D2D | Direct Communication | Device Discovery

Technology Reports

Further Development of LTE-Advanced—Release12 Standardization Trends—

D2D Communications in LTE-Advanced Release 12

Public safety radio systems are communications methods used during emergencies. Currently, LTE-based public safety radio systems are being considered to reduce network deployment and operational costs, and to convert these radio systems to support broadband. For this reason, Direct communication functions that bypass eNB were introduced in 3GPP Release 12 LTE for public safety radio systems so that communications can be provided even if an eNB is down due to a situation such as a large-scale disaster. Also, Device discovery functions that enable commercial D2D for functions such as distributing information to terminals in proximity were also introduced. This article describes the D2D Direct communication and Device discovery functions in Release 12 LTE.

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1. Introduction

Public safety radio systems are communication methods used in emergency situations. Currently, LTE-based public safety radio systems are being considered to reduce network deployment and operational costs, and to provide broadband communications with these systems. Public safety radio systems should ideally be able to provide communications when an eNodeB (eNB)*1 isn't operational due to a situation such as a large-scale disaster, or in areas outside of eNB coverage such as mountainous regions. Therefore, since the United States government and other administrations have demanded that "Device to Device (D2D)" direct communications be supported in LTE, the 3rd Generation Partnership Project (3GPP) has designed specifications for D2D communications functions that bypass core networks*2 [1]-[3]. Also, because commercial D2D usage is also under consideration to provide "Device to Device Proximity Services (ProSe)" to terminals in proximity, specifications were designed for technologies for Device discovery between terminals in proximity. Thus, as shown in **Figure 1**, D2D communications in LTE consist of two functions: Direct communication and Device discovery.

*1 **eNB:** A base station for the LTE radio access system.
*2 **Core network:** A network consisting of switching equipment and subscriber information management equipment etc. A mobile terminal communicates with the core network via a radio access network.

D2D communications in LTE are assumed to include two scenarios, the first being autonomous D2D communications outside eNB coverage areas, and the second being D2D communications with eNB assistance in eNB coverage areas. In the latter scenario, eNB assistance enables more efficient communications [4]. However, even if eNB assistance is available, in D2D communications data is transmitted and received directly between terminals without going through the core network. Furthermore, for effective frequency use and to minimize additional implementation required for existing terminals, D2D communications in LTE will use a subset of uplink radio resources*3. Therefore, co-existing while protecting the uplink is one of the major challenges for D2D communications in LTE with frequency sharing between D2D and the cellular uplink.

This article describes the functions introduced in 3GPP LTE Release 12 for D2D communications that bypass the core network.

2. Background of D2D Communications

2.1 Public Safety LTE

Currently, there are various communication methods for public safety communication systems in use around the world, such as Project25 (e.g. North America, Australia) and TETRA (e.g. Europe). Many countries have systems deployed independently by their organizations (e.g. fire and police services), which means there are challenges for network deployment, reducing network operating costs and improving interoperability between government agencies and their emergency services. Thus, many countries (e.g. The U.S., U.K. and Korea) are considering switching existing public safety network to LTE since it offers the following advantages:

- Lower network and terminal costs with the LTE economy of scale
- Lower costs through sharing of commercial LTE network facilities
- Interoperability ensured by standardized specifications
- Broadband communications

In 2012, in response to the September 11 terrorist attacks, the United States made a decision to build a nation-wide LTE-based public safety network (FirstNet) to enable communications between responders and first responders during emergencies such as terror incidents or natural disasters, and then in 2013 the US Department of Commerce presented use cases and requirements etc. to 3GPP [5] [6]. These requirements include support for Direct communications outside network coverage areas, group call and Push To Talk (PTT)*4, which are being

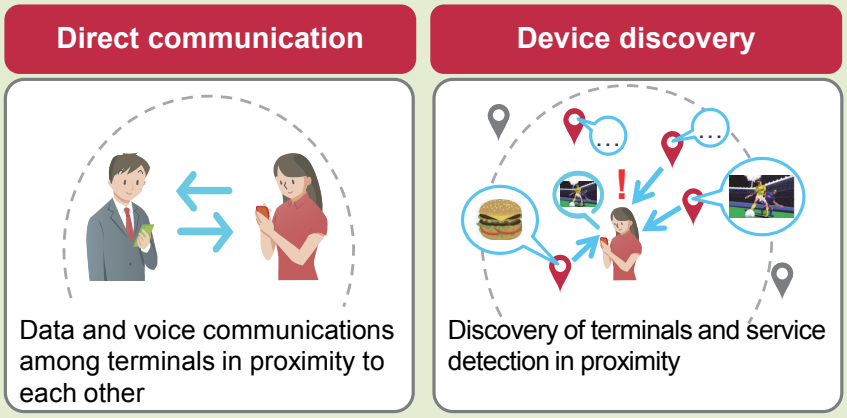


Figure 1 Direct communication and Device discovery

*3 **Radio resource:** Unit of time or frequency range allocated to each user for communication purposes.

*4 **PTT:** A half-duplex voice communications method in which only one party can transmit at one time. A communications method that enables group communications and that is generally used with transceivers.

standardized by 3GPP. As described above, it is expected that in many cases D2D communications, especially Direct communication will be used in addition to cellular communications in public safety LTE systems.

Frequency spectra for the public safety LTE systems are being discussed by the International Telecommunication Union-Radiocommunication sector (ITU-R) *5 as broadband public safety and Public Protection and Disaster Relief (PPDR). The 700 MHz frequency band with Frequency Division Duplex (FDD)*6 is planned for use in both the U.S. and Korea.

2.2 Commercial D2D

D2D communications for commercial purposes that have been attracting attention in recent years include various Device discovery and communications functions such as the Bluetooth® Low Energy*7 (BLE)-enabled iBeacon®*8 and Wi-Fi Aware™*9—functions that support beacon (ID data transmitted over the air) transmission for discovering devices in the vicinity. Generally, this type of Device discovery entails user ID and the ID associated with user interest information embedded in the beacon to enable various services. For example, this technology could be applied to the sharing economy*10 gaining attention in recent years to achieve services to share and exchange services, products or monetary funds based on the location of the user or their interests. These systems could also enable services such as local advertising distribution to terminals in the area, local guidance for tourists and remote pet monitoring.

These LTE-based Direct Discovery services can provide stable communications in a wide range of communications areas as well as telecommunication carrier-grade security (e.g. countermeasures for spoofing attacks).

3. Network Architecture

3.1 Overview

Figure 2 shows an example of LTE D2D architecture [7]. A terminal in the coverage area (User Equipment (UE)) interacts with ProSe Function [8], which is a logical function in Evolved Packet Core (EPC)*11 for D2D. ProSe Function authenticates the terminal using Home

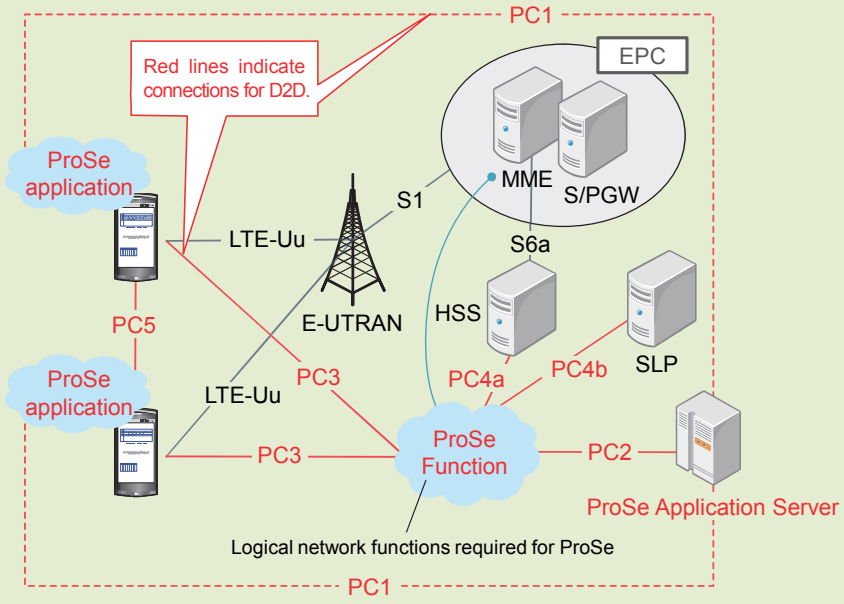


Figure 2 LTE D2D Architecture

*5 **ITU-R:** A department of ITU, an organization that specializes in the field of telecommunications. It manages and coordinates international matters related to radio communication, such as radio regulations and spectrum use in various countries.

*6 **FDD:** A method for implementing simultaneous transmission and reception with radio communications etc, in which transmission and reception are done using different frequencies.

*7 **BLE:** An extension function of Bluetooth®, and a standard defined for low powered devices as part of the Bluetooth 4.0 standard. Bluetooth is a short-range wireless communication specification for radio connection of mobile terminals, and is a registered trademark of Bluetooth SIB Inc. in the United States.

*8 **iBeacon®:** A short-range BLE wireless communication technology developed by Apple. The transmitter (the beacon terminal) broadcasts a unique ID, and the beacon ID is utilized for short data distribution and positioning by estimating distance between terminals based on signal strength. A registered trademark of Apple. Inc.

*9 **Wi-Fi Aware™:** A standard for detecting terminals in the vicinity using Wi-Fi. The Wi-Fi Alliance industry association set down this specification and published a draft specification in March 2015.

Subscriber Server (HSS)*12, while SLP (Secure User Plane Location (SUPL) Location Platform)*13 is used to distribute suitable communications settings according to the terminal location.

The ProSe Function enables configurations necessary for communications outside coverage areas. Settings for communications outside coverage areas are associated with the region, which prohibits transmission (and reception) in areas where regulation does not permit it. Also, by managing security keys with the network, high levels of security required for services such as group calling can be ensured [9]. Apart from this configuration via the network, there are also methods to pre-configure settings in terminals or Subscriber Identity Module (SIM)*14 cards.

In coverage areas, in addition to the configurations transferred from the ProSe Function, D2D radio parameters are indicated from eNB. Furthermore, EPC ProSe user IDs and ProSe Function IDs are stored in the ProSe Application Server which also associates the user ID in the application layer with the EPC ProSe user ID [10].

Terminals are enabled for Direct communication and Device discovery after setting these out-of-coverage parameters or configuration from eNB in coverage areas. However, Device discovery outside coverage areas is not supported in Release 12 although discussions of it are ongoing for Release 13.

3.2 Network Processing Example for Device Discovery

As shown in **Figure 3**, when the sending user registers the user ID or interest information (ProSe Application ID) and metadata such as telephone numbers and URLs in ProSe Function (fig. 3 A (1)), a 184 bit ID (ProSe Application Code) embedded in the actual transmitted beacon (called the LTE Discovery Message) is assigned (fig. 3 A (2)). Then, a reception filter for interest information registered at the receiver side (fig. 3 B (1)) is assigned (fig. 3 B (2)). The ProSe Application Code assigned to the sending user is notified to the other terminal (fig. 3 A (3), B (3)), and the results of matching to the reception filter of the receiving user's ProSe Application Code is reported to ProSe Function (fig. 3 B (4)), which enables the metadata registered by the sending terminal to be acquired via the ProSe Function (fig. 3 B (5)). Additionally, ProSe Application Code assigns namespace (an area availa-

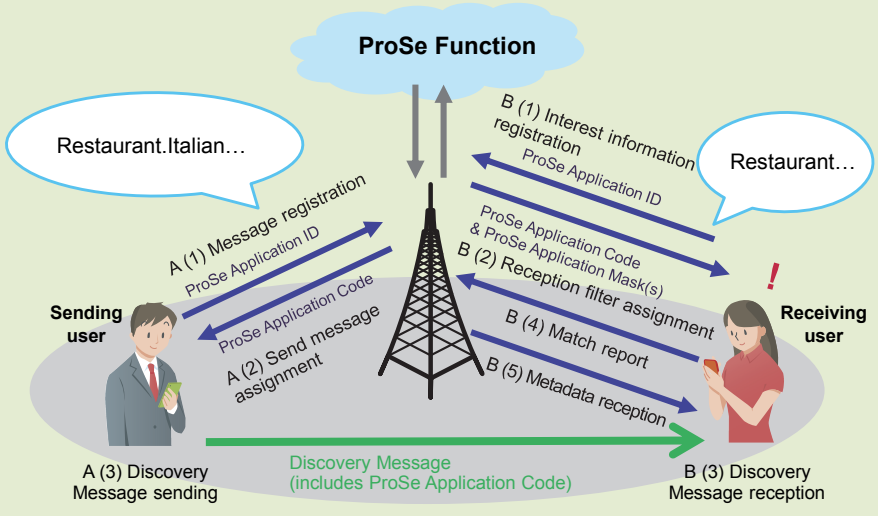


Figure 3 Network role in Device Discovery

*10 **Sharing economy:** An economy created by sharing or exchanging goods and services or by money lending. In a narrow sense, the sharing economy usually entails individuals offering their unused products or assets, or their services to others.

*11 **EPC:** A core network that can accommodate diverse radio access systems including LTE.

*12 **HSS:** A subscriber information database in a 3GPP mobile communication network that manages authentication information and network visiting information.

*13 **SLP:** A location information server in SUPL, which is a method of measuring location that entails sending and receiving location information between terminals and a server.

*14 **SIM:** An IC card which stores mobile phone subscriber information.

ble for a bit string) to each operator (a Public Land Mobile Network (PLMN)*15), which prevents ID conflicts on shared networks or with inter-operator Device discovery.

3.3 EPC Level Discovery

Apart from Device discovery that directly sends radio signals from UE, there are also provisions for EPC Level Discovery that notifies terminals about other terminals detected in the vicinity based on user interest information and UE location information registered by terminals in ProSe Function. A practical example of this function would be setting up and initiating Wi-Fi Direct*16 communication with EPC assistance.

4. Layers 1 and 2 Basic Structures

The following describes basic structure of the physical layer (layer 1*17) and the Media Access Control (MAC) layer (layer 2*18). As described in Chapter 1, a subset of the uplink radio resources of cellular communications are used for D2D communications, while physical channels*19 are structured as shown in **Figure 4**. The following describes the various signals, channels and their uses.

4.1 Synchronization and Radio Parameter Settings

1) Synchronization Method

(1) In eNB coverage areas

In eNB coverage areas, D2D transmission and reception are performed in synchronization with Primary/Secondary Synchronization Signal (PSS/SSS)*20, which is the synchronization signal*21 transmitted by eNB. Apart from some exceptions, D2D transmission timing is PSS/SSS reception timing, and Timing Advance (TA) used with transmission on cellular uplink is not applied.

(2) Outside eNB coverage areas

Primary/Secondary Sidelink Synchronization Signals (PSSS/SSSS)*22 transmitted by UE inside and outside coverage areas are prescribed as signals for synchronization between D2D terminals outside eNB coverage areas. Similar to PSS/SSS, PSSS/SSSS uses Zadoff-Chu sequences*23 and M sequences*24 respectively which are sent at 40 ms intervals using the center of the system bandwidth. As shown in **Figure 5**, when UE in a coverage area sends PSSS/SSSS based on the eNB sync timing, UE outside the coverage area can also perform Direct communication with eNB sync timing. In Direct communication, D2D frame number, system bandwidth, and Time Division Duplex (TDD)*25 UL/DL subframe*26 configuration etc. are transferred through Physical Sidelink Broadcast Control CHannel (PSBCH)*27 as well as PSSS/SSSS.

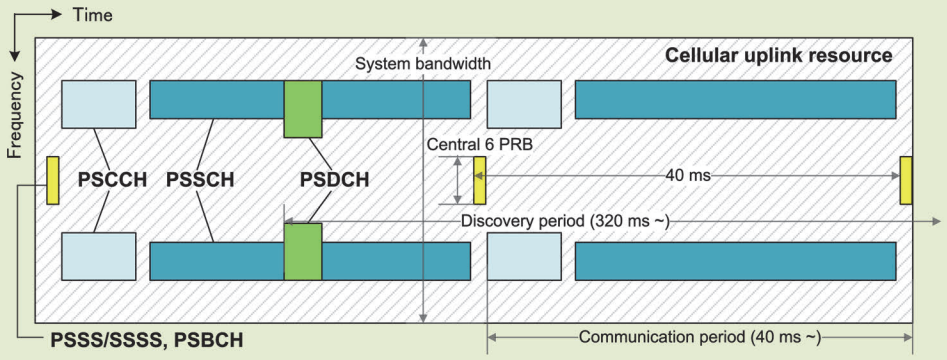


Figure 4 D2D channel structure example

*15 **PLMN:** Operators are identified in various countries by country codes or IDs assigned to them.
*16 **Wi-Fi Direct:** Specifications for D2D communications using Wi-Fi. The Wi-Fi Alliance industry association defines these specifications and certifies compatible equipment.
*17 **Layer 1:** The first layer (physical layer) in the OSI reference model.
*18 **Layer 2:** The second layer (data link layer) in the OSI reference model.
*19 **Physical channel:** Channels separated by physical resources such as frequency and time in radio interfaces.
*20 **PSS/SSS:** A synchronization signal sent by a base station in LTE.
*21 **Synchronization signal:** A physical signal that enables detection of the synchronization source identifier (cell ID etc.), and frequency and reception timing required by the mobile terminal to start communications.
*22 **PSSS/SSSS:** A synchronization signal sent by a terminal in LTE. This is a new specification for D2D communications in Release 12.
*23 **Zadoff-Chu sequence:** A type of orthogonal spreading sequence (number sequence) that uses cyclic shifting and that has superior autocorrelation and cross-correlation characteristics as well as constant amplitude and low PAPR in the areas of time and frequency.

Even with Device discovery only supported in coverage areas, PSSS/SSSS can be used for synchronization between UE in different cells.

In addition to relays*28 of the above synchronization timing, there are also plans to study network coverage extension to transfer UE data outside coverage areas enabled by UE relaying in layer 3*29 in coverage areas in Release 13.

2) Radio Parameters

D2D radio parameters are notified in broadcast information*30 from eNB in coverage areas. For example, these notices include PSSS/SSSS configurations, candidate time and frequency resources (a resource pool) used for sending and receiving Physical Sidelink Control CHannel (PSCCH), Physical Sidelink Shared CHannel (PSSCH) and Physical Sidelink Discovery CHannel (PSDCH)*31 and so forth. As described in Chapter 3, UE outside coverage areas uses pre-configured parameters for D2D.

4.2 Direct Communication

PSCCH and PSSCH defined with the ProSe Communication cycle (e.g. 40 ms cycle) are used in Direct communication. Similar to uplinks, to achieve low Peak to Average Power Ratio (PAPR)*32 in both channels, a signal structure based on Physical Uplink Shared CHannel (PUSCH)*33 is used. PSCCH is a control channel that notifies scheduling for data sent with PSSCH and part of the layer 2 destination IDs. PSSCH is a shared data channel for Direct communication. By sending multiple Media Access Control Protocol Data Units (MAC PDU)*34 in series in the ProSe Communication cycle, sending single control data in PSCCH enables multiple MAC PDU transmissions, which reduces the overhead due to control signaling especially with voice communications.

The address IDs attached to the layer 2 header are defined for Unicast/Groupcast/Broadcast respectively. Differing from conventional cellular communications, this achieves reception filtering in layer 2. Also, Direct communication does not support a feedback channel defined in the physical layer while many functions such as ACKnowledgement (ACK)/ Negative ACK (NACK) *35 transmission are kept in the upper layers.

4.3 Device Discovery

Device discovery uses PSDCH defined with the ProSe discovery cycle (e.g. 320 ms cycle), while UE sends Discov-

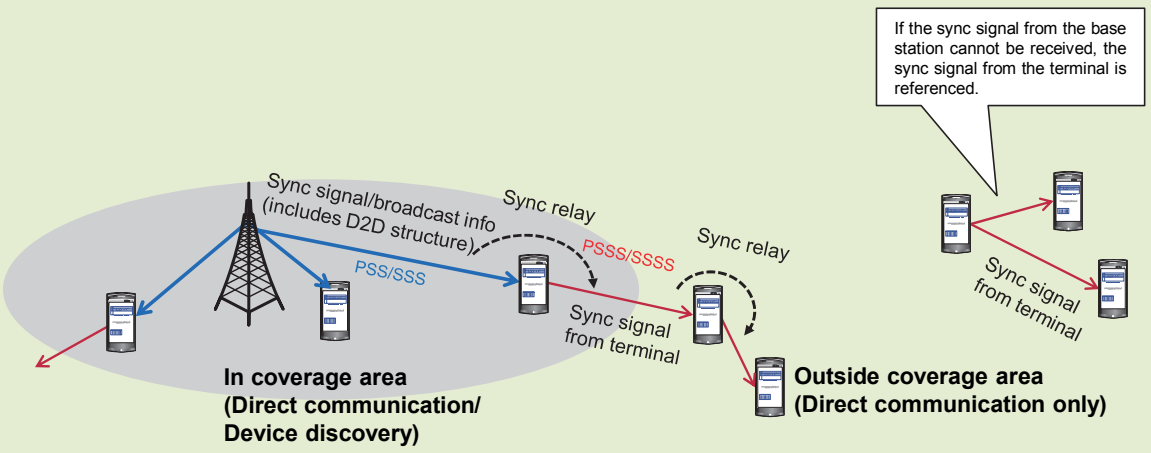


Figure 5 Sync timing relay with communications between terminals in and out of coverage areas

*24 **M sequence:** The maximum length shift register sequence. A type of pseudo-random number with sharp autocorrelation properties that consists of only two values, 0 (-1) and 1.

*25 **TDD:** A bidirectional transmit/receive system. It achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions that use the same frequency band.

*26 **Subframe:** A unit of radio resources in the time domain consisting of multiple OFDM symbols (typically 14 OFDM symbols).

*27 **PSBCH:** A broadcast channel transmitted by terminals in LTE D2D communications. This is a new specification for D2D communications in Release 12.

*28 **Relay:** Technology for repeating communications to transfer them.

*29 **Layer 3:** The third layer (the network layer) in the OSI reference model.

*30 **Broadcast information:** Information simultaneously broadcast to each cell that includes a location registration area number which is required to determine whether location registration is needed for a mobile terminal, surrounding cell data, info on radio wave quality of service etc. in those cells, and call restriction information.

ery Messages periodically. The signal structure is based on PUSCH in the same way as PSCCH/PSSCH. Differing from Direct communication, control information like PSCCH is not sent with Device discovery, but the receiving UE directly detects the Discovery Message in the PSDCH resource pool and performs reception filtering in the application layer based on the user interest information it contains. In general, since the content of Discovery Messages are not changed frequently, the ProSe discovery cycle is set comparatively long, ranging from 320 ms to 10.24 s. Discovery Message transmission and reception is performed for all UE in sync within the cell for PSS/SSS sent by eNB in the coverage area, which enables a low duty ratio (Discovery Message transmission time ratio) that achieves effects such as overhead and terminal power consumption reduction.

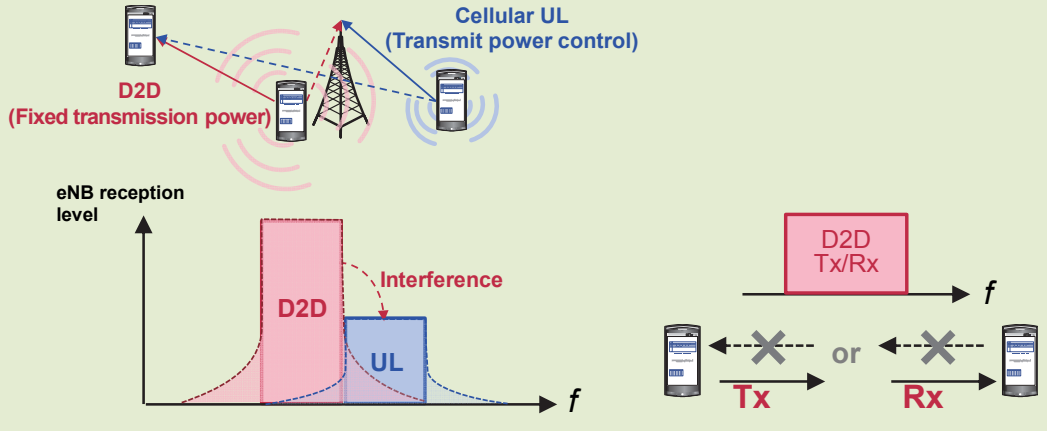
5. Issues and Solutions with D2D

The major issues in the physical layer with D2D are caused by radio resources sharing with the cellular uplink as discussed earlier. The most serious issue is to reduce interference impact on cellular communications (mainly uplink interference). There is a risk of unexpected interference because eNB cannot directly control D2D communication outside coverage areas, and even with UE in coverage areas and orthogonal multiplexing of radio resources for cellular communications and D2D communications, there is a danger of high-level interference in adjacent frequency resources due to in-band emissions*36, as shown in **Figure 6** (a).

As well as that, since D2D transmission and receiving use half duplex*37 with shared bands, there is the additional limitation that UE cannot transmit and receive D2D messages simultaneously as shown in fig. 6 (b). Also, if D2D communications use multiple carrier frequencies, carrier frequency switching is required which complicates terminal control. Release 12 offers the following solutions to these issues.

1) Resource Assignment

There are two resource assignment methods used with D2D—either eNB assigns transmission resources or the UE autonomously selects transmission resources. With the former, orthogonal resources can be assigned to terminals in coverage areas, and efficient resource sharing between cellular and D2D is



(a) Impact of in-band emission

(b) Half duplex constraint

Figure 6 Physical layer issues in D2D

*31 **PSDCH:** A physical channel for sending Discovery Messages in LTE D2D communications so that terminals can discover other terminals in the vicinity. This is a new specification for D2D communications in Release 12.

*32 **PAPR:** The ratio of the maximum power to the average power. If this value is large, the amplifier power back-off has to be large to avoid signal distortion, which is particularly problematic for mobile terminals.

*33 **PUSCH:** A physical shard channel for transmitting uplink data in LTE. Low-PAPR Single Carrier-Frequency Division Multiple Access (SC-FDMA) is used as the radio access method.

*34 **MAC PDU:** A protocol data unit on the MAC layer. PDU expresses protocol data including the header and payload.

*35 **ACK/NACK:** Request signals for retransmission.

*36 **In-band emissions:** Unwanted radiation in a band that can interfere with resources on adjacent frequencies.

*37 **Half duplex:** A method of alternating signal sending and receiving using the same carrier frequency and frequency band.

possible. In Direct communication, eNB resource assignment is signaled dynamically using downlink L1/L2 control signals (Physical Downlink Control CHannel (PDCCH)*38/EPDCCH), while eNB resource assignment in Device discovery is done by Radio Resource Control (RRC)*39 signaling*40.

UE autonomous selection of transmission resources is available both inside and outside of coverage areas, while the transmitting UE can send using any resources available in the resource pool discussed above. For this reason, transmission resource conflicts can occur in D2D.

2) Repetition Transmission and Time and Frequency Hopping

PSCCH, PSSCH and PSDCH transmission support repetition transmission of the same signal and time/frequency hopping with transmission. Having each piece of UE using a different time hopping pattern*41 with repetition transmission reduces the impacts of conflicts and half-duplex constraint. Also, because it is possible to obtain combining gain or time and frequency diversity gain*42 with repetition transmission and time/frequency hopping, these systems can provide sufficient coverage for public safety usage.

3) Transmission Power Control

The aim of the transmission power control in D2D is to balance between the interference level on the cellular uplink and D2D coverage without controlling transmission power depending on D2D link quality. For this reason, as shown in **Figure 7**, D2D transmission power is decided based on propagation loss from eNB using open loop transmit power control*43 similar to uplinks in both Direct communication and Device discovery in D2D. Because this type of power control is not feasible outside coverage areas, the fixed-level pre-configured transmission power in UE is used.

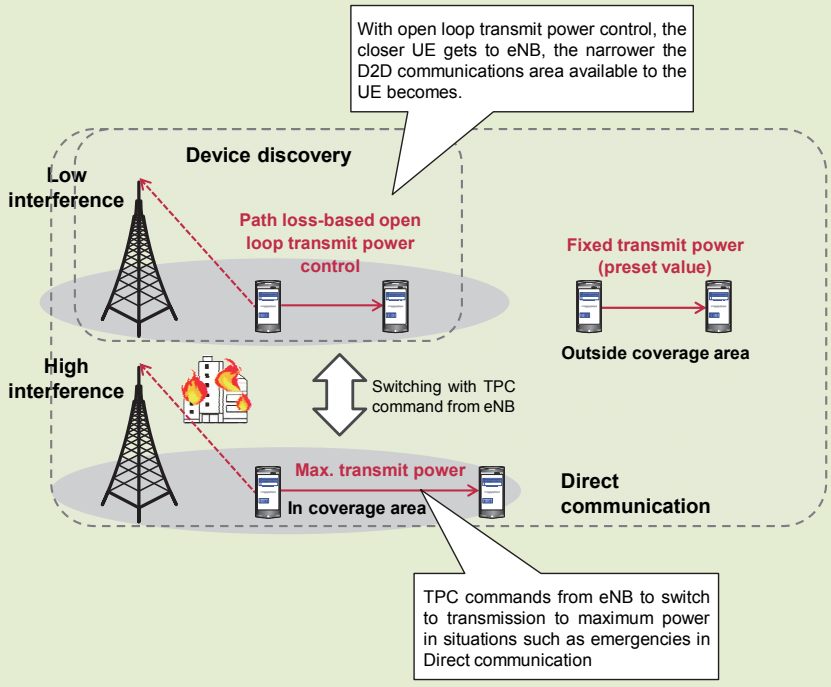


Figure 7 Transmit power control in D2D

*38 **PDCCH:** A physical channel for transmitting downlink control information in LTE, using a maximum of three symbols at the front of each subframe.

*39 **RRC:** A Layer 3 protocol for controlling radio resources.

*40 **Signaling:** Control signals necessary for a terminal to communicate with radio control and exchange equipment.

*41 **Hopping pattern:** A pattern of determining time and frequency resources for sending signals using discontinuous radio resources.

*42 **Time/frequency diversity gain:** Communications quality improvement attained by using radio quality variation with time and frequency.

*43 **Open loop transmit power control:** Transmit power control that does not involve feedback.

With open loop transmit power control, the closer UE gets to eNB, the narrower the area in which D2D communications from the UE are possible becomes, thus, a Transmit Power Control (TPC) command is sent from eNB to switch to transmission with maximum power to provide maximum coverage for Direct communication during emergency incidents. Moreover, with the 700 MHz band planned for use with American public safety LTE, UE capable of transmitting at a max. 31 dBm*44 has been prescribed which will increase the communications range compared to conventional UE (max. 23 dBm). In addition, for Device discovery, since optimum communications range relies on services and areas, the maximum transmit power can be adjusted to three levels to meet the UE request.

4) Device Discovery Between Operators

With Device discovery for commercial purposes, mutual discovery of UE from different operators is preferable. For this reason, UE should be able to receive Discovery Messages transmitted on frequencies of other operators. Release 12 anticipates UE switches reception frequency, and (1) acquires D2D radio resources structure from information broadcast by other operators, and (2) receives Discovery Messages on other operators' frequencies. So that UE's own cellular communications are not hindered, a delay to detecting UE of other operators is predicted due to the limited opportunities for this reception frequency switching. For these reasons, improvements to Device discovery between operators and carrier frequencies are to be considered for Release 13.

6. Conclusion

This article has described an overview of D2D communication introduced with LTE Release 12 and scenarios for its application. Various countries plan to deploy LTE-based public safety radio systems with D2D Direct communications, while LTE-based D2D also supports Device discovery which will enable services to distribute information to terminals in proximity.

There are discussions about expanding the public safety functions of D2D in Release 13, and it is anticipated that D2D communications will play a key role in responding to demands for service diversification, and will also form part of the 5G radio interface.

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*44 **dBm:** Power value [mW] expressed as 10log (P). The power value relative to a 1 mW standard (1 mW = 0 dBm).