetooth and WiFi working at the 2.4GHz unlicensed band. Up to now, wireless operators don't include the D2D function in the universal cellular network standards, e.g., Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS) and 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE). This is largely because the D2D function was only envisioned as a tool to reduce the cost of local service provision, which is fractional according to the operators' current market statistics. Recently, the wireless operators' attitude towards the D2D function is changing because of several new trends in the mobile market. First, the context-aware applications are emerging in smart phones which are envisioned as an important value added service since an wireless operator can provide a plurality of services to a user according to its location information and its working status. For example, a user may be informed of a nearby restaurant, and the user can reserve a seat and get a coupon by making a call or sending a short message. Since most of the context-aware applications involve discovering and communicating with nearby devices, the D2D function can facilitate the discovery of neighboring devices and reduce the communication cost between these devices. Secondly, M2M applications are fast growing recently. Since the cellular equipments are getting smaller and cheaper, the wireless operators have great opportunities to connecting consumer electronic devices to their networks, e.g., washing machines and ovens. Since most consumer devices work around their owners, the cellular phone can be the hub for these devices and used as the gateway to the cellular networks. The D2D function enables the communications between consumer devices and cell phones.

The above emerging services and applications are driving wireless operators to pursue the D2D function in their networks. However, the traditional D2D technologies are inadequate. First, there are more than 5 billion cellular users globally, who can only realize D2D function by WiFi or Bluetooth, which is not an integral part of the cellular networks and thus causes inconvenience customer usage experience. For example, both Bluetooth and WiFi require manual pairing between two devices. The distance of WiFi-direct is claimed to be 656 inches, which means that dozens of devices within the range may be on the list. This process will make the user quite cumbersome compared to making a phone call. Second, the traditional D2D technologies are unable to meet the requirements of some users or applications due to several technical limitations. Since most of the traditional D2D technologies work on the crowded 2.4GHz unlicensed band, the interference is uncontrollable. In addition, traditional D2D technologies cannot provide security and Quality-of-Service (QoS) guarantee as the cellular networks. Last but not the least, the wireless operators cannot make profits using traditional D2D technologies

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since they work independently without the involvement of the operators.

Unwilling to lose the emerging market that requires the D2D function, the wireless operators and vendors are exploring the possibilities of introducing the D2D function in the cellular networks. In [1], the concept of D2D communications as an underlay to an LTE-Advanced cellular network is introduced. A wireless technology called as the FlashLinQ that enables devices to directly sense their surroundings and directly communicate with each other is proposed in [2], which can be used in licensed band and as a complementary to the Wide Area Network (WAN). At the 3GPP meeting held in June 2011, a study item description on the radio aspects of device-to-device discovery and communication has been submitted by Qualcomm. Meanwhile, a study item description on LTE-direct is submitted to the 3GPP meeting held in August 2011, which proposes the study of the service requirement of direct over-the-air LTE device-to-device discovery and communication. Although interested in bringing the D2D function into cellular networks, the operators require to control the D2D services. Furthermore, the operator controlled D2D communications is facing a great dilemma in which if the users are charged for their D2D services, they may turn to traditional D2D technologies, which are free but with lower speed and less security. Therefore, the operators must answer the “pay for what” question before they can push forward the operator controlled D2D technology, which requires some analysis on the usage cases and business models.

In this article, we first classify the operator controlled D2D communication technologies into two broad categories according to the level of operator control over D2D communications. The usage cases and business models are analyzed, followed by some technical considerations on the radio aspects of operator controlled D2D communications. Finally, the article is concluded.

D2D CONTROLLED MODE

The operator controlled D2D (OC-D2D) communications are defined as the technologies with which the devices communicate directly with each other under a cellular network or an operator control. The operator controls over normal user communication process which mainly lies in four aspects: access authentication, connection control, resource allocation, and lawful interception of communication information. The last aspect is very difficult to achieve for D2D communications, since information is directly exchanged between users bypassing the operator deployed base stations. According to the level of operator control over D2D communications, two categories of operator controlled D2D technologies can be classified.

FULLY CONTROLLED D2D MODE

The D2D link between two User Equipments (UEs) is an integral part of the cellular networks, just like the common cellular downlink or uplink connections. The cellular network has the full control over the D2D connection, including control plane functions, e.g., connection setup and maintenance, and data plane functions, e.g., resource allocations. The D2D connections share the cellular licensed band with the normal cellular connections. The network can either dynamically assign resources to each D2D connection in the same way as a normal cellular connection or semi-statically assign a dedicated resource pool to all D2D connections. The operator can charge the users for using D2D service based on how many minutes or how much bandwidth they use.

LOOSELY CONTROLLED D2D MODE

The operators perform the access authentication for the D2D enabled devices. Apart from this, these D2D devices can setup D2D connections and start D2D communication autonomously with little or no intervening from the operators. To avoid interference to the normal cellular users, the D2D communications can make use of either the unlicensed band with WiFi or Bluetooth for data transmission or a dedicated carrier on the licensed band. The operators can charge a certain amount of fee per month for providing the D2D service irrespective of the actual D2D data flow in the network. However, the operators must be able to disable the D2D service if the users do not pay for it.

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USAGE CASES AND BUSINESS MODELS

The D2D usage cases can also be classified into two broad categories. The first category is referred to as the peer to peer case, in which the D2D devices are the source and destination of the exchanged data. The second category is the relay case, which means that one of the communicating D2D devices has to relay the exchanged information to the base station which further forwards the data to the destination device.

PEER TO PEER

Local Voice Service — OC-D2D communications can be used to offload local voice traffic when two geographically proximate users want to talk on the phone, e.g., people in the same large meeting room want to discuss privately, or companions get lost in a supermarket, as shown in Fig. 1a. However, this usage case is rare according to the operators’ current market statistics.

Local Data Service — OC-D2D communications can also be used to provide local data service when two geographically proximate users or devices want to exchange data, as shown in Fig. 1b. Some scenarios of D2D communications are illustrated below.

Content Sharing: Friends exchange photos or videos through their smart phones, or people attending a conference download materials from a local server.

Multiplayer Gaming: The famous Japanese game “Dragon Quest IX” has a co-op mode consisting of up to four players using local wireless connections to play together. The three guests join the host system’s world and can go anywhere that the host has explored.

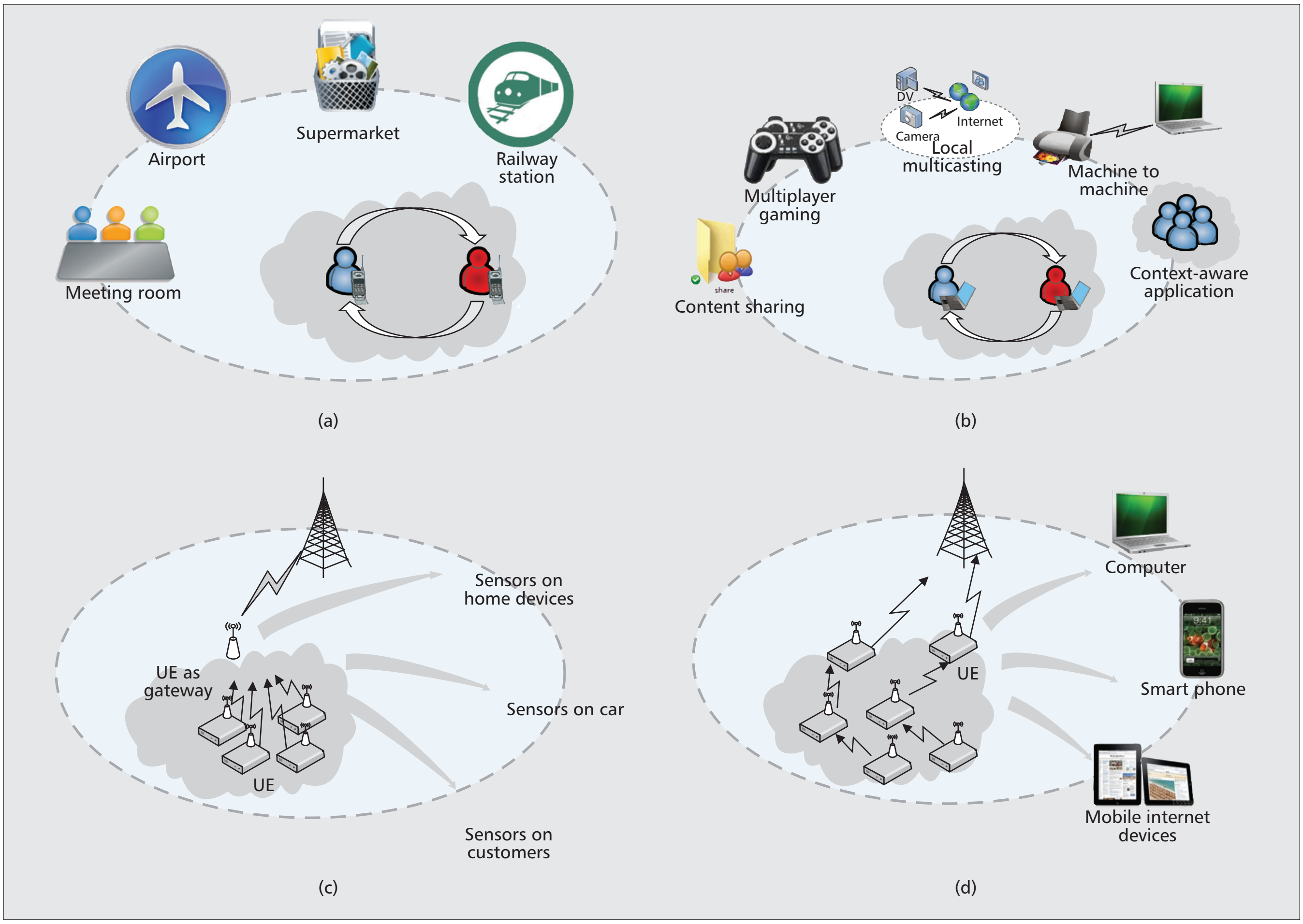

Figure 1. *D2D usage cases:a) local voice service; b) local data service; c) UE as gateway to sensor networks; and d) UE cooperative relay.*

Local Multicasting: The shops advertise the sale promotion information to the customers.

Machine to Machine: A laptop connects to a printer, or a smart phone connects to a television for the photo or video display.

Context-aware Application: It is a driving factor for the D2D technologies and is based on the people's desire to discover their surroundings and communicate with nearby devices (machines or people). One example is the "Dragon Quest IX" game, which has a tag mode allowing nearby game devices to discover each other and exchange messages automatically without the players' awareness. Therefore, a player can take his game device to a mall or a coffee shop and find he has "met" a lot of interesting people when he comes back. Another example is location aware social networking, such as Foursquare, where users "check-in" at venues using a mobile website, text messaging or running a device-specific application and selecting from a list of venues that the application locates nearby. Each check-in awards the user points and sometimes "badges". Therefore, context-aware applications may be based on any of the above four types of D2D communications, but they should be able to notice/interact when something nearby is interesting.

Although it is appealing, making consumers adopt the OC-D2D technologies is tricky. The toughest problem is the competition with the traditional D2D technologies, which are currently dominating the market and allow the users to use local data service freely. Therefore, the OC-D2D technologies have to be attractive enough for consumers to switch and be willing to paying for this service.

Some of the good reasons to attract users for operator controlled D2D services are listed below:

Pay for identity: Use loosely controlled D2D technologies to link cellular phone number with WiFi or Bluetooth identity, which facilitates D2D connection setup and provides value-added service through identity management. For example, the users can start photo or video exchange through WiFi by dialing phone numbers instead of searching for the WiFi name;

Pay for QoS and security: Use fully controlled D2D technologies for those services which require high QoS and/or security;

Pay for context information: Operators have deep contextual information about end users and have an emerging opportunity to leverage context to make it pay off competitively.

RELAY

UE as the Gateway to Sensor Networks — Most M2M devices are not "directly cellular". In other words, M2M devices usually first connect to an M2M gateway using Wireless Personal Area Network (WPAN), e.g., zigBee, and the M2M

Usage Cases	Peer to Peer		Relay	
	Local voice service	local data service	UE as gateway to sensor networks	UE cooperative relay
Benefits	Enhance capacity	Provide new services		Enhance capacity
Marketing Challenges	Rare occasion	Competition from traditional free D2D techniques		Users' concern on information security etc.
Potential Business Models		• Attract users to pay for identity, QoS and security, context information, and management, etc. • Charge the users based on how many minutes or how much bandwidth they use in fully controlled D2D communications; and charge a certain amount of fee per month irrespective of the actual D2D data flow in loosely controlled D2D communications		

Table 1. *Usage cases for operator controlled D2D communications.*

gateway connects to a cellular network. For many consumer M2M devices, e.g., sensors on home devices, cars, or even the onbody health care devices, cell phones on the consumers are the most suitable M2M gateways. The communications between these sensors and UEs can use the OC-D2D technologies.

Similar to the local data service usage case, the OC-D2D technologies also faces challenges from the traditional D2D technologies. The following are some possible answers to the "pay for what" question of the OC-D2D communications.

Pay for management: One possible business model for the OC-D2D communications is given in [3], where non-cellular devices are included into the operator's subscriber database and automatically associated with the owner's cellular devices. An M2M profile is created for such device to store its relevant information, such as the owner and device specific access policies. Authentication/key management can be provided for the sensor devices that require security. An operator can also separately meter the data from different devices behind a phone/gateway.

Pay for QoS and security: Use fully controlled D2D technologies for those applications that require high security and QoS, e.g., sensors for life care or security.

UE Cooperative Relay — In the wireless telecommunications systems that have a large number of subscribers, it is well known that one efficient communication method is to break a long path into a number of smaller hops so that the information is relayed between a number of terminals. The integration of cellular and ad-hoc networks to provide the UE relay capability has been well studied [4, 5]. 3GPP has even considered to apply this technique for the UMTS Time Division Duplex (TDD) under the concept of Opportunity Driven Multiple Access (ODMA) [6]. However, the UE relay faces a number of business model difficulties apart from the technical challenges. The biggest obstacle is the users' concern on the information security, wireless radiation and excessive consumption of their battery power, all of which are due to opening up their mobile devices to other users. Therefore, 3GPP has finally decided to give up the ODMA standardization. These problems still exist today and a proper business model with enough incentives for users needs to be designed if the OC-D2D technologies is to be applied to this scenario.

A further optimization for the UE relay is to apply the cooperative techniques [7], i.e., the D2D communications capability enables the users' cooperation to achieve the transmit diversity, multi-antenna transmission and network coding, etc.. These techniques are still mostly under the academic research and not mature enough for the standardization and implementation in the near future.

The benefits, marketing challenges and potential business models for different operator controlled D2D usage cases are summarized in Table 1. They should be taken into account in the design of various OC-D2D technologies.

TECHNICAL CONSIDERATIONS IN RADIO ACCESS NETWORKS

SPECTRUM FOR OPERATOR CONTROLLED D2D COMMUNICATIONS

The categories of spectrum that the OC-D2D communications can operate on are listed as follows.

Unlicensed band: The advantage is that operators do not need to sacrifice valuable licensed spectrum for providing D2D services. However, the uncontrolled interference condition makes this option rather unattractive to the users. One possible scenario of carrying D2D traffic on unlicensed band is that operators provide automatic device pairing, device authentication etc. using loosely controlled D2D technologies for the users.

Frequency Division Duplex (FDD) licensed band: In order to support D2D function in FDD band, UE has to add Rx chain in the uplink spectrum or Tx chain in the downlink spectrum or both, which will increase UE cost and complexity. Therefore, for those operators who only have FDD spectrum, providing D2D service may be more difficult.

TDD licensed band: Since UE has both Rx

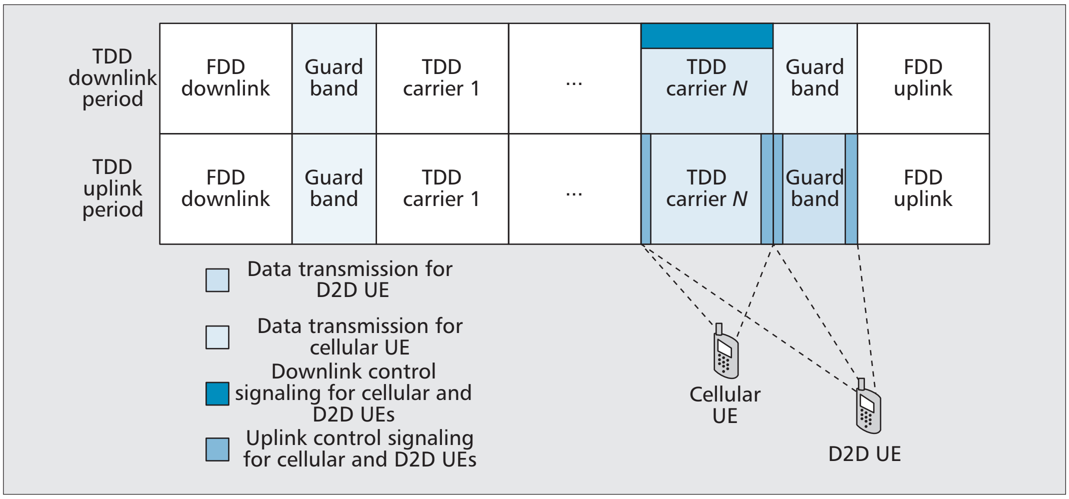

Figure 2. *Use of guard band between TDD and FDD for D2D communications.*

and Tx chains for data transmission and reception in TDD spectrum, no additional Rx/Tx chains are needed to support D2D communications, which makes TDD spectrum more suitable for carrying D2D traffic. For operators with both TDD and FDD spectrum, TDD spectrum can be dedicated to D2D communications. For operators with only TDD spectrum, D2D communications can share resources with normal cellular communications, or occupy one or several dedicated carriers.

Guard band between FDD and TDD: TDD and FDD wireless systems that are deployed in the same geographical area need frequency separation referred to as “guard band” to prevent Radio Frequency (RF) interference with one another. Normally, guard band cannot be used for the sake of interference coexistence between TDD and FDD. However, it is possible to transmit data on the guard band with properly designed techniques to increase resource utilization. For example, one approach is to apply half-duplex FDD in the guard band, where only uplink (or downlink) transmission is performed in the TDD uplink (or downlink) period on the guard band between TDD and FDD uplink (or downlink) carriers [8]. Using guard band for D2D communications can be more cost-efficient than using normal licensed band, which allows operators to provide low cost D2D services in competition with traditional D2D technologies. One possible method for transmitting the D2D service on the guard band between the TDD and FDD uplink carriers is shown in Fig. 2, where the carrier aggregation technique is used to transmit the downlink control signaling from the base station to the D2D UEs on the TDD carrier.

POWER CONTROL, RESOURCE ALLOCATION AND INTERFERENCE MANAGEMENT

Power control and resource allocation of D2D connections can be either distributively determined by the UEs themselves or centrally performed by the base station, which is referred to as the Evolved Node B (eNodeB) in LTE systems. In the former case, dedicated resources have to be allocated to all the D2D connections statically or semi-statically so that no interference should be caused to the cellular connections. In the latter case, the D2D connections may either use dedicated resources or share resources with cellular users, since the eNodeB can make sure that the mutual interference between cellular and D2D connections are acceptable via scheduling and power control.

An example of distributed resource allocation scheme is FlashLinQ, which is an Orthogonal Frequency Division Multiplexing (OFDM)-based synchronous MAC/PHY architecture for D2D communications. Unlike traditional D2D technologies, FlashLinQ is designed to work on licensed band, where interference is more controllable. The goal is to schedule a channel-state aware maximal independent set at any given time slot based on the current traffic and channel condition, and the scheduling algorithm leads to spatial throughput gains over an IEEE 802.11g system [9]. This resource allocation approach can be used in loosely controlled D2D communications on licensed band or fully controlled D2D communications where the base station semi-statically assigns a dedicated resource pool for all D2D users.

Significant research has been done on the centralized resource allocation and power control algorithms considering mutual interference between D2D and cellular connections, where D2D communication is considered as an underlay to LTE-advanced networks [10–14]. The resource sharing mode selection problem, which decides whether the network shall assign D2D communication mode or not to a user pair and whether a pair of D2D users shall share resources with cellular users or use dedicated resources instead, is considered in [10, 11]. In [12, 13], resource allocation algorithms among the cellular and D2D links are studied. Reference [14] investigates power control algorithms for the D2D mode communications. Although the emphases of these works are different, the resource sharing mode selection, resource allocation and power control algorithms are usually considered jointly in order to achieve the optimal performance.

Power control and resource allocation of D2D connections can be either distributively determined by the UEs themselves or centrally performed by the base station, which is referred to as the Evolved Node B (eNodeB) in LTE systems.

For the centralized resource allocation approach, the eNodeB has full control over the resources allocated to each D2D connection and needs to inform the D2D UEs of the scheduled resources for data transmission via L1/L2 control signaling, e.g., Physical Downlink Control Channel (PDCCH). However, this problem has not been adequately addressed.

In this article, we provide a resource allocation and data transmission procedure, as shown in Fig. 4. This procedure gives an example of how a centralized resource allocation approach could be implemented in an LTE-advanced system, identifying the possible control and data channels between the eNodeB and the D2D UEs for control signaling and data service transmission. Assume UE1 and UE2 have established an D2D connection and UE1 has data wait to be transmitted to UE2. The eNodeB is responsible for resource allocation. First, UE1 notifies the eNodeB that it has data to be transmitted to UE2. According to the LTE protocol, UE1 can send a buffer status report (BSR) [15] to the eNodeB through the Physical Uplink Shared Channel (PUSCH) [16] for this purpose. If no uplink resources are available for the BSR transmission, UE1 can send a one bit scheduling request (SR) [15] signaling through the Physical Uplink Control Channel (PUCCH) [16]. Once the eNodeB receives the SR from UE1, it will allocate a small amount of uplink resources for the BSR transmission.

After the eNodeB receives the notification (e.g., BSR) from UE1, it will allocate resources for the data transmission between UE1 and UE2. The specific resource allocation algorithms will not be discussed here. In an LTE system, the eNodeB usually considers the channel status when performing resource allocation. For the D2D communications, the eNodeB can obtain the channel status of D2D links between UE1 and UE2 by the periodic or aperiodic channel quality indication (CQI) [17] reports from UE1 and UE2 through the PUCCH. It is assumed that UE1/UE2 can perform the CQI estimation from the received Sounding Reference Signal (SRS) [16] transmitted by its D2D peer.

Once the eNodeB determines the allocated resources, it notifies the result to both UE1 and UE2 through the PDCCH. In an LTE system, a UE performs blind decoding using its identity (i.e., Cell Radio Network Temporary Identifier (C-RNTI) [18]) to locate the specific PDCCH for it [17]. Therefore, in order to simultaneously notify UE1 and UE2 the resource allocation result, two possible methods are described below.

Method 1: The eNodeB sends two independent PDCCHs to UE1 and UE2 with their own C-RNTIs. In order for UE1 and UE2 to know whether it should transmit or receive data on the allocated resources, the PDCCHs that the eNodeB sends to UE1 and UE2 can be in different Downlink Control Information (DCI) formats [19]. In this example, the eNodeB sends Uplink (UL) grant to the sending UE1 and Downlink (DL) grant to the receiving UE2.

Method 2: The eNodeB sends only one PDCCH to UE1 and UE2 with the C-RNTI of the sending UE (UE1 in this example). Therefore, UE2 needs to know the C-RNTI of UE1 in order to decode this PDCCH. This can be obtained during the D2D connection establishment phase. Compared with Method 1, this approach can reduce the signaling overhead but increase the blind decoding attempts.

After UE1 receives the PDCCH from the eNodeB, it will transmit data to UE2 on the allocated resources. In an LTE system, downlink and uplink data transmissions are carried on the Physical Downlink Shared Channel (PDSCH) [16] and the PUSCH, respectively. In the D2D communications, however, there is no differentiation between downlink and uplink since the two communicating devices are both UEs. Therefore, it seems that both the PDSCH and the PUSCH can be used to carry the D2D traffic. However, there are several issues if the D2D links are considered as downlink. In an LTE system, a UE needs to estimate the downlink channel by detecting the Cell-specific Reference Signals (CRS) [16] from the eNodeB to carry out downlink coherent demodulation. Since a D2D UE cannot transmit the CRS as an eNodeB does, or mutual interference between the eNodeB and the transmitting UE will arise and the signal demodulation may not be performed correctly. In addition, the PDCCH has to be transmitted one or several subframes prior to the PDSCH in the D2D case, which will cause the cross-subframe scheduling problem. On the other hand, it is more straightforward to consider the D2D links as uplink. In the current LTE systems, the uplink reference signals are UE-specific, so there is no interference problem for the reference signals from a D2D UE and a cellular UE. In addition, the eNodeB notifies the UE its scheduled uplink resources one or several subframes prior to the PUSCH transmission by the UE, the timing relationship between the PDCCH and PUSCH are suitable for the D2D case and there shall be no cross-subframe scheduling problem.

After UE2 receives the PDCCH from the eNodeB, it will receive data on the allocated resource from UE1, which are transmitted through the PUSCH as discussed above. It is assumed that UE2 has the Single-Carrier Frequency Division Multiple Access (SC-FDMA) baseband reception ability and uplink Demodulation Reference Signal detection ability. UE2 then provides an ACK/NACK feedback to UE1 according to whether the data is correctly received or not. In an LTE system, the eNodeB transmits an ACK/NACK to a UE for its PUSCH transmission by the Physical Hybrid ARQ Indicator Channel (PHICH) [16], which is mapped to the first three OFDM symbols. However, since UE2 may simultaneously transmit data to UE1 by the PUSCH, which cannot be multiplexed in the same subframe with the PHICH, it is proposed to use the PUCCH for the ACK/NACK transmission instead. In an LTE system, the PUCCH is used to carry ACK/NACK for downlink data transmission. However, the physical resources that the PUCCH is mapped to are related to the PDCCH that schedules the corresponding PDSCH. Unlike cellular connections, where the PDCCH

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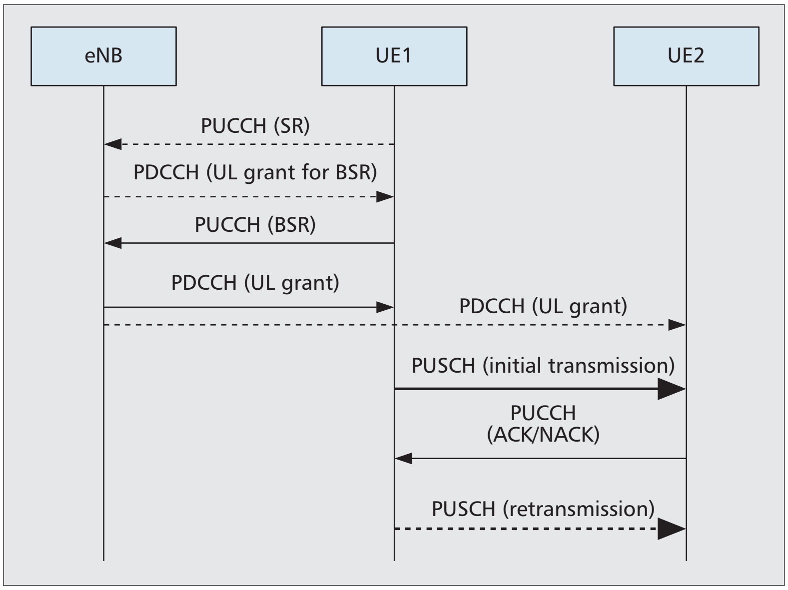

Figure 3. *Resource allocation and data transmission procedure for D2D communications.*

and the related PDSCH are transmitted in the same subframe, the PDCCH has to be transmitted one or several subframes prior to the actual data transmission for the D2D connections. Therefore, the PUCCH resource for D2D ACK/NACK may collide with a cellular ACK/NACK, since their corresponding PDCCHs are transmitted in different subframes. In order to solve this problem, two possible methods are provided.

Method 1: Reserve specific resources for the D2D PUCCH.

Method 2: Use the cross-carrier scheduling capability in the carrier aggregation technique, where a dedicated carrier is used to carry the D2D traffic and the related PDCCHs are carried on the other carriers for cellular traffic. In this way, the D2D ACK/NACK will be transmitted on a different carrier from the cellular ACK/NACK, which will avoid collision between them. One example is to use the guard band of TDD and FDD for D2D traffic.

Finally, when UE1 receives the ACK/NACK from UE2, it will decide whether to perform data retransmission or not. Since the LTE system uses synchronous HARQ in the uplink, UE1 and UE2 both know on which subframes to send and receive the retransmitted data. In addition, if non-adaptive HARQ is adopted, UE1 can retransmit the data on the same resource blocks as the initial transmission, so that the eNodeB does not need to send the PDCCH to UE1 and UE2 again. However, the eNodeB has to listen to the ACK/NACK from UE2 to determine whether it can schedule new data on these resources.

The control and data channels for the above D2D communication procedure is shown in Fig. 3. Since this article only discusses about the radio aspects of D2D communications, the resource allocation issue in core networks is out of our scope. However, it should be noted that no core network resources are needed to carry D2D traffic.

PEER DISCOVERY, PAGING AND CONNECTION ESTABLISHMENT

Before the resource allocation and data transmission phase, two devices need to find each other, i.e., peer discovery and D2D connection setup. The peer discovery phase is relatively independent of the D2D communication phase. Existing work can be classified into centralized and distributed approaches.

Centralized approach: A certain entity in the cellular network, e.g., Packet Data Network (PDN) gateway or Mobility Management Entity (MME), detects that it may be better for two communicating UEs to set up a D2D connection. This entity then informs the eNodeB to request measurements from the UE to check if the D2D communications offers higher throughput. If so, the eNodeB decides that the two UEs can communicate in D2D mode [1].

Distributed approach: The UE broadcasts identity periodically so that other UEs may be aware of its existence and decides whether it shall start a D2D communication with it. This approach does not need the involvement of the base station [2]. The distributed peer discovery approach is more flexible and scalable than the centralized one. However, the operator cannot forbid illegal users to announce or listen information to/from the D2D peers using the operators' licensed band.

For fully controlled and loosely controlled D2D communications, different paging and connection establishment methods may be used:

Fully controlled D2D communications: The paging and connection establishment procedure is mostly the same with normal LTE procedure [20]. However, since the D2D UEs shall exchange data directly over the air after the connections are established, it may be necessary to inform one D2D UE of the configured information of its peer regarding data transmission, e.g., C-RNTI, sounding reference signal configuration, and ciphering key etc.

Loosely controlled D2D communications on licensed band: When communication between two UEs is desired, contact can be initiated via a form of direct D2D paging to create a D2D connection without the intervention of the base station [2]. However, the operator should be able to control whether the D2D connection is allowed to be setup or not.

Loosely controlled D2D communications on unlicensed band: The cellular network perform authentication when two UEs want to start D2D communication. After that, the data transmission between these UEs takes place on unlicensed band with traditional D2D technologies.

CONCLUSION

In this article, we have studied the potential usage cases and technical design considerations in the operator controlled device-to-device communications. The potential usage cases have been analyzed and classified into four categories. Each usage case has its own marketing challenges and the design of the related techniques should take these factors into consideration. Furthermore, some technical considerations on the radio aspects of the operator controlled

D2D communications are discussed, including the usable spectrum, resource allocation and connection establishment, etc. Specifically, a signaling procedure of the resource allocation and data transmission of operator controlled D2D communications has been provided.

The operator controlled D2D communications should enable the operators to control their networks in order to provide better user experience and make profit accordingly. At the same time, they should be flexible and low-cost to compete with traditional free D2D communications. The operators still face several challenges in providing such a D2D solution that can address the above two "contradicting" objectives simultaneously.

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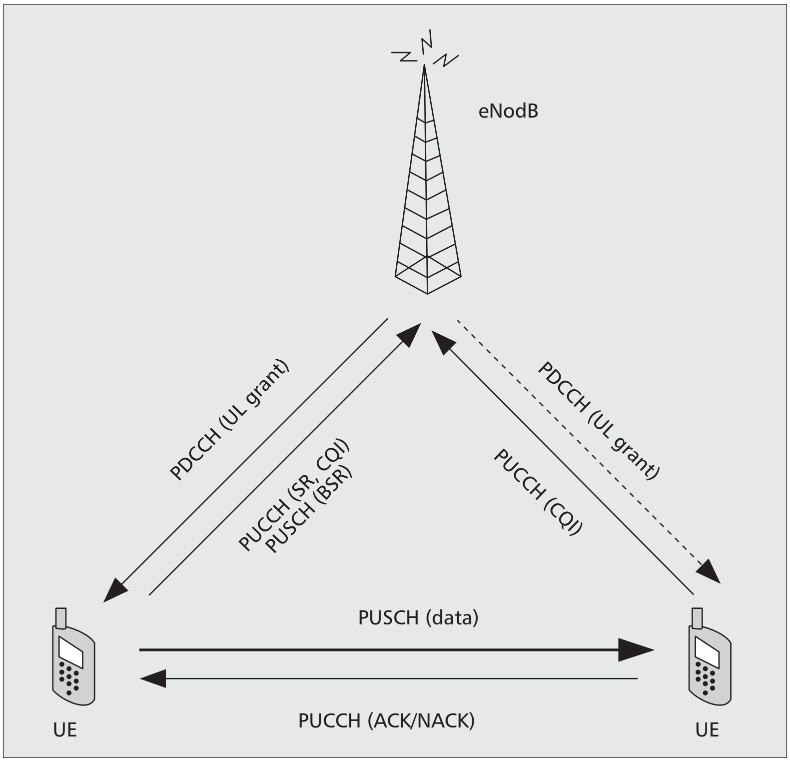

Figure 4. *Data and control channels for D2D communications.*

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