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**Implementing proximity based device-to-device communication in
commercial LTE networks in The Netherlands**

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Abstract and management summary

Standardization body 3GPP is currently including a new technique in standardization: proximity based device-to-device communication. The proximity part allows devices in physical proximity to discover each other and the device-to-device communication allows these devices to start a direct LTE radio communication path without using the mobile network infrastructure. This promising new technique could be an opportunity for mobile operators to recoup some of the revenue lost by third party applications replacing traditional revenue generating services, such as Voice over IP applications replacing voice calls and Instant Messaging replacing SMS.

This research focuses on how this new technique can be implemented on LTE networks in The Netherlands. A summary is given of the various implementation options that have been published and shows the main challenges in the implementation of this technique. Results show that these challenges are both technical and organizational. Especially the organizational part requires operators to start organizing in order to succeed in successful implementation of this new technique.

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1 Introduction

With the current roll-out of the 4th generation mobile telecommunications network (4G) in the Netherlands, the ever increasing demand for mobile bandwidth is being satisfied. While this may keep business and consumer users happy for at least a while, operators are being challenged with this new development.

The more traditional revenue generating activities such as voice calls and Short Message Service (SMS) are more and more replaced by over-the-top (OTT) services: Voice over IP (VoIP) and Instant Messaging (IM). The OTT principle leaves operators responsible only for transporting IP packets without providing any content. This development leads to smaller profit margins for operators, while on the other hand further increases demand for bandwidth.

The increasing demand for bandwidth forces operators into doing substantial investments in new networks and spectrum licenses. On the other hand, customers expect to pay less and less for their connectivity. This forces operators into new business models to retain profits. One way to achieve this, is by adding new value to the product which can not be replaced by OTT services from a technical point of view. In other words, exploiting the full potential of the new technical possibilities which come with the 4th and 5th generation of mobile telecommunication networks.

TNO is conducting research for the telecommunications industry into new and emerging technologies. One example of new technology in LTE is Proximity based services (ProSe). ProSe enables direct device to device (D2D) communication, and device discovery when devices are in physical proximity of each other. ProSe introduces opportunities for operators to compensate on lost revenues, however it's implementation comes with several challenges. In this research we identify these challenges and propose some solutions to overcome these challenges.

First we will give a summary of the ProSe / D2D technology, the technical background and related work. Second, two use cases will be introduced for the ProSe / D2D technology. Based on the use cases and study of the related work and literature an evaluation of the implementation options will be given. Finally a conclusion and advice to telecom operators will conclude this report.

For the ease of reading acronyms are used after the first occurrence of terminology. A list of acronyms is provided as appendix to this report.

1.1 Introduction to ProSe

Proximity based services enables direct device to device (D2D) communication and device discovery when devices are physically in each others proximity. This opens up the possibilities for:

- Providing services based on the users physical location (e.g. advertising)

- Enables more efficient use of the operators spectrum and can be used to offload the network
- Enables communication in emergency situations

An example use case to provide services based on the users location is advertising. Businesses can communicate daily offers to potential customers that are actually in the close proximity of the business. For example a restaurant can advertising the daily menu, or a store can advertise a special offer only valid for today.

D2D communication based on proximity can also be used to form mesh networks, in which devices communicate directly with each other. In LTE networks, the eNB (the LTE equivalent of the Base Transceiver Station in GSM) is used for communicating with the User Equipments (UEs). It sends and receives radio signals using antennas and provides data encryption and controls the radio resources (e.g. spectrum). eNBs have limited reach, which can lead to blind spots if eNBs are not positioned accordingly or if the radio signals are weakened (e.g. by building materials). One device may not be able to reach the eNB but may be able to reach a second device. The second device in turn is able to reach the eNB. In the D2D mesh network scenario, the second device can forward the radio communication between the first device and the eNB.

Another application is sending large data stream between devices. For example when sharing files. In a more traditional setup, this has to be routed over the base station therefore posing a load on the network. If a large file can be sent directly between devices this offloads the network.

D2D communication can also be used in case of an emergency situation. For example when communications infrastructures are destroyed by (natural) disasters. The US Federal Communications Commission has recently announced its support for the LTE standard for public safety purposes. [5]

1.2 Related work

ProSe is currently being standardized at the Third Generation Partnership Project (3GPP) [1]. The 3GPP is a partnership between leading entities in the field of cellular communications. This includes carriers, operators, device manufacturers, research facilities and governmental telecom bodies. 3GPP works in releases. Each release contains a new set of specifications for the next level of technology to be implemented. At the time of writing release 12 is being completed, which is planned for completion in September 2014. The use of ProSe / D2D for public safety applications is included in release 12.

A substantial amount of research has been done into ProSe and D2D communications. This includes research on sharing the radio spectrum and avoiding interference [28], (early) explorations of the commercial possibilities of ProSe and D2D communication

[25], exploration of privacy related aspects [21] and studies that summarize the current state-of-the-art [19] [10].

Besides the substantial research into the field of ProSe and D2D communication that is already conducted, there seems to be a lack of research into protocols and interoperability. The same conclusion is drawn by Asadi et al [10] in their recent survey: *The majority of researchers have addressed issues such as interference, resource allocation, power allocation, and so on. Only a few researchers propose protocols for D2D communications..* One concrete protocol specification has been proposed by Raghothaman et al [24]. Although this protocol specification in itself is fairly detailed, it lacks analysis on practical implementation and interoperability between carriers.

1.3 Research question

In this research we will determine the technical and organizational requirements for a practical implementation of ProSe / D2D communication. The research will be centered around the following research question:

What are the organizational and technical requirements for enabling proximity based services based on device to device communication on- and between the commercial LTE network operators in The Netherlands?

1.4 Subquestions

The research question has been divided into the following subquestions:

- What are the adaptations needed to the LTE infrastructure to support proximity based services in the chosen use cases?
- What are the additional technical and organizational requirements to support proximity based services in the chosen use cases between customers of different mobile operators?

1.5 Research Method

This research will be mainly literature study into the specifications of ProSe and D2D communication and into the protocol as proposed by [24]. The research will be centered around two use cases for ProSe. For both use cases, a set of organizational and technical requirements to implement the use case will be established. For the technical approach that best fits the requirements, the implications for enabling this cross-operator will be studied.

The first use case is centered around advertising. In this use case local businesses such as restaurants or shops advertise their daily offers using ProSe. Potential customers with a ProSe enabled subscription in proximity of the advertiser receive the offer.

The second use case is social networking. In this use case social network users can use ProSe to discover friends in their "buddy list" that are in physical proximity.

1.6 Scope

The scope of this research is limited to a theoretical approach, because only preliminary technical specifications are available and no implementation exists yet. Given the limited timeframe of 4 weeks, no simulations or real implementations will be built. The main focus will be on the mobile telecommunications market in The Netherlands. The research will be centered around two use cases: advertising and social networking. These use cases will be defined further in section 3. The public safety application of ProSe / D2D is outside the scope of this research. Commercial models for revenue generation, security and privacy are also outside the scope of this research.

2 Technical background

2.1 LTE architecture

One of the biggest differences between 3G and 4G is the core of the networks. While 3G networks still have both a circuit switched core for the handling of voice, as well as a packet switched core for the handling of data. LTE and 4G networks have the Evolved Packet Core (EPC) which is fully packet switched.

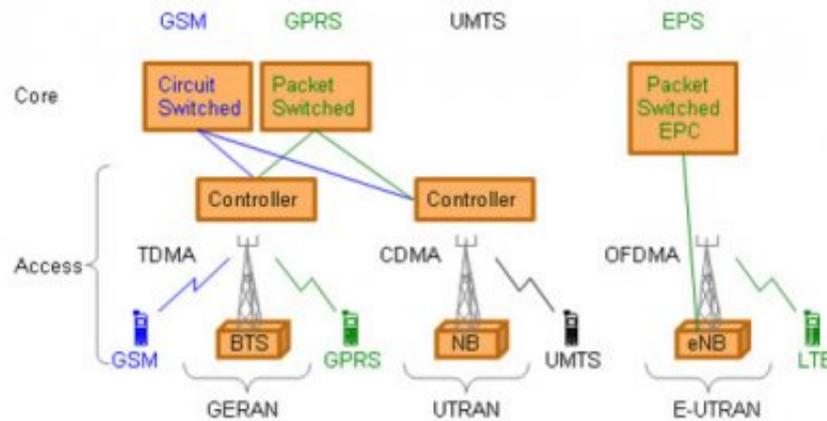


Figure 1: LTE architecture. Adapted from [1]

2.2 LTE in The Netherlands

Cellular operators started to introduce LTE in the first quarter of 2013. The introduction followed the frequency auction the Dutch government organized starting October 31, 2012.

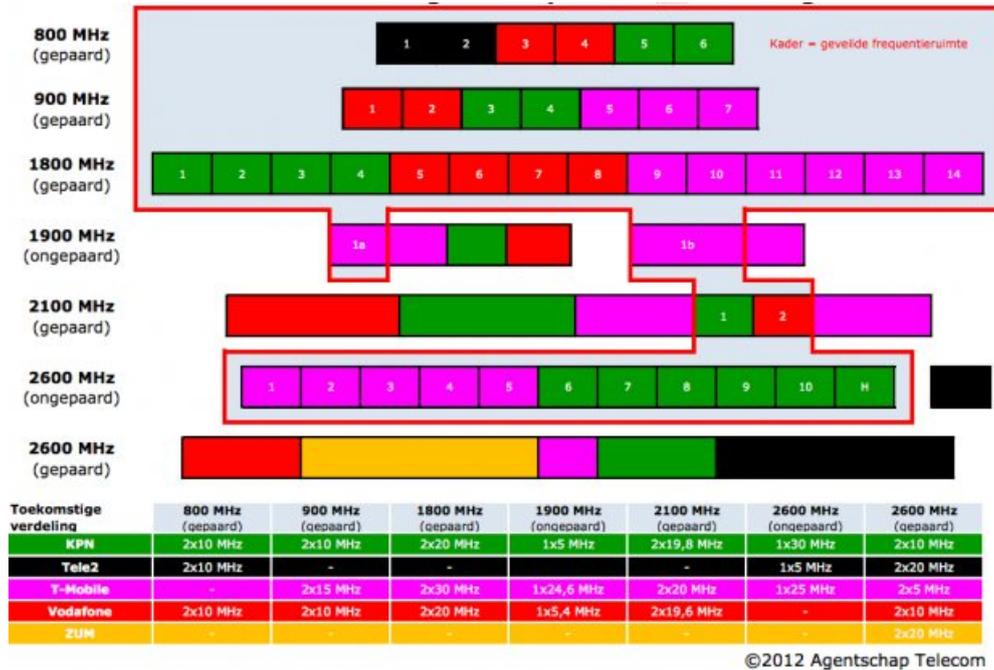


Figure 2: LTE frequencies in The Netherlands after auction. Adapted from [7]

Figure 2 shows the result of the frequency auction. The red ensquared area shows the auctioned spectrum. The colored bands show the operators: green is KPN, red is Vodafone, pink is T-mobile, black is Tele2 and Yellow is ZUM: a joint venture between cable providers Ziggo and UPC.

LTE spectrum can either be paired or unpaired. Paired frequencies are a pair of frequencies in which one frequency is used for downlink and one frequency for uplink. This principle is known as Frequency Division Multiplexing (FDM). Unpaired frequencies are single frequencies which are used for both downlink and uplink, in alternating fashion. This principle is known as Time Division Multiplexing (TDM)

2.3 ProSe spectrum management

One of the biggest challenges in implementing ProSe cross-operator, is the management of the radio spectrum. As there are various options on how to implement the Radio Access Network (RAN) part of the ProSe / D2D communication, we will first lay-out the various options.

Figure 3 shows the various options considered in the standardization process, as summarized by [10].

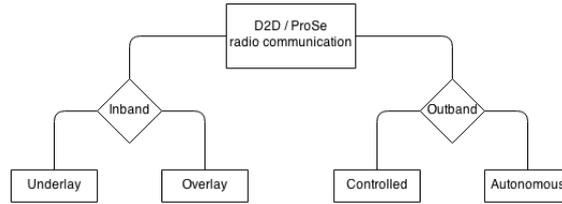


Figure 3: LTE D2D communication in radio spectrum

2.3.1 Underlay inband

The inband option involves the (re)use of the licensed cellular spectrum. This means the D2D communication and ProSe discovery operates in the licensed spectrum of the operator. Being underlay communication, there is no dedicated spectrum reserved for the D2D communication. This means the D2D communication between the User Equipment (UE) can interfere with the traffic between the UE and the eNB. Various options have been proposed to avoid interference. The main aspect of the proposed solutions is control over the spectral resources by the eNB.

2.3.2 Overlay inband

Overlay inband involves the use of licensed cellular spectrum, with a dedicated frequency or frequency spectrum reserved for use by ProSe / D2D communication. When looking at the frequency spectrum in The Netherlands, all operators have licenses for the 2600 MHz spectrum. These frequencies are in general not used for larger scale LTE networks because the coverage is limited. Operators usually use these frequencies for additional (temporary) capacity in a limited area. Therefore the 2600 MHz frequency spectrum might be a suitable candidate for a dedicated overlay inband spectrum for ProSe / D2D.

2.3.3 Controlled outband

Controlled outband is not using the cellular spectrum, but is using unlicensed spectrum instead. The most commonly used unlicensed spectrum is known as the Industrial Scientific and Medical band (ISM band). This is a set of radio frequencies which can be used without license. The ISM band is used by various devices including microwave ovens, medical equipment and scientific experiments. The most common use however is by 802.11 wireless LAN (WiFi) and Bluetooth techniques. The limited range of Bluetooth makes it less suitable for use in D2D communications. This leaves WiFi-direct as the most suitable option in this category. Controlled in Controlled outbound means the communication is still coordinated by the LTE network. Operators have the ability to monitor QoS, and therefore add value. This implies operators can charge customers for this service.

2.3.4 Autonomous outband

Autonomous outband is using the unlicensed spectrum, but UE's set-up, teardown and maintain connections in an autonomous fashion. Example techniques include Bluetooth and WiFi-direct. The autonomous aspect implies the operators do not have any control over the establishment, maintenance and teardown of the connections. There is no added value by the operator.

2.3.5 Spectrum summary and conclusion

As summarized in [2] the preliminary choice for D2D is underlay inband. Specifically an upstream (UL) carrier is used, since the downstream (DL) carrier is not permitted for transmission by the UE in Europe [22] [2]. D2D communication is assumed not to use full duplex on the given UL carrier for transmission/reception. For multiplexing D2D and regular (WAN) LTE communication on the given UL carrier TDM can be used.

2.4 ProSe discovery

ProSe discovery has two elements:

- Discovery ("seeing" the other UE)
- Identification (identifying the other UE)

Some applications require both elements, while others may only need to see which UE's are in proximity. Discovery has been specified as either open or restricted [3]. In the open discovery case, there is not explicit permission that is needed from the UE that is being discovered. Restricted discovery requires explicit permission from the UE that is being discovered.

In the service aspects for ProSe, discovery has been specified into two discovery models:

- Model A: "I am here"
- Model B: "Who is there?" or "Are you there?"

Model A: defines two roles for participating UEs. One UE is the announcing UE. This UE is sending out broadcast messages known as beacons indicating it's presence. The other UE is a monitoring UE that listens for broadcast messages to discover other UE that it is interested in.

Model B: defines two roles for participating UEs. One UE is the discoverer UE. This UE is sending out requests containing information on what it is interested in to discover. The other UI is the discoveree UE that receives the request and matches the description on what the discovering UE is looking to discover. It then replies to the request if a match is found.

2.4.1 Authorization for resource use

The 3GPP specification defines a ProSe function in a Public Land Mobile Network (PLMN). A PLMN is a mobile network in an area (e.g. country) exploited by a mobile operator. A country usually has multiple competing PLMN operators. In the context of ProSe / D2D this is referred to as Local PLMNs. A customer is subscribed to the service of a mobile operator. The operator supplies the customer with a SIM card. This SIM card may be used in the PLMN of the operator. In the context of this research this is called the Home PLMN (HPLMN).

Customers can use their SIM card in other (usually foreign) PLMNs if the operator has roaming agreements with the other operator. These agreements are both technical and commercial. Customers usually pay a surcharge for using the foreign network. If a customer is roaming, the foreign network is called the Visiting PLMN (VPLMN). These roaming agreements usually do not exist between Local PLMNs, as customers can use their HPLMN and avoid the surcharge for roaming. Although some operators offer national roaming services for mission critical applications, in general it is not widespread.

The ProSe function defined by 3GPP is a logical function in the PLMN involved with authorization, billing and regulation of ProSe functionality. Before a UE can start discovery it must first obtain authorisation.

Authorization is primarily given by the ProSe function in the Home Public Land Mobile Network (HPLMN) which is the network where the client is subscribed and belongs to the operator that supplied the SIM card. Authorization can be given for:

- **Discovery monitoring:** The authorization consists of a list of PLMNs in which the UE is authorized to perform discovery monitoring. The authorization for a given PLMN can be:
 - **pre-authorized:** the UE is fully authorized to perform discovery monitoring in the given PLMN.
 - **conditionally authorized:** the UE must contact the ProSe function in the given PLMN to obtain full authorization.
- **Discovery announcing:** the UE is allowed to transmit discovery announcements in the given PLMN. According to 3GPP specification this can only be the case if the UE is registered in the given PLMN. This automatically limits the number of possible options regarding spectrum bands.

The list of PLMNs can include VPLMNs and local PLMNs.

2.4.2 Network assistance

Discovery in ProSe / D2D communication can either be direct radio discovery or network assisted discovery. Figure 4 summarizes the options.

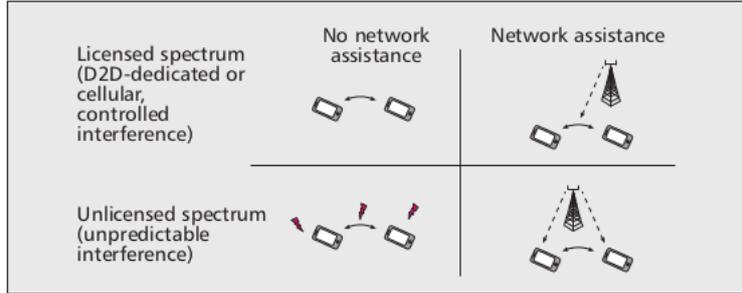


Figure 4: D2D discovery scenarios, adapted from [8]

As described in section 2.4 the discovery is performed by either sending out messages containing a identifier known as a beacon, or a request. Network assistance can help in improving the efficiency of the discovery procedure, as well as minimizing the impact from the sharing of the UL carrier. When network assistance is available, the discovery beacons or requests can be short unique sequences containing just enough information for the ProSe function in the PLMN to identify the UE. The receiving UE can then query the ProSe function in the PLMN to determine the identity of the other UE. This lowers the amount of data that has to be transferred over the radio interface and therefore lowers the resource requirements and interference risks.

When network assistance is not available, the UE is out or on the edge of coverage. This means the risk of interference is lower, but beacons or requests need to contain more information in order to both discover and identify UE's in proximity.

Network assistance can also be used to replace radio based discovery for certain applications. This is referred to as EPC based discovery. The location of UEs is known in the EPC, which makes it possible to determine which UEs are in proximity only from location data. EPC based discovery can be implemented in the ProSe function of the PLMN. UEs will be notified by the ProSe function when a proximity event occurs. This can be used to replace radio based discovery, or assist radio based discovery. In the latter option the proximity event serves as a trigger for UEs to start radio discovery. This will be explained in more detail later.

Location determination in LTE has been extensively researched by both the Open Mobile Association (OMA) and 3GPP resulting in increasingly more precise techniques with each release [23]. Figure 5 shows the positioning methods that currently exist for LTE networks, and whether they are based and/or assisted by the UE or the eNB.

| Method | UE-based | UE-assisted | eNB-assisted | 3GPP Release |
|----------------------------|---|---|--|--------------|
| A-GNSS | Yes Measurement: UE Estimation: UE | Yes Measurement: UE Estimation: LS | No | Rel-9 |
| Downlink (OTDOA) | No | Yes Measurement: UE Estimation: LS | No | Rel-9 |
| Enhanced Cell ID | No | Yes Measurement: UE Estimation: LS | Yes Measurement: eNB Estimation: LS | Rel-9 |
| Uplink (UTDOA) | No | No | Yes Measurement: eNB Estimation: LS | Rel-11 |
| RF Pattern Matching | ? | ? | ? | Rel-11 |

Figure 5: Supported positioning methods in LTE, adapted from [23]

U-TDOA is used as a standard method to locate emergency calls in the US (E911) and is therefore widely implemented in LTE networks. [27]. Enhanced Cell ID is also an option, but is UE assisted and therefore requires UE support for this functionality. Both options require support by the eNB. As Enhanced Cell ID is specified in 3GPP release 9 versus release 11 for U-TDOA, Enhanced Cell ID is more likely to be supported by networks (also outside E911 regions). Therefore the preferred option for location determination for use in EPC based discovery is U-TDOA.

3 Use cases

We will now introduce two use cases to allow for a structured evaluation of requirements for the implementation of ProSe / D2D communication. The use cases have been chosen because they are both primarily involved with discovery and not necessarily use D2D communication. This allows us to compare and show the diversity in requirements for the ProSe discovery part.

3.1 Use case: Advertising

In the advertising use case, local business owners can use ProSe to advertise their daily offers to potential customers in proximity. An (embedded) device subscribed to a ProSe enabled LTE network is placed at a local business premises and discovers other ProSe enabled UEs in proximity. Advertising content can then be broadcasted to the UEs that have been discovered. In this use case, we will focus on discovery. The communication needed to send and receive the actual advertising content is transmitted over the normal LTE connection and via the EPC.

Figure 6 shows the advertising use case and the actors associated.

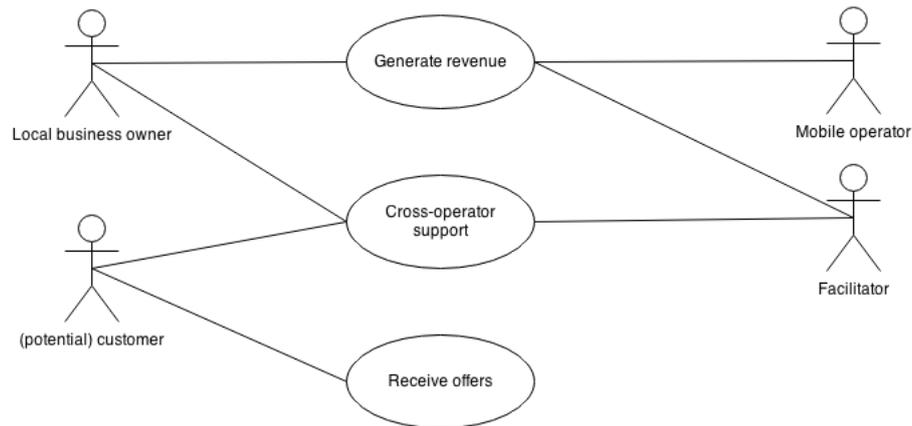


Figure 6: Mobile advertising use case and actors

A facilitator builds and sells the complete mobile advertising solution, including hardware and subscription for a mobile operator to the local business owner. The local business owner expects to reach all potential customers in proximity of the business. Not only customers subscribed to a particular mobile operator. The facilitator wants to sell a subscription to a single operator only, to save technical and organizational complexity and to keep costs down. Potential customers expect to discover all mobile advertising that is active in a given region, independent of the operator used by the advertiser. Operators finally want to generate revenue from subscriptions and use of ProSe.

3.2 Use case: Social networking

In the social networking use case, users of the social network can use ProSe to discover friends in physical proximity and can be discovered by friends in physical proximity.

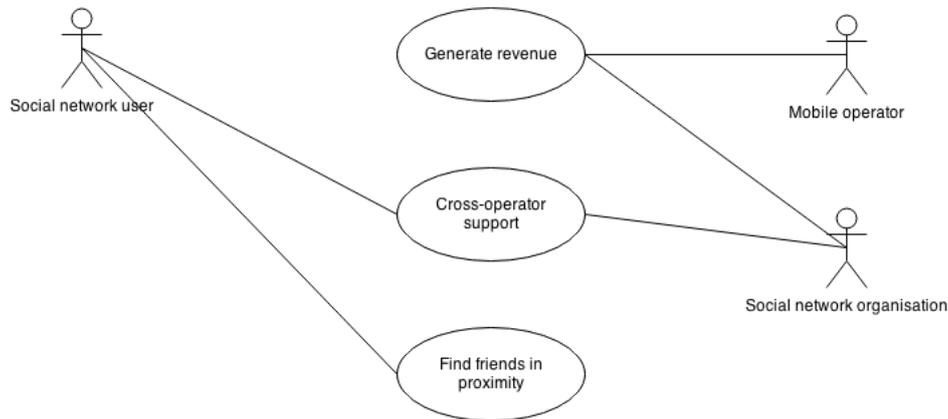


Figure 7: Social networking use case and actors

A social network organisation builds a social network, to which users subscribe. The social network organisation wants their users to be able to discover their friends in proximity using ProSe, regardless which mobile operator is used. Users will only effectively use the ProSe function if it works cross-operator.

4 Implementation options

In this section we explore the different technical implementation options for the use cases introduced in the previous section. For the advertising use case, either model A or B mentioned in 2.4 can be used.

In model A, UEs transmit beacons indicating their proximity to other UEs and their (concealed) identity. In model B the discovering UE transmit requests asking other UEs in proximity to reply and provide their identity. Roles can be defined either way (ie the advertising party discovering the potential customer, or the other way around).

For sending out beacons or requests, UEs need frequency spectrum resources. These resources can either be shared with regular LTE traffic or dedicated frequency resources can be used. We included four implementation options. Options one and two consider non-dedicated frequency resources. Option three considers dedicated frequency spectrum and option four does not use radio communication at all.

Implementation options two and three are not based on the 3GPP specification, but have been drawn up from experience gathered by literature study. Option four is briefly mentioned in the specification, but has been completed using own insight from the literature study.

| | Advertiser / Person A | Customer / Person B |
|------------|----------------------------------|----------------------------------|
| Model A | | |
| Option A1: | Transmits on own frequency band | Monitors on all frequency bands |
| Option A2: | Listens on all frequency bands | Transmits on own frequency band |
| Option A3: | Transmits on all frequency bands | Monitors on own frequency band |
| Option A4: | Listens on own frequency band | Transmits on all frequency bands |
| Model B | Advertiser / Person A | Customer / Person B |
| Option B1: | Transmits on own frequency band | Monitors on all frequency bands |
| Option B2: | Transmits on all frequency bands | Monitors on own frequency band |
| Option B3: | Listens on own frequency band | Transmits on all frequency bands |
| Option B4: | Listens on all frequency bands | Transmits on own frequency band |

Table 1: Various discovery options for both use cases

4.1 Implementation option 1: per current 3GPP specification

This implementation option used underlay inband communication and therefore has to share resources with regular LTE traffic between the UE and the eNB. This also implies the frequency resources used for the communication is dependant on the operator and the licenses this operator obtained in the frequency auction. UEs registered with different operators use different frequency resources and therefore cannot communicate with each other without either monitoring or transmitting on frequency resources assigned to other operators.

This introduces various combinations of transmitting and receiving between the two participants in the communication. These options are listed in table 1. The column titles refer to the actors in both use cases.

As by the preliminary 3GPP specification, an UE can only be authorized to transmit beacons or requests within the frequency resources of the operator it is registered to [3]. This eliminates the options A3, A4 and B2 and B3 because these options require one of the UEs participating in discovery to transmit on other frequency bands than the frequency bands used by the PLMN the UE is currently registered to.

4.2 Implementation option 2: Allowing transmission in any frequency resource

In this implementation option, we assume UEs can be authorized to transmit beacons or requests in frequency bands belonging to other operators than the one the UE is currently registered to. This implementation would make all options listed in table 1 possible.

4.3 Implementation option 3: dedicated radio resources ("shared spectrum")

Instead of using inband underlay, in this implementation option inband *overlay* is used. This means, dedicated spectrum bands are designated for D2D / ProSe usage shared across operators in one area (e.g. country). This implementation would, like implementation option 2, make all options listed in table 1 possible.

4.4 Implementation option 4: EPC based discovery

If the only objective is discovery as in these use-cases, and no D2D communication is needed, this can be achieved by using data already available in the EPC. The EPC in this context refers to the logical components that make up the IP network that together with the radio parts form the LTE network. As described before, LTE networks are equipped with mechanisms to locate UEs registered on the network. When using E-CellID or U-OTDOA, precision is somewhere between 50 and 150 metres [27]. In general this will be sufficient for the use cases in this research. Note that in the advertising use case, the location of the advertiser UE is static and power consumption is not a direct issue. Depending on protocols used for positioning, the location of the advertiser UE can be assisted by a GNSS technique such as GPS and therefore be highly accurate.

5 Evaluation

We will now evaluate the four implementation options, based on a number of technical and organizational metrics.

5.1 Technical

- Battery life

In the advertising use case, battery life is only important on the customer side. The advertiser side is a statically placed UE which can be powered by mains. Battery life is essential for this use case as potential customers will not use the functionality if it causes battery drain. Implementation option two would be the most efficient, with discovery option A3 because this is the most passive option. LTE radio, even in idle mode, still receives signals for PLMN selection, cell selection, paging, etc. Listening to discovery beacons can be integrated into this idle mode without significant increase of energy consumption. The customer UE in this case only has to monitor and only act if something of interest is received. This is comparable with the paging that "wakes" an UE from idle mode to receive a call. Contradictory to all options dependant on the B-model of discovery, no transmissions have to be made by the customer UE.

In the social networking use case, battery life is important on both the UE that is discovering as well as on the UE that is being discovered. Continuous sending of

discovery beacons or requests (model A or B) would put a significant burden on battery life. Given to the relatively large geographical distance in which friends in a social network could be located, this is far from efficient. Some form of network assistance will reduce this burden. Therefore, from the four options, implementation option four is definitely the most battery friendly as the UE can be notified on a proximity event.

Another option is a two-step approach, in which the UE is notified by the operator network of a possible proximity and then starts to listen for radio beacons containing a certain identifier. This will improve accuracy, and opens up possibilities for D2D communication. The latter could be useful in a social media use case for exchanging photos and other media.

- Interference

Interference exists in implementation options one, two and three. Interference can be between D2D / ProSe and regular LTE communication, or between D2D / ProSe users. To avoid interference, D2D communication should be properly coordinated and synchronised with other communication. In implementation options one and two, resources can be allocated by the eNB and therefore interference control and synchronisation can be performed by the eNB. In implementation option 3, this fully depends on the chosen frequency band used for D2D / ProSe communication. Higher frequency bands in the 2600 MHz spectrum do have limited reach, and therefore require a dense eNB deployment to control interference and provide synchronisation. The dense eNB deployment gives operators a larger overhead, which is the reason why the higher frequency spectrum is not used for large scale LTE deployments. Implementation option 4 does not use direct radio communication, and therefore synchronisation and interference are not an issue. Both use cases can be implemented using option four. This will allow for a quick start with ProSe / D2D. In the meantime, the 3GPP specification could be further finalized and more practical experience will be gathered with the technique. Once the radio part is finished, the advertising use case can be switched to direct radio and for the social media use case a two-step approach can be implemented.

- Quality of Service (QoS)

QoS can be a reason for operators to be reluctant to support D2D / ProSe because of possible interference with regular LTE traffic. Interference leads to degraded performance and poor user experience. To avoid jumping into the unknown, the gradual introduction of ProSe / D2D as described in the previous item can be followed.

5.2 Feasibility

- Costs

The implementation costs in implementation options one and two are expected to be similar, as the difference is only based on the implementation of the radio part. No additional hardware or spectrum resources are needed for one option above the

other. Option three requires a dedicated set of radio resources. Because D2D / ProSe communication has a limited range, a higher frequency band can be used. Higher frequency bands have a limited range, and therefore not used for large scale (e.g. national) LTE deployments. Because of these limitations, the higher frequency bands are turned out cheaper in the frequency auction. One option for a dedicated frequency band would in the 2600Mhz spectrum.

In the April 2010 license auction for the 2600 MHz spectrum resources in the Netherlands, frequencies were auctioned for 100.000 Euro per 5 MHz paired spectrum [6]. To stimulate fair competition amongst market players there were some corrections which we will not take in account here. Assuming there is still some spectrum for sale or can be acquired for a similar pricing, acquiring resources in the 2600 MHz spectrum is a viable option which opens D2D / ProSe possibilities with a limited investment. This option solves at least part of the interference problem with regular LTE traffic.

The use of the 2600 MHz spectrum has some disadvantages. The largest disadvantage is the limited reach. While it may be sufficient for D2D / ProSe communication, it is not possible to send signalling over the D2D / ProSe dedicated frequency between UE and eNB. To be able to do this, a very dense eNB deployment is needed which requires a substantial investment. The advantage of sending signalling over the D2D / ProSe dedicated frequency is that it limits the amount of changes needed to the existing LTE (production) network.

Signalling over a dedicated frequency would be possible if the reach was higher. This is the case in the 800 MHz spectrum. A dedicated frequency band can be used for both signalling and data traffic for D2D / ProSe. The new functionality can be added almost seamless. On the other hand, the spectrum license costs will be substantial. New market entrant Tele2 paid 160 million Euro for 2 blocks of 10 MHz paired spectrum. Again, additional fees for competition reasons were not taken into account. This comes down to 40 million Euro for a 5 MHz stretch of spectrum. Even if D2D / ProSe can use a subset of a 5 MHz block, costs are still substantial. Furthermore, investments are up front and return on investment is uncertain as this depends on the uptake of this new technology. Choosing the dedicated spectrum option will most likely result in operators reluctant to deploy D2D / ProSe.

- Time to Market

The time to market is highly dependent on the chosen implementation option. From the 4 options, options 1 till 3 require changes at the UE side in radio and firmware support for ProSe / D2D communication. As LTE UE vendors are likely to follow either 3GPP or OMA specifications in order to achieve interoperability with networks worldwide, it is to be expected that these changes are implemented after 3GPP release 12 has been finalized. As Release 12 only includes ProSe / D2D

for public safety purposes the necessary support might even be further away.

Option 4 does not require changes to the UE except for client software (mobile app) that can be easily installed by the end user. EPC based discovery can be implemented as "pre-ProSe". EPC based discovery is sometimes known as Location Based Services (LBS). Leading LTE equipment vendors known to be (partly) implementing LTE networks for Dutch operators such as Huawei (T-mobile) and Ericsson (KPN, Vodafone) already offer solutions for enabling LBS on operator networks [20] [15].

5.3 Resulting requirements

To summarize on the evaluation of the various options, option three is the least preferable option in terms of cost and technical complexity. Option four is the most preferable option in the short term, to be extended with radio communication as defined in options one and two in the mid to long term. As the technical evaluation shows, some use cases can benefit from radio options which are currently excluded by the 3GPP specification as shown in implementation option two. It is advised for this to be reconsidered.

Both option four, as well as options one and two require a backhaul infrastructure for the implementation of ProSe / D2D. The backhaul infrastructure contains the logical ProSe function and ProSe application server as mentioned in section 2.4.1. This is the minimal requirement to support ProSe / D2D communication within the PLMN.

PC6 is the logical link and interface between the ProSe function in the HPLMN and another PLMN when the UE is not roaming.

PC7 is the logical link and interface between the ProSe function in the HPLMN and the VPLMN when the UE is roaming.

In the context of a multi operator scenario, we focus on the PC6 and PC7 logical interface. On a functional level, the PC6 / PC7 interface must support the following functions between operators:

- Authorization for discovery
- Discovery of nearby UEs
- Authorization for identity
- Identity lookup
- Authorization for D2D communication
- Transport of user-plane data for D2D communication ¹
- Reservation of resources ²

We propose two options for achieving this interconnectivity between operators:

- Peering model: operators arrange connectivity between each other on a private agreement between the two operators
- Exchange model: a central exchange facility is established, to which all operators can connect on an open basis.

The ideal model depends mainly on the number of participants in the D2D / ProSe process. The most important question is if Mobile Virtual Network Operators (MVNOs) are to be included as autonomous identities. MVNOs provide mobile telecommunication services to their customer base without having their own Radio Access Network (RAN). Providing the RAN is still up to the 4 Mobile Network Operators (MNOs) at the time of writing, as this depends on licenses and substantial investments.

By Februari 2014, there were already 64 MVNOs in the Dutch mobile telecommunication market [12]. MVNOs can be more or less independent operators, operating more or less on their own backend equipment and infrastructure. With the introduction of ProSe / D2D, MVNOs can either use the ProSe functionality of the MNO or operate their own ProSe function. Based on the fact that MVNOs exist because of added value to the product (e.g. Fixed-Mobile integration, custom plans, granular cost control, etc) it can be expected that at least part of the MVNOs will at some point require independent

¹Depends on use case

²Depends on implementation model chosen

D2D / ProSe infrastructure.

Therefore in the long run, the exchange model is more flexible compared to the peering model and guarantees an open market in which new entrants are able to join independently.

Some analogy for this problem can be found in the issue of number portability. In 1999, Dutch telecoms law introduced number portability which made it mandatory for operators to allow their customers to retain a telephone number (both fixed and mobile) when switching operator. [14]. To facilitate the process of migrating telephone numbers between operators, an association has been established: Vereniging COIN. All leading operators in the Netherlands are members of the association and participate in the number portability process. A platform and protocol was established which is used for automated data exchange between operators.

The COIN example shows how an independent organization structure can be a successful way to organize a shared interest between operators. The D2D / ProSe case requires the same level of interoperability in order to deliver a good user experience. Mobile operators worldwide are organized in the GSM Association (GSMA) [16]. The existing organizational base of the GSMA can be used to establish a working group for further research into interoperability between operators and their networks.

6 Conclusion and discussion

After exploring the technical requirements and resulting organizational requirements in section 5.3 a conclusion can be drawn on the research question:

What are the organizational and technical requirements for enabling proximity based services based on device to device communication on- and between the commercial LTE network operators in the Netherlands?

This research shows that a step-up approach to ProSe / D2D is possible using the EPC based discovery implementation option. This option has mainly technical requirements, the most important being the changes to the backhaul infrastructure and UE support. When the EPC based discovery is extended with support for radio discovery, and when the multi-operator scenario is introduced the complexity is shifted to the organizational level.

It is advisable for operators to start exploring the possibilities for ProSe / D2D communication, as it may be one of the options to restore lost revenue. The investment towards infrastructure and interconnections is likely to be re-used as the generic outline for the 5th generation wireless networks, because the outline for 5G includes and relies on D2D communication to increase capacity. [26] [13] [11]. As EPC based discovery is

also mentioned in 3GPP SA2 on ProSe / D2D it is likely to be included in the final standard [3].

Although the EPC based discovery implementation has a short time to market and relatively low implementation costs, it is imaginable that over the top services eventually catch up with developing energy and bandwidth efficient services. To avoid being bypassed again, it is advisable for operators to add their unique value of direct radio communication to the product as soon as possible. Once the specification is finalized by 3GPP, equipment vendors will most develop the technical side of the solution. For operators there is a larger task in setting up a cooperative environment in which technical and commercial models are to be built. Ultimately, as the use cases point out, the success of ProSe / D2D depends on cooperation to build a service that works seamlessly across operators.

7 Future research

The broad subject of ProSe / D2D and inter-operator scenario need further research. Areas of research include:

- Commercial model. A commercial model must be developed that allows for revenue generation from ProSe / D2D by operators.
- Legal issues concerning ProSe and D2D. Issues such as lawful intercept, responsibility for illegal content in D2D mesh networking.
- Privacy and security. Both D2D and ProSe come with a large number of privacy issues. Examples include privacy on discovery, data privacy on mesh networking (one UE forwarding via another UE) forward secrecy and identity theft in discovery.
- In-depth technical specification of protocols for inter-operator communication.

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9 Appendix A: list of acronyms

- OTT Over The Top service. A third party offering a service based on IP connectivity over the Internet to replace services traditionally offered by operators to their customers. Examples include Voice over IP to replace traditional voice services, and Instant Messaging replacing SMS.
- D2D Device to Device, a direct communication path between two LTE enabled devices
- UE User Equipment, a LTE capable device (e.g. smartphone, mobile phone).
- LTE Long Term Evolution, the term to summarize the latest development in mobile communication networks
- eNB Short for eNodeB which stands for Evolved Node B. Evolved refers to the evolution in LTE. It is the successor of the NodeB in earlier UMTS networks. The eNB establishes a radio communication path with the UE.
- EPC Evolved Packet Core, refers to the core network to which the eNBs are connected. The EPC handles all data transmission and provides services to UEs.
- RAN Radio Access Network, the radio part of the mobile network. The radio part in LTE consists of the eNBs and network infrastructure needed to cover a specific area (such as a country) with radio signals.
- PLMN Public Land Mobile Network. A mobile network of a mobile operator in an area (e.g. a country).